DEPARTMENT OF ENERGY

The Public Inquiry into the Piper Alpha Disaster

The Hon Lord Cullen

VOLUME ONE

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Presented to Parliament
by the Secretary of State for Energy
by Command of Her Majesty
November 1990

LONDON: HMSO

Cm 1310

£38.00 net
(Two volumes not sold separately)

Frontispiece

A fast rescue craft near the 20ft level some time after the first riser rupture: photograph taken by Mr Miller from the *Tharos*.

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The Rt Hon John Wakeham MP
Secretary of State for Energy
Department of Energy
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19 October 1990

Dear Secretary of State,

PIPER ALPHA PUBLIC INQUIRY

On 13 July 1988 I was appointed by your predecessor as Secretary of State to hold a public inquiry to establish the circumstances of the accident on Piper Alpha and its cause. The public inquiry has been completed and I now enclose my Report which deals with all matters with the exception, as stated in paragraph 2.28, of any question as to the making of a direction in regard to costs.

Yours sincerely,

W Douglas Cullen

W DOUGLAS CULLEN

THE MINERAL WORKINGS (OFFSHORE INSTALLATIONS) ACT 1971 (c. 61)
THE OFFSHORE INSTALLATIONS (PUBLIC INQUIRIES) REGULATIONS 1974
(SI 1974/338)

WHEREAS on 6th July 1988 an accident involving loss of life occurred on and in connection with the operations of the offshore installation known as Piper Alpha situated in the United Kingdom sector of the continental shelf:

NOW THEREFORE the Secretary of State, in exercise of the powers conferred on him by the above-mentioned Regulations, hereby-

(1) directs that a public inquiry be held to establish the circumstances of the accident and its cause;

(2) appoints the Honourable Lord Cullen, a Senator of the College of Justice in Scotland, to hold the inquiry and to report to him on the circumstances of the accident and its cause together with any observations and recommendations which he thinks fit to make with a view to the preservation of life and the avoidance of similar accidents in the future.

13th July 1988 Secretary of State for Energy

STRUCTURE OF THE REPORT

VOLUME ONE

Page

SECTION ONE: INTRODUCTION

SECTION TWO: THE DISASTER

SECTION THREE: BACKGROUND TO THE DISASTER

VOLUME TWO

Page

SECTION FOUR: THE FUTURE

LIST OF FIGURES

LIST OF PLATES

ACKNOWLEDGEMENTS

The Inquiry was grateful for the assistance derived from the following plates:

Front Cover and Plate 19(b)
Robert Gibson

Frontispiece and Plates 14-16(b), 17(b) and 18(a)
Charles A Miller

Plates 1-2
Highlands and Islands Development Board

Plates 3, 4 and 6-9
Borowski (Photographers)

Plates 5 and 11(a)
Fleumer (Aerial Photography)

Plates 10(a), (b) and 12(b)
Occidental Petroleum (Caledonia) Ltd

Plate 11(b)
Nomis Ltd

Plate 12(a)
Osborne Boats Ltd

Plates 13 and 17(a)
Lindsay M T Macdonald

Plate 18(b)
Theodorus Vanus

Plate 19(a)
Alan A Ritchie

Plates 20(a) and (b)
Graeme Church

Plates 21, 22(a) and 23
Grampian Police

Plate 22(b)
Tucker Robinson

Plates 24(a) and (b)
Hank Johnson Flags

Plate 25(a)
Petreco

Plate 25(b)
Cremer and Warner

Plate 26(a)
Christian Michelsen Institute

Plate 26(b)
Nowsco Video, Courtesy of Occidental Petroleum (Caledonia) Ltd

APPENDICES

SECTION ONE: INTRODUCTION

Chapter 1

Executive Summary

1.1 Through the Inquiry I sought the answers to 2 questions -

- What were the causes and circumstances of the disaster on the Piper Alpha platform on 6 July 1988? and
- What should be recommended with a view to the preservation of life and the avoidance of similar accidents in the future?

1.2 In Chapters 4-10 I review the events which occurred in the disaster and its aftermath. In Chapters 11-15 I am concerned with the background to the disaster and deal with a number of further matters which were investigated in the light of what happened. In Chapters 16-22 I consider what is required for the future: and in Chapter 23 I set out my recommendations.

1.3 The present chapter should be understood as giving only a brief indication of the content of what follows in later chapters. The latter contain my full conclusions and observations together with the supporting reasoning and such of the evidence as I have considered it necessary to set out.

1.4 The first event in the disaster was an initial explosion at about 22.00 hours. In **Chapter** 5 I conclude that it was in the south-east quadrant of C Module, the gas compression module, and was due to the ignition of a low-lying cloud of condensate.

1.5 As most of the equipment on the platform was not recovered from the wreckage and as key witnesses did not survive the disaster a number of possible explanations for the leak of condensate are considered in **Chapter 6**. Particular attention was given in the Inquiry to events after 21.45 hours when one of the two condensate injection pumps tripped. I conclude that the leak resulted from steps taken by night-shift personnel with a view to restarting the other pump which had been shut down for maintenance. Unknown to them a pressure safety valve had been removed from the relief line of that pump. A blank flange assembly which had been fitted at the site of the valve was not leak-tight. The lack of awareness of the removal of the valve resulted from failures in the communication of information at shift handover earlier in the evening and failure in the operation of the permit to work system in connection with the work which had entailed its removal.

1.6 **Chapter** 7 is concerned with the way in which the disaster developed. The initial explosion caused extensive damage. It led immediately to a large crude oil fire in B Module, the oil separation module, which engulfed the north end of the platform in dense black smoke. This fire, which extended into C Module and down to the 68 ft level was fed by oil from the platform and by a leak from the main oil line to the shore, to which pipelines from the Claymore and Tartan platforms were connected. At about 22.20 hours there was a second major explosion which caused a massive intensification of the fire. This was due to the rupture of the riser on the gas pipeline from Tartan as a result of the concentration and high temperature of the crude oil fire. It is probable that this rupture would have been delayed if oil production on the other platforms had been shut down earlier than it was. The fire was further intensified by the ruptures of risers on the gas pipeline to the Frigg disposal system and the gas pipeline connecting Piper with Claymore at about 22.50 and 23.20 hours respectively. The timing of the start of depressurisation of the gas pipelines could not have had any material effect on the fire at Piper. The OIMs on Claymore and Tartan were ill-prepared for an emergency on another platform with which their own platform was connected.

1.7 The initial explosion put the main power supplies and the Control Room at Piper out of action. It appears that the emergency shutdown system was activated and the emergency shutdown valves on the gas pipeline risers probably closed although extended flaring pointed to a failure of the valve on the Claymore riser to close fully. The other emergency systems of the platform failed immediately or within a short period of the initial explosion. In particular the fire-water system was rendered inoperative either due to physical damage or loss of power. However, at the time of the initial explosion the diesel fire pumps were on manual mode so that, even if they had not been disabled, they would have required manual intervention in order to start them.

1.8 In **Chapter 8** I describe the effects of events on the platform personnel. Of the 226 men on the platform, 62 were on night-shift duty; the great majority of the remainder were in the accommodation. The system for control in the event of a major emergency was rendered almost entirely inoperative. Smoke and flames outside the accommodation made evacuation by helicopter or lifeboat impossible. Diving personnel, who were on duty, escaped to the sea along with other personnel on duty at the northern end and the lower levels of the platform. Other survivors who were on duty made their way to the accommodation; and a large number of men congregated near the galley on the top level of the accommodation. Conditions there were tolerable at first but deteriorated greatly owing to the entry of smoke. A number of personnel, including 28 survivors, decided on their own initiative to get out of the accommodation. The survivors reached the sea by the use of ropes and hoses or by jumping off the platform at various levels. 61 persons from Piper survived. 39 had been on night-shift and 22 had been off duty. At no stage was there a systematic attempt to lead men to escape from the accommodation. To remain in the accommodation meant certain death.

1.9 Many organisations, vessels and aircraft were involved in the rescue and subsequent treatment of survivors, as I narrate in **Chapter 9**. There was some initial delay and confusion onshore due to the lack of accurate information. However, this did not affect the toll of death and injury. The events demonstrated the value of fast rescue craft and the bravery of their crews in getting close to the platform even where the fire was raging at its fiercest. They also demonstrated the shortcomings of the type of standby vessel which was in attendance at Piper.

1.10 **Chapter 10** shows that the bodies of 135 of the 165 personnel on Piper who died as a result of the disaster were later recovered. The principal cause of death in 109 cases (including 79 recovered from the accommodation) was inhalation of smoke and fire. 14 apparently died during an attempt to escape from the platform. Few died of burns.

1.11 **Chapter 11** shows that the failure in the operation of the permit to work system was not an isolated mistake but that there were a number of respects in which the laid down procedure was not adhered to and unsafe practices were followed. One particular danger, which was relevant to the disaster, was the need to prevent the inadvertent or unauthorised recommissioning of equipment which was still under maintenance and not in a state in which it could safely be put into service. The evidence also indicated dissatisfaction with the standard of information which was communicated at shift handover. This had been the subject of criticism in the light of a fatality in September 1987.

1.12 As regards the fire-water system I find in **Chapter 12** that the practice of keeping the diesel fire pumps on manual mode during periods of diving was peculiar to Piper and in spite of an audit recommendation that it should be changed. It inhibited the operability of the system in an unnecessary and dangerous way. Further it is likely that if the fire-water system had been activated a substantial number of the deluge heads in C Module would have been blocked with scale. This was a problem of long standing but by the time of the disaster the necessary replacement of the distribution pipework had not been carried out.

1.13 Evidence as to training for emergencies, to which I refer in **Chapter 13** showed that the induction was cursory and, in regard to demonstrating lifeboats and life rafts, not consistently given. Muster drills and the training of persons with special duties in an emergency did not take place with the frequency laid down in Occidental's procedures. The OIMs and platform management did not show the necessary determination to ensure that regularity was achieved.

1.14 I point out in **Chapter 14** that Occidental management should have been more aware of the need for a high standard of incident prevention and fire-fighting. They were too easily satisfied that the permit to work system was being operated correctly, relying on the absence of any feedback of problems as indicating that all was well. They failed to provide the training required to ensure that an effective permit to work system was operated in practice. In the face of a known problem with the deluge system they did not become personally involved in probing the extent of the problem and what should be done to resolve it as soon as possible. They adopted a superficial attitude to the assessment of the risk of major hazard. They failed to ensure that emergency training was being provided as they intended. The platform personnel and management were not prepared for a major emergency as they should have been. The safety policies and procedures were in place: the practice was deficient.

1.15 In **Chapter 15** I examine the involvement of the Department of Energy with safety on Piper in the year up to the disaster. Installations such as Piper were subject to regular inspections, the purpose of which was, by means of a sampling technique, to assess the adequacy of the safety of the installation as a whole. Piper was inspected in June 1987 and June 1988. The latter visit was also used to follow-up what Occidental had done in the light of the fatality, which was in part due to failures in the operation of the permit to work system and the communication of information at shift handover. The findings of those inspections were in striking contrast to what was revealed in evidence at the Inquiry. Even after making allowance for the fact that the inspections were based on sampling it was clear to me that they were superficial to the point of being of little use as a test of safety on the platform. They did not reveal a number of clear cut and readily ascertainable deficiencies. While the effectiveness of inspections has been affected by persistent under-manning and inadequate guidance, the evidence led me to question, in a fundamental sense, whether the type of inspection practised by the DEn could be an effective means of assessing or monitoring the management of safety by operators.

1.16 I turn now to those chapters which are concerned with the future. By way of background to what follows, **Chapter 16** provides a brief outline of the existing United Kingdom offshore safety regime and, by way of comparison, the onshore safety regime and the Norwegian offshore safety regime.

1.17 The disaster involved the realisation of a potential major hazard in that an explosion following a hydrocarbon leak led to the failure of gas risers which added very large amounts of fuel to the fire. Although such remote but potentially hazardous events had been envisaged Occidental did not require them to be assessed systematically; nor did the offshore safety regime require this. As I set out in **Chapter 17**, I am satisfied that operators of installations, both fixed and mobile and both planned and existing, should be required by regulation to carry out a formal safety assessment of major hazards, the purpose of which would be to demonstrate that the potential major hazards of the installation and the risks to personnel thereon have been identified and appropriate controls provided. This is to assure the operators that their operations are safe. However it is also a legitimate expectation of the workforce and the public that operators should be required to demonstrate this to the regulatory body. The presentation of the formal safety assessment should take the form of a Safety Case, which would be updated at regular intervals and on the occurrence of a major change of circumstances.

1.18 Offshore installations have the unique requirement to be self-sufficient in providing immediate protection to personnel in the event of an emergency. I consider, as I set out in **Chapter 19**, that there should be a temporary safe refuge for personnel which should be a central feature of the Safety Case. Such a refuge should be able to provide temporary protection for personnel while the emergency is being assessed and preparations are made for evacuation should that be directed. The events which the refuge should be able to withstand and the acceptance standards for the endurance time and the risk of failure should be specified in the Safety Case. Likewise, the Safety Case should deal with the passability of escape routes and the integrity of embarkation points and lifeboats. Since the formal safety assessment should cover the safe evacuation, escape and rescue of personnel, the Safety Case should demonstrate that adequate provision is made for this also, as I set out in **Chapter 20**.

1.19 The safety of personnel on an installation in regard to hazards at large is, as I point out in **Chapter 21**, critically dependent on the systematic management of safety by operators. The present offshore safety regime does not address this in any direct sense; and current measures are, in my view, ineffective for the purpose of ensuring that the management of safety by all operators is adequate. Each operator should therefore be required in the Safety Case to demonstrate that the safety management system of the company and that of the installation are adequate to ensure that the design and operation of the installation and its equipment are safe. The safety management system of the company should set out the safety objectives, the system by which those objectives are to be achieved, the performance standards which are to be met and the means by which adherence to those standards is to be monitored.

1.20 It is essential, as I state in **Chapter 21**, that there should be assurance that each operator's safety management system is in fact adhered to. It is inappropriate and impracticable for the regulatory body to undertake the detailed auditing of operator's compliance with it. Operators should therefore be required to satisfy themselves by means of regular audits that the system is being adhered to. On the other hand the regulatory body should be required to review operator's audits on a selective basis and itself to carry out such further audits as it thinks fit and by regular inspection verify that the output of the system is satisfactory. This involves a completely new approach to regulation in the United Kingdom offshore safety regime. However it is totally consistent with the Health and Safety at Work etc Act 1974 and the concept of self-regulation. It represents a logical development from the requirement of a Safety Case for each installation.

1.21 In **Chapter 21** I set out my general findings in regard to the existing safety regulations and guidance relating to them. Many regulations are unduly restrictive in that they are of the type which impose 'solutions' rather than 'objectives' and are out-of-date in relation to technological advances. Guidance notes are expressed, or at any rate lend themselves to interpretation, in such a way as to discourage alternatives. There is a danger that compliance takes precedence over wider safety considerations; and that sound innovations are discouraged. The principal regulations should take the form of requiring stated objectives to be met. Guidance notes should give non-mandatory advice. On the other hand I accept that in regard to certain matters it will continue to be essential that detailed measures are prescribed.

1.22 In **Chapter 21** I also reaffirm the need for a single regulatory body. This is of particular importance for the future in which a greater burden will be placed on the expertise, judgement and resources of the regulator upon which his confidence and that of the industry will rely.

1.23 As I set out in **Chapter** 22, developments in regulatory techniques, experience of the capabilities and approach of offshore and onshore regulators, the imminence of major changes in the offshore safety regime and the evidence which I heard in Part 1 of the Inquiry caused me to entertain the question as to the body which should be the regulatory body for the future offshore safety regime. The choice as a practical matter lies between the DEn and the HSE, in either case being suitably strengthened. I come to the conclusion that the balance of advantage lies in favour of the transfer of responsibility to the HSE. The decisive considerations in my mind arise from considering the differences in approach between these 2 bodies to the development and enforcement of regulatory control. These differences are discussed in **Chapter** 22. I am confident that the major changes which I have recommended are ones which are in line with the philosophy which the HSE has followed. This alternative is clearly preferable to the DEn even if it was given a higher level of manning with greater in-house expertise. I also attach importance to the benefits of integrating the work of the offshore safety regulator with the specialist functions of the HSE.

1.24 The above summary has concentrated on the major elements in my recommendations. However in Chapters 18, 19 and 20 I have discussed, in the light of the lessons of the disaster and the expert evidence given in Part 2 of the Inquiry what should be done with a view to the prevention of incidents causing fires and explosions (**Chapter** 18); the mitigation of incidents (**Chapter 19**); and evacuation, escape and rescue (**Chapter** 20). In each of these chapters I have endeavoured to take account of the current state of the relevant technology and the extent to which further work is required; and to identify those matters which should, in my view, be the subject of regulations, either in the form of those which set objectives or those which prescribe fundamental essentials for safety. These include recommendations as to the operation of the permit to work procedures, the fire protection provided on platforms, the means of escape from platforms to the sea and improvements in the standby vessel fleet.

Chapter 2

The Scope of the Inquiry

The circumstances of the Inquiry

2.1 The Piper Alpha disaster, which occurred on the evening of 6 July 1988, claimed the lives of 165 of the 226 persons on board and 2 of the crew of the FRC of the *Sandhaven* while it was engaged in the rescue of persons from the installation. The death toll was the highest in any accident in the history of offshore operations.

2.2 In the weeks and months that followed the bodies of 137 of the deceased were recovered. Of these 81 were recovered from the wreckage of the East Replacement Quarters (ERQ), most of them in October and November 1988 after the ERQ had been raised from the seabed and transported to Occidental's terminal at Flotta in Orkney. 30 of the deceased remain missing.

2.3 On the morning after the disaster all that remained of the topside of the installation consisted of the wreckage of A Module which contained the wellhead area. It took several days for a number of wellhead fires to be extinguished. On 7 December 1988 after inspection of the remaining structure and the seabed Occidental obtained conditional approval from the Secretary of State for Energy under Sec 4 of the Petroleum Act 1987 of a plan for the abandonment of the installation which included the toppling of its jacket. I had been consulted in regard to the implications of that operation and indicated that for my part I had no objection in principle to the proposal. On 28 March 1989 the jacket of the installation was toppled.

Events leading up to the opening of the Inquiry

2.4 In terms of a minute dated 13 July 1988 the Secretary of State for Energy, in exercise of the powers conferred upon him by the Public Inquiries Regulations, (1) directed "that a public inquiry be held to establish the circumstances of the accident and its cause"; and (2) appointed me "to hold the inquiry and to report to him on the circumstances of the accident and its cause together with any observations and recommendations which he thinks fit to make with a view to the preservation of life and the avoidance of similar accidents in the future".

2.5 On the same date the Secretary of State, in exercise of the power conferred on him by Reg 13 of the Inspectors and Casualties Regulations, and the Health and Safety Commission (HSC) in exercise of its power under Sec 14(1) and (2)(a) of the Health and Safety at Work etc Act 1974 (HSWA), directed and authorised Mr J R Petrie, Director of Safety of the Petroleum Engineering Division (PED) "to investigate and make a special report with respect to the occurrence of casualties suffered as a result of the accident on and in connection with the operations of the offshore installation ...".

2.6 In a statement made on 14 July 1988 in answer to a Parliamentary Question the Secretary of State explained that the Government intended that the public inquiry should be as full and far reaching as necessary. On the other hand the object of the investigation by Mr Petrie was that if any early, even if provisional, lessons could be learnt from the disaster, they should be extracted and guidance issued to operators of North Sea installations.

2.7 In these circumstances the technical investigation which was conducted by Mr Petrie with the assistance of a team of inspectors from the Department of Energy (DEn) and the Health and Safety Executive (HSE) was carried out as a first priority and before preparations for the public inquiry could begin. Mr Petrie presented an

Interim Special Report dated 15 September 1988 to the Secretary of State and the Chairman of the HSC. I will refer to it as the Petrie Report. Copies of the report were made available to the public from 29 September 1988 in accordance with my wishes and a Preliminary Hearing for the Inquiry was fixed for 11 November 1988. At the same time I also decided that copies of the report of the DEn into the accident which had occurred on Piper Alpha on 24 March 1984 should be made available to persons with an interest in it.

2.8 I wish to record my admiration for the amount of work which Mr Petrie's investigation was able to achieve within 2 months of the disaster. I am sure that the Petrie Report was of considerable assistance both to the public and to potential parties in obtaining an understanding of the technical background to the events. So far as the Inquiry is concerned, it formed part of the evidence. However the Inquiry proceeded on the basis that the fact that a matter was dealt with in the report did not exclude the hearing of evidence in regard to it or exclude the challenging of any findings which Mr Petrie had reached.

2.9 Mr Petrie submitted a Final Report dated 20 December 1988. This report dealt with a number of additional matters which had been left over for further consideration and was treated by me in the same way as the Interim Report.

2.10 In due course the DEn issued guidance to operators in a number of forms. These were drawn to the attention of the Inquiry in the course of Part 2. I have taken them all into account and will discuss them in this Report to the extent that seems to me to be appropriate.

2.11 By the time when the Inquiry opened on 19 January 1989 3 Assessors had been appointed to assist me under Reg 3 of the Public Inquiries Regulations. They were:-

(i) Professor Frank Lees, Professor of Plant Engineering, Loughborough University of Technology;

(ii) Mr G Malcolm Ford, CBE, formerly the Managing Director of Britoil plc; and

(iii) Mr Brian Appleton, then Group Director, ICI Chemicals and Polymers Ltd.

To each of them I owe a great debt of gratitude for their knowledge, perception and selfless dedication. At every stage in the long task which this Inquiry has involved I have made great demands of them which they have more than fulfilled. However, for this report and any defects which it may have I bear the sole responsibility.

2.12 I appointed Messrs Cremer and Warner, Consulting Engineers and Scientists, to assist the Inquiry in the obtaining and preparation of technical evidence. Their work included: (i) the technical investigation of the ERQ and the AAW; (ii) assistance in the recovery of documents from the ERQ and the parties; the establishment of the technical library; and the identification and distribution of core documents; (iii) the supervision of a hazard and operability study of the operation of plant on Piper; (iv) technical support to the Crown Office and Counsel to the Inquiry; (v) the briefing and supervision of expert witnesses; and (vi) technical liaison with the parties and various regulatory bodies. Their work proved to be of great assistance in opening up and carrying through lines of investigation.

2.13 For the assistance of the Inquiry in the presentation of evidence the Solicitor-General for Scotland (Mr A F Rodger QC), Mr T C Dawson QC, Advocate-depute, Mr A P Campbell and Miss M Caldwell acted as Counsel to the Inquiry. Mr A D Vannet of the Crown Office acted as Solicitor to the Inquiry. I wish to express my thanks for the way in which they discharged their duties and assisted the Inquiry.

2.14 The administrative work in connection with the Inquiry was carried out by a Secretariat from the Scottish Office. I have had considerable support and assistance from every member of that team. They have helped most willingly. I must make particular mention of Cathie Forbes who headed the team. Her unique blend of efficiency and charm helped immeasurably in the smooth running of the Inquiry. I am also most grateful to Betty Charles, my personal secretary, who uncomplainingly carried the heavy burden of typing the entire text of this report and the many preliminary drafts and revisals. In the task of marshalling information which became available to me through the evidence I was assisted by Mr Ralph Pride, BSc CChem FRSC. For that I am most grateful. Finally I should pay tribute to the skill and helpfulness of the team of shorthand-writers from the Palantype Reporting Service.

The Inquiry

2.15 This Inquiry was the first which took place under the Public Inquiries Regulations. In considering the scope of the Inquiry I treated the "accident" as comprehending all that involved loss of or danger to life from the stage of the initial ignition to the stage when the last survivor reached help. The Inquiry was plainly intended to be a wide-ranging one. On the other hand, I took the view, which I expressed at the outset, that my remit did not entitle me to embark on a roving excursion into every aspect of safety at work in the North Sea or into every grievance, however sincere or well-founded, that was entertained. Accordingly in considering whether a particular line of evidence should be explored, whoever raised it, the question which I posed for myself was whether there was any tenable connection between that line of evidence and the events that occurred. In the light of the terms of my remit I decided that it was appropriate to divide the Inquiry into 2 parts.

Part 1

2.16 This part of the Inquiry, which opened on 19 January 1989 and closed on 1 November 1989 was concerned with how and why the disaster happened. Accordingly it examined the physical conditions, events and human conduct which contributed to the occurrence of (a) the initial and later explosions and fires; and (b) the loss of or danger to life; along with the actions taken by those who were concerned with dealing with the emergency. While the holding of an inquiry under the Fatal Accidents and Sudden Deaths Inquiry (Scotland) Act 1976 is a matter for decision by the Lord Advocate I have endeavoured to conduct the Inquiry in such a way as to make any additional inquiry under that Act unnecessary. (See Sec 6(5) of the Mineral Workings (Offshore Installations) Act 1971 (MWA)).

2.17 It was obvious from the outset that the detailed investigation of what happened on the installation itself would be made extremely difficult by the fact that it was impossible to examine most of it and by the fact that so many of those who had been on the installation, and in particular had been at work there, had died in the disaster. Messrs Cremer and Warner identified for the Inquiry's consideration a large number of possible scenarios for the initial explosion in addition to those which had been mentioned by Mr Petrie in his 2 reports. In order to find out whether and to what extent the range of possible causes should be narrowed down it was necessary, in addition to examining such evidence as survivors were able to give as to the events at or shortly before the time of the disaster, to look into conditions which had obtained on the installation during the preceding days, and to consider expert evidence as to the physical effects of given actions and process conditions.

2.18 From an early stage in this part of the Inquiry it became clear that there were a number of features in the physical arrangements on and the management of Piper Alpha which were such as to render it vulnerable to dangerous incidents, whether or not they contributed to the disaster. This led to a range of additional topics coming under consideration including permit to work procedure and practice, active fire protection and preparation for emergencies. This led the Inquiry to investigate how these deficiencies could have failed to be corrected by Occidental's management of safety or detected by the regular inspections and surveys which were carried out by regulatory bodies.

2.19 In this part the Inquiry heard 58 of the 61 survivors give evidence. Each of them was given the opportunity of making any comment which he wished to make as to how the means of securing safety could be improved. The written statements of the remaining 3 survivors who for various reasons were unable to give evidence were read to the Inquiry. The Inquiry also heard the evidence of 38 witnesses as to the response both offshore and onshore to the emergency created by the disaster, the recovery and examination of the deceased and certain investigations by the police; 5 eye-witnesses as to what they saw and photographed; 8 witnesses who were present on other installations with which Piper Alpha was connected; 32 present and former employees of Occidental on a variety of technical and management matters; 14 present and former employees of other companies; 35 witnesses who gave evidence as independent experts or provided independent technical evidence; and 6 witnesses who gave evidence on behalf of regulatory and other bodies.

2.20 At an early stage in this part of the Inquiry and prior to the toppling of the jacket I heard evidence as to the feasibility and practical implications of operations to recover debris from the seabed. My sole concern with this matter was the possibility of recovery of evidence which would assist in the investigation of the disaster. I do not recommend that such recovery be attempted: and none of the parties invited me to make such a recommendation. I have been able to come to conclusions as to the causes of the disaster in the light of the evidence put before me at the Inquiry. In any event the practicability of recovery by any one given method is uncertain. The exercise would be fraught with danger to divers who took part in it. Even if parts of the debris which were of interest were still undamaged at the time when the operations were begun, they would be likely to be damaged in the course of them.

Part 2

2.21 This part of the Inquiry which opened on 2 November 1989 and closed on 15 February 1990. It was concerned essentially with the part of my remit which empowered me to make observations and recommendations with a view to the preservation of life and the avoidance of similar accidents in the future.

2.22 Prior to the opening of Part 1 I announced that the Inquiry would in due course be considering the following subjects with a view to possible recommendations. At that stage I felt able to anticipate that these would require to be examined in due course in the light of evidence in Part 1. The subjects were (i) the location and protection of accommodation; (ii) the means of mitigating the effects of explosion; (iii) the means of ensuring the integrity of emergency systems; and (iv) the means of ensuring safe and full evacuation. Parties were given the opportunity to propose further subjects for my consideration. As the evidence in Part 1 unfolded I added the following additional subjects: (v) permits to work; (vi) the control of the process; (vii) risk assessment; and (viii) the offshore safety regime. Each of those subjects was selected on the basis of its connection with what was learnt in Part 1 of the Inquiry.

2.23 In this part the Inquiry heard 33 witnesses who were employed by various operators in the United Kingdom Continental Shelf (UKCS) and the Norwegian Continental Shelf (NCS) or their associated companies; 3 witnesses from operators and technical associations; 4 witnesses from trade unions; 4 independent experts; 13 witnesses from regulatory and other bodies; and 7 witnesses in regard to permit to work (PTW) procedure; and emergency equipment, training and response.

2.24 The conduct of this part of the Inquiry was assisted by the fact that the United Kingdom Offshore Operators Association Ltd (UKOOA) represented the interest of its 36 members as well as of the Association itself. UKOOA offered to assist the Inquiry with evidence on a wide range of subjects and in most instances this invitation was taken up. The witnesses led by UKOOA included 30 of the total of 33 mentioned in the last paragraph. In each instance the written statement of the witness had the prior approval of a committee of UKOOA.

2.25 The witnesses mentioned in para 2.23 include the Director of the Safety and Working Environment Division, Norwegian Petroleum Directorate (NPD) and 3 witnesses from Statoil, which is wholly owned by the Norwegian State. I would like to record my gratitude of the help which was so readily and fully given by these witnesses and their organisations.

Costs and expenses

2.26 In terms of Reg 9(2) of the Public Inquiries Regulations it is provided that:-

> "The court may direct that the costs of an inquiry shall be paid in whole or in part by any person who in the opinion of the court, by reason of any act or default on his part or on the part of any agent or servant of his, caused or contributed to the casualty or other accident the subject of the inquiry".

2.27 On 1 November 1989 I heard a motion made on behalf of the Trade Union Group for a direction under this provision that the expenses of the Group so far as properly attributable to its participation in Part 1 of the Inquiry should be paid by Occidental. On 9 November 1989 I rejected this application as incompetent in respect that it did not relate to "the costs of an inquiry". My reasons are set out in para A.10 of Appendix A to this Report.

2.28 As regards a possible direction under Reg 9(2) in regard to the proper "costs of an inquiry", it was clear at the conclusion of the Inquiry that until my findings as to causation and contribution were known it was not practicable for such a direction to be discussed. However it was and is my view that my findings should be communicated in the first instance to the Secretary of State - as I do in this Report. It should therefore be understood that I have specifically reserved the exercise by me of any power which I have to make a direction under Reg 9(2). It is my intention that, following the publication of this Report, I should give parties having an interest in the making, or who may be affected by the making, of such a direction the opportunity of addressing me.

2.29 At the conclusion of the Inquiry Counsel for the Trade Union Group invited me to make a recommendation to the Secretary of State on an extra-statutory basis that payment of the costs incurred by MSF and T & GWU should be made out of central funds. For the reasons set out in para A.11 of Appendix A to this Report I recommend that these trade unions should receive a contribution towards their costs; and that 40% would be an appropriate proportion, the costs being taxed, failing agreement, by the Auditor of the Court of Session.

Procedure

2.30 Details as to procedure in connection with the Inquiry are set out in Appendix A.

Visits

2.31 In connection with our duties I and the Assessors on separate occasions visited the Claymore installation and the *Tharos*. My visit to the *Tharos* (on 1 September 1988) included a brief period in A Module of Piper Alpha. We together saw the ERQ at Occidental's terminal at Flotta; and the *Silver Pit*. The Assessors also visited the Gullfaks A installation operated by Statoil in the NCS.

The results of the Inquiry

2.32 Before arriving at a recommendation I have endeavoured to ensure (i) that it is needed in the interests of safety; (ii) that it is reasonably practicable to implement it; and (iii) that there is an adequate basis for it in the evidence at the Inquiry. I have taken account of evidence as to the actions taken by the industry and the regulatory body in response to the disaster and the information which has come to light as a result of it. I have taken note also of the comments made by survivors and others on matters of safety in the light of events at the time of the disaster.

2.33 Finally I wish to record my appreciation and thanks for the immense amount of work put in by so many organisations and individuals to provide the Inquiry with evidence. That evidence was of a consistently high quality. While the conclusions and recommendations set out are my own I am conscious of how much is owed to that hard work. I trust that the impact of the Inquiry's recommendations does justice to the opportunity which the Inquiry has provided to point out a new and improved course in offshore safety.

Chapter 3

Piper Alpha

3.1 A description of the Piper platform, its context and its development, was given by Mr K R Wottge, Facilities Engineering Manager. Mr Wottge had been with Occidental at Aberdeen for 12 years. He had been involved with Piper for a long time and knew it well.

Development of the Piper field

3.2 The Piper oil platform was owned by a consortium consisting of Occidental Petroleum (Caledonia) Ltd, who had a 36.5% interest, Texaco Britain Ltd with 23.5%, International Thomson PLC with 20% and Texas Petroleum Ltd with 20%. In the fourth offshore licensing round in March 1972 the Occidental Group was awarded 2 blocks, Blocks 14/19 and 15/17. Oil was discovered in the Piper field in Block 15/17 in January 1973. The reservoir covered an area about 12 square miles. It was named the Piper Field and was exploited by the Piper Alpha platform. The location of the Piper field in relation to the other oil and gas fields in the northern North Sea is shown in Plates 1 and 2. Fig 3.1 shows the Piper Alpha platform and the associated platforms and the Flotta terminal.

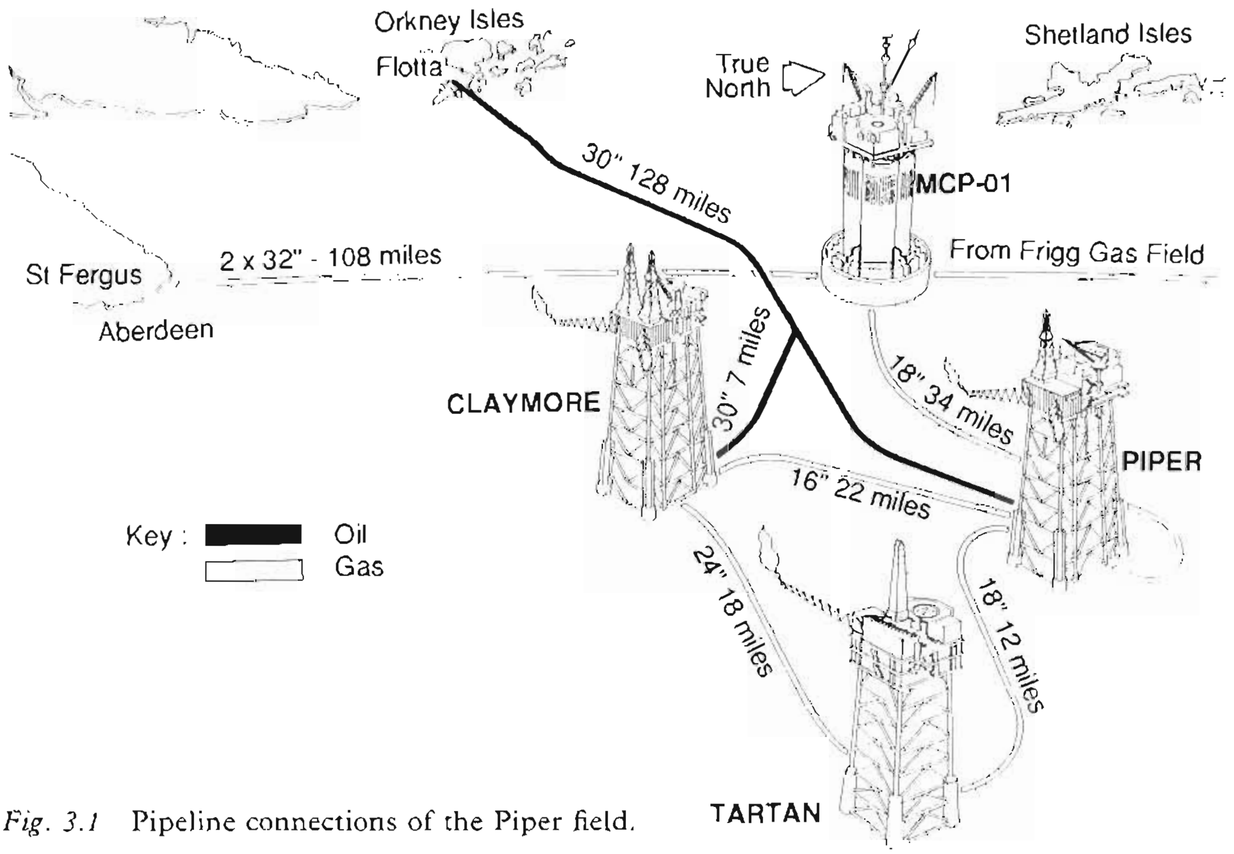


Fig. 3.1 Pipeline connections of the Piper field.

The Piper Alpha platform

3.3 The platform was located 110 miles north-east of Aberdeen, at latitude 58° 28' 01" north, longitude 00° 15' 36" east. The orientation of the platform was at 43 degrees to true north, or 317 degrees true bearing. In accordance with normal practice in the North Sea and with that of Occidental, directions are described hereafter in terms of platform north, rather than true north. The platform provided the facilities to drill wells to the producing reservoir and extract, separate and process the reservoir fluids, a mixture of oil, gas and water. Gas and water were separated from the oil in production separators. Gas condensate liquid was separated from the gas by cooling and was then reinjected into the oil to be transported with it to shore and there separated out again. The design throughput of the platform was 250,000 bbl/d of oil.

3.4 The platform started production in late 1976. Initially only the oil was exported to the shore, by a pipeline to the oil terminal at Flotta; the gas was flared. This situation lasted until 1978, when to conform with the Government's gas conservation policy gas surplus to platform requirements was purified and pumped to the MCP-01 gas compression platform and mingled with Frigg gas pumped to the British Gas collecting plant at St Fergus.

3.5 The layout of the platform topsides is described in more detail below. Briefly, the production deck at 84 ft above mean sea level consisted of 4 production modules, A-D Modules. A Module contained the wellheads, B Module the production separators, C Module the gas compression plant, and D Module the electrical plant and various facilities. Above these modules on the 107 ft level were a number of other modules and above these living quarters. There was a helideck on top of the main quarters module. Below the production deck at the 68 ft level was the deck support frame (DSF) which held the condensate injection pumps and the pipeline terminations and pig traps, except for that of the main oil line (MOL), which was in B Module. Below this were 2 further levels, the 45 ft and 20 ft levels. Other features were the drilling rig above A Module, the 2 flare booms at the south-east and south-west corners at the end of A Module, and the cranes, one on the east and one on the west side between B and C Modules.

Platform as of 1988

3.6 The general aspect of the Piper platform in the first half of 1988 may be seen from some of the photographs, models and drawings made available to the Inquiry. These are Figs 3.2, 3.3, J.1 and J.2, which show elevations of the platform; Plates 3-5, which give views of the platform; Figs J.3-J.7, which give plans of the decks, modules and accommodation; and Model B, a 1:33 scale model of the production deck and deck support frame, modules from which are shown in Plates 6-9.

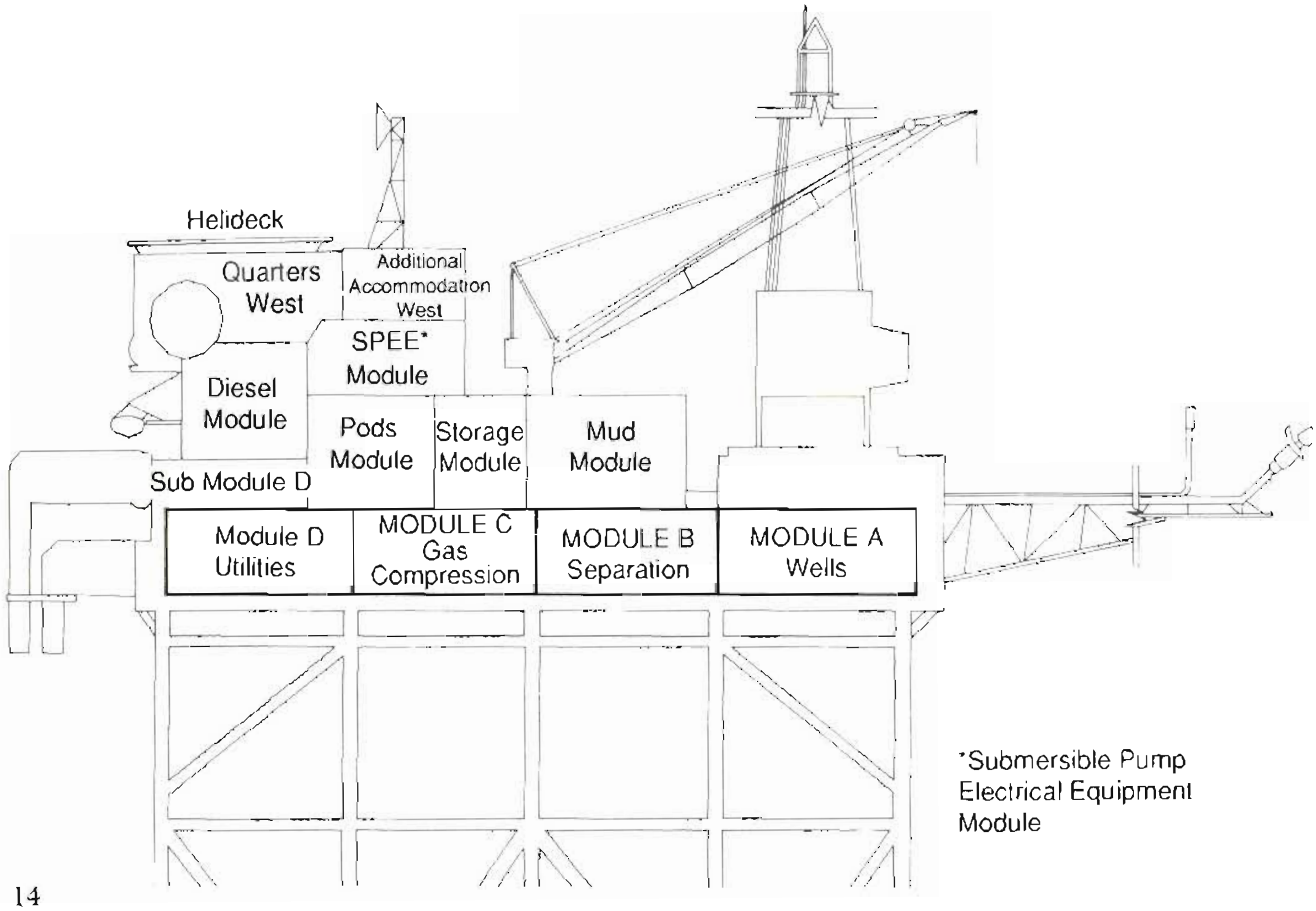


Fig. 3.2 The Piper Alpha platform: west elevation (simplified).

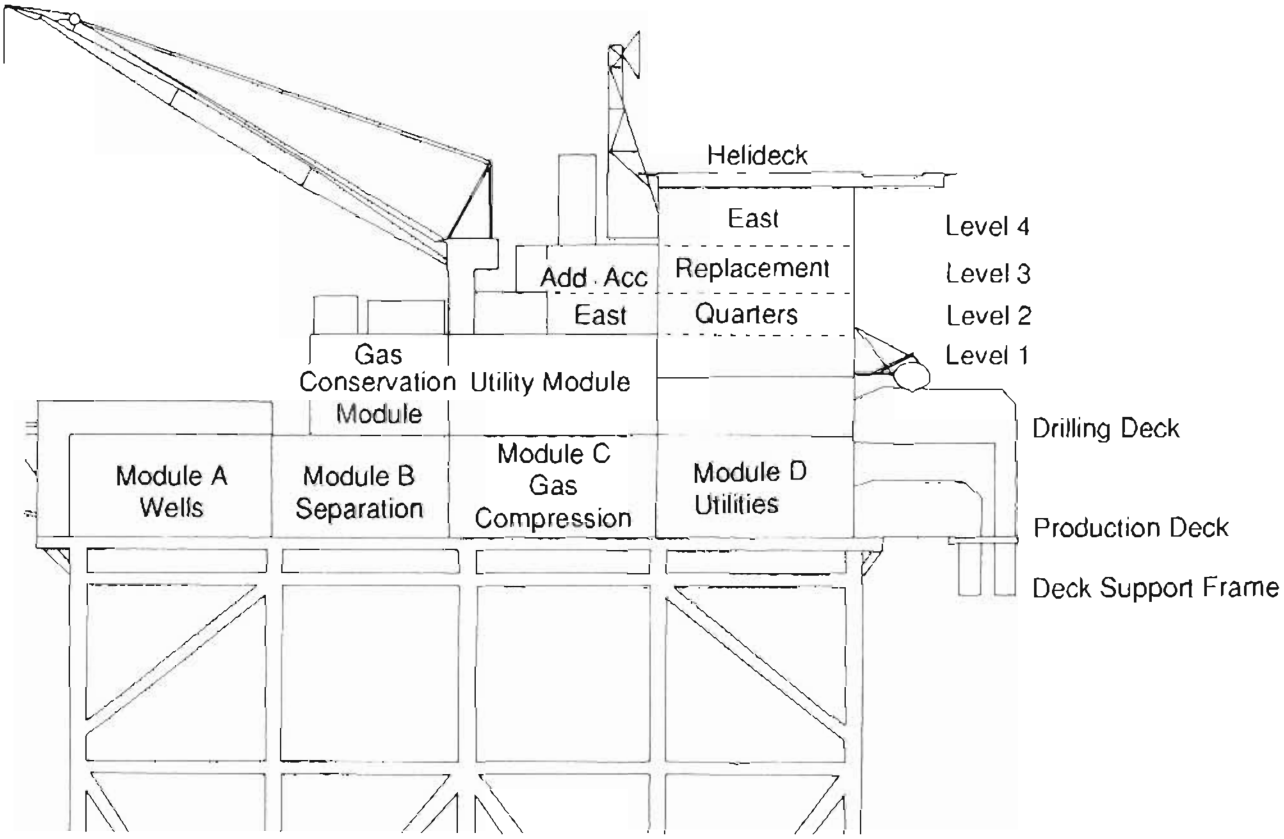


Fig. 3.3 The Piper Alpha platform: east elevation (simplified).

Operating modes

3.7 To enable Piper Alpha gas to be brought up to export requirements in 1978, first a gas dehydration unit and then a Joule-Thomson (JT) expansion valve were installed. In 1980 improved facilities for drying and expansion of the gas and a distillation column to remove methane gas from the condensate were installed. The dehydration unit was removed in 1983. The new Gas Conservation Module (GCM) occupied the space available after the second drilling derrick and support facilities were removed from the platform. The operation with the GCM in use was known as the phase 2 mode to differentiate it from the original phase 1 mode before gas treatment facilities were installed. Phase 2 was the normal mode of operation and the platform operated only in this mode from December 1980 to July 1988 with the exception of a period from April to June 1984, when it ran in the phase 1 mode, and of the period of a few days leading up to the disaster.

Jacket

3.8 The jacket was a steel structure standing in a water depth of 474 ft. On top of the jacket sat the deck support frame, the 68 ft level. Above the waterline there were 5 legs on each side of the platform. The east side was designated the A side and the west side the B side and the legs were numbered from south to north, those on the east side being therefore A1, A2, A3, A4, A5 and those on the west side B1, B2, B3, B4 and B5. The jacket was protected against corrosion by a cathodic protection system.

Topsides layout

84 ft level (production deck)

3.9 The production deck of the platform was on the 84 ft level and consisted of 4 modules, A-D Modules, all of approximately the same floor area.

A Module

3.10 A Module, the wellhead module, was located at the south end of the platform. The module was about 150 ft long east to west, 50 ft wide north to south and 24 ft high. Its floor was on the 84 ft level and its roof at the 107 ft level. This module contained the wellheads, or "Christmas trees", of which there were 36, arranged in 3 rows of 12 each.

B Module

3.11 The next module going northwards was B Module, the production module. This module contained the 2 main production separators, large vessels in which the gas and water were separated from the oil, together with a smaller test separator. At the west end of the module were the main oil line (MOL) pumps.

C Module

3.12 Continuing northwards, the next module was C Module, the gas compression module. At the east end of C Module were 3 centrifugal compressors, each in a separate enclosure with its turbine. In the centre of the module were 2 reciprocating compressors. Between these 2 sets of compressors was the centrifugal compressor gas skid, containing separator vessels and heat exchangers.

D Module

3.13 D Module at the north end of the platform was essentially the power generation module. At the east end of D Module were the main electrical, or John Brown (JB), generators, with their exhausts projecting out of the north side of the platform. Between the generators and the wall between C and D Modules were the fire pumps. In the centre of the module was Electrical Room No 2, containing switchgear, and at the east end the Mechanical Workshop, the Instrument Workshop, the HVAC room, and the emergency generator and the Emergency Electrical Room.

3.14 In addition to D Module proper, there were 2 other associated modules: the D Module mezzanine level and Submodule D. The former was located in the upper part of D Module and the latter on top of D Module. D Module mezzanine level was limited to the west side. At its east end, and therefore located approximately half way between the east and west faces, was Electrical Room No 1. Next came the Control Room. At the west end were the Electrical Workshop and the Safety Office.

107 ft level

3.15 At the next level up, the 107 ft level, there were a further set of modules. On the west side, starting above B Module and running south to north, were the Mud Module, the Storage Module, the Pods Module and Submodule D, above D Module. On the east side, starting also at B Module and running south to north, were the Gas Conservation Module, or GCM, and the Utility Module, which contained utilities for the GCM, primarily electrical switchgear. Reverting to the west side, there were 2 other modules, the SPEE Module (or SPEEM) above the Pods Module and the Diesel Module above Submodule D. The SPEEM was the submersible pump electrical equipment module and the Pods Module another storage module. The Diesel Module, or Diesel Generator Module, contained the diesel-driven electrical generator for the drilling operations.

133 ft level (drill deck and pipe deck)

3.16 The drilling derrick stood above A Module and could track across the width of the platform. The pipe deck also stretched across the full width of the platform, and from the drilling derrick to the accommodation modules. There was a crane on each side of the platform, at the join of B and C Modules. The pedestal of each crane was outside the face of the modules.

68 ft level (deck support frame)

3.17 The next level down from the production deck, or 84 ft level, was the 68 ft level, or deck support frame (DSF). At the centre of the 68 ft level were the riser terminations and pig traps for the Tartan and MCP-01 gas pipelines, under B Module, and the condensate injection pumps and the JT flash drum, under C Module. At the south end, under A Module, was the flare knockout drum and at the north end, under D Module, the Claymore gas riser termination and pig trap. On the west side at the centre there was the dive complex and in the corresponding position on the east side the produced water facilities.

Diving area

3.18 The dive complex at the 68 ft level consisted on the outboard side of the Dive Machinery Room, a switchgear room and a wet suit storage, and on the inboard side the Dive Workshop and Dive Offices and also a photographic laboratory, with to the south 2 decompression chambers. Below and inboard of the dive complex was the dive stage platform from which the divers descended into the water. Also at the platform was the divers' hut, or Wendy House. Since at this point there was no 68 ft level above, the hut was suspended from the 84 ft level. Intermediate between the dive complex and the dive stage platform both in plan position and level, suspended from the 68 ft level and entered from that level by a hatch, was the Dive Control Station, or gondola, from which the diving operations were controlled.

20 ft level

3.19 The lowest level on the platform was the 20 ft level. There was also a stage platform at the 45 ft level. Because of the proximity to the sea, access to levels below the 68 ft level such as the 20 ft and 45 ft levels was restricted to persons required to work there, on activities such as construction, maintenance and anode replacement.

Control Room and Radio Room

3.20 The Control Room was in D Module mezzanine level with its roof at the 107 ft level. The Radio Room was on the east side mounted on the Additional Accommodation East and with a view of the helideck.

Accommodation modules

3.21 The main quarters module, the East Replacement Quarters (ERQ), had 4 levels, Levels 1-4, denoted Decks A-D, respectively, and was the only accommodation at the bottom level, Level 1. At Level 2 there was in addition the bottom deck of the Additional Accommodation East (AAE). At Level 3 there were the top deck of the AAE and the bottom decks of 2 additional quarters modules, the Living Quarters West (LQW) and the Additional Accommodation West (AAW). At Level 4 there were the top decks of the LQW and AAW. The floor of A deck of the ERQ was at the 121 ft level and that of C Deck at the 147 ft level. A stairwell gave access to all 4 decks of the ERQ. Most of the module was bedrooms, either for 2 or for 4 men, with their own washing and toilet facilities.

3.22 A Deck consisted of the gymnasium, a changing room and bedrooms. Also in A Deck were the OIM's office, the general office and the production office. B Deck consisted of a changing room and bedrooms. It connected with the bottom deck of the AAE, which contained the laundry, the drilling offices, for Occidental and Bawden, and the construction offices, for the construction supervisor and the Offshore Projects Group (OPG), together with several other offices, were also on this deck.

3.23 C Deck contained the lounge, a changing room and bedrooms and also a switchgear room. It connected with the lower decks of the LQW and the AAE, the latter containing the recreation area, the TV lounge and the cinema. D Deck contained the dining-room and the kitchen, the store room and the plant room, for the heating, ventilation and air conditioning (HVAC) system; the kitchen and, apparently, the dining area too, was also referred to as the "galley". The reception area was also on this deck between the doorway to the LQW and the stairwell.

3.24 On the east face the ERQ had doors but no windows and on the north face windows but no doors. On Decks A-C the doors led out from the changing rooms and on D Deck from the dining-room. External stairways on the east face of the module led down from these exits to the 107 ft and 84 ft levels.

Emergency command centre

3.25 The reception area on D Deck of the ERQ was designated as an emergency command centre. It was from here that the Emergency Evacuation Controller would direct mustering and prepare and organise any evacuation required.

Offices, workshops, tea huts, etc

3.26 There were a number of offices, workshops, tea huts, etc, dispersed about the platform which figure in the accounts of the disaster and which therefore need to be mentioned. The constructors' tea hut and the drillers', or Bawden, tea hut were on the 147 ft level at the west wall of the AAE. The drill store, or White House, and the OPG Workshop, or fabrication shop, were at the south face of the LQW; they were on the 133 ft level, that of the pipe deck on to which they gave. The divers' hut, or Wendy House, was at the dive stage platform.

Helideck

3.27 The main helideck was on the roof of the ERQ at the 174 ft level. At the same level there was a second helideck on the roof of the LQW. There was access from the ERQ to the main helideck by 2 external stairways. One ran from a door at the reception area at the south-west corner of the ERQ and the other from a door in the dining area on the east face.

Risers

3.28 Piper was connected to other platforms and to shore by 4 pipelines, 1 oil and 3 gas (see paras 3.94-98). The risers of the MOL and the gas pipelines from Tartan and to Claymore came up the north face; that of the gas pipeline to MCP-01 up the east face. The MOL terminated in B Module and the 3 gas lines on the 68 ft level. The MOL came southwards just beneath the DSF at a level of 64 ft before rising into B Module.

Flare booms and heat shield

3.29 There were 2 flare booms, running out from A Module at the south-east and south-west corners of the platform. The provision of 2 flare booms allowed the flare used to be altered to suit the wind direction. The flare boom carried the high pressure (HP) flare, the low pressure (LP) flare and the atmospheric, or zero, vent. The HP flare was the main flare which took gas vented from high pressure sources. The LP flare burned gas from low pressure sources such as the deoxygenation towers. The zero vent, which was not continuous and had no flare, allowed intermittent venting of small volumes of gas at virtually atmospheric pressure. On the south face and round the east and west sides of A Module there was a heat shield, which consisted of 2 close mesh layers of wire and was intended to deflect radiant heat coming from the flare.

Production process

3.30 The flow diagram of the process operating in phase 1 mode is shown in Fig J.8 and a further diagram of the back end of the process in Fig 3.4.

Oil

3.31 The reservoir fluid from the production wells, a mixture of oil, gas and water, passed to the production separators operating at a pressure of 155 psia, where it was separated by gravity into the 3 phases. Oil from the 2 main separators was pumped by 2 booster pumps through metering equipment to the suction header of the MOL pumps, which then pumped it down the oil export pipeline to the Flotta terminal. Oil from the test separator was pumped by an oil transfer pump back to the 2 main separators.

Gas

3.32 The gas from the separators passed to the condensate knockout drum and into the 3 centrifugal compressors, where it was compressed to a pressure of 675 psia. It was then boosted to 1465 psia by the first stage of the 2 reciprocating compressors.

3.33 In phase 2 mode, the gas went next to the GCM, where it was passed through the molecular sieve driers. It was then cooled by reducing the pressure to about 635 psia across a turbo-expander and returned to the phase 1 plant at the outlet of the JT flash drum. Condensate formed in the GCM passed to a distillation column, the demethaniser, from which methane was taken off, and the stripped condensate taken back to the JT flash drum. In phase 1 mode the plant in the GCM was isolated and the gas from the first stage reciprocating compressor system was let down in pressure across the JT valve, PCV 721, into the JT flash drum. From the outlet of the JT flash drum the gas passed to the inlet of the second stage of the 2 reciprocating compressors, where it was compressed to 1735 psia. The high pressure gas from the second stage reciprocating compressors went 3 ways: to serve as lift gas or to MCP-01 as export gas or to flare.

Condensate

3.34 Condensate was knocked out of the gas at a number of points in the system and taken to the JT flash drum. This vessel served as a surge drum for the condensate pumps. Condensate was taken from the JT flash drum by 2 condensate booster pumps, which raised the pressure to 670 psia, and thence to the 2 condensate injection pumps, which raised it to 1100 psia. The condensate then passed through a meter into the MOL.

Produced water

3.35 The water from the production separators, known as the produced water, passed to the plate skimmer for further separation of oil and thence to the hydrocyclone, which separated out any remaining free oil; these units were both on the east side of the 68 ft level. The clean water than passed to the overboard dump.

Process plant

3.36 The process flow diagram, Fig J.8, shows the main items of equipment. Further details on the following items are given in Appendix F: centrifugal compressors (paras F.2-9); reciprocating compressors (paras F.10-14); JT flash drum and other condensate collecting vessels (paras F.15-18); condensate injection pumps (paras F.19-34);

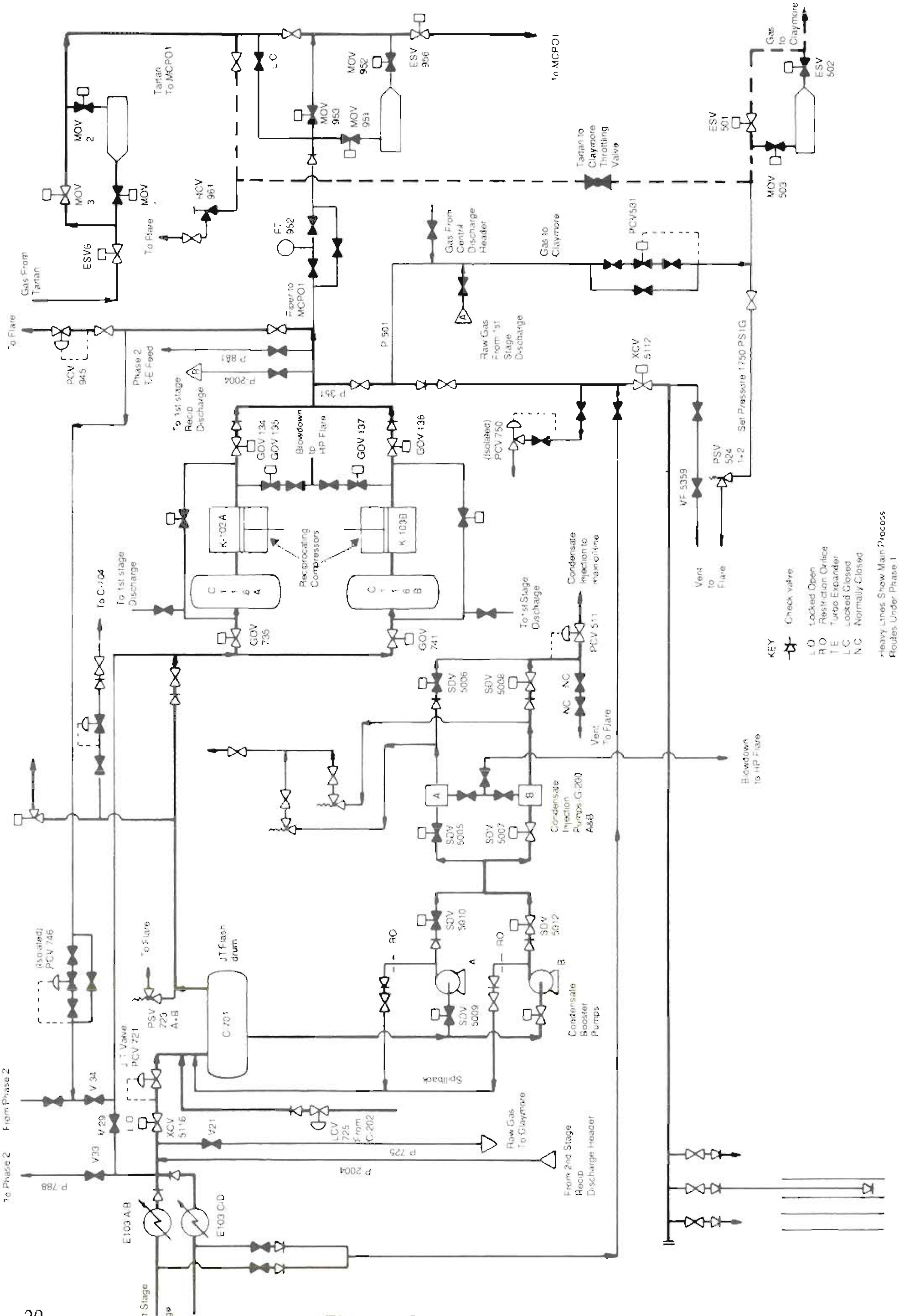


Fig. 3.4 Simplified flow diagram of the second stage reciprocating compressors and export and gas lift lines.

methanol injection system (para F.35); gas flaring and pressure relief (para F.36); and the Control Room (para F.37).

Wellheads

3.37 The line carrying oil from an individual well terminated in a Christmas tree. It passed first through a hydraulic master valve (HMV), which allowed the flow from the well to be shut off in an emergency, then into a manifold. The oil was taken off from this through pneumatic wing valves. The flow through a wing valve was adjusted by a choke valve and the oil then passed through a check valve, or non-return valve (NRV), into a header leading to one of the separators. There was a further valve down each well, the downhole safety valve (DHSV), which provided an additional means of shutting off the flow. There was a valve, XCV 5112, on the gas lift line just before it entered the gas lift manifold which supplied the individual wells. There was a further valve on the gas lift line to each individual well.

Separators

3.38 There were 2 main production separators and a smaller test separator. The separators were large vessels in which the oil, water and gas were separated and taken off as separate streams. In the bottom of the separator there was a weir and 2 liquid offtakes. The water collected behind the weir and was run off to the produced water system. The oil, which was lighter than the water, floated on it and flowed over the weir into the oil offtake. The gas passed through a filter pad to remove droplets and then went through the gas cooler to the condensate knockout drum. There were level control loops both on the water flow and on the oil flow from the separators. The oil was pumped from the separators manifold by 4 MOL pumps.

Centrifugal compressors

3.39 There were 3 parallel centrifugal compressor trains, located at the east end of C Module (see Fig J.4 and Plate 7), which compressed the gas to 675 psia. Each compressor was driven by its own gas turbine and each compressor set was housed in an individual enclosure, the gas turbine and the compressor being in separate compartments of the enclosure with the turbines outboard. The bulkhead between the compartments was designed to prevent any leak of flammable gas from the compressor entering the turbine compartment.

Reciprocating compressors

3.40 There were 2 parallel trains of reciprocating compressors with first and second stage compression. The first stage compression raised the pressure of the gas from about 675 psia to 1465 psia and the second stage to 1735 psia. The reciprocating compressor trains were located in the western half of C Module (see Fig J.4 and Plate 7). The 2 stages of compression in each train were performed by a single machine. There was a recycle loop around the first stage of each compressor and another recycle loop around the second stage. There were also facilities to unload the machines to allow them to operate at low gas flows.

JT flash drum and other condensate collecting vessels

3.41 Condensate in the gas leaving the separators was knocked out in the condensate knockout drum and pumped back to the separators by 2 condensate transfer pumps. The condensate suction vessel, located at the 68 ft level and operating at a pressure of 665 psia, collected condensate from the centrifugal compressor suction scrubbers. The condensate passed to the JT flash drum, also on the 68 ft level, entering the inlet pipe just downstream of the JT valve. In phase 1 operation the gas from the first stage of the reciprocating compressors passed through the JT valve, across which pressure was let down from 1435 psia to 635 psia. The Joule Thomson (JT) effect associated with this reduction in pressure gave a fall in temperature of the gas causing liquid condensate to form. In phase 1 operation the JT flash drum received condensate from the JT valve and from the condensate suction vessel. It acted as a surge tank supplying the condensate pumps which pumped the condensate into the MOL. The level of condensate in the drum was maintained by a level controller which controlled the speed of the condensate injection pump.

Condensate disposal

3.42 Condensate from the JT flash drum was pumped into the MOL by a pair of condensate booster pumps in series with a pair of condensate injection pumps. Both sets of pumps were on the 68 ft level. A simplified flow diagram of the condensate injection pumps is given in Fig 3.5 and details of the pumps are shown in Fig J.9. Each pump was provided with an isolation or shutdown valve, a gas-operated valve (GOV), on the inlet and another on the outlet. On the suction side there was a manual isolation valve upstream of the GOV and a pulsation dampener downstream of it. On the discharge side there was a pulsation dampener, a high pressure trip and then an NRV upstream of the GOV.

3.43 There was normally one pump operating and one on standby. There was no automatic changeover for the pumps. If the working pump tripped out or stopped, it was necessary to go to the pumps and start the standby pump manually.

3.44 The pressure safety valve on A pump was PSV 504 and that on B pump PSV 505. These valves were located on the next level up, in C Module. The relief lines to the PSVs ran up through the floor of this module. The discharge lines from the PSVs then returned to the condensate suction vessel, which was in the ceiling of the 68 ft level. PSV 504 was located in C Module at a height of 15 ft.

3.45 Condensate from the discharge header of the condensate injection pumps on the 68 ft level passed in a 4 inch diameter pipe through an orifice meter to measure the flow rate. The line then passed up into C Module, ran horizontally west for a few feet and then turned south and passed through the B/C firewall into B Module. There it travelled south a few feet, turned west, then south and then briefly east to enter the MOL just upstream of the emergency shutdown valve (ESV), ESV 208. The passage of the line, 2-P-517-4"-F15, through C and B Modules is shown in Plates 6-8.

Methanol injection

3.46 Under phase 1 (wet gas) process conditions there existed a risk of formation of hydrates, which are crystalline, ice-like solids composed of hydrocarbons and water. Hydrate slugs and blockages were undesirable and could be hazardous. In accordance with industry practice, methanol was injected at strategic points to lower the hydrate formation temperature and so eliminate hydrates. The methanol injection points are shown in Fig J.8 and the methanol injection system in use in phase 1 operations on 6 July 1988 is described in Appendix F (para F.35).

Gas flaring, venting and pressure relief

3.47 There were a number of pressure control valves, PCVs, through which gas passed, or could be passed, to flare. There were a large number of pressure safety valves, PSVs, which protected vessels and equipment against over-pressure. In almost all cases there were a pair of PSVs; the condensate injection pumps were an exception, there being only one PSV on each pump. Some of the principal PCVs and PSVs are summarised in Table 3.1.

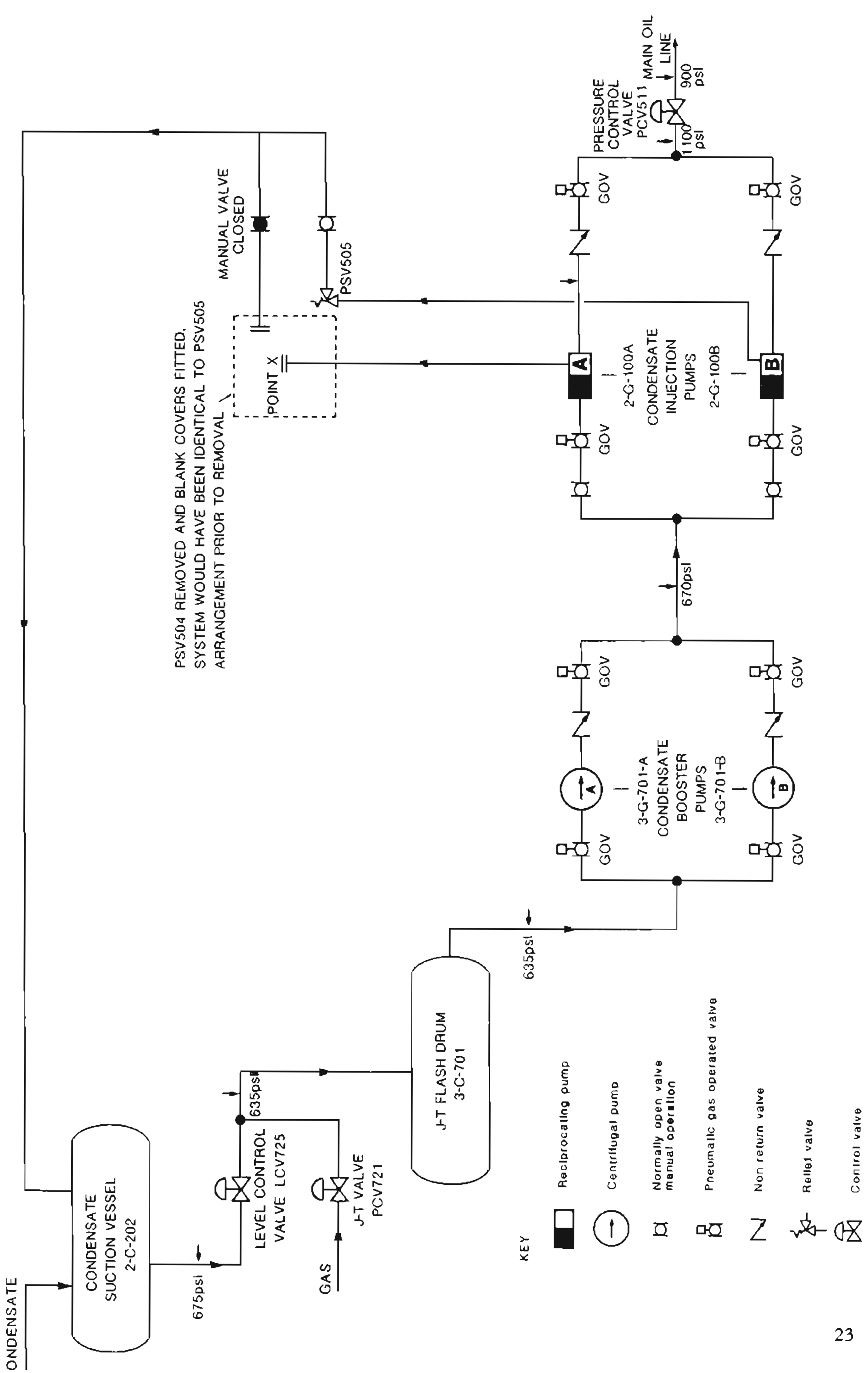


Fig. 3.5 Simplified flow diagram of the condensate injection pumps. *See also* Fig. J.9.

Control Room

3.48 The layout of the Control Room is given in Fig J.4(c) and some of the panels are shown in Plate 10(a). The instrumentation provided in the Control Room was oriented to monitoring rather than control. There were panel displays but few controls. The 2 principal panels were the main control panel, or mimic panel, and the main fire and gas (F&G) panel. There was also a separate alarm panel above the mimic panel.

3.49 Principal items of equipment had their own local control panels. If an alarm came up on any one of a number of instruments on the local panel, a "common alarm" would come up also in the Control Room. The Control Room operator would then radio the appropriate outside operator and ask him to investigate.

3.50 The gas detectors also were grouped in zones and an alarm on the F&G panel indicated only that one of the detectors in that particular zone had gone into alarm. However, in this case it was possible to determine which detector this was by going around the back of the panel and examining the individual gas detector modules.

3.51 If an item went into alarm, the alarm light for the particular equipment skid would be illuminated and the alarm annunciator, or buzzer, would sound; in most cases the light would also flash. The operator would then generally "accept" the alarm by pressing a button and silencing the buzzer. The alarm light would cease to flash but would stay on. In order to re-set it, it was necessary to go behind the panel. If, however, the alarm condition still existed the light would remain on.

3.52 There was also a computer VDU which showed the telemetry data, giving information on the status of the pipeline valves on the other platforms and the oil terminal.

3.53 The principal items of equipment were controlled from local control panels. For example, the centrifugal compressors and the condensate injection pumps could not be started and stopped from the Control Room but only at the local panels.

3.54 Facilities for emergency shutdown (ESD) available in the Control Room included a single button for initiation of platform ESD (PESD). On PESD the Emergency Shutdown Valve (ESV) on the main oil pipeline closed but not the ESVs on the 3 gas pipelines, that from Tartan and those to MCP-01 and Claymore. For these there were 3 further, separate buttons.

Platform systems

3.55 An account is now given of various platform systems. Further details on the following items are given in Appendix F: electrical supply system (para F.38); hazardous area classification (paras F.39-41); gas detection system (paras F.42-50); emergency shutdown system (paras F.51-63); and pipeline depressurisation facilities (para F.64).

Electrical supply system

Main generators and power supply

3.56 The main electrical supply came from 2 JB turbo-driven generators each rated at 24,000 kW and located in D Module (see Fig J.4). These generators had facilities for dual fuel firing. They were normally fired by fuel gas but could be fired by diesel. Changeover to diesel on falling fuel gas pressure was automatic.

3.57 The main generators supplied power to a 13,800V switchboard located in Electrical Room No 1 in D Module mezzanine level. Transformers located in D Module let the voltage from this switchboard down to 4,160V and 440V switchboards, located in Electrical Room No 2 in D Module, and to the drilling 600V switchboard, located in the Diesel Module. This main 440V switchboard fed the 440V system and also an emergency 440V switchboard and a drilling 440V switchboard (see below). The 4,160V supply was used to drive motors in the 100-1000 horsepower range such as those on the water injection pumps, the MOL pumps and the condensate injection pumps. It was also the sole supply to the electrically driven utility and fire-water pumps. The 440V supply was used for smaller motors.

Drilling generators and power supply

3.58 There was a separate power supply for drilling, which also had its own emergency back-up. There was a diesel-driven generator located in the Diesel Module, with its own emergency generator in the same module. The generator supplied the drilling 600V switchboard. Most of the drilling equipment ran off 600V DC. There was also in the module the drilling 440V switchboard. This supplied power to the quarters modules. Lighting for the quarters was supplied by a 208V switchboard fed from this 440V switchboard. When the drilling generator was on, it supplied the drilling 440V switchboard, and when it was not, the supply was from the main generators.

Emergency generators and power supply

3.59 There was in addition an emergency generator, turbine-driven and diesel-fired, rated at 800 kW and generating 440V, located at the west end of D Module, north of the Instrument Workshop (see Fig J.4(b)). This generator was designed to start up automatically on failure of the main generators. The emergency generator supplied the emergency 440V switchboard. Normally this switchboard was fed from the main 440V switchboard, but on loss of the main generator there was automatic switchover to the emergency generator. The function of the emergency generator was to supply critical services. These included HVAC, instrument air and strategic valves, and also emergency lighting. In the event of failure of the emergency generator, the emergency 440V switchboard could be supplied by the drilling generator, but this required manual changeover. The emergency 440V switchboard also fed the D Module 125V DC and 120V AC supplies.

Uninterrupted power supplies and other power supplies

3.60 Back-up for the D Module 125V DC and 120V AC supplies taken off the emergency 440V switchboard was provided by battery power supplies, the uninterrupted power supplies (UPS), located in D Module mezzanine level north of the Control Room. The function of the UPS was to provide power supplies to the critical systems during the momentary interruption while the emergency generator was coming up to speed or, in the event that this generator failed to start, to maintain that supply. There were 2 further UPS in the Utility Module, a 125V DC and a 120V AC UPS. In addition certain individual items of equipment had their own battery power supplies. These included a small number of emergency lights throughout the platform.

Power supplies to quarters and for lighting

3.61 Power was supplied to the accommodation from the drilling 440V switchboard. This switchboard could also relay power from the main generators. If the drilling generator was operating, the power supply for the quarters was taken from that generator, but if it was not operating, quarters power was supplied by the main generators. Power for lighting in the accommodation came from the drilling 208V switchboard. A limited proportion of the lighting, in the quarters and on the platform generally, was designated as emergency lighting. The emergency generator provided an emergency power supply for the emergency lighting in the quarters. The 125V DC UPS provided a back-up supply for the quarters emergency lighting. The emergency power supply for other emergency lighting on the platform was in the form of local battery packs. The 120V AC UPS provided an emergency power supply to the general alarm and personal address (GA/PA) system. The 120V AC UPS in the Utility Module was also given as a supply to the GA system.

Protective systems

Hazardous area classification

3.62 Areas in which a hydrocarbon leak might occur and from which it is necessary to exclude ignition sources were classified in accordance with international codes on hazardous area classification. The code specifically referred to was the Institute of Petroleum (IP) code.

Firewalls

3.63 The ERQ and AAW had A60 exterior firewalls. There were A60 firewalls around the fire pumps. There were firewalls between A and B Modules, between B and C Modules, and between C and D Modules (the A/B, B/C and C/D firewalls, respectively). The C/D firewall was of double layer construction. Details of the construction of the B/C and C/D firewalls are given in Chapter 5. Each of these 3 firewalls was provided with a water curtain, fed from the fire deluge ring main, to provide enhanced endurance. The extent of openings in the firewalls was shown in Fig 4.7 of the Petrie Report, which showed a spring-loaded double door in the A/B firewall on the line of the MOL pig trap and a pulley weight-closing single door in the B/C firewall on the same line, and explicitly stated that there was no opening in the C/D firewall, again on the same line. Evidence given by operatives on the possible existence of apertures in the firewall between B and C Modules is described in Appendix F (paras F.68-69). The platform did not have blast walls.

Gas detection system

3.64 The platform was provided with an F&G detection system. There were gas detectors in A-C Modules and at the 68 ft level.

3.65 In general, gas detectors were grouped in zones with several in each zone. A gas alarm on the F&G panel in the Control Room indicated therefore that one of the detectors in the zone had detected gas, but did not indicate which one. To determine this it was necessary to go behind the panel and observe the particular instrument.

3.66 The gas detection system in C Module is shown in Fig J.10. The module was divided into 5 zones, C1-C5. C1 was the west end of the module, C2 the east end and C3-C5 centrifugal compressors A-C, respectively. The gas detectors in C Module were located mainly in the roof to detect gas lighter than air, essentially methane, although there were some at lower levels.

3.67 In general, the low gas alarm level was set at 15% of the lower explosive limit (LEL) and the high gas alarm level at 75% LEL. Detection of gas at the lower alarm level resulted in an alarm in the Control Room; it did not lead to any automatic action such as activation of the fire-water deluge. The Control Room operator would, however, instruct the outside operator to investigate.

3.68 There were also gas detectors on certain individual items of equipment in safe areas such as D Module, to shut the particular equipment down on detection of gas.

Fire detection system

3.69 The fire detectors consisted of ultra-violet (UV) flame detectors and heat detectors. There were fire detectors in A, B and C Modules and at the 68 ft level. Detection of fire by a fire detector was designed to activate automatically the fire-water deluge system. It was practice, therefore, to disable the automatic action of the fire detection system in a particular zone if activities, such as welding, were taking place in that zone which might set off a spurious fire alarm. The fire detectors themselves were not disabled thereby and would still provide fire alarm.

Fire-water deluge system

3.70 The platform was provided with a fire-water deluge system. An area designated as a deluge area was protected by a deluge set fed by a ring main. On the production deck level there was foam deluge protection in the whole of A-C Modules and in part of D Module, including the fire pumps, whilst on the 68 ft level there was foam deluge at the Tartan and MCP-01 pig traps and water deluge at the condensate injection pumps, the Claymore pig trap, and part of the produced water area. There were fire-water ring mains on the 68 ft and 84 ft levels. The only part of the deluge activated automatically was that covering the area in the module where fire had been detected. Other parts of the deluge system could be brought on manually. The deluge system did not come on automatically on PESD. The ring mains were maintained full of sea water at a pressure of 110 psi by the utility pumps.

Fire pumps

3.71 The fire-water main for the deluge system was supplied by utility pumps and fire pumps. The utility water pumps provided cooling water for items such as the gas turbines and generators and for the lube oil systems. There were 4 pumps: 1 utility pump, 2 utility/fire pumps and 1 fire-water pump. Normally the utility pump, 1-G-124A, would be running to supply utility water and one of the utility/fire pumps, 1-G-124B, to supply utility water and keep the fire main pressurised. The former supplied primarily the utility main, although it could supply the fire main through a restrictor orifice plate. The latter supplied both the utility and fire mains. All 3 utility or utility/fire pumps were electrically driven and ran off the 4,160V switchboard supplied by the main generators and would be lost if this power supply failed; there was no alternative emergency power supply for these pumps. There was, however, a separate diesel-driven fire pump, 1-G-123, available to come in on loss of electrical power. In addition, utility/fire pump 1-G-124C also had a standby diesel drive. These 2 pumps were replacement pumps, installed in 1983. In a shutdown, pump 1-G-124C could be operated on diesel to provide cooling water for the main generators. With this exception, these 2 pumps would not normally be operating. If the pressure in the fire main fell, utility/fire pump 1-G-124C would come in to maintain the pressure. If the pressure continued to fall, then at a pressure of about 100 psi the diesel-driven fire pump 1-G-123 would start up automatically. The 4 pumps were located in D Module between the main generators and C Module (see Fig J.4(b)). The fire pump 1-G-123 and the utility/fire pump 1-G-124C were in a fireproof enclosure, and the utility pump 1-G-124A and the other utility/fire pump 1-G-124B were outside this enclosure to the west.

3.72 Stilling columns for the sea-water supply to the pumps were located on the east side of the platform near leg A4 (see Fig. 3.6). The pump intakes were at a level of about -120 ft. The intakes were some 5 ft apart and were furnished with protection cages to prevent divers from getting sucked in. The stilling columns were 2 ft diameter and the cages the same diameter and about 4 ft long. The 2 diesel-driven pumps, fire pump 1-G-123 and utility/fire pump 1-G-124C, could be put on manual start to protect divers against a sudden flow of water at the pump intakes. If these 2 pumps were on manual start, this was indicated in the Control Room by an alarm light. They could then be started only by going to the pumps themselves and starting them at the local control panel in the fireproof enclosure.

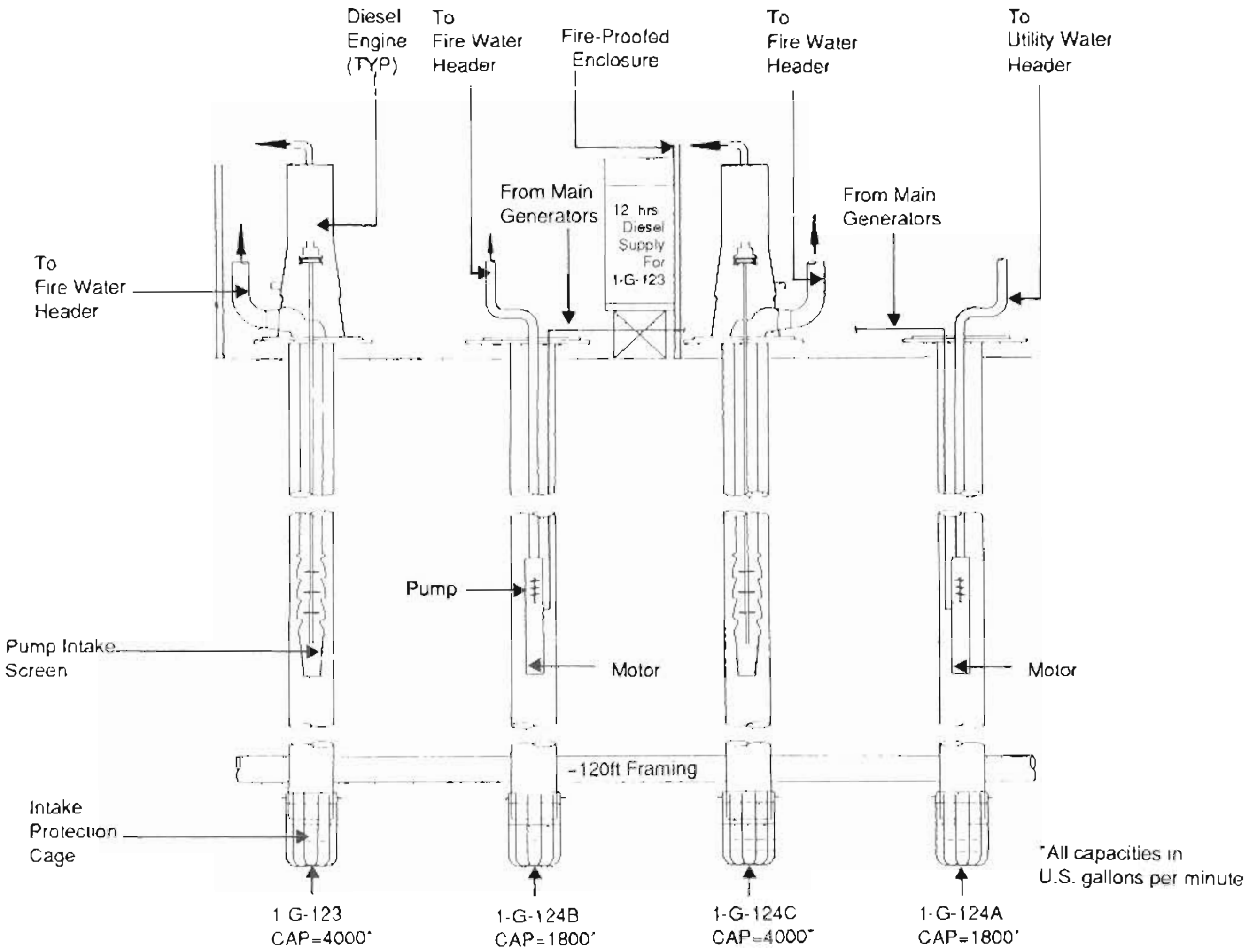


Fig. 3.6 The inlets of the fire pumps.

Foam system

3.73 In certain areas where an oil fire might occur there was automatic addition of a foam agent to the fire-water so that the fluid discharged was foam rather than water. An aqueous film forming foam system, located in Submodule D, injected foam into the fire-water header at specific deluge sets. Foam injection was by an electric pump backed up by a diesel-driven pump.

Other fire-fighting facilities

3.74 The fire-water and foam systems were supplemented by other fire-fighting systems and equipment, which included water hose reels, halon systems, twin agent units and fire extinguishers. In addition to the fire-water deluge system, there were fire-water hose reels and fire extinguishers at strategic points for local manual fire-fighting.

Emergency shutdown system

3.75 The platform was provided with an ESD system. The main ESVs are shown in Fig J.8. The main functions of the ESD system were:

- — to shut down and isolate the flow from the reservoir
- — to shut down and isolate the flow through the pipelines leaving and entering the platform

— to shut down all major items of process equipment
— to initiate automatic blowdown of platform inventories to flare.

Activation of PESD

3.76 A platform ESD (PESD) could be activated in a number of ways, automatic or manual. There were 2 systems, one pneumatic and one electrical, which could initiate a PESD automatically. The 2 systems had somewhat different direct effects. However, one of the effects of activation of the pneumatic system was to activate the electrical system and vice-versa. Hence the ultimate effects were the same. Pneumatic PESD was initiated by loss of pressure in a pneumatic pressure loop, maintained at 50 psi, which ran through the production modules. The loop had 58 fusible links which would melt in a fire and activate the ESD. The pneumatic loop also lost pressure if there was a loss of instrument air pressure. Electrical overall emergency shutdown (OESD), effectively PESD, was initiated by loss of power from the D Module 125V DC system. It was stated that loss of the main power supply would cause a PESD, but the mechanism by which this occurred was not clearly established.

3.77 PESD was activated automatically by a limited number of major process upsets. On the other hand shutdown of a major item of equipment did not necessarily involve a PESD. For example, high level in one separator would cause shutdown of that separator and of its associated wells, but not shutdown of the platform. As far as concerns fire, there was no mechanism other than the fusible links by which fire would activate the PESD. Neither a gas alarm nor a fire alarm would in itself initiate a PESD. Detection of gas at equipment located in a safe area activated shutdown of that equipment. This applied to the main generators and in this case the loss of main power would lead to a PESD. PESD could be activated manually from the Control Room or from manual push-buttons (break-glass time switches) at 20 locations on the platform. The procedure was that anyone aware of a possible hazard should contact the Control Room, but the purpose of having manual ESD points distributed around the platform was so that personnel could effect shutdown without having to communicate with anyone else and all operating personnel had the authority to initiate a PESD.

Pipeline shutdown

3.78 Each of the 4 pipeline ESVs could be closed by manual operation of its individual push-button in the Control Room. The MOL ESV, ESV 208, was the only one of the 4 valves which closed on PESD; those on the 3 gas pipelines did not. The 4 ESVs were fail-safe in that they closed on loss of power.

Communications systems

Personal address and general alarm system

3.79 The PA system, or tannoy, allowed persons at strategic points such as the Control Room or the Radio Room to address other personnel on all parts of the platform. It was piped into every bedroom in the accommodation and, although it was usually switched off in the bedrooms, it could be switched on from the Control Room so that personnel in their rooms could hear it. The GA system, or klaxon, also went to all parts of the platform, including the bedrooms.

Other internal communications

3.80 Piper was provided with 2 systems of telephones for internal communications. The main Mitel system had about 100 extensions throughout the platform. There was a separate manual sound-powered system for the drilling area. It was also possible to telephone the shore and the other platforms via the telecommunications links, described below. In addition, there were a number of ultra high frequency (UHF) radios.

External communications

3.81 The platform had 2 telecommunications links: a tropospheric scatter system and a direct line of sight microwave radio system. Piper was linked to the land station at Mormond Hill by a tropospheric link. There were line of sight links between Piper and Claymore, between Piper and Tartan, and between Piper and MCP-01, but these other platforms had no line of sight links with each other. The telecommunications links of Claymore and Tartan to shore were via Piper; they had no direct link. MCP-01, however, had its own tropospheric link to Mormond Hill, which therefore served as an alternative link for Piper, via the line of sight link to MCP-01. Mormond Hill was linked to Aberdeen by line of sight and there was a land line and radio link between Aberdeen and Flotta. The 2 telecommunications links carried telephone, telex, telemetry and computer traffic. The communications systems for Piper, Claymore and Tartan are illustrated in Fig 3.7. There was also a back-up INMARSAT system, which could relay by satellite a single telephone or telex channel. This was kept in a locker in the Plant Room in the AAW.

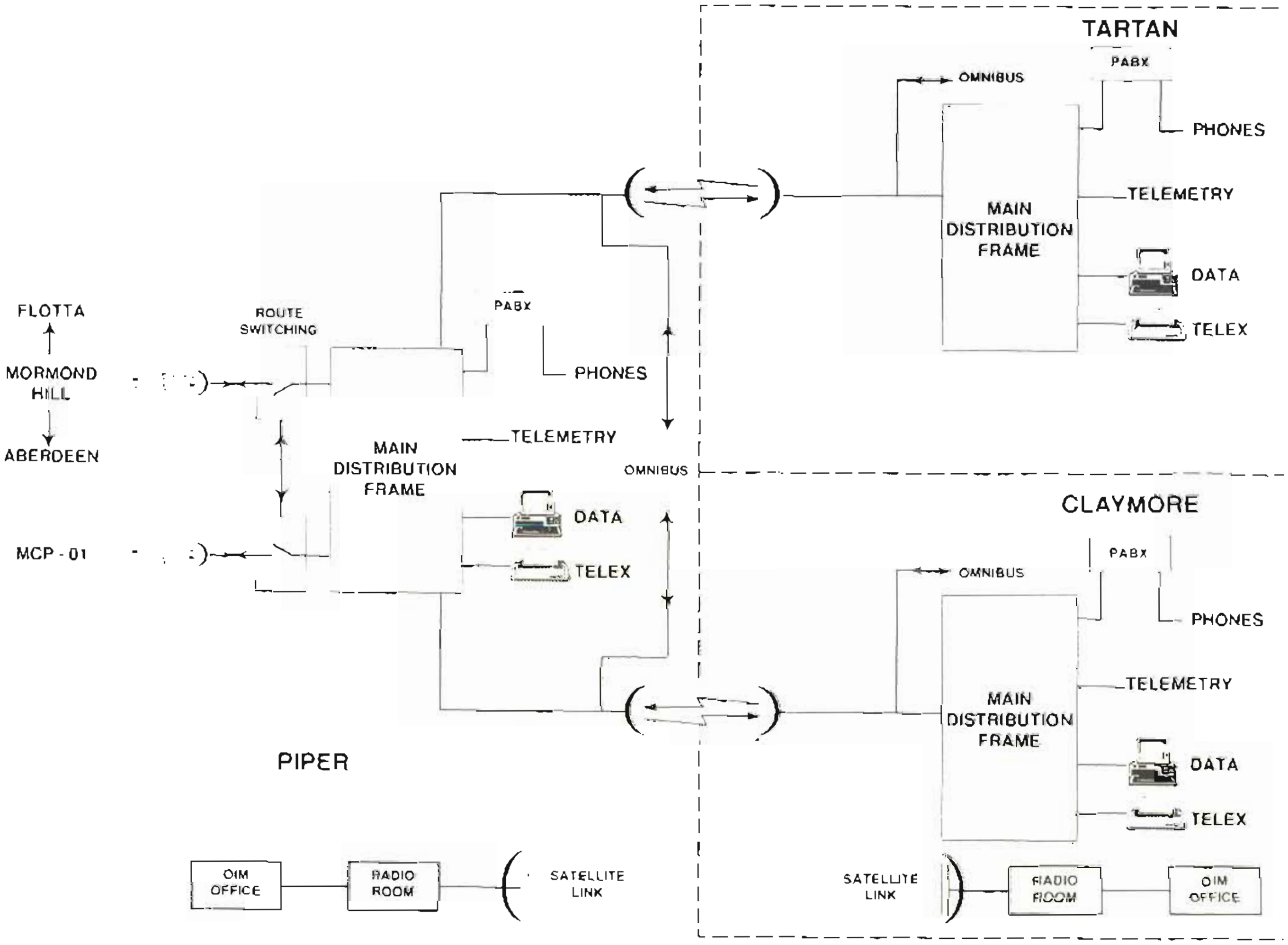


Fig. 3.7 Block diagram of the telecommunications system.

3.82 External communications could also be conducted by means of radio. There was a safety of life at sea (SOLAS) radio, the high frequency ship-to-shore (HF/SSB) radio, which operated at 2 megahertz and a very high frequency (VHF) radio for international marine, private marine and aircraft communications. There were some 50 hand held radio sets on the platform, of which 14 were the UHF sets already mentioned, and the rest VHF.

Evacuation and escape systems

Escape routes

3.83 There were escape routes on the platform with arrows painted to mark the routes and signs showing a general layout, an indication of the particular spot, and the direction of the lifeboats.

Life-saving appliances

3.84 The platform had a complement of 6 lifeboats and 13 life rafts, together with 31 life-buoys, 519 life-jackets and 12 knotted ropes. The maximum overnight capacity of the accommodation was 241 persons. There were 226 persons on board (POB) on 6 July.

Lifeboats

3.85 Lifeboats Nos 1, 2, 4 and 5 were located on the north face with lifeboats No 3 on the west face and No 6 on the east face, both towards the north end, as shown in Figs J.1 and J.2 and Plates 3-5. Lifeboat No 1 was at the 121 ft level and No 2 at the 124 ft level, lifeboat No 3 at the 107 ft level, and lifeboats Nos 4-6 at the 84 ft level. There was a seventh lifeboat ashore for maintenance at any given time. The lifeboats were totally enclosed motor propelled survival craft (TEMPSC). Each lifeboat held 47 people and was equipped with a water drench system to cool it in case it had to travel through a burning oil spill. An illustration of a lifeboat is given in Fig 3.8.

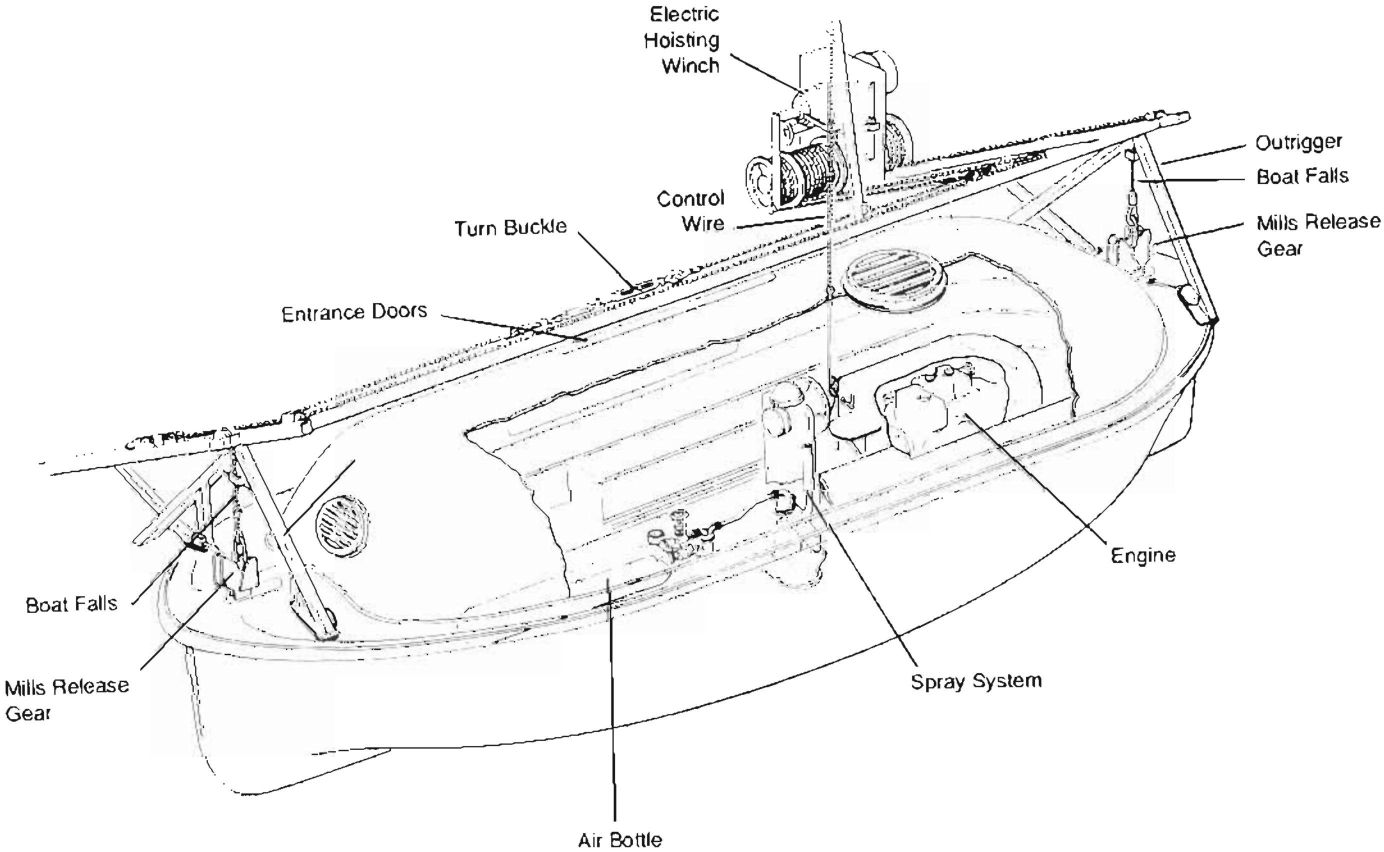


Fig. 3.8 A Piper lifeboat.

Muster points

3.86 The primary muster points were the lifeboat stations. Personnel were instructed that if a general alarm occurred, they should go to their lifeboat. There was an additional, or secondary, muster area in the dining-room, or galley, which would be used for helicopter evacuation. Personnel were told that if it were necessary to muster in the galley they would receive instructions to this effect when they were at their lifeboats. Personnel who could not reach their lifeboats would receive instructions from the emergency command post in the reception.

Life rafts

3.87 There was a nominal complement of 13 25-man life rafts situated at the 68 ft level, but at any given time there would normally be one life raft away for servicing. The life rafts were held in glass-reinforced plastic, throw-over containers. A life raft on its launching platform is shown in Plate 12(b). Once in the water the inflation sequence was initiated by pulling a rope.

Escape to the sea

3.88 Situated next to each life raft to allow escape to the sea was a single knotted rope.

Other life-saving equipment

3.89 There were 31 life-buoys, or Perrybuoys, on the platform. There was a complement of 519 life-jackets, distributed at various points, including the accommodation, lifeboat stations and life rafts. For each man there was a life-jacket in his cabin and at his lifeboat station. Each person travelling to the platform was given a survival suit at the heliport. He retained it during his tour, keeping it in his cabin, and wore it on the return journey to shore. There were no additional survival suits located at strategic points such as the lifeboat stations. There were 2 types of breathing apparatus provided. There were 26 Draeger working breathing apparatus (BA) sets and 19 Draeger "saver" sets. The former were intended for working in an environment where there might be a leak of gas such as hydrogen sulphide. The latter were suitable only for shorter periods. The BA sets were distributed about the platform.

Permit to work and handover systems

3.90 In accordance with industry practice, maintenance and construction work on the platform was controlled by a permit to work (PTW) system. A PTW system is a formal procedure, involving the use of written permits, used to ensure that potentially dangerous jobs are done safely. The system is designed to ensure in general that responsibilities are defined, information is communicated, precautions are taken, equipment is taken out of, and returned to, service safely, and specifically that

- the equipment to be worked on is identified, the maintenance work to be done is specified and is approved by a senior supervisor, the Approval Authority
- the equipment is isolated from the rest of the process and remains so for the duration of the work and the safety precautions necessary for the work, such as gas testing or use of protective clothing, are listed prior to the issue of the permit; these actions are the responsibility of the Designated Authority
- the maintenance work is carried out as specified by the permit, the safety precautions listed are adhered to, and upon satisfactory completion of the work the permit is returned to the Designated Authority; these actions are the responsibility of the Performing Authority
- finally, the equipment is checked to confirm that the work has been satisfactorily completed and the isolations removed so that the equipment can be returned to service; these actions are the responsibility of the Designated Authority.

3.91 Occidental operated a PTW system on Piper in which the Approval Authority was the production superintendent, the Designated Authority the shift lead production operator, and the Performing Authority the shift maintenance lead hand or, alternatively, the supervisor of a group of contractors' personnel. The PTW form used by Occidental is shown in Fig 3.9. There was a blue form for cold work, a green form for electrical work and a pink form for hot work.

3.92 Under the system operated by Occidental, a PTW was suspended if the maintenance work ceased for any length of time, for example if the work stopped overnight or stopped to await the arrival of a spare part. A PTW was suspended by the Performing Authority returning the permit to the Designated Authority and both signing that the work was suspended, the permit being reissued when the work was to be resumed. During the interval the equipment remained isolated.

3.93 Information on maintenance work was also included in the handovers between personnel which took place at shift changeover and in various types of log.

Platforms and terminals linked by pipeline to Piper Alpha

3.94 Piper was linked by pipelines, 3 gas and 1 oil, to the 3 other platforms - Claymore, Tartan and MCP-01 - and to the oil terminal at Flotta (see Fig 3.1). On each of the 3 production platforms - Piper, Claymore and Tartan - condensate was injected into the main oil line. The emergency shutdown and other valves on Piper are shown in Figs J.8 and 3.10 and those on the whole pipeline system for the 4 platforms in the latter figure. The pig traps are shown in Figs J.3(c) and J.6.

Claymore platform

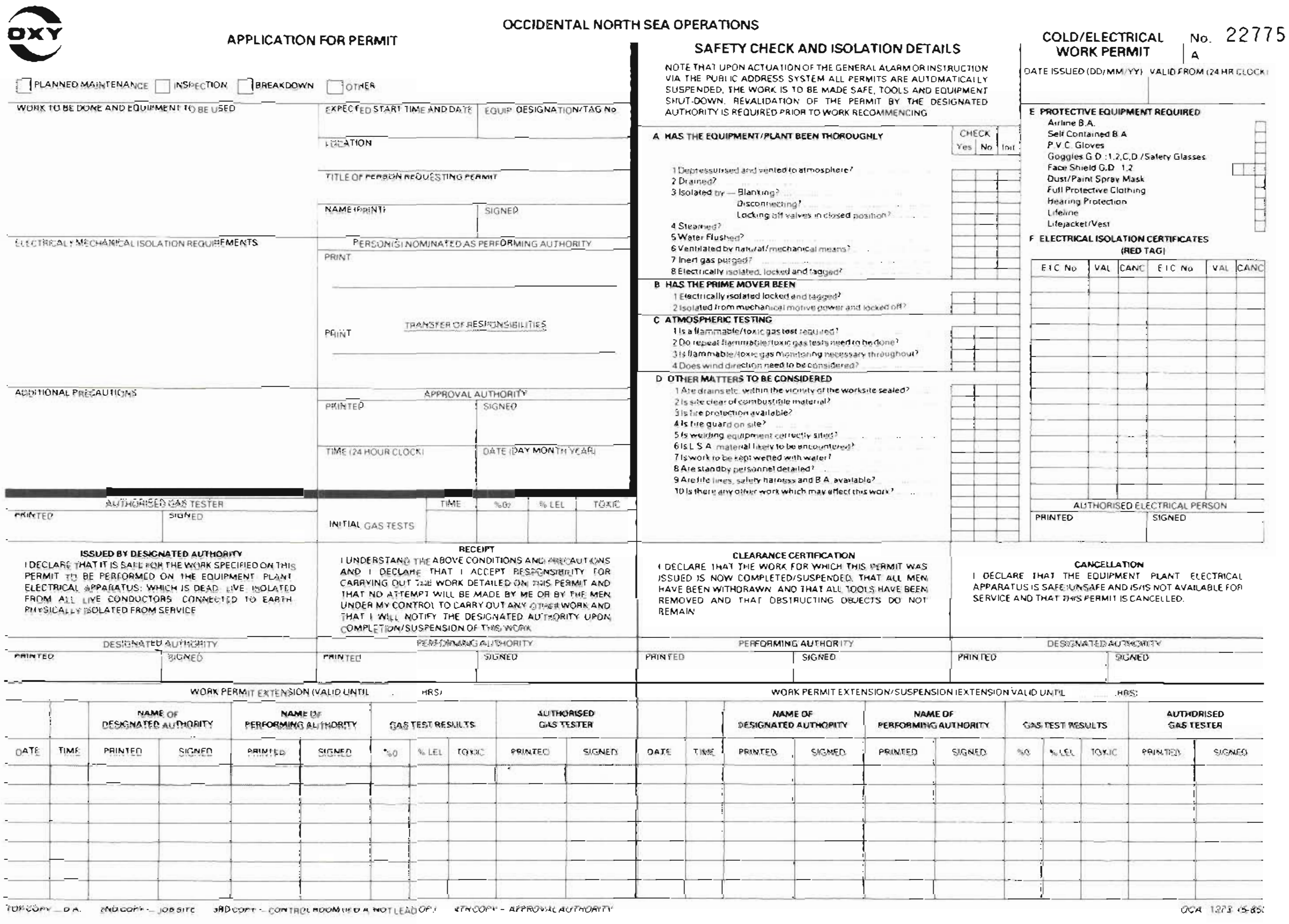
3.95 The Claymore platform was located at a point some 22 miles from Piper, approximately to the west. The platform, which was also operated by Occidental, is a production platform and started production after Piper in November 1977. Claymore was generally similar to its sister platform, Piper, as far as concerns structure. However, the reservoir fluid quality was quite different and Claymore exported oil but not gas, of which it had a deficiency. The Claymore oil export pipeline was tied in to the Piper oil export pipeline to Flotta. A gas pipeline was laid between Piper and Claymore to allow gas to be imported from Piper to make up Claymore's deficiency.

Tartan platform

3.96 The Tartan platform was located 12 miles from Piper, approximately to the south-west, and 18 miles from Claymore. The platform was a production platform and was operated by Texaco North Sea UK Ltd. Tartan produced both oil and gas for export. The oil export pipeline was routed via Claymore from which the oil went down the Claymore oil export line to Flotta. The Tartan gas export pipeline was routed via Piper, from which the gas went down the Piper gas export line to MCP-01 and thence to St Fergus.

MCP-01 platform

3.97 The MCP-01 platform was located some 34 miles from Piper, approximately to the north-west. The platform was a manifold compression platform (MCP) operated by Total Oil Marine plc to receive gas from the Frigg field, to compress it and transmit it to the gas terminal at St Fergus. In 1978 it also began to take gas by pipeline from the Piper platform.



OCCIDENTAL NORTH SEA OPERATIONS

APPLICATION FOR PERMIT

☐ PLANNED MAINTENANCE ☐ INSPECTION ☐ BREAKDOWN ☐ OTHER

WORK TO BE DONE AND EQUIPMENT TO BE USED

EXPECTED START TIME AND DATE

EQUIP DESIGNATION/TAG No

LOCATION

TITLE OF PERSON REQUESTING PERMIT

NAME (PRINT)

SIGNED

ELECTRICAL/MECHANICAL ISOLATION REQUIREMENTS

PERSON(S) NOMINATED AS PERFORMING AUTHORITY

PRINT

TRANSFER OF RESPONSIBILITIES

PRINT

ADDITIONAL PRECAUTIONS

APPROVAL AUTHORITY

PRINTED

SIGNED

TIME (24 HOUR CLOCK)

DATE (DAY MONTH YEAR)

AUTHORISED GAS TESTER

PRINTED

SIGNED

	TIME	%O2	% LEL	TOXIC
INITIAL GAS TESTS				

ISSUED BY DESIGNATED AUTHORITY

I DECLARE THAT IT IS SAFE FOR THE WORK SPECIFIED ON THIS PERMIT TO BE PERFORMED ON THE EQUIPMENT PLANT ELECTRICAL APPARATUS: WHICH IS DEAD, LIVE ISOLATED FROM ALL LIVE CONDUCTORS CONNECTED TO EARTH PHYSICALLY ISOLATED FROM SERVICE

DESIGNATED AUTHORITY

PRINTED

SIGNED

RECEIPT

I UNDERSTAND THE ABOVE CONDITIONS AND PRECAUTIONS AND I DECLARE THAT I ACCEPT RESPONSIBILITY FOR CARRYING OUT THE WORK DETAILED ON THIS PERMIT AND THAT NO ATTEMPT WILL BE MADE BY ME OR BY THE MEN UNDER MY CONTROL TO CARRY OUT ANY OTHER WORK AND THAT I WILL NOTIFY THE DESIGNATED AUTHORITY UPON COMPLETION/SUSPENSION OF THIS WORK

PERFORMING AUTHORITY

PRINTED

SIGNED

SAFETY CHECK AND ISOLATION DETAILS

NOTE THAT UPON ACTUATION OF THE GENERAL ALARM OR INSTRUCTION VIA THE PUBLIC ADDRESS SYSTEM ALL PERMITS ARE AUTOMATICALLY SUSPENDED. THE WORK IS TO BE MADE SAFE, TOOLS AND EQUIPMENT SHUT-DOWN. REVALIDATION OF THE PERMIT BY THE DESIGNATED AUTHORITY IS REQUIRED PRIOR TO WORK RECOMMENCING

	CHECK		
	Yes	No	Init
A HAS THE EQUIPMENT/PLANT BEEN THOROUGHLY			
1 Depressurised and vented to atmosphere?			
2 Drained?			
3 Isolated by — Blanking?			
Disconnecting?			
Locking off valves in closed position?			
4 Steamed?			
5 Water Flushed?			
6 Ventilated by natural/mechanical means?			
7 Inert gas purged?			
8 Electrically isolated, locked and tagged?			
B HAS THE PRIME MOVER BEEN			
1 Electrically isolated locked and tagged?			
2 Isolated from mechanical motive power and locked off?			
C ATMOSPHERIC TESTING			
1 Is a flammable/toxic gas test required?			
2 Do repeat flammable/toxic gas tests need to be done?			
3 Is flammable/toxic gas monitoring necessary throughout?			
4 Does wind direction need to be considered?			
D OTHER MATTERS TO BE CONSIDERED			
1 Are drains etc. within the vicinity of the worksite sealed?			
2 Is site clear of combustible material?			
3 Is fire protection available?			
4 Is fire guard on site?			
5 Is welding equipment correctly sited?			
6 Is L S A material likely to be encountered?			
7 Is work to be kept wetted with water?			
8 Are standby personnel detailed?			
9 Are life lines, safety harness and B A available?			
10 Is there any other work which may affect this work?			

CLEARANCE CERTIFICATION

I DECLARE THAT THE WORK FOR WHICH THIS PERMIT WAS ISSUED IS NOW COMPLETED/SUSPENDED, THAT ALL MEN HAVE BEEN WITHDRAWN AND THAT ALL TOOLS HAVE BEEN REMOVED AND THAT OBSTRUCTING OBJECTS DO NOT REMAIN

PERFORMING AUTHORITY

PRINTED

SIGNED

COLD/ELECTRICAL WORK PERMIT

No. 22775

A

DATE ISSUED (DD/MM/YY)

VALID FROM (24 HR CLOCK)

E PROTECTIVE EQUIPMENT REQUIRED

- Airline B.A. ☐
- Self Contained B.A ☐
- P.V.C. Gloves ☐
- Goggles G.D.:1,2,C,D/Safety Glasses ☐
- Face Shield G.D. 1,2 ☐
- Dust/Paint Spray Mask ☐
- Full Protective Clothing ☐
- Hearing Protection ☐
- Lifeline ☐
- Lifejacket/Vest ☐

F ELECTRICAL ISOLATION CERTIFICATES (RED TAG)

E I C No	VAL	CANC	E I C No	VAL	CANC

AUTHORISED ELECTRICAL PERSON

PRINTED

SIGNED

CANCELLATION

I DECLARE THAT THE EQUIPMENT PLANT ELECTRICAL APPARATUS IS SAFE/UNSAFE AND IS/IS NOT AVAILABLE FOR SERVICE AND THAT THIS PERMIT IS CANCELLED.

DESIGNATED AUTHORITY

PRINTED

SIGNED

WORK PERMIT EXTENSION (VALID UNTIL HRS)

		NAME OF DESIGNATED AUTHORITY		NAME OF PERFORMING AUTHORITY		GAS TEST RESULTS			AUTHORISED GAS TESTER	
DATE	TIME	PRINTED	SIGNED	PRINTED	SIGNED	%O2	% LEL	TOXIC	PRINTED	SIGNED

WORK PERMIT EXTENSION/SUSPENSION (EXTENSION VALID UNTIL HRS)

		NAME OF DESIGNATED AUTHORITY		NAME OF PERFORMING AUTHORITY		GAS TEST RESULTS			AUTHORISED GAS TESTER	
DATE	TIME	PRINTED	SIGNED	PRINTED	SIGNED	%O2	% LEL	TOXIC	PRINTED	SIGNED

TOP COPY — D.A. 2ND COPY — JOB SITE 3RD COPY — CONTROL ROOM (IF D.A. NOT LEAD OP.) 4TH COPY — APPROVAL AUTHORITY

OCA 1273 (5-85)

Fig. 3.9 The Occidental North Sea operations permit to work form for cold/electrical work.

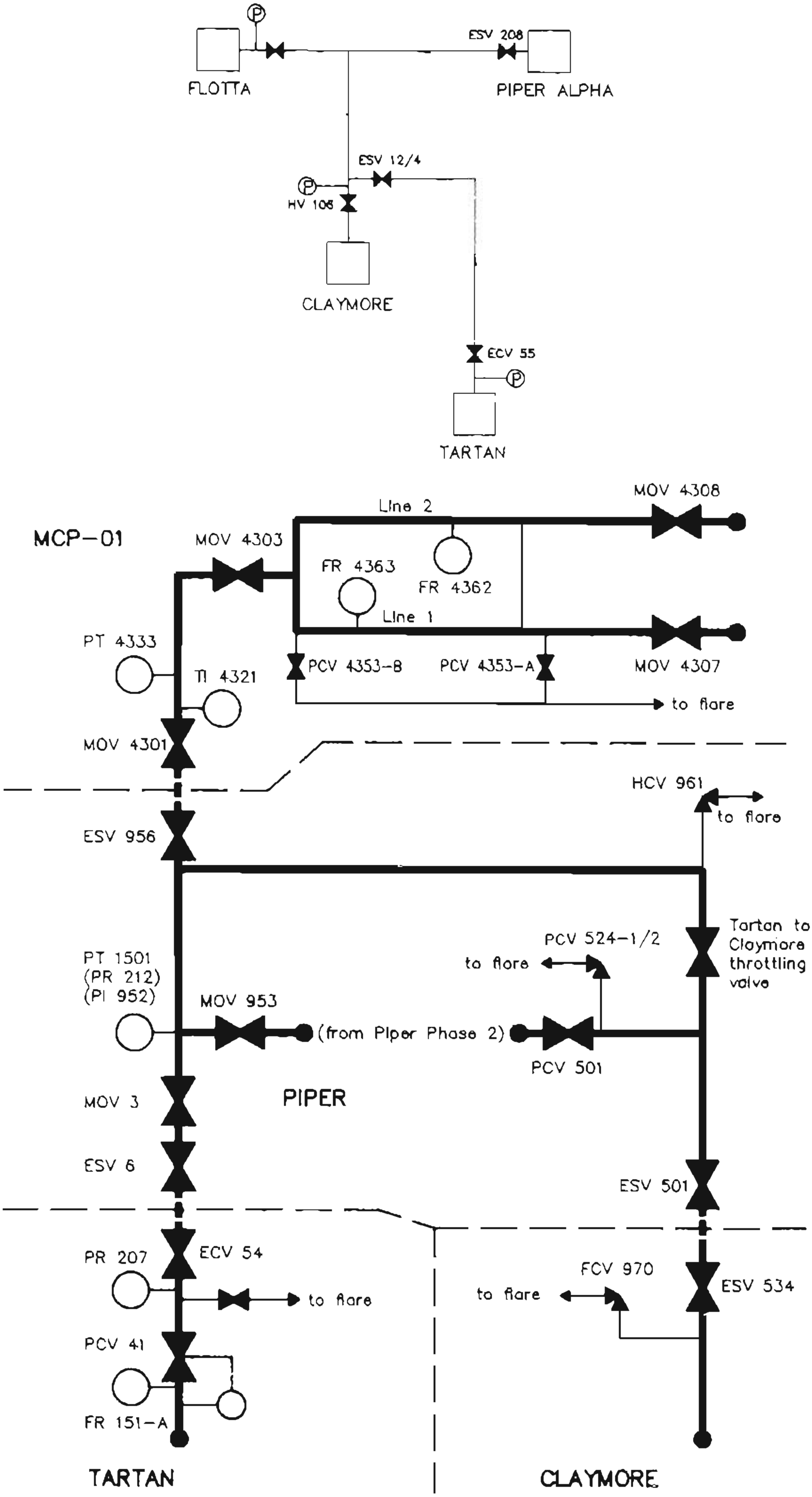


Fig. 3.10 Simplified flow diagram of the emergency shutdown of the oil and gas pipelines and of the gas flaring arrangements: (a) oil pipelines; and (b) gas pipelines.

Flotta

3.98 The oil terminal to which oil from Piper, Claymore and Tartan was pumped was at Flotta at Scapa Flow in Orkney. The function of the terminal was to separate from the oil the water, condensate and methane gas which it contained. The light components were taken out of the oil in 4 stabilising trains. The methane was burnt at the terminal as fuel gas and the oil and condensate were stored for transhipment, the latter as liquefied petroleum gas (LPG).

Piper gas export pipeline to Claymore

3.99 The gas pipeline from Piper to Claymore was 22 miles long and 16 inch diameter. There was an emergency isolation valve, ESV 501, on the line after the pig launcher, which was at the north end of the platform on the 68 ft level. There was an emergency isolation valve, ESV 534, at the Claymore end. The pressure in the line was allowed to vary, the line being topped up from Piper when the pressure fell due to gas offtake at Claymore. The policy was to keep the line at a pressure of 900-1000 psia in order to minimise the pressure drop between the Tartan and Claymore lines.

Tartan gas export pipeline to Piper

3.100 The gas export pipeline from Tartan to Piper was 12 miles long and 18 inch diameter. There was an emergency control valve, ECV 54, on the line at the Tartan end and an emergency shutdown valve, ESV 6, on the line at the Piper end. The latter valve was on the Tartan line as it entered the pig receiver at the 68 ft level. The pressure drop in the line was some 5 psi (0.3 bar) and the pressure and temperature of the gas in the line were essentially the same as those in the Piper-MCP-01 line.

Piper and Tartan gas export pipeline to MCP-01

3.101 The gas export pipeline from Piper to MCP-01 was 34 miles long and 18 inch diameter. There was an emergency isolation valve, ESV 956, on the line after the pig launcher, which was in the centre of the platform on the 68 ft level. There was an isolation valve, MOV 4301, at the MCP-01 end. The flowsheet pressure of the gas at the Piper end was 1735 psia. Typical conditions were pressure 1740 psia (120 bara), temperature 50°F (10°C), density 180 kg/m^3.

Piper oil export pipeline to Flotta

3.102 The oil export pipeline, or MOL, from Piper to Flotta was 128 miles long and 30 inch diameter. This line was joined by the MOL from Claymore at a point 22 miles from Piper. There was an emergency isolation valve, ESV 208, on the Piper MOL. The pig launcher for the MOL was in B Module. ESV 208 was in that module on a vertical section of the line as it went down to the 68 ft level. The pressure of the oil at the delivery of the MOL pumps was 905 psia and the temperature 153°F.

Tartan oil export pipeline via Claymore to Flotta

3.103 The oil export pipeline from Tartan to Claymore was 18 miles long and 24 inch diameter. This line entered the MOL on Claymore downstream of its MOL pumps. There was an emergency isolation valve, ESV 55, on the line at the Tartan end and another one, ESV 12/4, at the Claymore end before the line joined the Claymore MOL.

Claymore export pipeline joining Piper-Flotta line

3.104 The oil export pipeline from Claymore to the junction with the MOL from Piper to Flotta, the Claymore T, was 7 miles long and 30 inch diameter. There was an isolation valve, HV 106, on the line at the Claymore end upstream of the tie-in of the Tartan MOL.

Routing of Piper gas to Claymore

3.105 Gas was routed from Piper to Claymore by taking gas from the discharge of the second stage reciprocating compressors and passing it to the pipeline to Claymore through PCV 501 (see Fig 3.4).

3.106 It was also possible to take gas back from the Claymore pipeline to provide fuel gas for the main generators in the event of loss of gas from the centrifugal compressors. Gas could be routed back to the discharge of these compressors via Valve 1, which was normally open, and via Valve 2 and PCV 501, which were normally shut. PCV 501 was at the west end of C Module adjacent to the B reciprocating compressor and Valve 2 was almost in the same location, just 3 or 4 ft to the east.

Routing of Tartan gas to Claymore

3.107 It was also possible to route Tartan gas to Claymore. This was done by opening the "Gas to Claymore" (GTC) valve on the line connecting the Tartan pipeline and the Claymore pipeline (see Fig 3.4).

3.108 The topping up of the Claymore line with Tartan gas was not usual practice. Normally in phase 2 operation Piper gas was used. But in phase 1 operation the Piper gas was wetter and the risk of hydrate formation or corrosion greater, and it was policy to use the drier Tartan gas.

Depressurisation facilities

3.109 There were on the 4 platforms facilities for depressurising the 3 gas pipelines by flaring the inventories, but they were limited by the gas flows which could safely be flared and such depressurisation normally took days rather than hours.

Status of Piper Alpha in early July 1988

3.110 There were various aspects of the platform in early 6 July which were unusual. There was a large construction programme and changeout of the GCM. This required changeover to, and operation in, phase 1 mode. This in turn resulted in a high level of flaring.

3.111 There was some evidence given of the existence of apertures in the firewall between B and C Modules. Details of this are given in Appendix F (paras F.68-69).

Work programme

3.112 In the period immediately preceding 6 July the platform was engaged in a work programme involving a number of major items, including

- installation of the Chanter riser (68 ft level)
- changeout of the GCM and changeover from phase 1 to phase 2 operation
- structural modifications to steelwork (B Module)
- overhaul of the prover loop and metering skid (B Module)
- work on the gas lift lines at the wellheads (A Module)

There were also various lesser projects.

Construction work

3.113 One major item of work was the installation of a riser for the flow line from the Chanter satellite field to the platform. The work done prior to 6 July consisted of preparatory work, principally the installation by the OPG of a gantry which projected from the floor of the 84 ft level on the west face to the north of the crane pedestal and of a 6 inch oil flow line at the 68 ft level (see Plate 10(b)).

3.114 The prover loop and metering skid were situated in B Module just east of the MOL pumps. In the period 2-5 July, modifications to platform steelwork at the site of the prover loop were being done by the OPG. By 6 July the prover loop had been removed for repair, whilst work was being done on the metering skid. There was some evidence which implied the existence of an aperture in the deck of B Module at the prover loop. Details of this are given in Appendix F (para F.70).

3.115 During the period up to 6 July work was being done by the OPG on welding of gas lift lines to wellheads.

Phase 1 operation and GCM changeout

3.116 Production continued whilst the work just described was in progress, but since one of the tasks was the changeout of the GCM, it was necessary to change from the phase 2 mode of operation to the phase 1 mode. The last time the platform had operated in phase 1 mode had been in 1984.

3.117 The changeover took place on Sunday 3 July. At 06.00 hours the gas plant was shut down except that one centrifugal compressor was left running to supply fuel gas. By the afternoon things were ready for startup of phase 1 operation. Following depressurisation, valves were closed in a specific order to ensure that lines were at atmospheric pressure and were locked off. Valve status lists were maintained. The molecular sieve driers were spaded off, but not the GCM itself. Further details of the GCM changeover are given in Appendix F (paras F.65-66).

Maintenance work

3.118 On 3 July, while the gas plant was shut down and prior to startup of the phase 1 operation, the opportunity was taken to carry out various maintenance tasks. These included removal of a redundant vessel, 2-C-209, on the 68 ft level; changeout of the flare side isolation valves on PSV 524A, B on the gas to Claymore line in C Module, which were seized; and fitting the extra methanol injection line, a hose, from pump head F to the line upstream of the JT valve.

3.119 On 4 July MOL pump C tripped on high outboard bearing temperature. This was said to be either a genuine alarm due to a faulty bearing or an alarm caused by heat from the flare.

3.120 There were several leaks recorded on 4 July. One was a leak on a nipple on Valve 17 (the GTC valve). It was necessary to shut down, isolate and depressurise the line to allow maintenance to fit a new nipple. Another resulted from an attempt to insert a spade into a line under the floor of the GCM beneath the molecular sieve driers, which turned out to be pressurised. There was a release of gas, with a strong smell of hydrogen sulphide. Safety officers attended and the area was evacuated for a period. Another gas release was recorded that day due to the breaking of a pressurised line at the Christmas trees. A leak also occurred on 4 July on the LP suction pressure switch on condensate injection pump B. The switch was found to be rated below the 0-700 psi pressure range required at this point in phase 1 operation. The problem apparently arose because at some earlier time a switch suitable for pressures in both phases had been replaced by one suitable only for the lower pressure range in phase 2. After an abortive attempt to obtain a suitable switch from Claymore, a switch with a 0-3000 psi range was fitted.

3.121 Other maintenance work included the tail end of a PSV recertification programme, which involved some 300 valves, and a 24 month preventive maintenance (PM) on condensate injection pump A. This work is described in Chapter 6.

Operational aspects

3.122 In the period leading up to 6 July there were problems with the production separators. The amount of water coming from the wells was high. This water should have been removed in the separators but due to work on the Chanter riser modifications had been made to the dump line from the hydrocyclone to the sea. This increased the pressure drop and despite any compensatory action of the water level controller in opening wider the offtake valve, the head available was insufficient. A proportion of the water therefore passed not through the water removal system but into the oil. Hydrocarbons were also getting into the produced water. In June welding work was said to have set fire to gas discharged from the hydrocyclone.

3.123 In the week leading up to and on 6 July gas smells were reported on a number of occasions. Some incidents were attributed to hydrogen sulphide and others to attempts to light the flare. A gas release from the GCM on 4 July involved temporary evacuation. There were also various gas smells in the dive complex area in the period 3-6 July, leading on 5 July to a precautionary shutdown of the diving compressors.

3.124 For a period up to 6 July there had been a number of apparently spurious gas alarms on C centrifugal compressor. An opportunity was being awaited to change out the gas detectors.

Flare conditions

3.125 In phase 2 operation the volume of gas flared was of the order of 1-5 million standard cubic feet per day (MMSCFD). In phase 1 operation it was much greater, approaching 30 MMSCFD, or more in upset conditions. In the period leading up to 6 July there were reports of abnormally high levels of heat from the flare. One consequence of the high flare heat was the need to cool the oxygen cylinders, or quads, at the south-west corner of the dive complex platform on the west face. Hose cooling was applied to other equipment. Another effect reported in the period leading up to 6 July was icing of the 24 inch flare line passing through the dive area, the ice layer being estimated as 2 inches thick.

Status of Piper Alpha on 6 July 1988

Management of, and personnel on, platform

3.126 The management structure of the platform and the complement of personnel on the evening of 6 July are shown in Fig 3.11 and in Table 3.2. Some personnel described as off duty were on 24 hour call. Details of personnel involved in the events of that night are given in Chapter 6.

Construction activities

3.127 Work on the Chanter riser, including scaffolding and hot work, was in progress on the gantry on 6 July. Work continued in the evening. There was a hot work permit out for the 68 ft level. This was a category of work which would normally cease by 21.00 hours.

3.128 Another area of additional activity was the prover loop and metering skid in B Module. The state of the site early in the evening of 6 July was said to be quite unrecognisable; welding equipment and tools were lying about and the work in progress seemed to be extensive. There was no hot work permit out that evening for B Module.

Operational aspects

Production conditions

3.129 The record was available of the 24 hour average production conditions logged at 07.00 hours on 6 July. The oil production, expressed as oil and water leaving the

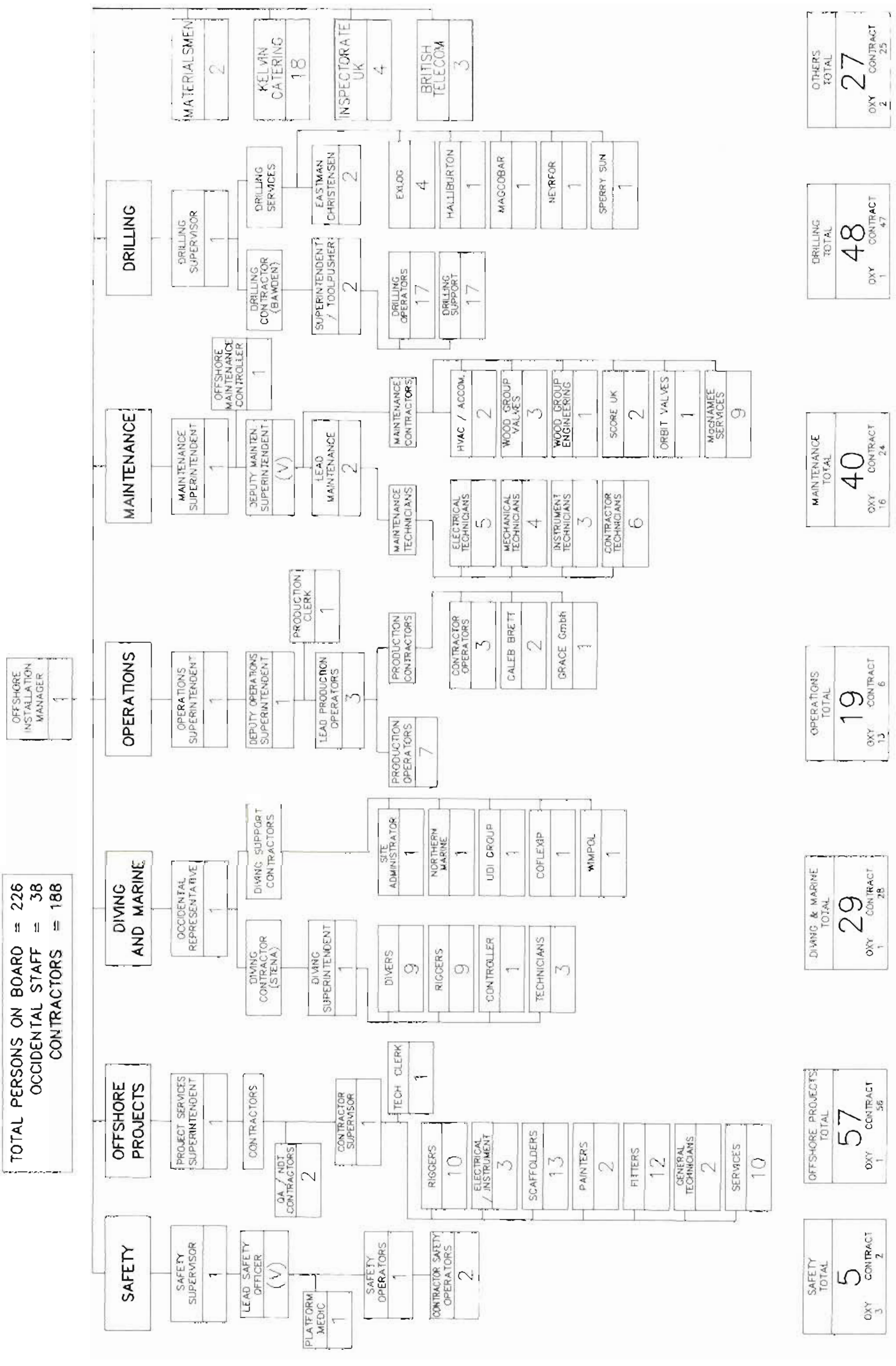


Fig. 3.11 Management structure of Piper Alpha, and of Occidental Petroleum (Caledonia) Ltd in relation to Piper.

separators was 138,294 barrels per day (BPD), corresponding to an oil export (stock tank barrels) of some 119,000 BPD. The condensate flow was 7,500 BPD. There was no export of Piper gas to MCP-01, but the export flow of Tartan gas across Piper was 33 MMSCFD. There was a lift gas circulation of 50 MMSCFD on Piper.

3.130 The flowsheet for the process on 6 July (PSK-A1-1229-1) computed subsequently by Occidental, is shown in Table J.1, which should be read in conjunction with the process flow diagram Fig J.8.

Water content of oil

3.131 On the evening of 6 July it was observed that the meter giving the water content in the MOL in the Control Room gave a value of about 10%. It was uncertain how long this situation had persisted; the figure was recorded by the chemist in his log for that evening, but he did not search back through the records. A value of about 2% or less was more normal. The higher figure was attributed to operational upsets in the production separators. The Control Room operator was unaware of a water content of 10%, which he considered would require action.

Gas in produced water

3.132 The produced water passed to a hydrocyclone to remove any free oil in the water. The discharge pipe from the hydrocyclone went down close to sea level and the water then fell into the sea. On 6 July there was scaffolding at the 20 ft level near the discharge pipe and welding work was going on. A hose pipe had been attached to the discharge pipe extending down to sea level. This was attributed to the need either to prevent gas being discharged in the area or to prevent workers there being splashed by the discharge; the sea was described as bubbling up, evidently due to gas. It was normal for there to be gas entrained in the water.

Welding activities and permits

3.133 On the evening of 6 July there was welding work going on at the 68 ft level and the automatic deluge system was therefore switched off, but the fire and gas detection system remained operational. A UV alarm in fact occurred at that level in the condensate pump area at about 20.15 hours that night, which was attributed to welding work on the Chanter riser. The Control Room operator had no recollection of any other hot work permits out, and, specifically, there was no such permit out for B Module. The deluge systems in A, B and C Modules were on automatic.

State of certain equipment

3.134 On 6 July the direct tropospheric link between Piper and Mormond Hill was down for servicing and the link in use was that via MCP-01.

3.135 The speed control setting on condensate injection pump B was faulty and it was not possible to turn it back to the zero setting; 40 rpm was the lowest setting attainable.

3.136 The injection points nominally served by the main methanol pump are given in Fig J.8. Several of these were not in use on 6 July. Head F was out of service for 4 hours on the evening of 6 July due to a leak. This reduced the flow of methanol to the JT flash drum by about a half during that period.

3.137 At the time of the initial explosion, one of the drilling diesel generators was operating, supplying power for drilling.

Environmental conditions

3.138 The weather conditions at Piper were recorded in the official log book of the *Tharos* at midnight on 6/7 July as follows: wind direction 160-170 degrees; wind speed

10-15 knots; sea conditions: significant wave 0.5-1.5m, maximum wave 2.0-3.0m; visibility 10+ miles. The wind direction given by the dynamic positioning system of the *Lowland Cavalier* at 22.00 hours was 164 degrees true and the estimates of wind speed and direction recorded by her watchkeeper were south-south-east 3 at 20.00 hours and south-south-east 4 at 24.00 hours. The first information on environmental conditions sent by the *Tharos* as on-scene commander (OSC) and recorded by Wick radio was as follows: wind direction 180 degrees true (due south); wind force: Beaufort Scale 5; sea height 4; swell height 2 (moderate); visibility 3 (good). The wind went from south-east to south-west during the incident and these data are consistent with a wind direction of 160-170 degrees true at its start.

Table 3.1 - Some principal pressure control and pressure safety valves

A—Pressure control valves

PCV 51/1,2	Inlet of centrifugal compressors to flare
PCV 1000A,B	Inlet of first stage reciprocating compressors to flare
PCV 721	JT valve at inlet of JT flash drum
DPCV 723A,B	Inlet of second stage reciprocating compressors to flare
PCV 945	Outlet of second stage reciprocating compressors to flare
PCV 501	Outlet of second stage reciprocating compressors to gas pipeline to Claymore
PCV 511	Outlet of condensate injection pumps

B—Pressure safety valves

PSV 155,156;157,158	Production separators A,B
PSV 728	Condensate knockout drum
PSV 200/1,2; 202/1,2; 204/1,2	Centrifugal compressors A,B,C
PSV 504; 505	Condensate injection pumps A,B
PSV 524A,B	Line downstream of PCV 501
PSV 130/1,2; 131; 133/1, 2 (also PSV 843/1,2)	Reciprocating compressors A,B
PSV 864	Fuel gas

Note:
See Fig J.8 for valve locations.

Table 3.2 - Personnel on platform on 6 July 1988

Category	On Duty	Off Duty	Total	Contractors(a)
OIM	-	1	1	-
Safety	1	4	5	2
Operations	7	12	19	6
Drilling	17	31	48	47
Maintenance	13	27	40	24
Marine & Underwater	20	9	29	28
Offshore Projects	2	55	57	56
Materials	1	1	2	-
Inspectorate UK	1	3	4	4
British Telecom	-	3	3	3
Kelvin Catering	-	18	18	18
Total	62	164	226	188

Note:

(a) Contractors are included in the previous columns. The total number of POB was 226.

SECTION TWO: THE DISASTER

Chapter 4

General History of Events

4.1 The purpose of this chapter is to provide a short account of the development of the disaster by way of introduction to Chapters 5-10 in which a more detailed account and explanation of events will be found.

4.2 An initial explosion occurred on the production deck of Piper at about 22.00 hours on 6 July 1988. This was followed immediately by a fire at the west end of B Module and a fireball which erupted from its west face. The fire spread rapidly in B Module and extended into C Module and down to the 68 ft level. From the outset dense black smoke from the fire engulfed the upper parts of the northern end of the platform. The initial explosion was followed by a series of smaller explosions. Most of the emergency systems of the platform, including the fire water system, failed to come into operation.

4.3 In response to the initial explosion the *Silver Pit* which was on standby duties off the north-west of the platform launched its fast rescue craft (FRC) and moved in towards the platform. The *Lowland Cavalier* which was close to the south-western corner of the platform broadcast a mayday. The *Tharos* which was about 550m off the west side of the platform launched her FRC and began to move in towards the platform. The *Maersk Cutter* which was off the north-eastern corner of the platform moved to the south and started fire-fighting. Thereafter a number of other vessels and FRCs became involved in a large operation for the recovery of survivors and the dead.

4.4 At the time of the initial explosion 226 persons were on board the platform, of whom 62 were on night-shift. The great majority of the remainder were in the accommodation. Between 22.04 and 22.08 hours 3 maydays were sent out from the Radio Room of the platform. The third announced that the room was being abandoned due to fire. Personnel in the accommodation began to assemble on D Deck of the ERQ. An emergency evacuation team assembled at the reception area, but owing to the flames and dense smoke outside the accommodation it was impossible for evacuation to be carried out by helicopter or lifeboats.

4.5 Diving personnel, who were on duty, assembled at the dive complex on the 68 ft level and, since it was impossible for them to go up to their lifeboat, were led to the north-west corner of the platform where they got down to sea level by means of a knotted rope. They were joined by personnel from D Module and lower levels of the platform. By 22.20 hours 22 survivors had left the platform.

4.6 The remainder of the survivors who were on duty mainly made their way to the accommodation where they joined those who were already there. The normal lighting in the accommodation had gone out shortly after the initial explosion. It was followed by emergency lighting which lasted for 10-15 minutes.

4.7 At about 22.20 hours there was a major explosion which was due to the rupture of the Tartan gas riser. This caused a massive and prolonged high pressure gas fire which generated intense heat. When the explosion occurred it caused a number of men at the north-west corner and other parts of the platform to jump into the sea. The effects of the explosion were felt on vessels several hundred yards away.

4.8 Most of those who were in the accommodation had congregated in the mess area on D Deck. Conditions there were tolerable at first but deteriorated due to the entry of smoke. At 22.33 hours a message from Piper was received on the *Tharos*: "People majority in galley area. Tharos come. Gangway. Hoses. Getting bad."

4.9 Shortly before 22.45 hours the cascade from the fire monitors of the *Tharos*, which had been approaching the platform, began to reach it. The gangway of the *Tharos* was not landed on the platform.

4.10 A number of men, including 28 survivors, made their escape from the accommodation at various levels. Some went up to the helideck; most went down to the pipe deck, from which some went to the drill floor; others sheltered at the side of the pipe deck.

4.11 By about 22.50 hours about 39 survivors had left the platform. At that point a further massive explosion occurred. This is likely to have been caused by the rupture of the MCP-01 gas riser. It added to the intensity of the high pressure gas fire. The explosion destroyed the FRC of the *Sandhaven* and killed most of its occupants. Debris from the explosion was projected 800m and vibration was felt up to a mile away. The explosion caused men to jump off the helideck and other parts of the platform. The *Tharos* then pulled back. Structural collapse at the 68 ft level below B Module started.

4.12 The structural collapse of the platform was hastened by a series of major explosions, one of which was about 23.20 hours and was due to the rupture of the Claymore gas riser. Shortly thereafter the west crane collapsed from its turret. The drilling derrick collapsed across the pipe deck. The structure of the platform took a slight tilt to the east. This was followed by the sudden collapse of the pipe deck to the west. This forced men out of shelter on to the pipe deck. A number of survivors then had to jump off the pipe deck into the sea.

4.13 The ERQ, which had suffered severe external attack by fire on its east and north sides, suffered loss of structural support. It tipped to the west, probably crushing the LQW; and then tipped northwards into the sea. Between 22.30 and 00.45 hours the centre of the platform collapsed. The risers from the gas pipelines and the MOL were torn apart. The north side of the platform slowly collapsed until the AAW slipped into the water at about the latter time.

4.14 Meanwhile at about 23.27 hours a Nimrod aircraft, which functioned as a flying communications platform, reached the scene, followed shortly thereafter by helicopters from Lossiemouth, Boulmer and Shetland. These helicopters were used to transfer personnel, search for survivors and transfer the injured.

4.15 A total of 62 survivors from Piper (one of whom died later in hospital) and one survivor from the crew of the *Sandhaven*'s FRC had by then reached a variety of vessels either by being picked up directly or having been picked up by the crew of FRCs. They were transferred to the *Tharos*, where medical attention was given. At 02.26 hours on 7 July the first casualties left the *Tharos* by helicopter for the shore. At 02.02 hours fire fighting had stopped. At 08.15 hours the survivors had all reached the shore.

4.16 Aircraft searched the area for survivors until the afternoon of 7 July; surface vessels did so until 22.45 hours on that date.

4.17 On 7 July the bodies of 15 personnel from Piper and 2 crew members of the *Sandhaven*'s FRC were recovered from the surface of the sea. During the remainder of the month of July a further 27 bodies were recovered from the seabed. Between August and November a further 10; and one on 2 June of the following year. A total of 81 bodies were recovered from the ERQ, mainly after it had been recovered from the seabed and taken to Flotta in October 1988. The bodies of 30 personnel from Piper remain missing.

Chapter 5

The Initial Explosion

5.1 The initial explosion had all the characteristics of an explosion of a cloud of flammable gas, which must have formed as the result of a leak. The problem faced by the Inquiry in determining the source of that leak was peculiarly difficult in that there was available no physical evidence from the installation. Most of the first hand evidence obtained on the initial explosion came from survivors and observers at various distances from the platform. This evidence included what was seen and heard of the explosion itself and what was observed of the damage which it caused. This latter included observations both of damage to particular equipment and of the effects of damage on equipment function. Much evidence was heard from experts, but in contrast to the situation at most inquiries, in which experts are able to examine debris directly, in the present case experts giving evidence on matters such as equipment damage had to rely for information on this damage on eye-witness evidence.

5.2 In this chapter I consider the characteristics of the initial explosion and seek, in particular, answers to the following questions:

When did the explosion occur?
Where did the explosion occur?
What was the size of the gas cloud?
What was the fuel in the gas cloud?

There were gas alarms reported in C Module just before the explosion and a major fire in B Module just after it. It was fairly clear at an early stage that the explosion had occurred in one or other of these 2 modules. This led therefore to the questions:

In which module did the explosion occur?
If the explosion was not in B Module, what was the cause of the fire observed there within seconds?
Whereabouts in the module did the explosion occur?

The nature of the explosion itself and the size of gas cloud give rise to the questions:

What sort of an explosion occurred?
What over-pressures did the explosion generate?
Were these over-pressures sufficient to destroy the firewalls of the module?
What was the source of ignition?

There were also certain features of the explosion which required explanation, including the questions:

Were there further explosions almost within seconds of the initial explosion?
How can the various experiences of personnel be explained?
How can the various reported damage effects be explained?

5.3 The evidence on which I draw in this chapter is of 2 kinds. Firstly, there is the evidence of survivors and other eye-witnesses. This includes the observations of, and photographs taken by, persons off the platform; the noises heard by survivors just before the explosion; the effects of the explosion on survivors; and the damage done and debris created by the explosion. Secondly, there is a body of expert evidence commissioned prior to the Inquiry by other parties which bore on the nature of the explosion. In this chapter I use these 2 types of evidence to draw certain broad conclusions about the initial explosion and the leak which gave rise to it. The expert evidence considered here is that on the probable over-pressures generated given by Dr R A Cox of Technica Ltd, Dr J R Bakke of the Christian Michelsen Institute

(CMI), Dr N F Scilly of the HSE; the evidence of Dr Cox on the over-pressures required to cause failure of the firewalls in C Module; and an overview of both the eye-witness and expert evidence by Dr P A Cubbage, a consultant.

5.4 I begin with the accounts of eye-witnesses, including those on timing (paras 5.5-16); of photographs (paras 5.17-20); and of noises (paras 5.21-29). I then review the effects of the explosion on personnel, the damage and debris, and certain explanations of these (paras 5.30-62). From this evidence I draw certain conclusions about the location of the explosion, the fuel involved and the size of gas cloud (paras 5.63-79). I then consider the nature of the explosion itself, its strength and its effect on the firewalls (paras 5.80-102) and finally give my conclusions on the initial explosion (paras 5.103-110).

Eye-witness evidence

5.5 Mr D H Kinrade, the radio operator, was in the Radio Room at the time of the initial explosion. He turned round to his colleague Mr J Dawson, stepped across the room, and looked out to the south, all within a matter of seconds. He saw smoke and flames coming from the west face south of the crane pedestal. He had no recollection of anything on the east face.

5.6 Mr C A Miller, a mobile diving unit pilot, was on the deck of the *Tharos*, which was 550m off the west face of Piper, standing with his camera raised, intending to take some photographs for his child's school project. He heard a thump like a flare starting up, lowered his camera, and apparently looked at the flare. He did not see anything unusual immediately, but within a second or two observed grey smoke issuing from the west end of C Module. The next thing he saw, only a few seconds later, was thick black smoke and large flames, obscured by the smoke, coming out of the west end of B Module. He raised his camera and took his first photograph (Plate 14(a)).

5.7 Mr J Murray, a helicopter engineer, was in the heli-reception of the *Tharos* with Mr W J Flaws, a deck foreman on the vessel. There was a desk between them. Mr Flaws stood looking over the desk directly at Piper and Mr Murray stood on the aft side of the desk. He described his position as looking side on at the platform. He saw just to the right of the crane pedestal a vapour mist, orange or pinky-orange, which persisted for just a few seconds; he compared it to the flares used at airfields for scaring birds. A split second later he heard the explosion. He then saw at the same spot flame and orange smoke. The flame was being blown by the wind northwards and upwards, giving it an oval appearance. At that stage it was smaller than that shown in Mr Miller's first photograph.

5.8 As just described, Mr Flaws was standing facing the platform. He heard an explosion and looked up. He saw a cloud of smoke coming out from the far side of the platform and flames coming through the platform at the 84 ft level towards the *Tharos*; it was the smoke which caught his eye first. The smoke emerged beyond the outline of the platform; it was greyish and thick. The flames were orange in colour and moved horizontally rather than vertically. The flames were to the left of the crane pedestal; he was sure about the position. He continued looking at the platform for some seconds after the explosion. He saw no missiles coming from the platform.

5.9 Captain M Clegg, the master of the *Lowland Cavalier*, was on the bridge at the time of the initial explosion. The vessel was positioned 25m off the south-west leg of Piper with its stern towards the platform. It was 72m long with the bridge some 50m from the stern and some 15m above the waterline. Captain Clegg said he was at almost the same height as the 84 ft level, looking up at an angle of only a few degrees. He stated that he was looking at the platform at the time when the explosion occurred. He described it in the following words:

> "Well, I actually saw the explosion; I did not hear it. I actually saw it before I registered anything else. What I saw I can only explain as like the starting of a gas

> burner, a water heater. It seemed to go along the bottom of the platform; like a very light blue explosion or ignition more than anything else, then contracting again, and then a further explosion coming from a certain point which I believe to be below the crane pedestal and slightly to the left."

5.10 Other descriptions of the explosion given by Captain Clegg are:

> "What I saw was what afterwards seemed the igniting of some sort of gases within the platform and after that coming outwards from the platform smoke and flame which was probably the initial start of the explosion which came more and more as it went on, within seconds."

and

> "What I am saying is it went across the platform. It looked to be within inside the structure itself, not emanating from the structure. When the initial blast, if you want to call it that, had gone back, seconds or whatever afterwards it seemed to be coming from just to the right of the crane pedestal in the area that has been indicated around the ladder. That is the picture I have in my mind. That is all I can say."

Another way he put it was that what he saw was like a body of gas igniting, flaring up and then contracting and dying out.

5.11 Captain Clegg described the flame as travelling from the crane pedestal in both directions, the one to the right being longer than the one to the left, although at one point he agreed the lengths were equal on the 2 sides, and at another he said the flame went further on the left. Then within a split second the flame contracted. The flame ran above and below the 84 ft level. He stated that he could not say for certain whether the initial ignition was to the left or right of the crane pedestal. Asked to identify the point on a photograph of the platform he indicated one to the right of the pedestal and towards the top of B Module, but said he could not be sure which side of the pedestal it occurred. However, he later stated that the order of events was the blue flame, smoke and then seconds later a bright flame emerging from the smoke; it was evidently this latter flame to which he was referring when first questioned about the "initial ignition".

5.12 Captain Clegg had no recollection of hearing any sound associated with the blue flame. Asked whether he heard a 'woomph' he said "I did not hear the explosion. I felt it and saw it. I cannot say if I heard it or not." Prior to this blue flame, he saw nothing; he did not see any smoke.

5.13 Captain C I Morton, master of the *Maersk Cutter*, was sitting drinking a cup of coffee on the bridge when he experienced the initial explosion as a shaking of his vessel, which was abeam to the east face of the platform, and thought perhaps it had struck something. The bridge gave a 360° field of vision. He went to look aft and then as he came back to look forward again he looked to the side at the platform; the time elapsed since the explosion was perhaps some 10 seconds. He saw a light grey cloud, which he described as like cement dust, in front of, and apparently issuing from, the centre of the east face; he believed it came from C Module. He made no mention of the fire on the north face or the large plume of black smoke drifting north which are seen on Mr Miller's first photograph (Plate 14(a)).

Time of the initial explosion

5.14 There was a large volume of evidence which indicated that the initial explosion occurred at, or within 1 or 2 minutes of, 22.00 hours BST. Some half dozen witnesses on the platform were listening to radio or television, some having just tuned in for the news or sports programmes. Some heard the 10 o'clock time signal, others did not. None claimed to have heard more than the very start of the news programme.

5.15 On the *Maersk Cutter*, Captain Morton went to the mess room to get some milk. The 10 o'clock news on Radio 2 and ITV News at Ten had just started. He went back up to the bridge, a matter of seconds, poured his coffee, and had just sat down to drink it when he felt the ship vibrate, presumably from the explosion. Captain Clegg, on the *Lowland Cavalier*, observed the development of an explosion on the west face of the platform. He instructed his second mate, Mr Barrie, to send a mayday signal. The ship's official log gave at 22.00 hours the entry "Explosion on Piper A". This log was made up from notes on a scrap of paper which had been written down as time allowed. On the *Tharos* events were logged by the officer of the watch, Mr D I Blair, in the manned control room scrap log. His first entry referred to an explosion on Piper at 22.01 hours. The Chief Engineer, Mr W N Paterson, responded to the explosion by initiating startup of the additional generators. This action was timed at 22.2.29 hours, ie 29 seconds after 22.02 hours, on the computer printout. At the time of the explosion he was in the forward control room and he estimated that it took no more than a minute to get from there to the engine control room. The official log of the *Tharos* had the explosion timed as 22.02 hours, which Captain A Letty stated was derived from the log of the radio operator, who would be meticulous in such matters.

5.16 Wick Radio picked up a mayday call "Explosion on board Piper A. No numbers of personnel known yet." from the *Lowland Cavalier* which was recorded in the radio telephone log at 21.01 hours GMT (22.01 hours BST). At the Flotta terminal the log, written up later by the panel operator, recorded a telemetry failure alarm at 22.00 hours and a fall in oil import at 22.02 hours. However, the recollection of the duty lead process operator, Mr L Stockan, was that the import reduction occurred at 21.55 hours. He also said that the telemetry fault alarms came up 7 minutes later at 22.02 hours. Despite repeated cross-examination, the witness was adamant that he had the time of the import reduction correct.

Photographic evidence

5.17 The explosion and fire on Piper were documented by an unusually large number of photographs, many taken within the first few minutes. A selection of these photographs is given in Plates 14-20. However, most of these are more relevant to the escalation rather than to the initial explosion and their consideration is deferred to Chapter 7. There are just 1 or 2 which have a significant bearing on the initial explosion.

5.18 As already described, Mr Miller was standing on the deck of the *Tharos* with his camera raised. His first photograph (Plate 14(a)) shows a fireball emanating from the west side of B Module just to the south of the crane pedestal. The timing of this photograph is not certain, but it is estimated in Chapter 7 that it was taken some 15 seconds after the initial explosion. Mr Miller's photographs were the only series started within seconds of the initial explosion.

5.19 A photograph (Plate 18(a)) taken by Mr L M T Macdonald, an electronic technician on the *Lowland Cavalier*, is also of interest in so far as it might bear on the state of the firewalls after the initial explosion. It was taken from the deck of the vessel about 30 seconds after that explosion.

5.20 A project to enhance photographs of the Piper disaster undertaken by the Hughes Aircraft Co, a sister company of Allison Gas Turbine in the General Motors Group, was described by Dr M E Stickney, a Senior Systems Engineer, led by Allison. He gave a demonstration of the application of computer-aided image enhancement techniques to Mr Miller's first photograph of the fireball in B Module (Plate 14(a)) and to Mr Macdonald's photograph of the fire in that module (Plate 18(a)). Dr Stickney was asked whether the photograph by Mr Miller could be used to estimate the temperature of and the fuel burning in the fireball. He said he was not himself able to assist on this and indicated that deductions would not be a straightforward matter. He was not able to say whether the fireball came from a small pipe or a large vessel. With regard to Mr Macdonald's photograph, the question was explored whether any information could be gleaned on the state of the B/C firewall. There was in C Module a large white potable water tank and it would be expected that if there were a hole in the B/C firewall opposite this tank, light would be reflected from this object; white objects are particularly good diffuse reflectors. From the photographic enhancement done there was no evidence of such reflection. The question was explored to what extent this finding might be due to the limitations of the information on the negative. Dr Stickney agreed this was a limiting factor. It was also established that it was not possible to tell from the photographs how far into B Module the fire penetrated. Dr Stickney was able, however, to draw the conclusion from this photograph that the fireball did not project very far from the platform. The photograph showed no reflection off the heat shield. The Inquiry was invited to commission further work, but decided not to do so.

Noises associated with initial explosion

5.21 A number of survivors stated that they heard unusual noises just before the initial explosion. An account of these noises is given here, since they have potential bearing on the location of the explosion. The interpretation of these noises in relation to the cause of the explosion is given in Chapter 6. The noises were the subject of a report by Mr A H Middleton of Anthony Best Dynamics Ltd, which included a summary of survivors' evidence on the noises.

5.22 There were 5 survivors from the Mechanical (or Maintenance) Workshop. Mr D Ellington heard a very high pitched screaming noise. He thought it was some of the scaffolders "acting the goat". He believed the noise lasted some 10-15 seconds and stopped a few seconds before the explosion. Mr I Ferguson heard a high pitched scream which he put down to the air starter on a divers' unit on the 68 ft level. He did not think it sounded like escaping gas. It lasted less than a minute and stopped long enough before the explosion for the men to decide to make a cup of tea - he said a matter of minutes. He stated that the men in the tea room discussed the noise. Mr R J McGregor heard a "banshee" noise, which he attributed to the air starter on the crane. He stated someone in the tea room likened it to somebody strangling a woman. The noise was slightly louder than normal, but not particularly unusual. It did not sound like the centrifugal or reciprocating compressors venting. It lasted about half a minute and stopped just before the initial explosion. Mr D M Thompson heard a loud screech lasting for about 10 seconds; maybe 10 seconds later the initial explosion occurred. These 4 survivors were in the workshop tea room. The only one in the workshop itself, Mr C W Lamb, heard nothing. In the Instrument Workshop Mr N G Cassidy heard a very high pitched grinding noise, like "metal to metal grinding together", which he thought came from the 84 ft level and which he found frightening. The pitch and loudness stayed constant throughout. He was sure the noise was not the flare; it was a different quality such as he had not heard before. He believed that it went on for 3-4 minutes and that the initial explosion occurred directly the noise stopped.

5.23 Of the 10 survivors from the cinema, lounge and Bawden Office, 3 reported hearing a noise before the first explosion. Mr J S Meanen heard a loud wailing noise, very high pitched, which lasted 5 seconds. He likened it to a car slamming on its brakes and skidding, but much more high pitched. If there was a gap between the noise and the explosion, it was a very short one. Mr W J Lobban also heard a very loud or high pitched screeching noise but 1 or 2 minutes before the explosion; he too was unsure if it stopped before the explosion. Mr W P Barron stated that about 30 seconds before the initial explosion there was a sudden high pitched, hissing noise; he believed it stopped before the explosion. All 3 tended to attribute the noises which they heard to the flare, as did Mr W F Clayton who also heard a noise. The 6 other survivors questioned heard nothing unusual.

5.24 A noise prior to the initial explosion was heard by 4 of the 14 survivors from the diving area; all were in the Wendy Hut. Mr S J Middleton heard a very loud hissing noise like a bunsen burner at the flare stack. It was similar to noise he had heard before, but louder. He did not associate it with any noise in the pipework in the dive area. He was certain the noise he heard was not that of the air starters on the diesel engine. He thought the noise ceased before the initial explosion but could not remember how long before. The 3 others attributed the noise they heard to the flare.

5.25 Survivors from the Bawden tea hut, the drill floor, the GCM, the Mud Module and the 20 ft level described noises just before the initial explosion which they associated with the flare. The occupants of the Control Room, Mr G Bollands and Mr A G Clark, and of the Radio Room, Mr Kinrade, heard no unusual noises from outside. Both rooms were well insulated for noise.

5.26 As far as concerns the sound of the initial explosion itself, most survivors described it as a single "thump", "whoomph", "bang" or "boom". Mr M J Bradley at the 20 ft level said it was like a gun going off. The diver under water, Mr G P Parrydavies, described it as a very loud bang. The noises associated with the initial explosion heard by Mr E C Grieve and Mr W H Young are described below. On the *Tharos* Mr Miller said he heard a thump. Mr Flaws said the explosion sounded like a large bang. Mr Murray said the explosion was a fairly loud bang; the conditions were calm, there was no wind howling and it was clearly audible. On the other hand Captain Clegg, on the bridge of the *Lowland Cavalier*, said he felt but did not hear the initial explosion. Likewise, Captain Morton on the *Maersk Cutter* felt vibration but did not really hear anything.

5.27 Three survivors in the vicinity of the dive complex heard just after the initial explosion a noise like escaping gas. One described it as a sort of high pitched whooshing like someone lighting an acetylene torch but a hundred times worse. He could not remember how long it went on but it seems to have been short-lived. However, the platform had gone so quiet that any noise would be noticeable.

5.28 In his analysis of the initial explosion Dr Cubbage made little use of accounts of the noise. Mr Middleton, whose evidence came after Dr Cubbage's, believed that the only survivors who heard a noise other than that of the flare were those in the Mechanical and Instrument Workshops and Mr Young on the 68 ft level and that this noise came from C Module. He stated that he had not investigated the possibility that the noise might have come from B Module, but said that if it did, it would have had to have been a very loud one.

Explosions reported within seconds of initial explosion

5.29 Several witnesses reported experiencing an explosion,or an event which might be interpreted as such, within seconds of the initial explosion. The only diver in the water, Mr Parrydavies, who was operating between legs B4 and A4, experienced a flash and a bang simultaneously. Some 10 seconds later there was a second flash and bang, indistinguishable from the first. Despite repeated questioning, he was quite clear that there were 2 events. One survivor from the Mud Module described the initial explosion as a thump. Seconds later there was another thump, perhaps not as big as the first. Another, who was in the doorway of the cinema by the projection room, experienced the explosion as 2 bangs, almost simultaneous. He recollected that after he had walked quite a short distance towards his cabin, there was another explosion, this time minor; the time elapsed since the initial explosion was perhaps 20 seconds. On the 20 ft level Mr N E Ralph experienced a second explosion, larger than the first but from the same area, but was unclear whether the interval between them was minutes or seconds.

Effects on personnel of initial explosion

5.30 The shock of the initial explosion was felt by people in various parts of the platform. Personnel in the Control Room and on the 68 ft and 20 ft levels were knocked over, as described below. All 5 occupants of the Wendy Hut were thrown to the floor. Personnel in the dive gondola and dive module offices were lifted off their chairs and others in the LQW and ERQ were thrown off their beds. Of the 5 survivors from the Mechanical Workshop 1 was thrown forward in his chair by the collapse of the east bulkhead behind him, whilst 2 others experienced a rush of cold air. There were 2 survivors from the Instrument Workshop. One, who was standing at the north bench in the centre of the workshop, was knocked off his feet towards the east wall. The other, who was at the entrance, between the inner and outer doors, did not recall feeling any blast.

Control Room

5.31 Mr Bollands, the Control Room operator, was in the Control Room, facing the main F & G panel with his left hand out to accept a gas alarm. The blast of the explosion caught him on his right side and threw him some 15 ft to the north. His left thumb was cut and his right hip injured. If he was knocked unconscious, it was for no more than a second or two. The other occupant of the Control Room, Mr Clark, the maintenance lead hand, was standing on the west side of the control desk, facing north and experienced the explosion as a deep thump coming from C Module. It blew him some 6-8 ft against the well status board, which he hit with his whole body. He was hit with some force on the shoulder and side of the neck by the computer terminal. He fell to the floor but did not lose consciousness.

68 ft level

5.32 On the 68 ft level Mr Grieve was on the west side of condensate injection pump B when the initial explosion occurred. He heard a loud bang, which seemed to come from above, and fell, or was forced, down to the floor; he was not aware of any blast. Mr Young also was at the condensate injection pumps. He heard a short-lived loud rushing noise. He had just turned towards the stairs leading up to C Module and was facing north-west when there was a dull bang from an explosion above him. He felt a rush of hot air, hotter than body heat, and was blown on his back between the 2 pumps, losing his safety hat, ear defenders and glasses; he was unsure if he was knocked out. As he made his way towards the light on the west side, Mr Grieve turned round and saw an orange ball of flame coming down through, or under, the roof just between the 2 condensate injection pumps. The orange ball was about half the size of the pump skid and transparent, with no real body to it or power behind it. He made towards the Ansul fire-fighting unit, but the flame went out; it had lasted only 5 or 10 seconds. He was not aware of any damage to the floor above, but there were pipe penetrations. Mr Young observed in the roof space what he described as dust or gas, white or greyish in colour.

5.33 Also on the 68 ft level were 2 riggers working on the west side at the north landing just north of the dive complex. Mr D Elliott, who was standing facing west, was knocked over by the explosion, losing his hard hat and glasses; he did not hear anything or feel any shock wave. His first recollection was picking himself up and his first reaction was that the explosion had come from the Coflexip workshop on his left. It was his belief that the explosion came from directly behind and thus from inboard the platform. His colleague, Mr B Jackson, was standing on the north landing by the railings facing north. He had headphones on to communicate with dive control. The first thing he knew he had been knocked to the floor, losing his hard hat and headphones. He heard no noise, which he attributed to his wearing headphones, and was unaware of any blast. He did not lose consciousness. His first reaction was that the grit blasting compressor had blown up. There was thick black smoke coming from the 84 ft level above his head and falling down to the sea.

5.34 Just below the 68 ft level Mr C I Niven, a diver, was on the way up the stairs to the decompression chambers from the Wendy Hut, some 3 or 4 steps up from the latter and thus not able to see the chambers, being some 10-12 ft below their level. He was standing on the stairs, looking down to his left at the *Lowland Cavalier*, and thus facing west. He heard a loud bang which he thought came from the oxygen quads, felt on his chest from the left the shock of a blast wave which seemed to be made visible by the burning particles in it and felt also a strong wind but he saw no flames or smoke. He believed the explosion came from the module which he initially referred to as C Module but later realised was B Module. He saw debris drifting down from below the area of the oxygen quads. He stepped back involuntarily and, expecting a fireball, dived into the Wendy Hut and was inside within 3 seconds.

20 ft level

5.35 On the 20 ft level there were 2 other riggers working. Mr Bradley was at the B4 leg just by the boat bumper, facing north. He heard an explosion, like a large gun going off; it appeared to come from above and behind him. The other rigger on this level was Mr Ralph, who was also by the B4 leg. His account was not completely clear. He referred to 2 explosions, separated by times which he described variously as seconds and minutes. One of these explosions he described as a loud bang, a shock wave and a flash of flame. The flame appeared to come from the same direction as the blast, from a point on the 68 ft level between legs A3 and A4 and inboard the platform from the east side by a quarter of the platform width. He thought the flash of flame was a distressed electric motor. One of the explosions knocked him against the leg so that he lost his safety helmet and glasses. He was facing east and received the full force of the explosion on his chest. Mr Ralph said he did not take much notice of the flame because he had got oil on his eyes. The oil was a light one, like diesel oil. He was unsure of its temperature but it was not hot oil. Mr Bradley said that Mr Ralph asked him whether he had oil on his face. His face was in fact speckled with drops of oil which Mr Bradley described as between a small finger nail and a thumbnail in size. This incident occurred within the first 2 minutes and while the 2 were still on the 20 ft level. Mr Ralph agreed that the 'oil' could possibly have been condensate.

Damage caused by initial explosion

5.36 The shock from the initial explosion caused minor damage in various parts of the platform. Analysing this damage, Dr Cubbage distinguished between areas where the items dislodged were fixed and those where they were not. Areas where unsecured items fell to the floor included the dive gondola, the Wendy Hut, the Oil Laboratory, the LQW and the ERQ. Fixed items fell in the Instrument Workshop, the Radio Room and the AAE. In certain areas more serious damage was reported, as described below.

Dive skid complex

5.37 There were 2 doors in the south-east corner of the main dive complex, containing the workshop and offices. Mr Niven stated that after the initial explosion one of them was hanging askew on its hinges. Mr E Z Amaira, another diver, said the inner door was not closing on its self-closer as it normally did. This was not noticed by 3 other survivors who also passed through. In the dive module offices most of the shelving and the wall and ceiling fittings fell down and one man was hit by falling ceiling. The Dive Machinery Room had double emergency doors facing south. Mr J O Wood, a diving technician, stated that both doors had been blown open and buckled at their hinges. He said that the explosion came through the ventilation trunking forcing the doors from the inside. Everything fell from the bulkhead panels, including lights, pipework and storage bins.

No 2 decompression chamber

5.38 To the south of the main dive complex were 2 decompression chambers. The outer entry lock door of No 2 decompression chamber, the more northerly, was observed by Mr Parrydavies to be off its hinges. This damage was also observed by 3 other survivors. According to Mr S R MacLeod, the diving superintendent, the door and its hinge were very heavy, but where they joined there was a very weak pin, allowing rotational movement to assist the door seal.

Control Room

5.39 Mr Bollands assumed that the initial explosion had blown in the Control Room wall between C and D Modules. The Control Room itself was devastated. Free-standing equipment and tables were thrown about the room. There was considerable debris of telephones, computer equipment and furniture scattered about. He described the smoke coming from the south end of the Control Room and drifting northwards. The main lighting had gone off, though he believed the emergency lighting came on initially. In any event visibility was poor and though he could see the smoke at the south end, he could not see the south wall.

5.40 It is convenient to mention here Mr Bollands' evidence of his observations and actions before he left the Control Room. He was pretty sure the mimic panel was intact, though he could not say if the lights were on; he was not able to see as far as the F & G panel. He went to the ESD button, which was in its usual place directly beneath the mimic panel and appeared intact, and pressed it. He did this as soon as he recovered himself, but he thought that the ESD system would already have operated. He did not press any of the 3 buttons for the 3 ESVs on the Tartan, Claymore and MCP-01 gas pipelines.

Mechanical and Instrument Workshops

5.41 Survivors from the Mechanical Workshop stated that the east bulkhead of the tea room was buckled, that the emergency door on the west face of this room was blown in and that the east bulkhead of the workshop itself was buckled. The south bulkhead of the workshop, facing C Module, was buckled inwards and the door on this bulkhead leading to the cable room or cupboard had been blown completely off its hinges.

Gas Conservation Module

5.42 Mr J A Craig was standing in the GCM when there was a massive explosion. Several flickering flames broke out along the north wall in the north-west corner of the module, which prevented him passing through the door into the Sack Module. These flames would have been located approximately above the second stage reciprocating compressor scrubber 1-C-116A in C Module.

Skid deck slot hatches

5.43 Two survivors described how slot hatches on the skid deck had lifted. Mr V Swales described the larger hatches, which covered a single well head, as of metal plate and frame construction, measuring some 9 ft x 5 ft and held in place by their own weight. In the centre of these was a smaller hatch 2.5 ft x 2.5 ft bolted on. He arrived on the skid deck some 6-7 minutes after the initial explosion to find that at least 1 or 2 of the larger hatches had lifted and quite a few of the smaller ones had been knocked off, maybe with only 1 bolt remaining to keep them from being blown away. Later he passed across this deck again but did not notice any difference in the state of the hatches. Lifting of the slot hatches was also observed by Mr S Rae, who stated that those which had lifted were mainly on the north side of the skid, west of the derrick; however, at the extreme west of the deck there were containers standing on the hatches.

A/B firewall

5.44 Several survivors gave evidence on the state of the A/B firewall. Of these witnesses the most positive was Mr J L Gutteridge, the toolpusher. He looked into A

Module from its south-west corner as he was making his escape. He saw various small fires in it, but he was sure that the A/B firewall was intact. Mr Rae went down the staircase on the south side of A Module into the module itself. He saw quite large flames from the west side of the module and various small fires at the north side. The whole of the north side was affected by smoke and sometimes flames. He was unable to say whether the A/B firewall was intact. He thought the flames and smoke might be seeping over the top of the firewall. Mr J M McDonald also went down the staircase on the south side of A Module. He saw the Christmas trees on fire in the western third of the module. He was unable to see the A/B firewall until he got down to the foghorn platform. When he got down there, he saw flames coming under A and B Modules. He could not see the separators in B Module and took this as evidence that the A/B firewall was intact. There were several other witnesses who had a view into A Module, but who were unable to say whether the A/B firewall had remained intact.

5.45 Attempts were also made to assess the state of the A/B firewall from the photographic evidence. Examination of Mr Miller's first photograph (Plate 14(a)) of the fireball in B Module immediately after the initial explosion showed flames either behind or reflected from the heat shield. Dr Stickney stated that the heat shield would not be a specular reflector and that therefore the flames seen would be behind the heat shield. There was, however, a passageway between the west side of the heat shield and the west end of the A/B firewall, so that flames observed behind the heat shield to the south of B Module were not evidence of any breach in that firewall. Other attempts to interpret photographic evidence to show that the A/B firewall was breached were unconvincing.

Lowland Cavalier

5.46 Some damage was also done to the *Lowland Cavalier*. Mr L M T Macdonald stated that all 4 windows in the starboard and rear sides of the handling shack at the stern of the vessel were smashed.

Debris from initial explosion

5.47 A few of the eye-witness accounts of the initial explosion mentioned ejection of debris or missiles from the platform. The principal missile was that observed by Mr G Carson, the medic on the *Silver Pit*, who was in the galley facing a porthole on the port side and pouring a cup of tea when the explosion occurred. Something flew past which was not bird-shaped and was big enough momentarily to blot out the 11 inch porthole. At the time the vessel was lying to the north of the platform with her bows pointing towards it. (The fact that it was the port-side porthole through which Mr Carson observed the flying object does not create a difficulty provided it is assumed that the vessel was lying somewhat to the north-west and with bows pointing roughly south south-east).

5.48 Evidence of another possible missile was the damage to the Chanter riser gantry observed by Mr Bradley. He identified the gantry as that shown in Plate 10(b). It projected from the platform on the west side between the 68 and 84 ft levels and was in 2 sections, the northerly having a projecting horizontal section with a triangular end and the southerly one with a rectangular end. Only the former was visible to him from the 20 ft level at the B4 leg. On this section a diagonal member running down from the 84 ft level to the projecting triangular end of the horizontal section had been crushed and twisted at the 68 ft level end by a force acting towards the north. Mr Bradley observed the damage from 50 ft below and some 5-10 minutes after the initial explosion. He was shown Mr Miller's 21st photograph, taken during the fire, and agreed this seemed to show the diagonal member undamaged, but he stuck to his statement that it had suffered damage. Mr Elliott also was questioned on the state of this gantry but had no recollection of any damage to it. Asked to estimate the diameter of the diagonal pipe, he thought it was about 10 inch.

5.49 The evidence of Mr Ralph should also be mentioned. He spoke of 2 explosions, separated by a time varying between soon after to a couple of minutes. The amount of debris which came out from the second was greater, but he saw some at the first one, and believed that oil drums and timber which he saw come out did so even with the first explosion.

5.50 Missiles were suggested as a potential cause of various types of damage from the initial explosion. The evidence on this is described in Chapter 7.

Platform vibration caused by initial explosion

5.51 A number of witnesses spoke of the severe vibration associated with the initial explosion. People were thrown off chairs or knocked over. Some thought that a container had been dropped or that a vessel had collided with the platform.

5.52 Dr Cubbage took the view that this vibration was a significant feature of the explosion and one which might in large part account for the physical forces experienced by personnel and causing damage to equipment. He compared the shock with that which might be produced by an earthquake. Earthquake induced accelerations are measured on the Modified Mercalli Intensity Scale: an acceleration of 100 mm/s^2 renders it difficult for people to remain upright, while one of 400 mm/s^2 is destructive to some buildings.

5.53 Dr Cubbage worked from the hypothesis that the initial explosion was in C Module. He presented the results of a computer simulation of the vibration which would be induced in the platform by an explosion. The simulation was performed by Offshore Design Engineering using the program FESDEC. The explosion was characterised by a pressure pulse of 0.68 bar (10 psi) and 0.4 seconds duration applied to the east face of C Module. This produced a lateral movement with a maximum acceleration of 360 mm/s^2, a maximum velocity of 60 mm/s and a maximum displacement of 30 mm. This acceleration is in Group 8 of the Mercalli Scale, which corresponds to shock sufficient to knock people over.

5.54 Dr Cubbage was questioned on several aspects of this work, which was a simplified study, done in a limited time. He was not able to speak to the errors in the model used. With regard to the simulation performed, the pressure pulse was applied to the compressor compartments and ducting at the east end of C Module. He stated that if these were blown away, and there was no direct evidence that they were, it was probable that the reaction would have been effective before they had time to move away. He agreed that there would be forces on the 2 firewalls and on the floor and the ceiling, but since in both these cases the forces would act in opposite directions, they would to some extent cancel each other out; it was desirable to take them into account also, but this would have been a much more complex exercise. With regard to the magnitude of the over-pressure, he accepted the value used was higher than that derived elsewhere in his report; the latter results were not available when the vibration study was commissioned. However, the acceleration was proportional to the over-pressure, so that an over-pressure of 0.34 (5 psi), half the value used, would give an acceleration of 180 mm/s^2, which came within Group 7 of the Mercalli Scale and still corresponded to shock sufficient to knock people over.

Hypothesis of a dive complex explosion

5.55 It was postulated by Dr Cubbage that there may have been a second explosion, almost coincident with the initial explosion, above the dive complex on the 68 ft level. He presented this hypothesis in his report as a possible explanation of the blue flame seen by Captain Clegg. He suggested that unburnt fuel might have been forced from C Module via B Module into the area of the dive complex, where it ignited. The blue flame described would be consistent with low velocity venting of unburnt gas. The amount of hydrocarbon involved might have been no more than half a kilogram.

5.56 He believed that such an explosion could have caused the damage effects observed at the dive complex. The effects on the complex were very localised and could have been caused by explosion of a semi-confined gas cloud. This could also have caused flames to be projected along the corridor between the Machinery Room and offices and the air cylinder bank, which may have allowed gas, flame and/or combustion products to invade the areas of the north landing and the Coflexip container and could account for some of the effects observed there. Dr Cubbage suggested that some of the effects experienced by Mr Bradley and Mr Ralph may have been due to a dive complex explosion, but did not attribute those felt by Mr Elliott and Mr Jackson to this cause. He agreed that such an explosion would fit with the fact of 2 flashes as reported by Mr Parrydavies, but not if there were a time interval between them of 10 seconds as reported by that witness; it would have to be more like 2-3 seconds. He was questioned whether such an explosion was consistent with the evidence of Mr Niven. He admitted that the fact that Mr Niven experienced no heat was a difficulty for his hypothesis.

5.57 Dr Cubbage believed that the gas for a dive complex explosion could have been unburnt fuel forced ahead of the flame travelling through C Module into B Module and then down into the dive complex area. Failure of the B/C firewall would allow unburnt gas to pass into B Module. He referred to the evidence of Mr M R Khan, the chemist, that the deck gratings in the area of the metering and prover loop skid were raised and also to the existence of other penetrations such as that around the MOL. He was evidently under the impression that removal of the grating meant that there was an opening to the deck below and was not aware of the evidence that the grating constituted a false floor above a solid deck. Questions were raised in cross-examination whether there could have been a sufficient flow rate of gas and whether gas would not have been dispersed by the wind. Asked whether an alternative possibility might be condensate flowing along the south wall of C Module and spilling over as heavy gas at the west side, he replied that this would require that it then went back inboard some 10 ft or so; he did not rule it out, but thought it unlikely. With regard to the source of ignition for the dive complex explosion, Dr Cubbage said he had assumed that this would be the flame continuing through the gas cloud which had been forced into B Module. He rejected the possibility that the damage to the decompression chamber and the Machinery Room of the dive complex might have been caused by an explosion in B Module or in both C and B Modules.

Interpretation of personnel and damage effects of initial explosion

5.58 The initial explosion affected personnel and caused damage in various parts of the platform. One of the principal tasks attempted by Dr Cubbage was to give an explanation of some of the more puzzling effects.

5.59 As far as concerns personnel, Dr Cubbage drew attention to the evidence of survivors who were thrown from chairs and beds. In seeking to explain the effects experienced by people who were knocked over by the explosion, he suggested that the severe vibration of the platform may have played a role. His explanation of the effects of the initial explosion on Mr Bollands and Mr Clark is given below. He believed these to be consistent with those of a blast wave from an explosion in C Module. Mr Elliott and Mr Jackson were standing on the north landing almost directly under the west end of C Module and about 10 ft out from the overhang. Dr Cubbage believed that the effects which they experienced were consistent with those to be expected from venting of the explosion from that end of the module, supplemented by platform vibration, and perhaps some effect from blast along the corridor of the dive complex. Dr Cubbage took the view that Mr Bradley and Mr Ralph at the 20 ft level probably experienced a number of different effects. To reach them the pressure wave from venting of the explosion at the west end of the C Module would have had to travel down some 60 ft and then eastwards some 30 ft; Mr Ralph said he was moved westwards. Probably therefore these men were affected not only by this venting but also by platform vibration and by any dive complex explosion.

5.60 The principal damage effects which Dr Cubbage addressed were those to the doors of No 2 decompression chamber and of the Dive Machinery Room. The circular door of the decompression chamber was described as 3 to 3½ ft diameter and 2-3 inch thick. The door, hinged at its northern end, was secured to a hinge arm by a boss which passed through a collar on the end of the hinge arm, the boss and collar being held together by a split pin. It was held at its southern end with a 'dog' swivel catch, secured with a screw. The door was described as off its hinges and lying in the bottom of the outer airlock. If the door had been swung open by an over-pressure in the region of the decompression chamber, it could have gone back to hit the curved side of the chamber. The only thing restraining the movement of the hinge arm would have been a 0.25 inch split pin. Dr Cubbage stated that it had been calculated that the over-pressure required to cause failure would have been between 0.5 and 3 psi (0.035 and 0.2 bar). However, he also stated that the damage might have been the result of platform vibration, but had done no calculations on this.

5.61 The Dive Machinery Room was fitted at the south end with double emergency, or fire, doors which opened outwards. One door was bolted at the top and bottom, the other was a crash door, latched with an emergency push bar. They were heavy metal doors each with 3 hinges. These doors were described as bowed outwards, or burst open, and were too distorted to close. Dr Cubbage stated that this type of door fitting is relatively weak. It would be easy for the bolts to be drawn out of the U-bracket into which they slotted when the doors were closed. He thought it likely that the doors had been sucked out by the negative pressure which follows the positive pressure of an explosion or by a vortex from the hypothesised dive complex explosion.

5.62 Overall, Dr Cubbage doubted whether the damage described in the dive complex area would have been caused by the initial explosion and preferred the explanation of a dive complex explosion together with platform vibration.

C Module as site of initial explosion

5.63 The evidence of survivors and other eye-witnesses points strongly to either B or C Module as the seat of the initial explosion. The evidence of the Control Room operator, Mr Bollands, was that a series of gas alarms culminating in the initial explosion came up in C Module. He gave no evidence of any gas alarm after 21.30 hours except in C Module. The effects of the initial explosion included blast effects felt by Mr Bollands and Mr Clark in the Control Room; a fire which occurred within seconds in B Module and became the main area of flame and smoke; emissions of smoke and outbreak of fire on the west face about the centre and at the 84 ft level; emission of smoke from the same level just north of centre on the east face; and blast effects felt by Mr Grieve and Mr Young on the 68 ft level. The explosion also apparently disabled the main power supply, for which the generators and switchboard were in D Module. There was no evidence given that the initial explosion was in D Module, A Module, the 68 ft level or, indeed, anywhere other than B or C Module.

5.64 The occurrence of gas alarms in C Module is clearly strong evidence of a flammable gas cloud in that module. The absence of gas alarms in other areas might in principle be due to disabling of the fire and gas alarm system; the main reason for this would be to prevent alarms being set off by welding work. Mr Bollands stated that although it was the practice to disable the automatic deluge system in an area if welding work was being done in that area, it was not the practice to disable the fire and gas detection system itself. As far as welding work on the night is concerned, it was his evidence that welding work was going on at the 68 ft level and that the automatic deluge system was therefore switched off, but the fire and gas detection system remained operational. A UV alarm in fact occurred at that level in the condensate pump area at about 20.15 hours that night. Mr Bollands said he was told this was due to welding work on the Chanter riser. He stated that he had no recollection of any other hot work permits out and, additionally, that there was no such permit out for B Module. The deluge systems in A, B and C Modules were on automatic.

5.65 Despite this strong evidence pointing to C Module as the site of the initial explosion, the facts that within seconds of the initial explosion a fire was observed at the west end of B Module which for some time was the main fire, giving rise to a large plume of smoke, and that once the initial explosion subsided there was little, if any, fire in C Module gave rise to the alternative hypothesis that the initial explosion may have occurred in B Module. Captain Clegg's evidence that the slow, blue flame which he saw extended right across the mouth of B Module provided some support for this. Although the investigative work performed prior to the Inquiry tended to concentrate on description and explanation of an initial explosion in C Module and although no explicit evidence was led by any party in support of the B Module hypothesis, it was kept alive during the Inquiry by persistent questioning. Some further support for the hypothesis came from some of the difficulties in the C Module theory. One such problem was the statements of the Control Room occupants that the rush of air which they experienced was cold rather than hot. However, it is shown in Chapter 6 that this particular effect is not inconsistent with an explosion in C Module.

5.66 The B Module hypothesis requires not only that the B/C firewall should be largely destroyed but also that serious damage should be effected to the C/D firewall. Such damage might be caused either by over-pressure or missiles. Assuming that the effects are broadly symmetrical, it would be expected that an explosion in B Module of the strength described would both destroy the A/B firewall and cause substantial damage to the heat shield. The evidence on the state of the A/B firewall has already been described. The testimony of the survivors indicated that it was substantially intact, whilst analysis of the photographs was inconclusive. Another pointer to the state of the A/B firewall was the damage to the skid deck slot hatches, which were located in the skid deck at the 107 ft level above A Module. The evidence of Mr Swales and Mr Rae that some of these hatches had lifted has been described. Dr Cubbage stated that his estimate of the over-pressure required to "just lift" the hatches was 0.003 bar (0.05 psi), a very low value, and that he would expect an explosion in B Module to have blown the hatches some distance. He explained the movement of the hatches as the result of vibration of the platform due to an explosion in C Module. More conclusive is the state of the heat shield as shown in photographs of the shield viewed from the south; one such photograph is shown in Plate 19(a). An explosion in B Module strong enough to do substantial damage to the C/D firewall would be expected to damage the heat shield also. It was Dr Cubbage's expectation that there would be damage from projectiles. No damage to the heat shield is apparent in these photographs.

5.67 I conclude from this evidence that the initial explosion occurred in C Module.

Location of initial explosion within C Module

5.68 The gas alarm pattern described by Mr Bollands was an initial low gas alarm in zone C3, C centrifugal compressor, followed after an interval by a further group of low gas alarms and a single high gas alarm; these low gas alarms were C2, C4 and C5 for C Module East and A and B centrifugal compressors, respectively, but he was not sure of the high gas alarm zone. The evidence of these gas alarms indicates a gas cloud in the south-east quadrant of C Module. The explosion damage to the main and emergency power supplies points to the eastern half of C Module as the site of the explosion and the absence of hot gas in the Control Room is unfavourable to an explosion in the north-east quadrant. Dr Cubbage stated that the gas alarms indicated a gas cloud in the east of the module and that ignition at the west end, which was more open, would not have given an explosion of sufficient strength, but felt unable to go beyond that.

5.69 From this evidence I conclude that much the most likely location of the initial explosion was the south-east quadrant of C Module.

Nature of fuel

5.70 The main hydrocarbon fuels on the platform were oil, gas and condensate. Oil itself cannot form a gas cloud, although volatile components in it conceivably might do so. Gas and condensate are, however, much more likely candidates. As far as concerns C Module, the 2 types of hydrocarbon stream present in the pipework and capable of forming a gas cloud were methane and condensate. The latter is conveniently approximated by propane, although the more volatile components in it should not be neglected. There are 2 principal pieces of evidence which bear on the choice between these 2 as the fuel in the gas cloud formed. These are the pattern of gas alarms in C Module and the slow, blue flame seen by Captain Clegg.

5.71 For an explosion of sufficient strength to have occurred in the module, it was necessary for a fairly large gas cloud to have built up. There were in C Module a number of gas detectors in the roof to pick up methane. There was in the east end of the module only one detector near the floor, apart from those at the centrifugal compressors. If the hydrocarbon released had been methane, it is difficult to see how a cloud of sufficient size could form without setting off a number of the gas alarms in the roof of the module. If on the other hand it was condensate, which is heavier than air, it is possible to envisage the formation of quite a large low lying cloud which might not set off the single gas detector. These qualitative arguments are confirmed by the wind tunnel tests described in Chapter 6.

5.72 The other main pointer is the evidence of Captain Clegg, who saw a slow, blue flame apparently at floor level in B and C Modules.

5.73 Dr Cubbage stated in his report that he based his assessment of the nature of the fuel entirely on Captain Clegg's evidence. Even so he clearly found difficulty with it. He thought the slow, low lying blue flame seen by Captain Clegg would be consistent with ignition of a lean mixture of gas heavier than air at the west end of C Module which then burnt towards the east end, but that this would not have generated a sufficiently high over-pressure. He did not think Captain Clegg would have seen such a flame from ignition at the east end. He was driven to postulate either a further source of ignition at the east end or a separate explosion in the region of the dive complex. He did not initially state whether he believed the gas was lighter or heavier than air, except to say the latter was consistent with the first interpretation of Captain Clegg's evidence. However, in cross-examination Dr Cubbage did confirm that he believed the gas was heavier than air. Still basing his view on Captain Clegg's evidence, he referred to the fact that a heavier-than-air gas was consistent with all the interpretations which he had put on this evidence and that there was no report of flame at a high level.

5.74 The possibility was explored that if the material released was condensate, heavy condensate gas would tend to flow by gravity along the floor of the module and possibly out the end and could thus give rise to secondary fires and explosions. The wind tunnel work, described in Chapter 6, showed that the ventilation conditions pertaining were unfavourable to any significant upwind gravity flow of gas. This does not, however, preclude flow of condensate liquid, at least over the solid part of the module floor.

5.75 The conclusion which I draw from the above is that the gas released was heavier than air and came from a leak of condensate.

Nature and volume of gas cloud

5.76 Evidence bearing on the volume of the gas cloud included the damage to the firewalls and the Control Room wall and the effects on personnel in the Control Room and the Mechanical Workshop as well as Captain Clegg's observations. The C/D firewall suffered severe damage towards the east and centre of the module, but the sections of both the B/C and C/D firewalls at the extreme west end apparently survived. Mr Bollands and Mr Clark in the Control Room did not feel an inrush of hot gas, while 2 survivors in the Mechanical Workshop felt a rush of cool air.

5.77 In assessing the probable volume of the cloud, Dr Cubbage referred to these effects on personnel and observed that if the module had been full of gas, he would have expected Captain Clegg to see a large amount of flame issuing from the west side of the module. He believed that the cloud could not have exceeded two-thirds of the volume of the module, basing this estimate on the fact that the Control Room, which was not reached by the flames, was some one third of the way into the module from the west end. With regard to the height of the cloud Dr Cubbage was able to say little more than that he believed it was a low lying one. Its height would depend on the angle at which the jet issued. Since all the streams in C Module were at high pressure, the leak would be a high pressure jet, so that the cloud would be well mixed with air, although presence of obstacles would result in some lack of homogeneity. Dr Cubbage agreed that in forming a view on the size of the gas cloud he had in mind the minimum size of cloud required to give the over-pressures apparently experienced, as estimated by Technica and CMI, and by his own simulations.

5.78 I conclude from the above that the gas cloud was at the east end of the module, that it did not reach the Control Room and probably extended no further than the centre of the module and filled only the lower part of the east end. This would give a cloud volume of no more than 25% of the module and likely less.

Location and nature of source of ignition

5.79 Evidence on the source of ignition was limited to the interpretations which Dr Cubbage placed on the eye-witnesses' observations. He took the view that the initial explosion was that of a gas cloud in the east end of C Module ignited at that end. There remained the difficulty of explaining Captain Clegg's evidence. It was put to Dr Cubbage that ignition in the centre of the module rather than at the east end would have the advantage of giving a stronger explosion and that this might have been what Captain Clegg saw. Dr Cubbage replied that Captain Clegg was firm that the flame he saw was at the mouth of the module and that the only explanation he could give of this evidence of Captain Clegg, other than the hypothesis of a dive complex explosion, was that there were 2 sources of ignition, one at the east end and one at the west. He was unwilling to choose between these 2 explanations. Dr Cubbage's attention was drawn to a work permit approved at 18.30 hours on 6 July for hot work in a location known as the 'habitat' at the east end of D Module. He agreed that this could be a possible source of ignition for a gas cloud somewhere round the east side of D Module. Dr Cubbage assented to the proposition that a gas cloud in the module would almost certainly find a source of ignition. He mentioned hot surfaces, broken light fittings and sparks. With regard to the strength of any ignition source, Dr Cubbage stated that the amount of energy required to ignite the gas cloud concerned is very small.

Nature of initial explosion

5.80 Accounts of combustion phenomena were given by Dr Cox and by Dr Cubbage. Combustion of a flammable gas cloud may in principle be either a deflagration or a detonation. In a detonation the flame speed is very high, in excess of the speed of sound in the medium. In deflagrations the range of flame speeds which occur is wide, from speeds of a few metres per second up to those applicable to detonations, but in most cases the flame speed is much lower than in a detonation. The over-pressures generated in detonations tend to be much higher than those given by deflagrations. A completely unconfined flammable gas cloud normally burns as a deflagration. A flammable mixture burning in a pipe, on the other hand, tends to accelerate until detonation is reached. Combustion of a flammable mixture in a closed vessel normally gives a deflagration and this is also the type of combustion which would be expected in a containment such as a module on a platform. Computer simulations of deflagrations in modules and of detonations in pipes were shown on video by Dr Bakke. The simulations included the effect of turbulence promoters.

5.81 The question of the type of explosion to be expected in a module was addressed by Dr Cox, by Dr Scilly and by Dr Cubbage. On the basis of his assessment of the turbulence promoters in the module, Dr Cox determined an empirical value of the ratio of the actual flame speed to the burning velocity and obtained flame speeds much less than those for detonation. Dr Scilly considered detonation highly unlikely, the gas cloud not being large enough and the turbulence promoters being insufficient. Dr Cubbage also judged detonation unlikely, the aspect (length/diameter) ratio of the module being too small.

Over-pressures generated by initial explosion

5.82 The magnitude of the initial explosion was one of the main features addressed in the Petrie Final Report, which included 2 annexes on the topic. Annex 3 gave computer simulations by the Christian Michelsen Institute (CMI) using their FLACS model and Annex 4A an analytical study by Dr N F Scilly and Dr D Carter. This work was spoken to by Dr J R Bakke and by Dr Scilly, respectively. In addition, there was made available to the Inquiry a study done for Occidental by Technica Ltd, spoken to by Dr R A Cox, of firewall failure. There was a further Technica report for Occidental, also spoken to by Dr Cox, on projectile damage, but the explosion models given in this latter report related to projectile velocity rather than explosion over-pressures and therefore it is not considered here. The Technica firewall study included results from the CMI FLACS computer code; this work was separate from that commissioned by the DEn. With regard to the FLACS model, this is described in Chapter 6 and Appendix G. The account here is confined to the results obtained by CMI for the DEn and for Technica. Estimates of the explosion strength were also made by Dr Cubbage. The evidence of these experts is summarised below. The account of Dr Cox's evidence is confined to the explosion over-pressures; the effects of these on failure of the firewall and on damage by projectiles are considered later in this chapter and in Chapter 7, respectively. Later in the Inquiry work was presented on the formation and explosion of a hydrocarbon gas cloud related to possible accident scenarios, utilising wind tunnel tests and further FLACS code simulations, respectively, and this is described in Chapter 6.

5.83 The outcome of this work was estimates of the over-pressures generated by the explosion. At a given point the over-pressure will rise to a peak value, which is referred to as the peak over-pressure. The maximum value of the peak over-pressures at the various points in the module is referred to here as the maximum peak over-pressure. Reference is also made to the dynamic pressure. This is the pressure associated with the wind effects generated by an explosion.

Evidence of Dr Cox

5.84 Taking first the Technica report on firewall failure and the supplement to this report, Dr Cox began with an account of the factors which influence the severity of a semi-confined gas explosion such as that occurring in a module. For a continuous leak the formation of the gas cloud will depend on the material leaking, its pressure and temperature, the hole size and location, and the ventilation rate. The over-pressures generated by ignition of the cloud will depend on the layout of the module, particularly obstacles and vent areas, and on the location of the ignition source. The speed of the flame through the flammable mixture depends partly on the burning velocity, which is a property of the mixture, and partly on the enhancement of this basic velocity caused by turbulence. A high flame speed and large flame area will result in rapid combustion, which will generate high over-pressures. These in turn will increase the bulk flow of the flammable mixture, thus creating a positive feedback loop.

5.85 Initially ranging estimates were made to obtain order of magnitude estimates of the over-pressure. An upper bound was obtained by assuming a module filled with a stoichiometric mixture of hydrocarbon and air and with no venting either through the walls or the ends. For this case the estimated peak over-pressure was 7-8 bar. Empirical formulae, or models, were then used to obtain estimates for the case where venting occurs. The vent area was assumed to be 50% of the areas of the 2 ends of the module; additional venting by firewall collapse was not taken into account. Two scenarios were considered. Case 1 was a stoichiometric mixture of hydrocarbons, consisting of 89% methane and 11% propane, filling the whole of the module; case 2 was the stoichiometric mixture filling only the intercooler section, and hence 25% of the module. The former was chosen as a 'worst case', the latter as a somewhat more realistic scenario. These empirical models gave estimates of the maximum peak over-pressure in the range 1-3.6 bar; the figures refer to the full range of results obtained for the 2 scenarios using the different methods. Values were quoted of several bar for case 1 and of about 1.2 bar for case 2.

5.86 Following these ranging calculations, more refined estimates were obtained using the FLACS code of CMI. The work was on similar lines to that done by CMI for the DEn, as described below. The layout of the equipment in C Module was entered into the code and the explosion of the flammable gas cloud was simulated. The details of and results for the 2 runs done by CMI for Technica are shown in Table 5.1, as Runs T1 and T2, corresponding to cases 1 and 2 as just described. In this work the vent area at the end of the modules was that obtained from the module layout entered into the computer, but again it was assumed that the firewalls would not fail. It was also necessary in this case to specify the location of the ignition source. For case 1 this was taken as being in the eastern end of the module and 1.5m off the floor. For case 2 it was taken as lying on the border between sections 3 and 4 and thus one quarter of the way in from the east end. In these simulations pressure measurement points were located along the centre line of the module, starting with P1 at the west end and ending with P10 at the east end. For case 1 the maximum peak over-pressure was about 0.45 barg with a duration of 0.4 seconds and for case 2 it was about 0.25 barg. In each case the peak over-pressures at points P9-P3 down the centre line of the module were broadly similar, with some tailing off at points P2-P1. (It should be noted that these points, which are not shown here, were different from those used in the CMI work for the DEn.) Significantly lower pressures were obtained at points P2-P1 and P10. For case 1 the peak over-pressure at points P2-P1 was about 0.2 barg and that at P10 about 0.3 barg. For case 2 the peak over-pressures at P2-P1 were "very low"; the values on the figures presented were about 0.05 and 0.02 barg, respectively. With regard to location of the ignition source, Dr Cox stated that for case 2 location of the source within the cloud rather than at its eastern edge might well have given higher over-pressures, particularly at points P2-P1.

5.87 The associated analysis of firewall failure showed that the firewalls would fail even at the lower of these 2 peak over-pressures, with the possible exception in the second case of the walls at the west end of the module. Thus venting would have occurred additional to that assumed in the simulation, so that the peak over-pressures predicted by the latter would be to that extent too high. The work did, however, serve its purpose of demonstrating that there would be firewall failure. Comparing the differences between the results of the empirical models and those of the computer simulations, Dr Cox adduced as features which may have been significant the enhancement factor used to obtain the flame speed in the former and the location of the ignition source in the latter. He was clear that the computer simulation was to be preferred and stated that if they had been able to wait for the CMI results they might have dispensed with the use of the empirical models. He was cross-examined on the scenarios chosen, the assumptions made for the simulations and on the results obtained. He agreed that the results would be sensitive to these assumptions. He pointed out that the purpose of the work was to determine whether the over-pressures generated would be sufficient to destroy the firewalls rather than to calculate over-pressures *per se* and that the results were sufficient for this purpose.

Evidence by Dr Bakke

5.88 Shortly after the Piper disaster CMI was commissioned by the DEn to perform simulations using the FLACS code for a number of scenarios of explosions in C Module. The report on this work was spoken to by Dr Bakke. The layout of C Module entered into the code is shown in Fig 5.1. The figure also shows the 8 points, P1-P8, at which the pressures were measured and the locations X and Y of the ignition sources. 5 cases were considered. Cases 1, 2 and 4 involved natural gas and cases 3 and 5 condensate. The module fill was 50% in each case, except for case 4, for which it was 30%. Wall failure was allowed for in all cases except case 5. For cases 1 and 4 the location of the ignition source was at the eastern end of the cloud, for cases 2, 3 and 5 at the centre of the module. The details of and results for these cases 1-5 studied by CMI for the DEn are given in Table 5.1 as runs 1-5. This work showed that there are a number of scenarios which would lead to pressures high enough to cause failure of the firewalls. It also illustrated a number of important trends. It showed that higher over-pressures are generated if the hydrocarbon cloud is larger, if there is no failure of the firewalls, if the ignition source is at the centre and if the fuel is condensate rather than natural gas. Further details of the work are given in Appendix G.

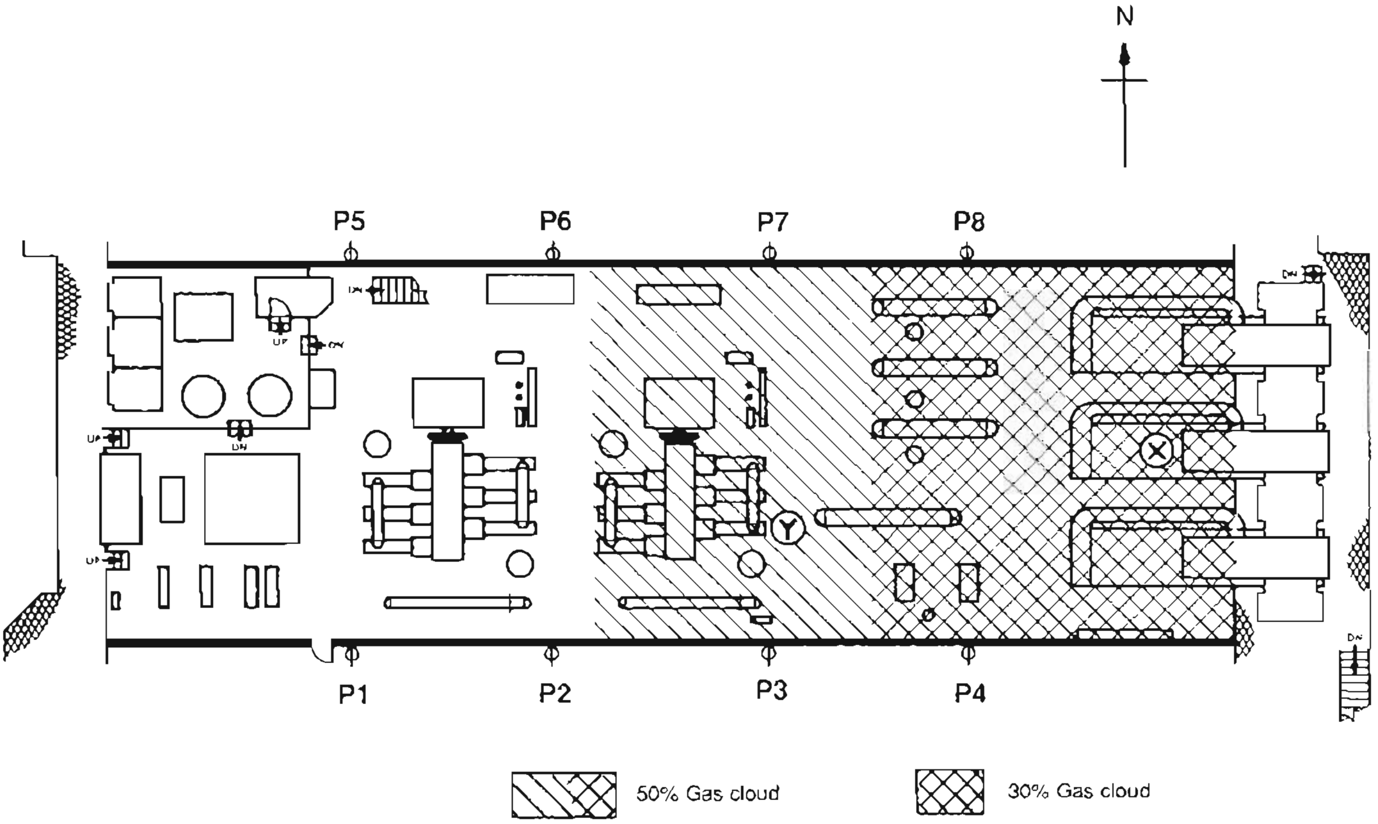


Fig. 5.1 Plan view of C Module, showing pressure points P1-P8, 30% and 50% fill gas clouds and ignition sources X and Y used in the CMI explosion simulations.

5.89 The approach taken in the work of Dr Cox and Dr Bakke just outlined was to explore a range of theoretical scenarios for the initial explosion and to identify those which might cause failure of the firewalls. Other studies were done, as described below, to try to deduce the over-pressure of the explosion from evidence of its other effects.

Evidence of Dr Scilly

5.90 A study to estimate the strength of the initial explosion based on the bodily translation suffered by Mr Bollands and Mr Clark was made by Dr Scilly and Dr

Carter of the HSE and was spoken to by Dr Scilly. The estimate was based on the use of a TNT equivalent model for the gas cloud explosion and on the assumption that the firewall between C Module and the Control Room gave way at a pressure well below the peak pressure attained in C Module. Both Mr Bollands and Mr Clark were thrown across the Control Room by the blast, but neither received serious injury. For a man in the standing posture exposed to a blast wave, data exist which give the degree of injury as a function of the impact velocity. Dr Scilly postulated that the injury received by these 2 was at the threshold of injury, which corresponded to an impact velocity of 10 ft/s. For a man weighing 160 lb and presenting an area of 9 ft^2 the dynamic pressure impulse required to achieve this velocity was 54 psi-ms. Taking a typical value for the dynamic duration time of 225 ms gave a dynamic pressure of 0.48 psi. There is a unique relationship between the dynamic pressure and the peak over-pressure such that for this case the latter was found to have a value of 4.5 psi. This value of the peak over-pressure related to the point where the 2 occupants were standing.

5.91 This peak over-pressure could have been given by a number of gas clouds of different shapes. Dr Scilly considered 3: hemispherical clouds of 3m and 6m radius and a cylindrical cloud of 7.5m radius and 6m height. For these clouds the volumes were respectively 57, 452 and 1060m^3 and the peak over-pressures at the edge of the cloud 72, 23 and 16 psi. For stoichiometric mixtures these volumes equated to 4.4, 35.0 and 81.9 kg of propane or 3.7, 29.2 and 68.5 kg of methane, respectively. Dr Scilly suggested that the smaller release sizes, 4.4 kg for methane and 3.7 kg for propane, were unlikely. He therefore confined his attention to releases of between 35 and 82 kg for propane and between 29 and 69 kg for methane.

5.92 He gave estimates of the hole size necessary to obtain these releases. Assuming a release time of 30 seconds, the corresponding release rates were 1.2 to 2.7 kg/s for propane and 0.97 to 2.3 kg/s for methane. He estimated that these release rates might be given by the following conditions:

Material	*Pressure* (bar)	*Temperature* (°C)	*Hole size* (mm^2)
Propane	62	15	5.5-8.5
Methane	7.9	15	37-55
	49	32	15-23
	101	32	10-15

The set of conditions for propane was representative of that in the condensate lines and the 3 sets of conditions for methane of that between the production separators and the centrifugal compressors, that between the centrifugal compressors and the first-stage reciprocating compressors and that between the first and second-stage reciprocating compressors, respectively. The hole sizes given were consistent with a significant flange/gasket failure.

Evidence of Dr Cubbage

5.93 Dr Cubbage examined a number of effects of the initial explosion to try to deduce from them the over-pressures generated. These effects were the bodily translation of the occupants of the Control Room; the trace of the *Tharos* barograph; the damage to the windows of the *Lowland Cavalier*; and the over-pressure experienced by the Chief Engineer of that vessel. Taking first the effects on the occupants of the Control Room, he deduced from the fact that neither was severely injured that the impact velocity which they attained would be less than 8-10 ft/s, which had been shown by work at the Lovelace Institute to be equivalent to a dynamic pressure of 0.3 psi, for which the corresponding air velocity was 58 m/s. In turn this air velocity was related to the explosion over-pressure, or pressure difference between the module and the Control Room. Assuming no wall between these 2 spaces and an over-pressure of 0.5 bar, the air velocity would be 265m/s, or 5 times that apparently experienced by the 2 occupants. This latter velocity would therefore be in keeping with a firewall failure resulting in a 20% wall porosity. Questioned about the failure of the wall between C Module and the Control Room, Dr Cubbage replied that the wall must have failed for anything to come into the room, and that, given that situation, he would not expect to learn much more from calculations on wall failure. Asked about the effect of his assumption on wall porosity, he agreed that if the porosity were higher, the explosion over-pressure would be less.

5.94 At the initial explosion the *Tharos* itself was some 550m off the west face of Piper, but its barograph, located in the forward control area, was some 620m off. The barograph trace showed between 22.00 and 24.00 hours a deflection equivalent to about 18 mbar. Although the over-pressure from a fuel-air explosion is inversely proportional to the distance in the far field, this relationship breaks down in the near field. For the latter an alternative decay law has been given by Butler and Tonkin; the relationship is valid where there is no significant confinement of the shock wave and the direction is normal to the vent opening, conditions satisfied in the present case. The over-pressure estimated using this equation was 0.675 bar. It was possible, however, that the barograph trace might derive from a later event on Piper when the *Tharos* was 60m and the barograph some 130m off the west face. In that case the trace would correspond to an over-pressure of 0.156 bar. Questioned on the significance of the barograph trace, Dr Cubbage stated that he could go no further than that it was not inconsistent with the other evidence. There was only a single vertical trace. The response characteristics of the instrument were unknown. Apart from its mounting on rubber feet, no special measures had been taken to isolate it from mechanical shocks, which could, therefore, mask the response to pressure changes.

5.95 The *Lowland Cavalier*, lying some 30m off the west face of Piper in line with leg B1, suffered damage to the windows of the handling shack, located near the stern of the vessel and some 45m from the face of C Module. The windows, which were understood to be of standard glass 4-6 mm thick and some 1 metre square, were blown into the shack. The pressure to break such windows is 50-70 mbar, though since the windows were held by a rubber grommet a lower pressure would have sufficed. The Butler and Tonkin equation was again used, although in this case the vessel was not square on to C Module. Assuming a pressure of 50 mbar on the windows, the explosion over-pressure obtained was 0.18 bar. If the explosion was assumed to have occurred in one half of the module, the explosion over-pressure obtained was 0.21 bar. Thus given the assumption on window strength, this case gave a lower bound for the explosion over-pressure of some 0.2 bar.

5.96 According to Captain Clegg, his Chief Engineer was blown from his position on the deck near the bridge superstructure into the bridge bulkhead. To have this effect the pressure exerted on his body would have to exceed 70 mbar. The Chief Engineer would have been some 50m from the crane pedestal. Use was again made of the Butler and Tonkin equation; the explosion over-pressure obtained was 0.39-0.48 bar.

5.97 From the foregoing investigations, Dr Cubbage concluded that the over-pressure generated by the initial explosion was in excess of 0.2 bar and probably in the range 0.4-0.7 bar. He later summarised his evidence to the effect that a reasonable range for the over-pressure was 0.3-0.7 bar.

5.98 Dr Cubbage gave consideration to the use of empirical equations to predict the over-pressures which might be generated by various theoretical release scenarios, but came to the conclusion that such equations could not be applied with any great confidence. He did, however, present results of explosion over-pressure calculations performed using the CLICHE code of British Gas. The code is based on a spherical flame front. It was originally intended for use in simulating explosions in vessels with a high degree of confinement and low flame speeds, but has since been extended to include an external explosion model and to allow investigation of the effects of different fuels and flow conditions. It has been used successfully to study the effect of these parameters on flame acceleration through obstacles and to predict explosion pressures much higher than those for which it was originally designed. Two cases were studied using the CLICHE code. Both were for a 50% fill of the module with ignition at the east end of the cloud and with firewall failure. Case 1 was for natural gas and case 2 for propane. The vent area at the east end was taken directly from the model and was 25%; it was assumed there was no failure of the centrifugal compressor ductwork. The firewalls were assumed to fail, giving a porosity of 20%. The details of and results for these cases are shown in Table 5.1, where runs C1 and C2 correspond to cases 1 and 2, respectively. The maximum peak over-pressure shown is 0.4 bar for natural gas and 0.5 bar for propane. Run C1 is directly comparable with run 1 of CMI and it can be seen from the table that the results obtained are very similar.

Over-pressures required to destroy firewalls

5.99 Another indication of the over-pressures generated by the initial explosion is the pressures required to destroy the B/C and C/D firewalls. The strength of these firewalls is therefore considered here. However, consideration of the potential missiles from the failure of these firewalls is deferred to Chapter 7 dealing with escalation. As described above, failure of the firewalls in C Module was the subject of a report to Occidental by Technica, spoken to by Dr Cox. The objective of the work was to determine whether the firewalls of either C or B Modules would have failed under the transient pressure imposed by the explosion of a hydrocarbon gas cloud. The work thus involved identifying the mode of failure and the pressure level at which such failure would occur. An account of this work is given here. Further details of the work are given in Appendix G.

5.100 The B/C firewall was a single-layer 4.5 hour integrity wall. It consisted of an array of rectangular panels, bolted into rectangular frames, with adjacent frames bolted together, forming a 'lattice'. The lower edge of the wall was welded to the production deck and its top edge attached to the underside of the upper truss beam by an arrangement of bolted and welded joints. The wall was further supported by clamping to the truss columns. The firewall is illustrated in Fig 5.2; the figure is schematic and is not to a consistent scale. The view seen in the figure is that seen from the inside of C Module looking south. In the analysis of failure of the single-layer firewall the following failure modes were considered: panels, panel bolts, lattice framework, frame bolts, clamps and welds to the deck and to the truss. Dr Cox summarised the analysis as follows. The capacities of both panel and frame bolts would be exceeded at a pressure of about 0.1 barg. Of the 2, the frame bolts were more critical in that failure of these would lead to failure of the lattice. Failure of the clamps would occur at about 0.12 barg and of the panels themselves at about 0.15 barg. In effect, the firewall would disintegrate at over-pressures somewhere in the region of 0.1-0.15 barg. He took the effective failure pressure of the single-layer firewall as 0.1 barg. The behaviour of the single-layer firewall in failure would be as follows. At pressures below about 0.1 barg the panels would start to deflect; at about this pressure frame and panel bolts would start to fail; at pressures above it frames would start to separate and, where the lattice was still intact, panels would start to collapse, whilst the clamps holding the whole wall might start to fail.

5.101 The C/D firewall was a triple-layer 6 hour integrity wall. This wall also differed from the single-layer wall in that the panels were of different size; the frames were smaller, being 7 rather than 3 frames high; there was a complex offset bolting arrangement; the arrangement of the panel and frame bolts was different in detail; and the clamping arrangements were different. The firewall is illustrated in Fig 5.3; the figure is again schematic but in this case the panelling is on the remote side of the lattice. The view in the figure is that seen from the inside of D Module looking south. An analysis similar to that on the single-layer firewall was performed on the triple-layer firewall. Again the frame bolts were the weakest component. Failure of these bolts was predicted to occur at a pressure of 0.12 barg. Failure of the panel bolts in

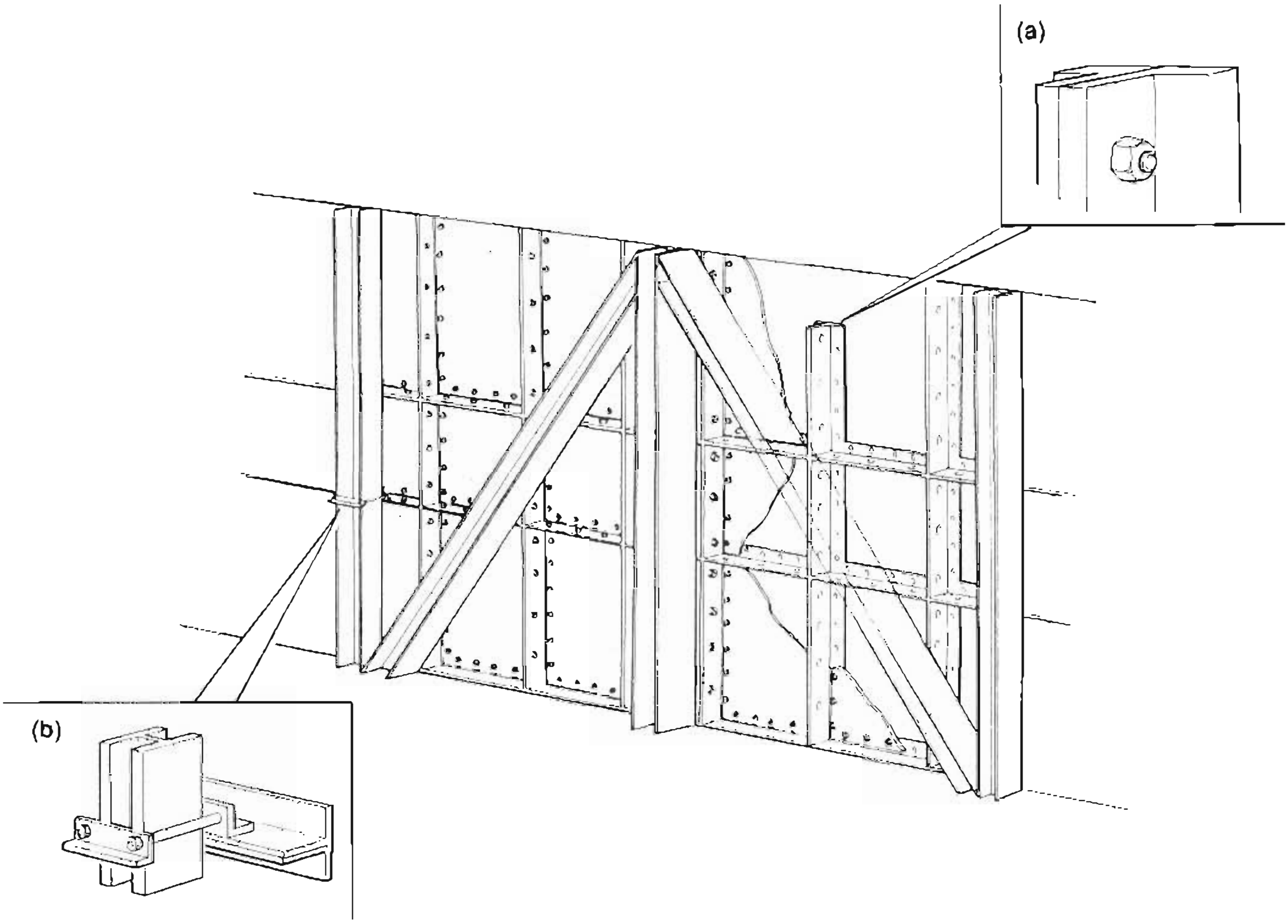


Fig. 5.2 Schematic of single-layer firewall between B and C Modules: insert (a) frame bolt; insert (b) clamps.

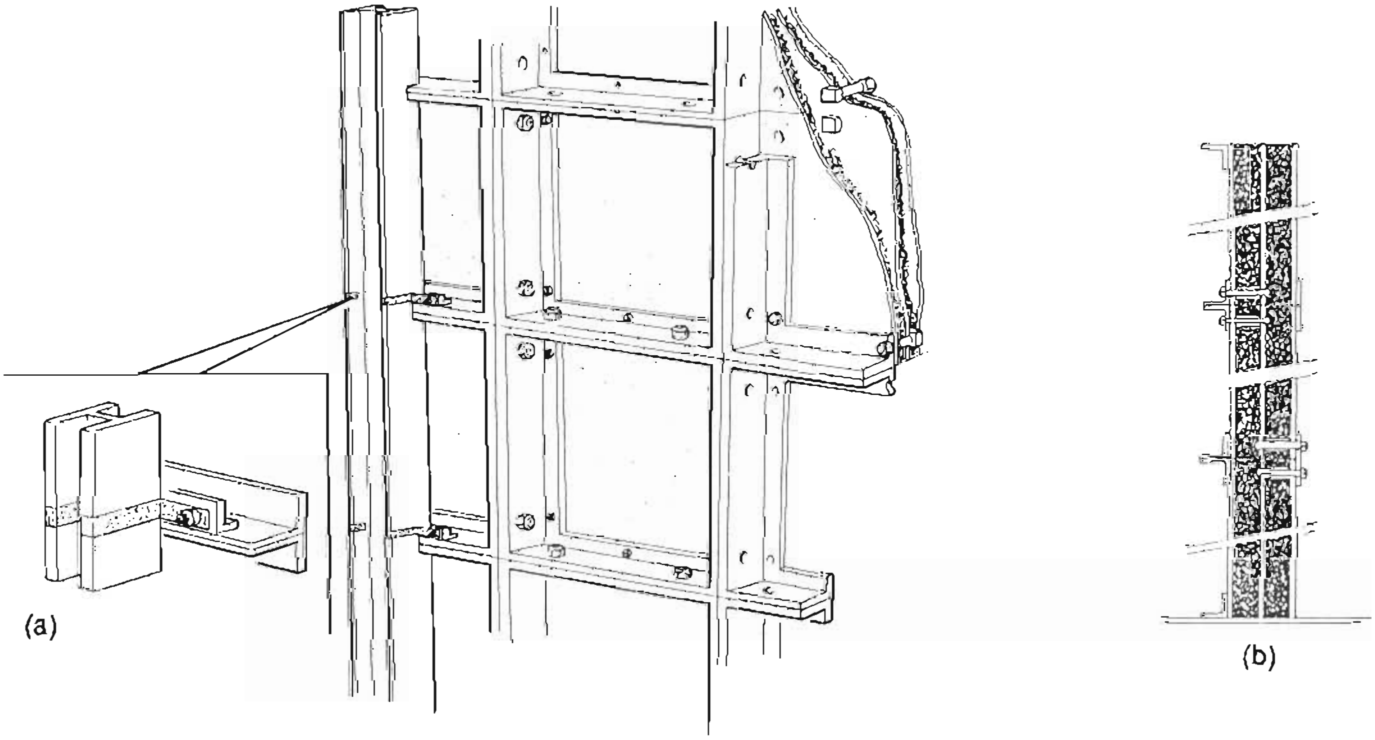


Fig. 5.3 Schematic of triple-layer firewall between C and D Modules: insert (a) clamps; insert (b) cross-section through fire wall, showing three sheets with mineral wool between.

shear loading or tearing of the panel would occur at about the same pressure. The outer sheet of the panels, supported only by very narrow bolts, would also start to fail at about 0.12 barg. However, the inner sheet, being more strongly supported, would not fail until a pressure of about 0.36 barg. This is a higher pressure than the failure pressure of the panels of the single-layer firewall because the panels of the latter are larger. Dr Cox took the effective failure pressure of the triple-layer firewall as 0.12 barg. As far as concerns the failure behaviour of the triple-layer firewall, at pressures below about 0.12 barg the panels would start to deflect; at about this pressure frame and panel bolts would start to fail and panels to tear; at pressures above it frames would start to separate and panels to separate from the frames but not to push through until higher pressures are reached.

5.102 This analysis therefore showed that the pressures required to destroy both the B/C and C/D firewalls, 0.1 and 0.12 barg, respectively, were less than most of the values estimated for the maximum peak over-pressure caused by the initial explosion.

Conclusions

5.103 I draw from this evidence the following conclusions. In terms of the basic questions on the initial explosion posed at the start of the chapter, the conclusions may be summarised as:

1. The explosion occurred at 22.00 hours BST.
2. The explosion was in C Module.
3. The explosion was in the south-east quadrant of C Module.
4. The cause of the fire in B Module was rupture of a pipe which resulted in a fireball and a large oil leak.
5. The 'second explosion' immediately after was probably the pipe rupture and fireball in B Module.
6. The fuel involved was condensate.
7. The gas cloud was a low lying cloud, filling no more than 25% of the module, probably less.
8. The mass of fuel within the flammable part of the cloud was probably in the range 30-80 kg.
9. The location and nature of the source of ignition are unknown, but the location was probably such as to favour high over-pressures.
10. The explosion was a deflagration.
11. The maximum peak over-pressure of the explosion was probably in the range 0.2-0.4 bar.

The explanation of the effects on personnel and of the damage to equipment are complex and are considered below.

5.104 The time of the initial explosion was about, and quite possibly almost exactly at, 22.00 hours BST. A number of witnesses recalled hearing the start of the 10 o'clock news. The *Lowland Cavalier* and the *Tharos* logged the event as 22.00 hours and 22.02 hours respectively, and Wick radio the mayday from the former at 22.02 hours.

5.105 The facts that the gas alarms occurred in C Module; that there was severe damage in D Module, particularly to the main and emergency electrical systems, and in the Control Room and Mechanical Workshop, indicating destruction of most of the C/D firewall; that the A/B firewall was apparently intact and that the heat shield on the south side of A Module was undamaged, are the principal factors in holding that the initial explosion was in C Module. The gas alarms were in the south-east quadrant of C Module. The explosion was strong enough to destroy most of the firewalls. There was, however, no inrush of hot gas into the Control Room. These facts point to the south-east quadrant as the location of the explosion within C Module.

5.106 The initial explosion was followed immediately by a large oil pool fire in B Module, giving rise to a massive plume of black smoke. A large fireball issued from the west end of the module. There was clearly a rupture of equipment containing hydrocarbons in that module. The fireball appears to have issued from a pipe. Several witnesses described as a "second explosion" an event which occurred within seconds, or maybe up to 20 seconds, of the initial explosion. One explanation is that this was the rupture and fireball in B Module. This fits in particular with the flash and bang experienced by Mr Parrydavies, though there must be some doubt as to how loud such an event would have been.

5.107 The strength of the initial explosion was such that it must have been caused by ignition of a gas cloud of considerable size. If the gas had been of positive or neutral buoyancy, a different pattern of gas alarms would be expected. The flame described by Captain Clegg was in the lower half of the module. These 2 factors point to a cloud of gas heavier than air, in other words condensate. However, although there is a minimum cloud size consistent with the strength of the explosion, there is also a maximum size. It is difficult to see how a cloud much larger than about 25% fill of the module could develop without setting off a different pattern of gas alarms. Moreover, the fact that there was no rush of hot gas into the Control Room is a further factor limiting cloud size. It is probable that the size of the gas cloud was appreciably less than 25% fill. The analysis of the explosion effects is relatively crude but points to a mass of fuel in the flammable part of the cloud within the range 30-80 kg.

5.108 There is little to assist in determining the location or nature of the ignition source. However, given the strength of the explosion and the limited size of the cloud, the location of the ignition source was probably such as to favour higher rather than lower over-pressures. It was the unanimous view of the expert witnesses that it was unlikely that the initial explosion was a detonation and this view is adopted. The explosion is therefore held to have been a deflagration. The over-pressure required to cause failure of the firewalls, about 0.1 bar, sets a lower limit to that of the initial explosion. Moreover, since failure seems to have occurred over a large proportion of both firewalls, the lower limit for the peak over-pressure at that point in the cloud where it was at a maximum is probably about 0.2 bar. Dr Cubbage's estimates of this maximum peak over-pressure based on various effects, including those on the occupants of the Control Room, ranged between 0.2 and 0.7 bar. Dr Scilly's estimate based only on effects in the Control Room was about 0.3 bar. All these estimates are very approximate. The higher values are more difficult to explain in terms of cloud size and ignition source. Hence the most probable range for the maximum peak over-pressure of the initial explosion is considered to be 0.2-0.4 bar.

5.109 With regard to the effects of the initial explosion on personnel, those experienced by Mr Bollands and Mr Clark in the Control Room and by Mr Elliott and Mr Jackson on the north landing are explicable in terms of an explosion occurring in, and venting from, C Module. The effects on Mr Bradley and Mr Ralph at the 20 ft level were more complex, but they are probably explicable in terms of an explosion venting from C Module and of platform vibration. No clear explanation emerged of the effects experienced by Mr Niven and the damage in the dive complex area, particularly that to the doors of the decompression chamber and the Dive Machinery Room. I note, however, the possibility that there may have occurred at the east end of C Module an external explosion, a phenomenon which was not considered in Part 1, but which was described in the evidence given by Dr Chamberlain in Part 2. In any event, these effects do not materially affect my conclusions.

5.110 The conclusions which I have just given relate to the initial explosion and to the flammable gas cloud involved. They are drawn from the evidence presented in this chapter. Further relevant evidence is given in Chapter 6 and results in some refinement, but no major revision, of these conclusions.

Table 5.1 - Details and results of explosion simulations using FLACS and CLICHE codes

Code	FLACS							CLICHE	
Sponsor	DEn					Technica		Inquiry	
Run	1	2	3	4	5	T1	T2	C1	C2
Type of fuel	NG	NG	C	NG	C	NG	NG	NG	P
Location of ignition source									
(a) in module	EE	M	M	EE	M	EE	M	EE	EE
(b) in cloud	E	C	C	E	C	E	E	E	E
(c) point X or Y in Fig 5.1	X	Y	Y	X	Y	-	-	-	-
Proportion of module filled (%)	50	50	50	30	50	100	25	50	50
Wall behaviour	FL	FL	FL	FL	FX	FX	FX	FL	FL
Over-pressure (barg)									
P1/P5	0.43/ 0.37	0.55/ 0.51	0.69/ 0.62	0.11/ 0.10	1.54/ 1.89	-	-	0.4	0.5
P4/P8	0.34/ 0.37	0.67/ 0.72	0.77/ 0.84	0.19/ 0.19	1.48/ 1.62	-	-	0.3	0.4

Notes:

(a) NG = natural gas; C = condensate; P = propane
(b) EE = east end; M = middle
(c) E = edge; C = centre
(d) FL = wall fails; FX = wall fixed, does not fail. For wall porosity after failure see Appendix G (para G.18).
(e) The location of points P1-P8 is given in Fig 5.1
(f) The over-pressures for Runs T1 and T2 were measured at different points. The maximum values for the 2 runs were 0.45 and 0.25 bar, respectively.
(g) The over-pressures for Runs C1 and C2 were obtained by interpolation.
(h) See also Table 6.2.

Chapter 6

Explanation of Initial Explosion

6.1 In the previous chapter I described the initial explosion and drew certain conclusions about it. In particular, I concluded that:

1. The explosion occurred at 22.00 hours BST.
2. The explosion was in the south-east quadrant of C Module.
3. The fuel involved was condensate.
4. The mass of fuel within the flammable part of the cloud was probably in the range 30-80 kg.

As far as concerns the leak, however, whilst it follows that it was one of condensate and that it occurred in the minutes leading up to 22.00 hours, I have at this stage drawn no conclusion as to the location of the leak, as opposed to that of the gas cloud, or as to the leak rate. It is to the leak, therefore, and the cause of the leak, that I now turn in this chapter. I describe first the events and activities centring on the Control Room (paras 6.2-17). Next I consider a body of evidence bearing on the characteristics of the leak, namely the noises heard just before the initial explosion (paras 6.18-22), wind tunnel tests on the formation of the gas cloud (paras 6.23-37), computer simulations of the explosion of the flammable gas cloud (paras 6.38-43), and source of ignition (paras 6.44-46), and give my observations on the leak (para 6.47). I then state scenarios to explain the leak (paras 6.48-54), explore these scenarios (paras 6.55-176) and finally give my conclusions on the cause of the leak together with certain observations (paras 6.177-197).

Events and activities centring on the Control Room immediately before initial explosion

6.2 Evidence on the events in the Control Room just before the explosion was given by Mr Bollands, the Control Room operator, and Mr Clark, the maintenance lead hand, and that on activities at the condensate injection pumps by these 2 and by Mr Grieve, the phase 2 operator, and Mr Young, an instrument technician. The other 2 principal participants, Mr R A Vernon, the lead operator, and Mr R M Richard, the phase 1 operator, died in the disaster. I begin by describing the events in the Control Room, and the evidence of its occupants on those at the condensate injection pumps. I defer my account of the evidence of Mr Grieve and Mr Young on the activities at these pumps. The personnel on duty on the night and on preceding shifts are shown in Table 6.1.

6.3 It is appropriate to mention at this juncture that the pressure safety valve, PSV 504, on condensate injection pump A had been removed for recertification work and had not been replaced. PSV 504, which was the only pressure safety valve on the pump, was just to the east of the reciprocating compressors in the south-east quadrant of C Module, as shown in Plate 9. PSV 504 was 15 ft above the floor of the module and there was scaffolding up, with a working platform to give access to the valve at waist height.

Condensate injection pumps

6.4 About 21.45-21.50 hours the working condensate injection pump, B pump, tripped. Evidence on this was given by the Control Room operator, Mr Bollands. He estimated the time of the trip as "10 to tenish". Mr Vernon was in the Control Room at the time and left at once. He did not say where he was going, but Mr Bollands was sure it was to the condensate pumps. Mr Bollands stated that, following normal procedure, he got in touch by radio with the phase 1 operator, Mr Richard who was probably in C Module. Mr Richard acknowledged and Mr Bollands told him that the condensate pump had tripped. Mr Bollands did not know where Mr Richard was at the time, but he did not appear to be aware of the trip. Mr Richard did not reply, but Mr Bollands was confident that he would have gone straight to the pump. Mr Bollands believed that Mr Vernon left before contact was made with Mr Richard. Mr Grieve gave the time when he heard Mr Bollands call to Mr Richard as 21.45 hours, but was very unsure. On the other hand Mr Clark was quite firm that it was 21.45 hours when he was first contacted by tannoy to go to the Control Room; he looked at his watch, as was his habit.

6.5 While Mr Vernon was out an alarm came up in the Control Room for JCP 057, the local condensate injection pump panel. Mr Bollands interpreted it as the JT flash drum high level alarm. He pressed the button to acknowledge it; the light stayed on. He contacted Mr Richard. He told him that he had a JCP alarm and that it would be the JT flash drum high level alarm. Mr Bollands said it was standard practice on receipt of a JT flash drum high level alarm to unload the reciprocating compressors. This would reduce the flow of condensate into the JT flash drum. He believed that he asked Mr Richard to do this and that Mr Richard would have done so anyway as he went down to the 68 ft level. At this stage he regarded the situation as urgent, but there was no panic. He estimated that with the reciprocating compressors unloaded they would have about half an hour before they would need to shut down.

6.6 Mr Clark stated that unless recovered, loss of the condensate pump would lead in due course to loss of the gas plant and hence of the gas supply to the JB generators. If the automatic changeover to diesel fuel then failed, which it sometimes did, there would be a total loss of power and what he described as a "black start". He had experienced it quite a few times. He regarded this as a situation of some urgency. For example, if drilling were taking power from the main generators and they were down a hole and their own generator did not kick in quick enough, the drill could get stuck. There were differing views as to how frequent and how serious loss of power was and therefore how much pressure operators would be under to keep the plant running.

6.7 Soon afterwards Mr Vernon came back into the Control Room. Mr Bollands asked him what was the matter. Mr Vernon said B pump would not restart. He was not sure what the problem was, but mentioned lube oil and said that he could see quite a bit of oil around the pump. However, Mr Bollands said that he believed hydrates were also being considered as a cause of the trip. Mr Vernon said the A pump was out for maintenance. An instrument PM was underway on it and it was electrically isolated. He wanted to get the pump PTW signed off so that the pump could be electrically reinstated. He made no mention of PSV 504 being off. He got on the PA system to Mr Clark. Mr Vernon retrieved the PTW for A pump. Mr Bollands believed he got it from the box holding the permits for the 68 ft level, though he did not actually see him put his hand in the box. It was possible he had got it from the Safety Office. Mr Bollands understood the PTW was for an instrument PM. There were 2 red tags on it, which he interpreted to mean that the switchgear and the lube oil pump were both electrically isolated. Mr Bollands checked with Mr Vernon that the reciprocating compressors were unloaded and on recycle and was told they were; he was quite sure about this. He was rather less sure about his dealings with Mr Richard on this.

6.8 On the events which now followed there was some conflict between the evidence of Mr Bollands and Mr Clark. According to Mr Bollands, Mr Clark telephoned in and Mr Vernon told him that he wanted work stopped on A pump so that it could be electrically reinstated and started up. Mr Clark came down to the Control Room. Mr Bollands stated that Mr Vernon and Mr Clark signed off the tags together. He did not actually see them signing, but that was the procedure. He said he could recollect Mr Vernon speaking to Mr Clark. He also stated that Mr Clark tannoyed for the day electrician, Mr J J D Savage, from the Control Room; he did this by using the telephone which accessed the PA system. He had to call twice before Mr Savage answered. Mr Clark then tried to get in touch with the night-shift electricians.

6.9 Mr Clark's recollection was different. He was in the maintenance superintendent's office with Mr K White, the acting maintenance superintendent, when he heard the tannoy call for him. He rang the Control Room. He was unsure who answered the 'phone, but he believed it was Mr Bollands; he did not recollect speaking to Mr Vernon either on the 'phone or in the Control Room. He was told that condensate injection pump B had tripped and could not be restarted. He stated that it was agreed on the 'phone to start the other pump. Mr Vernon would sign off the isolation tags and he, Mr Clark, would come down and sign them off also. He was unsure who first suggested this plan of action; it was instantaneous really. Mr Clark said he tannoyed for an electrician, Mr Savage, to contact him in the Control Room and then set off there. He believed that the only person there was Mr Bollands and that Mr Vernon was not there. He found the red tags, already signed off by Mr Vernon, on the desk, but no PTW. He was about to start signing the red tags when Mr Savage rang through; he spoke to Mr Savage while still signing the tags. Mr Savage said he was going off shift, so Mr Clark told him not to bother; he decided it would be quicker to get one of the 2 night-shift electricians who were on duty.

6.10 Some difficulty arose over the timing of Mr Clark's movements. He stated that he heard the tannoy message at approximately 21.45 hours; he was sure of this as it was his practice to look at his watch when he received a message. It was put to him that in his statement to Occidental he had given a time of 21.45-21.50 hours, but he stuck to his evidence that the call was at 21.45 hours. He stated that he left the maintenance office within 1 or 2 minutes of the tannoy call. He ran down so as to reach the Control Room before Mr Savage rang through. He estimated that his journey down to the Control Room would take 2-3 minutes. He stated that he had just arrived and was about to start on the red tags when Mr Savage rang in. He then signed the tags and checked the time on his watch as a few minutes past 10 (sic). It was put to him that there was a period of some 10 minutes unaccounted for, but he was unable to explain this. He agreed that some time must have elapsed between the initial trip of B pump and the tannoy call to him, since attempts had been made to restart B pump. He believed he may have had a conversation with Mr Bollands. He also said that he looked on the mimic panel to see if the reciprocating compressors were unloaded and saw that they were.

6.11 In any event, Mr Vernon went back down to the condensate injection pumps. Asked to estimate timings, Mr Bollands put the interval between Mr Vernon's departure and the initial explosion as some 5 minutes; the figure was approximate, it might have been 4, 6 or 7 minutes. Given that he was in a hurry, it would have taken him no more than 2 minutes to get down to the pumps. He would have had at least 3 minutes there before the initial explosion.

Compressor trips and gas alarms

6.12 About this point there began the sequence of trips and alarms which terminated in the initial explosion. Mr Bollands stated that 2 centrifugal compressors tripped; he was sure B was one of them, but uncertain whether the other was A or C. He informed Mr Richard of this and the latter acknowledged. He believed, but was not sure, that by this time Mr Vernon had gone. He estimated the timing as some 5 minutes after the initial pump trip and 5 minutes before the initial explosion.

6.13 There also occurred a low level gas alarm in C Module. The alarm was on C centrifugal compressor (zone C3); Mr Bollands was quite sure of that. He did not go round the back of the panel to check which of the individual detectors it was, but contacted Mr Richard, who acknowledged. Mr Bollands stated that he was able to talk to Mr Richard about this alarm. Mr Bollands did express some uncertainty as to whether the 2 compressor trips or the low gas alarm occurred first; he said he tended to get mixed up about the order. At one point he had a feeling that the low gas alarm came first. However, in his statements both to Occidental and to the Crown he stated that the compressor trips came first, and this was also the burden of his evidence.

6.14 With the loss of the condensate injection pump and of the 2 compressors the situation had become more serious; as Mr Bollands put it, the gas plant was just about lost and they were 90% into a shutdown. However, in his 8 or 9 years he had experienced this situation perhaps a dozen, even 20, times; he was unsure if he had met it in phase 1 operation before, though he thought it probable. He had confidence in the operators and felt the situation was under control. He could not recollect a total shutdown due to such a situation and did not consider initiating a shutdown.

6.15 Then, as Mr Bollands described it, things happened very quickly. The third centrifugal compressor tripped. He accepted the alarm. There passed through his mind the desirability of carrying out a manual changeover of the main generators from fuel gas to diesel, to avert any failure of the automatic changeover to diesel which would be initiated if the gas supply were lost completely. He had no time to take action, however, before a further set of gas alarms then came up, 3 low gas and 1 high gas. The 3 low gas alarms were for C Module East (zone C2) and for A and B centrifugal compressors (zones C5 and C4); the high gas alarm was for one of the centrifugal compressors, but he did not know which. These alarms came up in such rapid succession that he was unsure of the order; he never had time to silence the audible alarm. He made contact with Mr Richard again by radio but conversation was impossible due to the noise of the alarm. He was still trying to speak to Mr Richard, the alarm was still sounding and he had his hand out to silence it when the initial explosion occurred. Mr Bollands said that he did not know whether Mr Richard had reached C Module; though he did at one point say Mr Richard identified the first gas alarm as C centrifugal compressor.

6.16 The other person in the Control Room was Mr Clark. He said that he was unaware of the 2 centrifugal compressors tripping but he did experience the first low gas alarm. He could not say if this alarm came up before he had signed the tags or just after; everything seemed to happen at once. He put the time at 22.00 hours or just after. Mr Bollands accepted the alarm and radioed Mr Richard and asked him to check it out. Mr Clark said that this low gas alarm was for C Module East. He did not see this himself on the F & G matrix and appeared to rely on his recollection that Mr Bollands had said "C Module East" in his message to Mr Richard. Then just as he was about to leave the Control Room a further gas alarm came up, Mr Bollands went to accept it and the initial explosion occurred.

6.17 Mr Bollands was questioned on a number of aspects of the gas alarms. With regard to timing, he gave various estimates of the time intervals after the first gas alarm. He put the interval between that alarm and the final group of alarms as a minute or so. The final group came up within seconds of each other. He described the first gas alarm as occurring within the last couple of minutes before the explosion. He estimated the interval between the first gas alarm and the explosion as a couple of minutes, but this was not an exact time, it could have been more. As for the pattern of gas alarms, he believed the fact that several centrifugal compressor zone gas alarms came up indicated that the leak was outside the compartment of any single compressor. It was put to him that the pattern was consistent with a leak from the site of PSV 504, but he was non-committal.

Noises immediately before initial explosion

6.18 I now turn to consider the further evidence on the leak which gave rise to the gas alarms, starting with the noises heard just prior to the initial explosion, which were described in Chapter 5. As there mentioned, these noises were analysed in a report by Mr A H Middleton of Anthony Best Dynamics Ltd. Mr Middleton was of the view that all the noises except those heard in the Mechanical and Instrument

Workshops were explicable as noises from the flare or its pipework. For the analysis of the noises heard in these workshops he used a variety of information, which included details of the workshop construction, a noise survey of Piper, recordings of air starter motors made onshore and on Claymore, of human screams and of flange leak tests. He was discouraged from interviewing survivors. For the Mechanical Workshops he estimated that the background level of noise was about 62 dBA and that for a sound to be described as very loud it would need to be 15-20 dBA in excess of this, in other words at least 77 dBA in the workshop. He also estimated the noise attenuation between C Module and the workshop as about 27 dBA, so that the source would need to be at least 104 dBA.

6.19 Mr Middleton discussed the quality of the noise heard. He explained the term quality as a combination of the pitch, or frequency of the fundamental note, plus the levels of any harmonics. The noise was described variously as like an air starter motor or a human scream. He stated that analysis of these 2 types of noise showed them to have frequency spectra which compared fairly well. He believed that the noise would have comprised a harmonic series of tones within the 6-500 kHz range. As far as concerns the noise from a leak of high pressure fluid, he explained that the loudness, or sound power, of the noise would depend on the mass flow. But the noise heard was evidently not just a broad band noise; it contained strong tones. He stated that most leaks of fluid would give a noise like a hiss rather than a scream. For strong tones to be generated something more complex than a simple hole would be required. An edge tone might be generated by a hole with complex geometry or a tone might be generated by a mechanical oscillator. He also stated that there would be greater variations in individuals' perception of tones than of broad band noise.

6.20 Mr Middleton played to the Inquiry a tape of the Nowsco leak tests, described below (paras 6.122-123). The noises produced by most of these tests did not correspond with the descriptions given by the witnesses in the workshops nor with the frequency analysis of air starters and human screams. There was, however, one test which did have a particular degree of correspondence. This was a test in which a Metaflex gasket was used. Mr Middleton stated that he observed this test on video and postulated that oscillation of the gasket might be the cause of the tone, but he also said that such oscillation was only one of many possibilities. He was of the view, however, that there were a variety of geometries which might produce tones and that it was immaterial that one particular test reproduced tone generation whilst others did not.

6.21 With regard to the noise heard in the workshops, Mr Middleton listed 3 most likely sources of noise: metal-to-metal grinding; pressure letdown across a control valve; and leak of a high pressure fluid. Metal-to-metal grinding could produce tones, but tended to be very short-lived, and was unlikely to be the source. For pressure letdown across a control valve, he eliminated all possibilities except PCV 501, but considered that this was unlikely to produce a noise with scream-like quality. He judged the most likely source to be a high pressure leak. Given the right geometry such a leak could produce a high noise level with pure tones or a harmonic series of tones. He stressed that his judgement was based on the descriptions of the noise as being like an air starter or a human scream; however, he ruled out these specific events as the source of the noise. He believed that the noise heard by the 4 survivors from the tea room of the Mechanical Workshop and Mr Cassidy in the Instrument Workshop was a fluid leak as was the noise heard by Mr Young. He could find no reason why Mr Lamb should not have heard the noise. For the duration of the noise, he preferred the estimate of some 30 seconds on the basis that this was the most common figure. Mr Cassidy estimated the duration of the noise, which he found frightening, as 3-4 minutes. Mr Middleton believed this must be an over-estimate, since he would expect the hearer not to wait so long before taking action. Asked whether the noise described was consistent with a leak of fluid diminishing in pressure, Mr Middleton replied that he believed it was. Gradual reduction in pressure would cause the pitch to fall, but the noise might still be like a scream. He put the probable location of the source of the noise in C Module. He had not investigated the possibility that it was in B Module, but considered that if it were, it must have been very loud.

6.22 I think it likely that the noise heard in the workshops was from the leak. The principal thing which I take from this evidence about the noise is that the leak lasted for some 30 seconds. Also the evidence lends some support to the view that the release was a high pressure leak from a flange.

Formation of flammable gas cloud

6.23 The evidence on the initial explosion described in Chapter 5 pointed to a leak in the south-east quadrant of C Module of a size sufficient to cause the formation of a large cloud of flammable gas containing within the flammable limits some 30-80 kg of fuel. It was not clear, however, whether this could be reconciled with the evidence of Mr Bollands on the pattern of gas alarms. It was difficult to envisage how a leak of sufficient size could occur in this quadrant without first setting off gas alarms on the nearby gas detectors, G101/1 and G101/2, both in zone C2 and without setting off the second group of gas alarms more rapidly. In other words, there was a problem of both sequence and timing of the gas alarms. The Inquiry therefore decided to commission wind tunnel tests to explore the types of gas leak which might give rise to the observed pattern of alarms. In view of the pattern of gas alarms, the events and activities at the condensate injection pumps and the information that PSV 504 had been removed and not replaced, the possibility of a leak from the site of PSV 504 was one of the principal scenarios under consideration and such a leak was one of the main cases explored in the tests. The wind tunnel tests were performed by BMT Fluid Mechanics Ltd at their wind tunnel site at Teddington and were spoken to by Dr M E Davies, Managing Director. An account of this work is given here and further details are given in Appendix G.

Wind tunnel tests: first set

6.24 Two sets of experiments were carried out, each consisting of a number of runs; each run was termed a 'series' since a given run was often repeated. The first set of experiments investigated a number of different leaks, with emphasis on leaks from the area of PSV 504. The second set was concerned with leaks of neutrally buoyant gas. The aim of the first, and main, set of tests was to study the dispersion characteristics of different leaks, principally leaks of condensate near PSV 504, not so much to replicate any particular leak scenario but to explore the sequence and timing of alarms and the formation of the flammable gas cloud. Another feature of interest was the possible effect of ingestion of air into the centrifugal compressor turbines and of exhaust from these machines.

6.25 The set of tests conducted is shown in Table G.2. The 2 gases simulated were propane at -42°C and a cold methane, propane and ethane mixture modelled as neutrally buoyant. The latter was used only in the last series, series 44. The locations of the leaks investigated are denoted as positions 1-3 in Fig J.10, position 1 being the site of PSV 504 and therefore of particular interest. Series 10-42 simulated a leak at position 1. The leak rates ranged from 1 kg/min in series 38 up to 100 kg/min in series 42. Various leak configurations were covered. In series 10-11, 16-26 and 41 the leak was a jet. The jet was a hole in a horizontal pipe running in the north-south direction with the jet directed downwards and towards the east (at the 5 o'clock position looking towards the north). In series 27 it was a jet impinging on a flat plate at 1m distance, the plate simulating the scaffolding platform. In series 29-33, 35, 36, 38-40 and 42 it was a partial circumferential leak with one 120 sector open; in series 28 a similar partial circumferential leak but with 2 sectors open; and in series 12-15 and 34 a full circumferential leak with all 3 sectors open. Series 43 simulated a leak from position 2 with a 1-sector partial circumferential aperture and series 44 a leak from position 3 with a full circumferential aperture and with neutrally buoyant gas. Results presented included for the concentrations seen by the gas detectors the steady-state concentrations, the times to low level alarm and the times to high level alarm. A selection of the results is given in Table G.3. Results for series 43 and 44, which are for locations other than position 1, are included in Table G.4.

6.26 The concentrations and, to a lesser extent, the cloud development times, were affected mainly by changes in leak rates. They were not greatly influenced by detailed source configuration. Within the range tested the cloud concentrations and development times were relatively insensitive to compressor/turbine ingestion rates. A range of leak scenarios at PSV 504 produced a low cloud beneath sensor G101/1. For such leaks zone C3 generally saw the highest gas concentrations and gave the earliest low and high level alarms. However, whether the first low level alarm occurred in C3 or C2 depended on the configuration of the leak. Where the release was a jet or partial fan oriented generally downwards or towards the east, the first low level alarm occurred in C3 rather than C2. This is illustrated by series 16, 19, 26, 32, 35 and 42. Where the release was a full circumferential leak or a jet impinging on a plate that alarm occurred in the C2. This is illustrated by series 15 and 27. In particular, series 26 and 27 are directly comparable. Increasing leak rate decreased the time to alarm, but made much less difference to the sequence of alarms. This is illustrated in series 35 and 42 which were for identical conditions except that the leak rates were 10 and 100 kg/min, respectively. For any significant release the time delay between the low level alarms in C3 and C4 was less than 20 seconds. As far as concerns small leaks, a leak of 4 kg/min, series 36, gave an alarm in C3 followed 35 seconds later by an alarm in C2 and a further 15 seconds later an alarm in C4, but no alarm in C5 and no high alarm. Still smaller leaks, say less than 2 kg/min, gave a low level alarm only in C3. For the leak of condensate on the north side (position 2) the first low level alarm was in zone C2.

6.27 It became apparent that only the larger leaks could give a flammable gas cloud containing the quantity of fuel evidently necessary to cause the observed explosion effects. Interest centred therefore particularly on series 42, which was the only test at a leak rate of 100 kg/min. In this test the low level alarms occurred first for C3 in 5 seconds, then for C2, C4 and C5 in 15, 20 and 25 seconds, respectively. A high level alarm occurred first at C3 in 10 seconds. Thus the alarm levels in most areas occurred rapidly. This leak gave a gas cloud containing 30 kg of fuel within the flammable limits in 30 seconds and 45 kg within 120 seconds.

Wind tunnel tests: second set

6.28 The second set of tests is shown in Table G.2. The neutrally buoyant gas mixture was used in all series in this set and 4 different locations, positions 1-4, shown in Fig J.10, were used. Also considered here are the last 2 tests of the first set, series 43 and 44, which were for positions other than position 1. Series 43 was for propane and series 44 for neutrally buoyant gas. Series 45-48 simulated a leak of 100 kg/min from a jet at different locations and series 49-51 a leak of 1 kg/min from different locations. Series 52 simulated a release from a $3\frac{1}{2}$ inch diameter pipe directed horizontally towards the south wall at position 1. Results presented were similar to those for the first set of tests. A selection of the results is given in Table G.4. The tests showed that the 1 kg/min leaks of series 49-51 gave steady-state gas concentrations which did not exceed 0.4% and did not set off even the low level alarms. A 100 kg/min leak near PSV 504, series 45, rapidly activated low level alarms with the C2 alarm being last. It did not, however, trigger any high level alarm. The other 100 kg/min leaks, series 46-48, activated low level alarms but with larger time intervals and with the C2 alarm being first. They also set off high level alarms, notably in the C2 area. The 100 kg/min release from the pipe, series 52, gave rise to both low and high level alarms with the C2 alarm the first to be activated. With the exception of the pipe release, the size of the flammable clouds formed from the 100 kg/min leaks tended to be smaller than that produced by a similar release of propane. Differences in the flammability limits of the 2 gases appeared to be more important in producing this effect than differences in the concentrations. The possibility was raised that there might have been a massive, near-instantaneous release, say 100 kg/s, from the open pipe at position 1. Dr Davies felt that such a 60-fold increase was outside the range of values for which extrapolation could sensibly be attempted.

Shape and size of flammable cloud

6.29 The detailed development of the flammable gas cloud for the 100 kg/min leak in series 42 is shown in Fig 6.1. Figs 6.1(a)-(c) give the contours of the LEL of the cloud at low, medium and high levels, respectively, at times 15, 30, 45 and 100 seconds and Fig 6.1(d) the LEL contours at different heights at 30 seconds. The floor level LEL contour at 100 seconds was close to the final steady-state contour. Information on the mass of fuel within the flammable part of the cloud for different leak rates was presented in 2 ways. Fig 6.2 shows the growth of the mass of fuel, both total mass and mass within the flammable region, as a function of time for series 15, 42 and 45. For the first 2 cases a steady state is reached after about 100 seconds, and for the third after about 140 seconds. For the 100 kg/min leak of series 42 the mass within the flammable region is some 30 kg at 30 seconds, 40 kg at 60 seconds and 45 kg at steady-state at about 100 seconds. Fig 6.3 shows the effect of increasing leak rate on the mass of fuel within the flammable limits, based on series 15 and 42. The graph shows that after 30 seconds as the leak rate increases the mass of fuel reaches 30 kg at a leak rate of 100 kg/min, 45 kg at a leak rate of 110 kg/min and thereafter rises rapidly and that at steady-state the mass of fuel reaches 30 kg at 85 kg/min, 45 kg at 100 kg/min and thereafter rises rapidly.

2-stage leak hypothesis

6.30 From his results Dr Davies concluded that if the time interval between the initial alarm in C3 and the final set of alarms was as long as Mr Bollands believed, this could be explained only on the hypothesis of a 2-stage leak or of 2 independent leaks. He thought the latter highly improbable. The 2-stage leak would be a leak initially at a low rate, say 1-2 kg/min, which then became a leak at a much larger rate or perhaps a large but non-continuous release.

6.31 As discussed in Appendix G the wind tunnel tests were subject to certain limitations and uncertainties, both in respect of the experiments and of the data furnished for the Piper conditions. They illustrate trends rather than give absolute values.

Observations on wind tunnel tests

6.32 The estimate of the mass of fuel within the flammable limits of the gas cloud required to cause the initial explosion was given in Chapter 5 as some 30-80 kg. The results of the explosion simulation described below (paras 6.38-43) indicate that a cloud containing much less than 45 kg of fuel would not give a sufficiently large explosion. It follows that at least in its final stages the leak was some 110 kg/min or more. The figures of 45 kg and 110 kg/min derive from test series 42 and it is convenient to use them as a basis for discussion, but they probably lie towards the lower limit of the true values. Attention is therefore concentrated primarily on those tests at the higher leak rates.

6.33 What the wind tunnel tests show is that at these higher leak rates the times to, and time intervals between, the low level alarms are very short. In none of the large leak tests is the interval between the first and second low level alarms more than 10-15 seconds. The gap between such a time interval and the interval between the first alarm and final group of alarms described by Mr Bollands appears unbridgeable. The conclusion that the leak occurred in 2 stages, or rather that there was an increase, gradual or sudden, in the size of the leak, seems inescapable.

6.34 The tests point to the later, larger leak as being one of propane from position 1, from a downward pointing jet or partial fan. The 2 sets of test results given taken

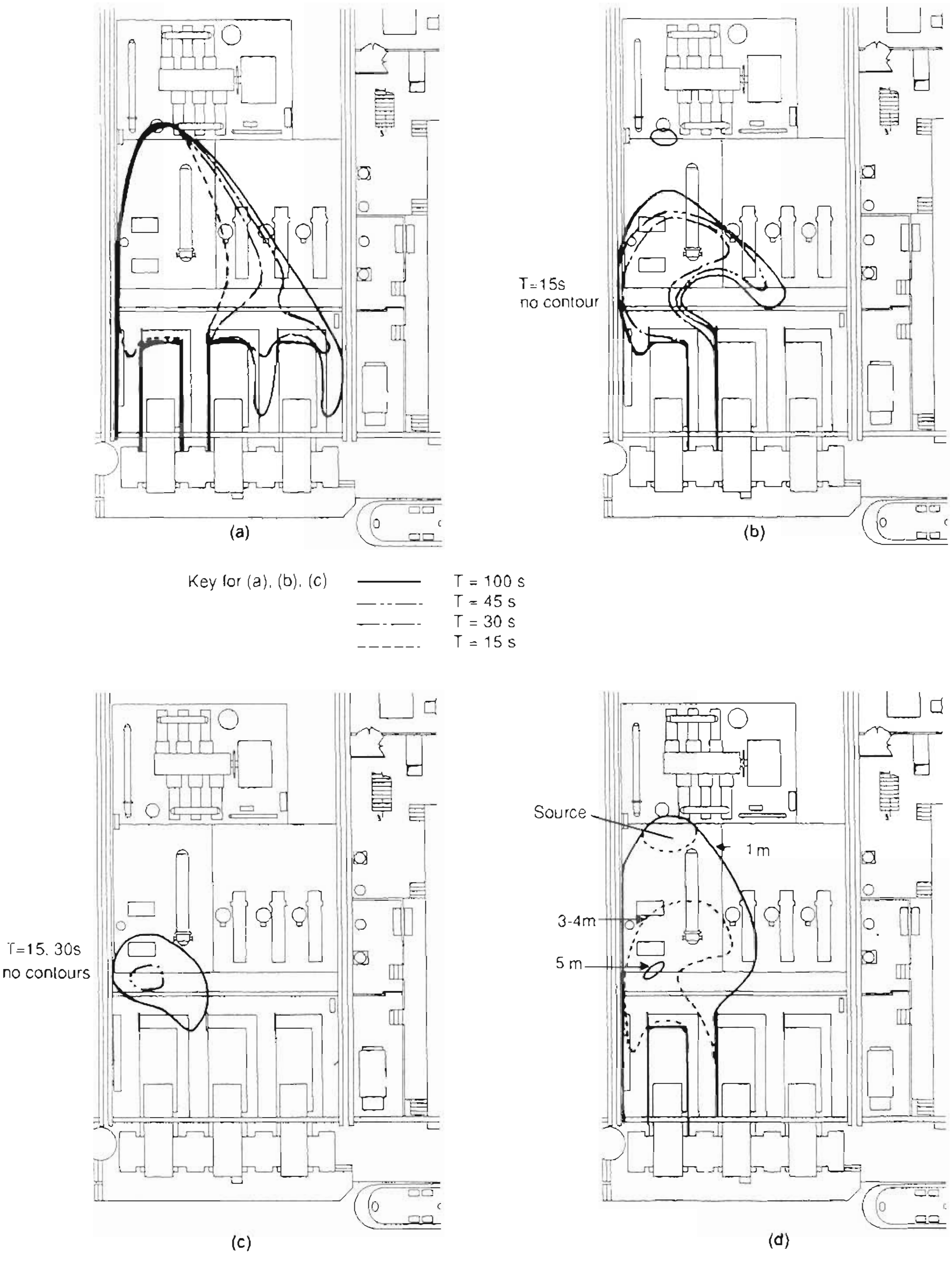


Fig. 6.1 Growth of the flammable gas cloud for leak of 100 kg/min (Series 42) in the BMT wind tunnel tests: (a) LEL contours at low level (< 1.7m); (b) LEL contours at intermediate level (ca. 3.5m); (c) LEL contours at high level (ca. 5.5m); and (d) LEL contours at 30 seconds.

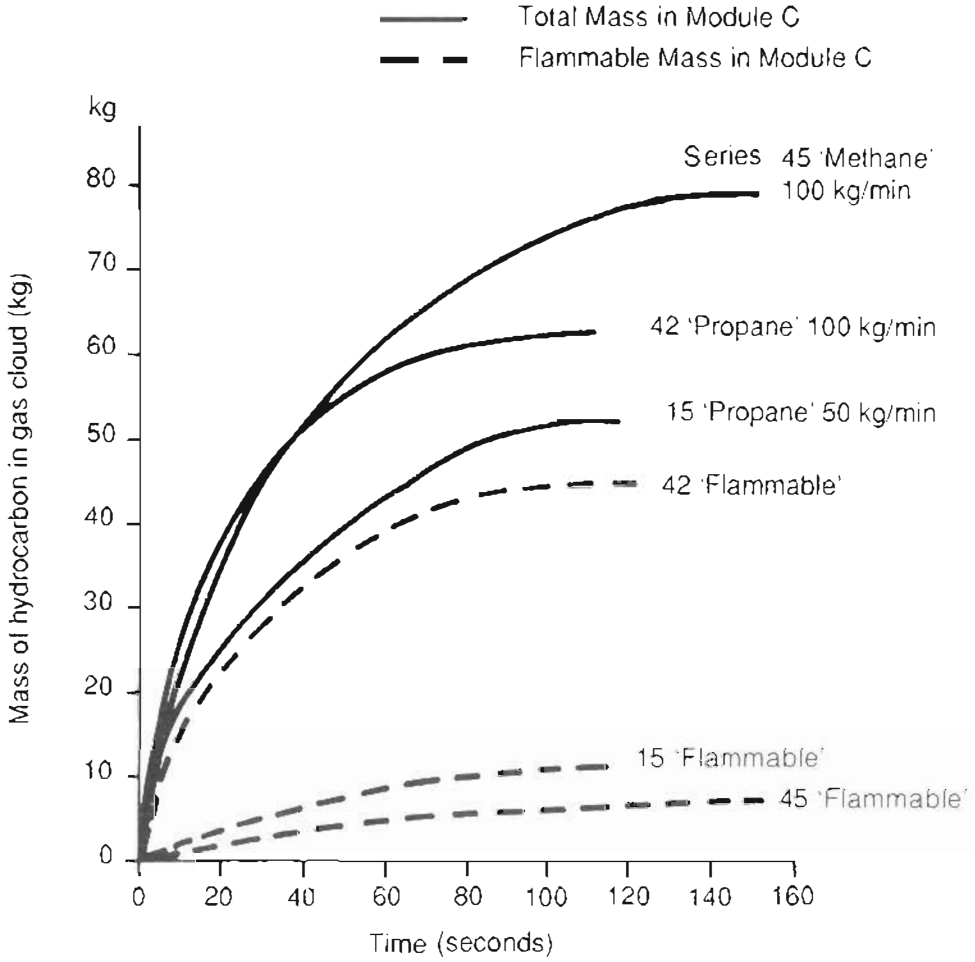


Fig. 6.2 Mass of fuel in the flammable gas cloud in BMT wind tunnel tests (total mass and mass within flammable range): variation with time.

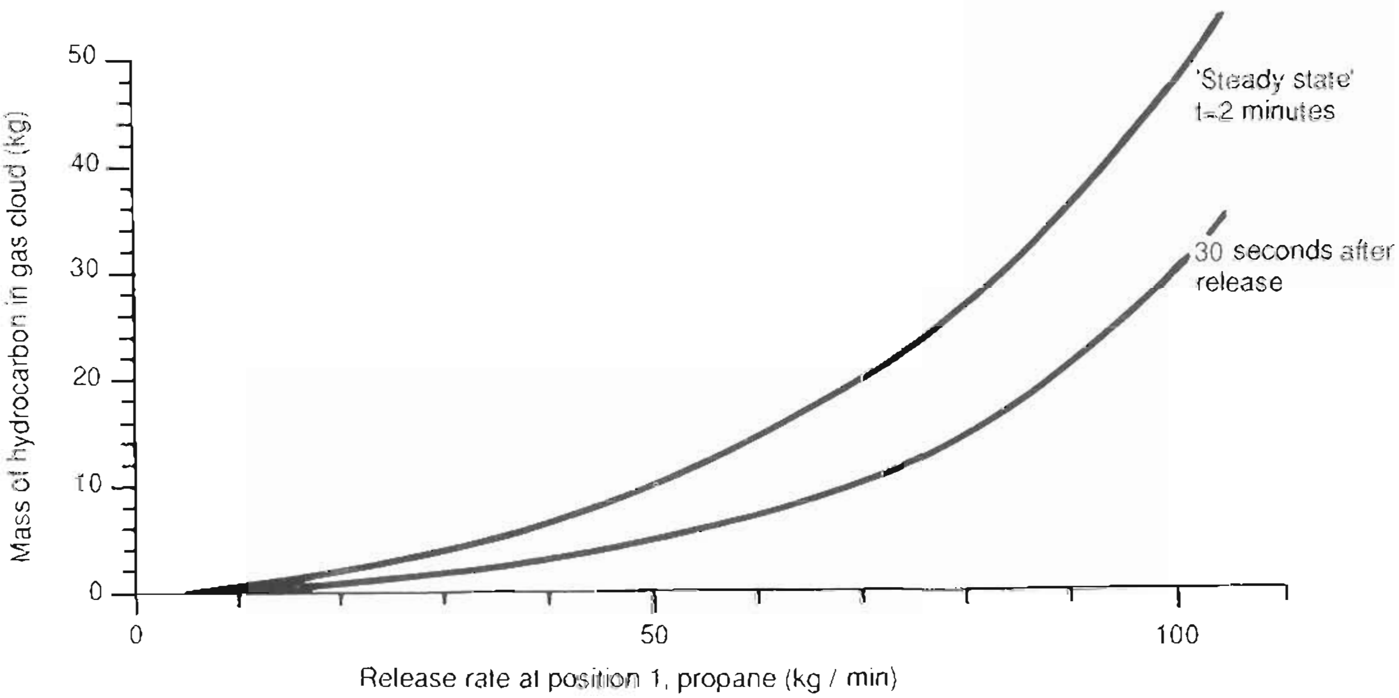


Fig. 6.3 Mass of fuel in the flammable gas cloud in the BMT wind tunnel tests (mass within flammable range): variation with leak rate.

together show that the C3 low level alarm came up first only in tests with these features. Tests involving a leak of neutrally buoyant gas in any of the 4 leak positions gave the C2 rather than the C3 low level alarm first. Moreover, these tests tended to give a much smaller gas cloud, which again tells heavily against them; the exception was the release of neutrally buoyant gas from the horizontal pipe at position 1, for which the flammable cloud was larger.

6.35 Turning to the duration of the larger leak, the relevant features are the time to the first low level alarm triggered by this leak and the time interval between this alarm and the last alarm in the final group, which consisted of the other low level alarms and one high level alarm. In attempting to determine these times, it has to be borne in mind that the postulated initial, smaller leak set off one low level alarm, so that the first low level alarm in the final group would have to be that for a different zone. The delay between the start of the leak and the first low level alarm in the final group would depend on whether this was in C2 or in C4 or C5. In the first case it would occur within seconds; in the second case, given the air speed of some 0.5m/s through the module, it could take some 15 seconds. The final group of alarms was spread over perhaps 5-10 seconds. To these times must be added the time lag of the gas detectors, which was at least 10 seconds. On this basis the duration of the final, large leak would be some 25-35, say 30, seconds. As for the leak rate of the larger leak, from Fig 6.3 the leak rate required to give a 45 kg mass of fuel in the flammable part of the gas cloud within 30 seconds is about 110 kg/min. The tests do not in themselves appear to rule out the alternative possibility that the larger leak was a massive, near-instantaneous release of propane from an open pipe at position 1, since this was simply beyond the range of sensible extrapolation.

6.36 With regard to the postulated initial, smaller leak it is virtually certain that this would resemble the later, larger leak in all but leak rate. Then taking the gas as propane and the source as position 1, as for the later, larger leak, a leak as small as 4 kg/min would give a steady state concentration well in excess of the low level alarm and would trigger a low level alarm in C3 first. It may be noted that this earlier, smaller leak would result in a build-up of a background concentration of flammable gas which would increase the concentrations resulting from the later, larger leak.

6.37 Since position 1 is close both to PSV 504 and PSV 505, the tests are equally consistent with a leak at the site of either valve.

Explosion of flammable gas cloud

6.38 The next stage of the investigation was to determine the effects which would result from the explosion of the flammable gas cloud. In particular, there was some doubt whether a cloud small enough to give the observed pattern of gas alarms would give an explosion strong enough to give the observed explosion effects. As explained in Chapter 5, prior to the Inquiry, work on explosion simulation using the FLACS computer code had been commissioned from CMI both by Technica and by the DEn. Following the wind tunnel tests, the Inquiry commissioned a further run. The work for the DEn was presented by Dr Bakke of CMI, as already described. Dr Bakke later returned to present the further work commissioned by the Inquiry. An account of this work is given here and further details are given in Appendix G.

Simulation of a gas cloud containing some 45 kg of fuel

6.39 The wind tunnel tests suggested that a plausible scenario for the flammable gas cloud was a cloud consisting of condensate, containing within the flammable range some 45 kg of fuel, filling about 12% of the module, located in the south-east quadrant and, being condensate, in the lower, or floor level, half of that quadrant. A further simulation was therefore commissioned of this case. The mass of gas actually used in the simulation was 46.1 kg. The ignition source was arbitrarily located at the centre of the cloud. The cloud simulated, the ignition source location and the pressure points are shown in Figs 6.4 and 6.5. The firewall failure pressures used were revised values based on the evidence of Dr Cox, namely for the B/C firewall 0.10 bar and for the C/D firewall 0.12 bar. Wall porosities used were again for the B/C firewall 20% and for the C/D firewall 40%. The results obtained are shown in Table 6.2 as case 6. For comparison the table also shows as cases 1-5 the results of the earlier runs for the DEn.

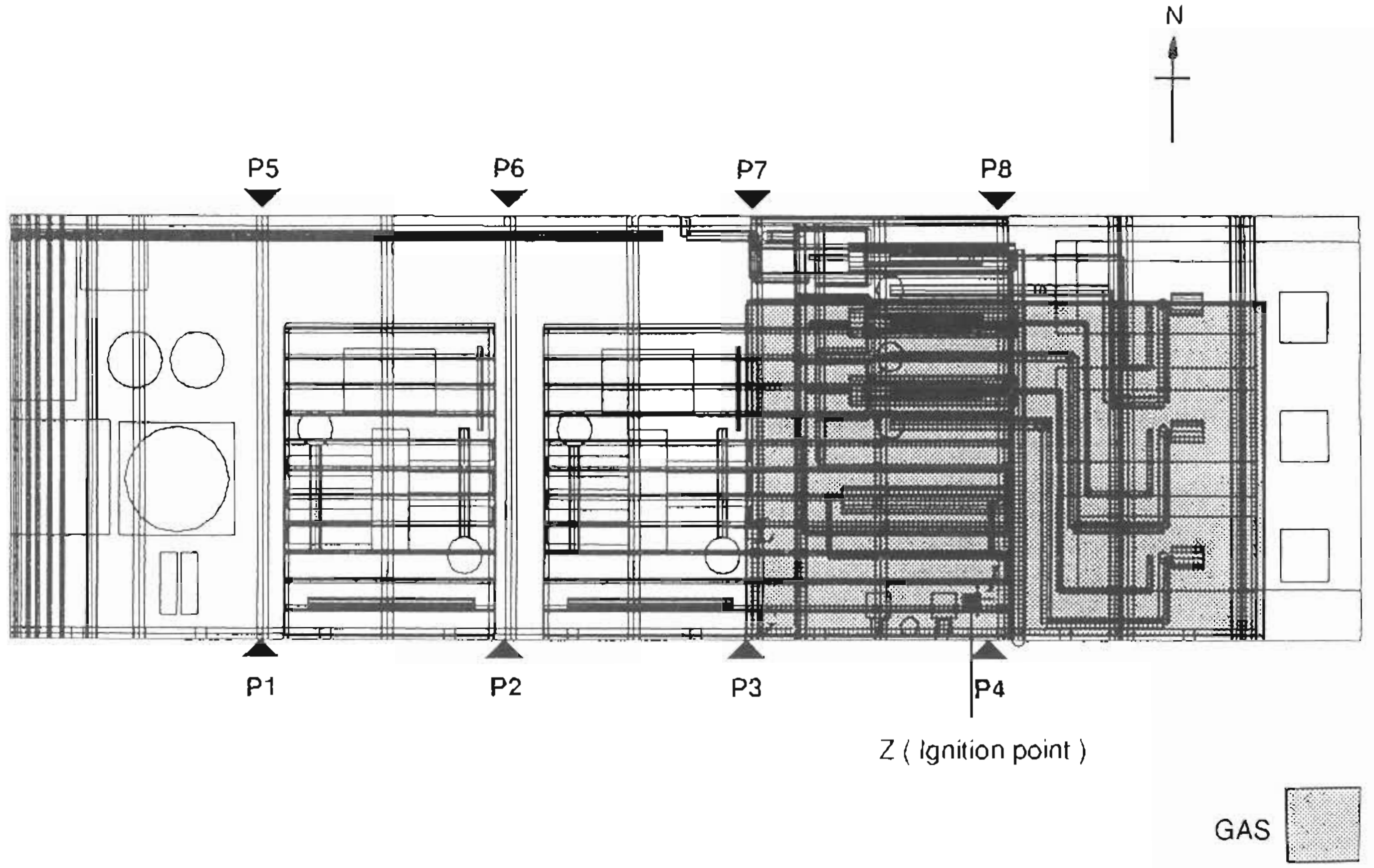


Fig. 6.4 Plan view of C Module showing pressure points P1-P8, 12% fill gas cloud and ignition source Z used in the final CMI explosion simulation.

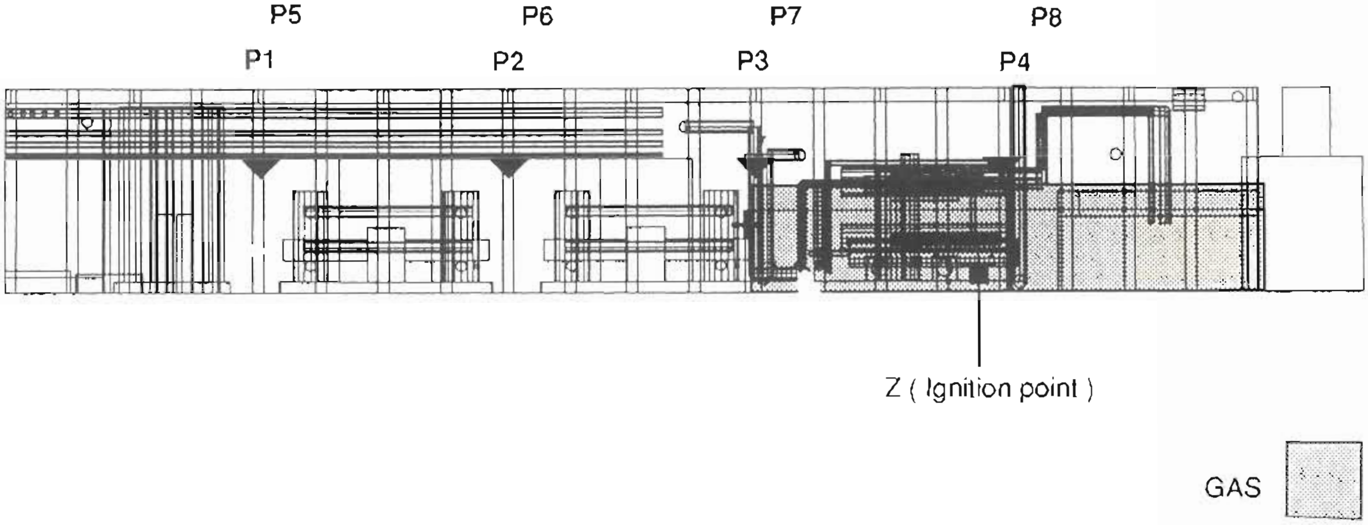


Fig. 6.5 Elevation view of C Module looking north, showing pressure points P1-P8, 12% fill gas cloud and ignition source Z used in the final CMI explosion simulation.

6.40 The simulation for case 6 showed that the B/C and C/D firewalls would fail along most of their length. However, although the pressures experienced at point 5 are sufficient to cause failure of the north wall at that point, the pressure plots indicated that there was a short section at the west end of that wall which did not see pressures high enough to cause failure. The mass of fuel in the flammable gas cloud in the case 6 simulation was judged by Dr Bakke to be close to the lower limit for a cloud capable of causing substantial failure of the firewalls.

6.41 Another relevant matter is the effect on the Control Room and its occupants. Graphs were presented which showed that the peak pressure at point 5, the location of the Control Room, occurs at about 0.9 seconds. The pressure then falls and this over-pressure is followed by a negative pressure, or under-pressure, which is most pronounced at about 0.95 seconds. The effect of these pressure changes is to cause a reversal of gas velocity first in to and then from the Control Room. Plots of the hot combustion products showed that this flow reversal occurs before the hot gases reach that point, so that the occupants would experience first an inrush of cold air from C Module, then an inrush of cold air being drawn through into that module. For purposes of comparison case 3, which was that of a gas cloud of condensate filling 50% of the module, was re-run. The results showed that this case was more likely to give an inrush of hot gas into the Control Room and flames issuing out the west side of the module.

6.42 The limitations of, and uncertainties in, the work are reviewed in Appendix G. As far as concerns the model, Dr Bakke stated that simulations tended to give peak over-pressures within some plus or minus 30% of those obtained in experimental module explosions. Another area of uncertainty was the extent of venting due to firewall failure in the course of the explosion. In view of these uncertainties both in the explosion model itself and in the data furnished for the Piper explosion, the results of the simulation cannot be regarded as highly accurate. Rather they should be regarded as illustrating trends.

Observations on explosion simulations

6.43 What the explosion simulations show is that the gas cloud explosion simulated, that of a cloud located at the east end of and filling some 12% of the module, containing some 45 kg of fuel within the flammable range and with an ignition source at its centre, has the characteristics sought in terms of its effects on the 2 firewalls and on the Control Room occupants. Given the known variation between computer simulations and experimental results and the variability of experiments themselves, the minimum mass of fuel may be estimated as perhaps about 35 kg. The only information on the upper limit is given by the re-run of case 3 with a fuel mass of 186 kg, for which the simulation suggests that there would have been an inrush of hot gas into the Control Room, but though the mass of fuel is likely to have been somewhere between these 2 figures it is likely to have been much closer to the lower one. In estimating its value it is necessary to take into account not only the explosion simulations but the wind tunnel tests. It is taken in subsequent discussion to have been of the order of 45 kg. The mass of fuel required to give an explosion of a particular strength would vary with the location of the ignition source.

Source of ignition

6.44 Another possible pointer to the nature of the cloud which caused the explosion was the source of ignition, since an ignition source inside the module would tend to give a stronger explosion than one at the eastern edge as would a strong rather than a weak ignition source. Such evidence as there was on this from witnesses was described in Chapter 5. A review of sources of ignition was given by Dr J G Marshall, a consultant, originally instructed by Allison Gas Turbine, but led by the Crown. His evidence is considered here only in so far as it bears on the explosion and the leak. Since much effort is devoted by engineers to the elimination of sources of ignition and the question is of concern in its own right, further details of his evidence are given in Appendix G.

6.45 Ignition sources considered by Dr Marshall included electric arcs and sparks, static electricity, flames and hot gases, hot surfaces, hot particles and chemical energy. One possibility was an electrostatic spark. A release of liquid condensate under pressure would give a jet of vapour containing liquid droplets. If such a jet impinged on a body which was a conductor but was insulated from earth, an electrostatic charge could build up and in due course discharge to earth. Something as simple as a spanner lying on a rag would constitute such a conductor. The possibility that the hot surface of the centrifugal compressor gas turbines might have acted as the source of ignition was explored in some depth, but no way in which this might have occurred was identified and if it had the explosion would have initiated in the compressor enclosure, which was not borne out by the witness evidence.

6.46 I have not been able to come to any conclusion about the source of ignition, either as to what the source was or where it was located, though I consider that an electrostatic spark from the jet itself must be a real possibility.

Observations on the leak

6.47 I now give the conclusions which I have reached from this evidence about the leak. The gas cloud gave rise to a number of gas alarms, as described by Mr Bollands. I consider his account sufficiently reliable and credible that I have looked to see whether other evidence is consistent with it. I have already stated my conclusions that the gas cloud was one of condensate and that it was in the south-east quadrant of C Module. The wind tunnel tests indicate that of the necessarily limited range of tests conducted only a leak of condensate from the area of PSV 504 or 505, provided it is 2-stage, could give a cloud with sufficient fuel, say some 45 kg, within the flammable range while still giving the gas alarm pattern observed. The explosion simulations confirm that explosion of the gas cloud from such a leak would have the effects reported; in particular it would destroy the 2 firewalls in the module and would cause the occupants of the Control Room to be knocked over and experience a rush of cold air, but not hot gas. The leak pattern which I have settled on, as approximating to the middle of a range of similar cases, is a gas cloud containing some 45 kg of hydrocarbon within the flammable range, arising from a 2-stage leak, in the second stage some 110 kg/min lasting some 30 seconds and in the first stage perhaps some 4 kg/min. Virtually complete vapourisation to vapour and spray is assumed.

Scenarios for the leak

6.48 I now move to the consideration of the cause of the leak. I start from the features of the leak which I have just described and use them both to narrow the field of search to those scenarios which could give such a leak and to define the parameters by which I shall assess those scenarios. The leak was one of condensate in the south-east quadrant of C Module. The only equipment containing condensate in that area was the relief lines and the PSVs from the 2 condensate injection pumps. The leak occurred just before 22.00 hours. Therefore the characteristics of the leak itself have led me to look to see if there was anything unusual at the condensate injection pumps in the period just before 22.00 hours.

6.49 In fact at that time it was at these pumps that the initial trip occurred and around them that the activities of the operators centred. There was extensive exploration in the Inquiry of the event which caused condensate injection pump B to trip and events consequent upon its tripping, including events associated with attempts to start up the condensate pumps such as admission of condensate to A pump or attempts to restart B pump and events associated with inability to pump condensate away from the JT flash drum such as back-up into the reciprocating compressors. There emerged from this the following hypotheses, or scenarios:

1. Leak from the site of PSV 504 through a blind flange assembly which was not leak-tight.
2. Leak from the site of PSV 504 caused by some phenomenon due to admission of condensate, particularly autoignition.
3. Leak at or near PSV 505 due to hydrate blockage.
4. Leak at the reciprocating compressors due to ingestion of hydrocarbon liquid.

6.50 The first scenario is that admission of condensate into condensate injection pump A led to a leak from the site of PSV 504 through a blind flange assembly which was not leak-tight (paras 6.55-130). It arose from evidence that PSV 504 had been removed that day for recertification. In examination of this scenario I describe the actions of the operators at A pump and the state of that pump (paras 6.55-74); outline the removal of PSV 504 and the fitting of a blind flange to the end of the relief pipework (paras 6.75-100); consider the probable state of knowledge of the operators (paras 6.101-109); review the evidence bearing on the probable state of the blind flange assembly (paras 6.110-121); describe leak tests on blind flange assemblies which showed the extent to which they might leak given different degrees of tightness (paras 6.122-125); and consider the ways in which admission of condensate could give rise to a leak with the characteristics sought (paras 6.126-130).

6.51 The second scenario is a variant of the first. It is to the effect that even if the blind flange had been leak-tight, there might have been some effect consequent on the admission of condensate to the relief line on condensate injection pump A which caused rupture of that line (paras 6.131-140). The effects considered were autoignition, shock loading, brittle fracture and over-pressurisation by methanol injection.

6.52 The third scenario is that hydrates caused a blockage on the discharge side of condensate injection pump B and that this led to over-pressurisation and rupture of the relief line (paras 6.141-163). It arose from evidence that there had been an interruption of the methanol supply to the JT valve that day.

6.53 The fourth scenario is that when the only working condensate injection pump, B pump, tripped, condensate liquid started to fill the JT flash drum and backed up into a reciprocating compressor, causing it to rupture (paras 6.164-170). It arose from the evidence that B pump had tripped and that the JT flash drum level had started to rise.

6.54 I end the chapter by considering some additional scenarios described by Mr R Sylvester-Evans and Dr K E Bett (paras 6.171-176) and by giving my conclusions on the cause of the leak and my observations on the PTW system, the shift handover and the methanol injection (paras 6.177-197).

Admission of condensate to condensate injection pump A

6.55 The first scenario involving a leak at the site of PSV 504 is that following the trip of B pump Mr Vernon took steps to bring A pump back on line, that as a result condensate was admitted to the relief line and that a leak occurred from a blind flange assembly on that line which was not leak-tight. The first step in assessing this scenario is to consider whether condensate was admitted to the relief line.

Actions of operators

6.56 Evidence on activities at the condensate injection pumps was given by Mr Grieve and Mr Young. Mr Grieve knew that it was B pump which had been operating. He had no idea of the state of A pump and believed that it was in the normal standby mode. He did not know it was shut down for maintenance. He was unaware that PSV 504 had been removed; he learnt this only when he was in hospital after the disaster. Mr Grieve was uncertain exactly when he overheard Mr Bollands' first call to

Mr Richard. He was also unsure how much time elapsed before he went down; his estimates ranged up to 10 minutes. He may have arrived at the condensate pumps some 2-3 minutes before the initial explosion. He came down the staircase on the extreme east of the plate skimmer platform, walked past the plate skimmer, the JT flash drum and the pump main control panel (see Fig J.6). He described Mr Vernon's position when he first saw him variously as in the area of the GOVs on A pump, as between the 2 pumps and as at the push-pull button for the GOVs on A pump. Mr Grieve also stated that Mr Vernon was not stationary but was moving between one area and another.

6.57 In a statement to Occidental on 29 July 1988 he stated:

> "As I said I had just arrived there, just sort of walked down and they were busy trying to get the GOVs open, reset them get ready for another start at the pump. I just sort of walked up beside B pump and they gave me a nod to push the button."

The exchange continued:

> Q. "Do you think they tried "A" as well?"
>
> A. "I would have thought so the way that they were going around down there."

Earlier in the statement there occurred the following exchange:

> Q. "Did you have time to speak to anyone at the condensate pumps?"
>
> A. "No. As I said I spoke to Bob Vernon and said 'What's the score?' and he said more or less that they couldn't get the pumps to work and that was about it."
>
> Q "Can you remember whether he said pump or pumps?"
>
> A. "I would say pumps, because they were at the stage of trying to open the GOVs on both of them then."
>
> Q. "They were actually opening the GOVs on both then?"
>
> A. "Aye, they were just sort of picking whichever one they could get away."

and earlier still in the exchange:

> Q. "Did you have a go at starting both of them?"
>
> A. "Well I don't know. When I went in there they'd just had a go at starting one of them. But I take it they'd been starting to try another one before I got there. It had been a good 5 minutes or so before I got there."

Similarly, in a statement to the DEn Mr Grieve stated "When I initially arrived in the DSF I observed Vernon at the GOVs. I believe that he was lining up the GOVs on both A and B injection pumps." "Lining up" was the term used by the operators to describe the process of opening the GOVs prior to pump startup.

Further Mr Grieve stated in evidence that if the A pump had been on standby, then lining up its GOVs and trying to start it would have been the obvious thing to do in the circumstances.

6.58 However, when he learnt what effect the activities at the 2 pumps may have had, Mr Grieve became more cautious. As he said: "I realised you could only say what you actually saw. You were not allowed to assume what could have happened." His evidence on any actions taken to line up the GOVs on A pump was guarded. He was unaware of any action to line up the GOVs on A pump before he arrived. When he did arrive, nothing was said about A pump. He could not honestly say that either operator opened the GOVs on A pump or even touched the GOVs or the pump. He was not aware of any attempt to start up A pump or of any instructions by Mr Vernon to this effect. He was clear that while he was there no one pressed the start button on A pump. Mr Vernon did not start the pump. Mr Grieve himself did nothing to the pump. At one point in the evidence Mr Grieve confirmed that although he was not prepared to state positively that any action was taken on A pump, the statement he gave to the DEn to the effect that Mr Vernon was lining up the GOVs on both pumps was still his recollection. Later he said concerning this statement "I was probably going on what I thought he could have been doing at the time. I would never say for definite. I never saw him open the GOVs on A pump at all. He opened the GOVs on B pump for me before I started it. That is the only action I can recall him taking."

6.59 As described above, it was indicated to Mr Grieve on his arrival that he should assist Mr Vernon and Mr Richard in restarting B pump. Mr Richard was apparently to go to the pump main control panel JCP057 to reset the system and Mr Vernon was at the B pump push-pull button while Mr Grieve himself went to the local pump panel to push the start button. Before the actual attempt to restart B pump Mr Richard was called away; he did not participate in the restart. It is not clear from Mr Grieve's evidence whether Mr Richard had time to effect the reset or whether Mr Vernon had to do it. Mr Grieve said that he thought Mr Richard did the reset but shortly before he stated that Mr Vernon went to the control panel. The attempt to restart B pump failed. In Mr Grieve's words "The electric motor kicked in and turned a few revolutions and then stopped." Mr Grieve then set off to reopen the GOVs on the B pump. At this stage he lost track of Mr Vernon and was unable to say what the latter was doing. Asked whether Mr Vernon might then have attempted to start A pump on his own, Mr Grieve described the actions which he would have had to take. These were to go to the main control panel JPC057 and reset the system; to open the push-pull button on the pump GOVs; to adjust the pump speed controller setting; and then to go to the local pump panel to push the start button. Mr Grieve was clear that Mr Vernon did not push the start button of A pump, but agreed that there was certainly plenty of time for Mr Vernon to have pressurised the discharge of A pump by "jagging", the term used by the operators to describe the action of repeated, brief opening of the GOV. The route taken by Mr Grieve after this abortive attempt to restart B pump passed along the north side of B pump. He was making his way when the initial explosion occurred.

6.60 The other witness of events at the 68 ft level was Mr Young. There is some conflict of evidence between Mr Grieve and Mr Young as to who arrived last. Mr Grieve believed Mr Young had arrived first. At any rate, he remembered him being in the area and did not see him arrive so assumed he got there first. Mr Young on the other hand was firm that Mr Grieve was there when he arrived. Mr Young came down the stairs from C Module at the north-west corner of B pump. Mr Vernon and Mr Grieve were there, but he never saw Mr Richard at all. Mr Grieve was coming away from the local pump panel on B pump. He saw Mr Vernon at the edge of A pump, walking away from it. Mr Young stated that before he had a chance to speak to either of them, he heard a loud rushing noise and then the dull bang of the initial explosion. I should add that when he recovered from the explosion Mr Young started to make his way up the staircase to C Module and met 2 men coming down, who told him to get back because the place was filling up with black smoke. The men, who went off towards the east, were never identified, though Mr Young said they were not Occidental employees, since they were not wearing the distinctive company flash.

6.61 In the submission of Score there is no direct evidence that any action was taken to admit condensate to the discharge side of A pump nor can it be inferred from the actions of the operators. Score argued that Mr Vernon must have known PSV 504 had been removed. By way of illustration Score gave 5 possibilities for Mr Vernon's actions on return to the pumps. These may be summarised as follows: (i) that he did nothing to A pump but attempted to restart B pump; (ii) that he started on A pump, found the pneumatic supply disconnected, remembered that PSV 504 had been removed and desisted; (iii) that he was dissuaded by Mr Richard from starting on A pump; (iv) that he found A pump spaded; and (v) that he did reconnect the pneumatic supply on the A pump GOVs and opened them. I agree that there is no direct evidence that Mr Vernon admitted condensate to A pump. The evidence does, however, support the view that he had the intention and opportunity to do so. Any inference that he did is a matter to be considered in the light of the whole of the evidence.

Status of condensate injection pump A

6.62 Before turning to Mr Vernon's intentions, it is necessary to consider the status of condensate injection pump A. Evidence on this was given by Mr T A Henderson, a lead operator, and Mr A C B Todd, the maintenance superintendent. On 4 July condensate injection pump A was on standby for 18 hours. At 18.00 hours this pump was started up and pump B was shut down for repair to the LP suction pressure switch. This work was completed on 5 July and by 21.50 hours the pump had been test run and put on standby. Pump A then ran overnight until it was taken out for the maintenance work on the morning of 6 July. By the evening pump A was still out for maintenance, but the work to be done on it had changed.

6.63 According to Mr Henderson, there had been a problem of noise on the Voith coupling on the pump for quite some time. The problem had been highlighted in a vibration survey. The pump was also due in August to have a preventive maintenance overhaul which was done every 24 months - the 24 month PM. The unhealthy state of the coupling was discussed at the Monday morning meeting between maintenance and the beach on 4 July and it was decided to bring forward the 24 month PM and to do the coupling at the same time. Arrangements were made for the spares necessary for the PM to be sent out to the platform. They were due to arrive with the supply boat on the night of Tuesday 5 July. This was the situation when Mr Henderson left the platform at 11.00 hours on 5 July; he was not able to say whether the spares arrived that night. He expected the work to take some 2 weeks. The essentials of this account were confirmed by Mr Todd, who stated that the supply boat would be expected to arrive at the field on the Wednesday morning and to be unloaded by midday. He said that personally if he knew the spares were in the field on the boat he would start to strip down the pump, but not otherwise.

6.64 Mr R H Seddon, the senior maintenance superintendent, stated that he was aware that there was an intention to bring forward the PM work on A pump. He spoke to Mr White at about 16.50 hours on 6 July and told him that "he should possibly only do the torque converter work". Mr Seddon said that he did expect that his recommendation would be carried out. His reason for putting off the PM was that his team were fully committed and that although the overhaul itself was of known duration, the running in time was an unknown quantity. It could take up to 5 days and he did not wish to embark on the unknown. He had had the thought of deferring the PM some time before but had not got round to communicating this to anyone else. As far as others on the platform were concerned, therefore, until about 17.00 hours on 6 July the plan was to carry out a 24 month PM on A pump.

6.65 At 07.00 hours on 6 July, Mr J Lynch, the first day-shift lead production operator, was asked by Mr B Curtis, the acting operations superintendent, to take A pump off, put B pump on and release A pump to maintenance. Mr W H Smith, the night-shift lead maintenance hand, brought the PTW, a pink hot work permit, for the PM about 07.45 hours. It was for a 24 month instrument, electrical and mechanical PM. The PTW was not signed on when Mr Lynch left because the pump was not ready. It would have been handled by Mr H E G Flook, the day-shift lead production operator who took over from Mr Lynch. The general rule was that PTWs should not be issued until the work was to be started, but this was a planned job and the PTW might be made out in advance. The pump had to be isolated and depressurised and there was therefore a good deal of work for the operators to do first.

6.66 Mr Clark said he understood when he came on shift on the evening of 6 July that the PTW for the Voith coupling had been written, but had not actually been taken out. The electrical isolation had been done. Mr Smith had told him in the handover that the PTW was in the Safety Office; it would remain there until it was taken out and signed on.

6.67 The general procedure for mechanical isolation of equipment was described by Mr Lockwood. The usual method was to close isolation valves and chain them off.

The valves were not necessarily tagged. It depended largely on the size of the job; tags would be used on valves for the isolation of the phase 2 plant but not on a small job with just 2 valves. There was nothing on this in the written procedures. All operators carried keys to the locks. Mr Bollands stated that if an item of equipment was being worked on there would not necessarily be anything on the mimic panel to indicate this. It is also relevant to note that for full mechanical isolation the preferred procedure given in the Occidental General Safety Procedures Manual was to remove a piece of the pipework, or spool piece, and to blank off only the live end of the pipework.

6.68 The methods of isolation of a condensate injection pump were described in a second appearance by Mr Henderson. Different procedures would apply for a 24 month PM, a coupling repair and removal of the PSV. For a 24 month PM the procedure would be to effect electrical isolation, disconnect the air line to the GOV and to spade off the pump; this spading would be done by maintenance. For removal of the PSV the valves on the pump would be locked off and the air line disconnected but he himself would not isolate electrically. For work on the Voith coupling the pump would be electrically isolated but not depressurised. It is not known how pump A was isolated that day. There was evidence, however, that it was electrically isolated and that it was valve isolations which were checked by the operator prior to the removal of PSV 504. No witness said it was spaded off.

Electrical isolation of GOVs

6.69 The evidence described earlier is that condensate injection pump A had been electrically isolated. The air supply to its GOVs would be disconnected. In order to be able to move the GOV using the push-pull button, or plunger, all that was required was to reconnect the air supply, a simple task which could be done by an operator; the GOV would then remain open as long as the button was held. It is not known whether electrical isolation of A pump had been effected by locking off or racking out. Mr P Lloyd, a Senior Electrical Engineer, stated that in his time on the platform up to 1980 both methods were used but that he had been told that since then racking out was the normal method. Mr Bollands also stated isolation was by racking out and that when a pump was electrically isolated there was no amber light on the mimic panel. If isolation was done by racking out, the GOV could be kept open only by holding on to the push-pull button, whereas if it was done by locking off, the GOV would stay open when the button was pulled and would close only if it was deliberately pushed back again.

6.70 The evidence on whether or not A pump was electrically de-isolated was conflicting. Mr Clark was unsure if he signed the red tags before or after the first gas alarm. There was a period of some minutes which he could not account for and there may well have been a lapse of some time between his signing the tags off and the initial explosion. His evidence was that it was his intention to get the de-isolation done by one of the electricians on the night-shift. Mr Bollands stated that he heard Mr Clark speaking on the telephone first to Mr Savage and then to one of the night-shift electricians. Mr Clark stated that the final set of gas alarms came up just as he was leaving the Control Room, evidently to give the red tags to the electricians. What is not clear is whether these electricians had taken any action to de-isolate A pump before receipt of the red tags. This would not be normal practice, but there was a degree of urgency.

6.71 Mr Bollands stated that the amber light for A pump on the mimic panel had been off that evening. It came on at some time but was not continuous. It was on some time before Mr Vernon first left the Control Room. Mr Bollands was non-committal as to whether it was on in the minutes preceding the initial explosion. Mr Clark in several of his original statements stated that the amber light on A pump was on at the time of the explosion, but told the Inquiry that he must have been mistaken; A pump was electrically isolated. When Mr Vernon returned for the A pump PTW, he told Mr Bollands that the A pump was electrically isolated, that an instrument PM was going on and that he wanted the pump reinstated. Mr Bollands also stated that Mr Vernon told him instrument technicians were working on the pump and that he knew Mr Young had a PTW for work on the pump; he assumed that this was the reason for the amber light. It was Mr R F Carey's evidence that he was not aware of any action which he, as an instrument technician, could take while working on the electrically isolated pump which would bring up the amber light.

6.72 I consider this evidence is inconclusive as to the state of the electrical isolation of A pump just before the initial explosion. However, there was reason to effect prompt de-isolation and there appears to have been sufficient time to do so. I conclude that A pump had been electrically isolated, almost certainly by racking out, and that it could well have been de-isolated some time in the last few minutes before the initial explosion.

Intentions of operators

6.73 It is clear from Mr Bollands' evidence that when Mr Vernon returned to the Control Room it was his intention to bring A pump back into service. Possible explanations of Mr Vernon's intent are that:

1. He did not know that PSV 504 was off, because
    (a) he did not know it had been taken off, or
    (b) he knew of this, but believed the valve had been put back on.
2. He knew the valve was off but
    (a) he believed there was another duplicate valve on,
    (b) he forgot the valve was off, at least initially,
    (c) he went ahead knowingly.

6.74 It would be bad practice to start up A pump without the protection of a relief valve. Witnesses were agreed that Mr Vernon was an experienced and conscientious man who would not do so. I regard it as highly unlikely that he would have attempted to start the pump knowing that it had no PSV on. Moreover, Mr Clark was involved in the decision and Mr Richard in the activities at the pumps. Both might have been expected to oppose such an action. Evidence was given that the pressure relief protection arrangements on the condensate injection pumps differed from other systems on the plant in having only one PSV on each pump. It is conceivable, though unlikely, that Mr Vernon knew that PSV 504 was off, but believed that the pump was still protected by another duplicate valve or that he simply forgot that the PSV was off. In both cases it is necessary to assume that neither Mr Clark nor Mr Richard intervened. Mr Clark knew of the plan to start up A pump; he had discussed it on the telephone. Mr Richard was at the condensate injection pumps both before and after Mr Vernon's visit to the Control Room to get the permits signed off and it is highly unlikely that he did not know Mr Vernon's intention. These arguments point to the alternative that neither Mr Vernon nor Mr Clark nor Mr Richard knew that PSV 504 was off at 21.45 hours that evening, that this information was not transmitted through the handover and PTW systems, and that the status of A pump was a contributory factor in this.

Work on Pressure Safety Valve PSV 504

6.75 In order to take further the question of the state of knowledge of the operators it is necessary to give an account of the recertification work done on 6 July on PSV 504 and the information which was communicated about this work. The account includes the background to the contract and touches on the availability of suitable blind flanges, which bears on the question of the leak-tightness of the blind flange assembly, but consideration of the latter is deferred until later.

6.76 As already indicated, on 6 July condensate injection pump A was out of service to allow maintenance work to be done on it. Its pressure safety valve, PSV 504, was removed for recertification. Evidence on the PSV recertification programme was given by Mr Seddon and Mr D Whalley, a supervisor of Score (UK) Ltd, the specialist company doing the valve recertification work; on the work on PSV 504 itself on 6 July, and the associated PTW, by Mr A D Rankin, the supervisor of the 2-man Score team and other witnesses; and on handovers between shifts by Mr Clark and Mr Bollands.

PSV recertification programme

6.77 According to Mr Seddon, there were on Piper some 300 pressure safety valves and they were recertified at an interval of approximately 18 months. This was a fairly large workload and it was contracted out to specialist contractors. Towards the end of 1987 the contract was awarded to Score (UK) Ltd. Mr Seddon was involved in the negotiation of the contract and had a number of meetings with Mr C B Ritchie, Managing Director of Score, and with other Score personnel, Mr Whalley and Mr Wood. Occidental put the contract out to competitive tender with 6 contractors and carried out an appraisal of the bidders. A collection of documents on this contract was produced at the Inquiry. The appraisal would involve visits to Score's premises and review of its quality assurance (QA) procedures and quality manual; Mr Seddon was unsure whether training procedures would be checked. There were favourable assessments of management, facilities and the PSV workshop, and the stores, the offshore containers, curriculum vitae of personnel and QA procedures were acceptable. The safety organisation was noted. Score was given a rating of 8 on a scale of 1 to 10, where 1 is poor and 10 very good. The Score bid was not the cheapest received, but the engineering side held out for award of the contract to Score which they rated more highly from the technical point of view; a special meeting was held and the contract went to Score.

6.78 Score was provided with the Occidental Safety Procedures Manual, the 'Red Book'. This manual gave details of the isolation and PTW procedures. The question was raised whether this version of the manual, dating from 1982, was that actually current on 6 July. A new manual, General Safety Procedures Offshore Operations, was issued as a working draft in September 1987. Mr Seddon stated that in his meetings Score personnel were made aware of Occidental's PTW system, that work permits would be required for removal of PSVs and that the PTW was described in the Safety Procedures Manual. In any event personnel from such a company would be expected to be familiar with PTW systems in general. The requirements for blind flanges were also discussed between Mr Seddon and Score personnel.

6.79 Mr Whalley stated that he and Mr Wood had a meeting onshore with Mr Seddon about the work and that in December 1987 he and Mr J Tait paid a familiarisation visit to Piper. They were shown the areas where work on PSVs was required. Mr Whalley said that he was told by Mr Seddon that blind flanges were to be fitted on removal of PSVs. One of the reasons for the visit was to check that there was a sufficient supply of blind flanges. He was given to understand that there were sufficient blind flanges available on the platform. He investigated the blind flanges available on the platform. On the 68 ft level he found a stock of blind flanges painted blue. There were blind flanges in other areas dedicated to those areas. He found that not all the blind flanges required were available and that it would be necessary for Score to supply some. Following this visit Mr Whalley had a further meeting with Mr Seddon, with blind flanges as the main topic. The discussion centred on the lack of smaller size blind flanges on Piper. It was decided that Score should supply those which were deficient. Two delivery notes were produced dated 19 and 21 January 1988 for the delivery to Piper of blind flanges; Mr Whalley stated that these were only part of the blind flanges supplied by Score.

6.80 Work on the recertification programme began in January 1988 with a 4-man team from Score. The Score supervisor was responsible to the Occidental maintenance superintendent. The release of particular PSVs for recertification was discussed on a daily basis with the lead operator. On an average day the team would do 3-4 valves. By the middle of March a large proportion of the work had been done and it was decided to reduce the Score team to 2. On 11 April the team was demobilised, because the remaining valves could not be made available until the June/July shutdown. During May Mr Whalley was asked by Occidental to attend at their Aberdeen offices to assist in a review of the recertification test certificates. A programme for the remaining work was drawn up and a 2-man Score team returned to the platform on 13 June. The Score container, which had been taken away in April, was brought back to the platform. On 27 June the Score personnel who went out were Mr Rankin and Mr T J Sutton, with the former as supervisor.

6.81 This was Mr Rankin's first tour offshore as a supervisor. Evidence on the training which he received for this, particularly on the responsibility of the supervisor in relation to the PTW system, was given by Score personnel and by Mr Rankin himself. Mr Ritchie stated that the company safety officer, Mr A Buchan, gave both Mr Rankin and Mr Sutton instruction on the Safety Procedures Manual and the PTW system of Occidental. There was no specific training for supervisors. Mr Whalley said that he himself had had a 15-30 minute meeting with Mr Rankin before the latter went offshore and was sure that the PTW system was part of it. He had no doubt Mr Rankin knew how the system worked. He also believed that the Occidental maintenance superintendent would have gone through the PTW system with Score. The training of supervisors was "on the job". Mr Rankin himself said that he was first made a supervisor just before going offshore on 27 June and that this was therefore the first platform where he had been a supervisor offshore and had been concerned with the PTW system. The only instruction which he received was from a Score director, Mr J Scott, to the effect that he should adhere to the Occidental PTW system. He did not recall being instructed in the Occidental procedure before going offshore; he could not recollect any briefing by Mr Buchan. He had instructions about the PTW system on his previous trip on the platform from Mr Whalley and there was a notice about the system pinned up on the wall of the Score container. Mr Rankin said that he knew that he had to go to the maintenance lead hand to obtain a permit and to the operations superintendent to get it approved and that he knew the Designated Authority was the "Control Room lead hand", whom he understood to be the lead operator in the Control Room. He said he knew how to validate and suspend a permit. He had not, however, suspended a permit before. Mr Todd, the Occidental maintenance superintendent, said that Mr Rankin came to his office on 28 June. He was new to Mr Todd as a supervisor so Mr Todd asked him if he knew the PTW system. Mr Rankin said he was happy with it and knew how to work it. Mr Todd did not question Mr Rankin further on this.

Removal of, work on and permit for PSV 504

6.82 The removal of and work on PSV 504 were described by Mr Rankin. This valve was the last which needed to be done and only this work kept Mr Rankin and his colleague, Mr Sutton, on the platform. On 5 July Mr Rankin inspected the job site in C Module. On 6 July he came on shift at 06.00 hours. He met Mr Smith who told him that pump A had been shut down for work to be done on it and hence that PSV 504 would be available some time that day.

6.83 Mr Rankin went with Mr Sutton to the site of PSV 504 to check the need for scaffolding and rigging and to check the blind flanges and tools needed. Then at about 07.00 hours or a bit later they got the PTW and took it along to the maintenance office where Mr White signed it and, Mr Rankin believed, wrote in the tag number, PSV 504, and the location, C Module; Mr Rankin had not put these details on the permit. At about 07.40 hours Mr Rankin took the PTW to the production office where it was signed by Mr Curtis. One copy of this permit, No 23434, signed by Mr White and Mr Curtis was recovered from the accommodation module at Flotta and was produced to the Inquiry. On the permit under "Work to be done and equipment to be used" was the entry "PSV refurbishment injection pump discharge condensate" and under "Additional precautions" the entry "Open pipework to be fitted with blind flanges. Liaise with lead operator. Operator to isolate as required." The entry under "Tag No" was "PSV 504" and that under "Location", "C Module".

6.84 From there Mr Rankin went straight to the Control Room, arriving sometime before 08.00 hours, to inform the lead operator and get the PTW signed (Visit 1). He went to the desk where the lead operator usually sat and asked for his PTW to be signed and said he would need scaffolding but was unsure about rigging; he had no recollection of discussing isolation. He could not say who this person was or if he had ever seen him before and he did not ask him if he was the lead operator, but the man did not demur at being asked to sign the PTW. He left the PTW in the Control Room. He was unsure how long the visit lasted.

6.85 Mr Rankin and Mr Sutton then had a break while the scaffolding was put up and the isolation effected. In the container they made their preparations, Mr Sutton getting ready the blind flanges and tools and Mr Rankin the test equipment. Some time before lunch the latter went down to the site but the scaffolding had not been started; he understood the scaffolders had another job. Between 13.00 hours and 14.00 hours Mr Rankin and Mr Sutton went for lunch. At some time after 14.00 hours the scaffolding was ready with the Safety Department green tag on it.

6.86 Mr Rankin went alone to the Control Room (Visit 2) to retrieve the PTW. He saw the "lead operator", who filled in the PTW, which he did without consulting Mr Rankin. Mr Rankin could not say who this person was or whether it was the same man as on his first visit. He had little recollection of the precautions specified; he believed mechanical isolation was by locking off valves but had no recollection of the electrical isolation or of any red tags and none of any gas test. The operator telephoned Mr P Grant, the phase 1 operator; Mr Rankin presumed this was to ask for the isolation to be done. The visit lasted about a minute.

6.87 Mr Rankin then went down to the job site. Mr Sutton and Mr Grant were already there. He showed Mr Grant the PTW. The latter then attended to the isolations. Mr Rankin thought that he was checking rather than performing them; he did not see him close a valve. Mr Grant went down to the level below and also checked an isolation valve in C Module; Mr Rankin observed from the floor of the module. Mr Rankin was at the site while the flanges were opened up. Then, with the valve still in position, he returned to the Control Room (Visit 3), where he again saw the "lead operator". Mr Rankin could not say who this person was and was unsure if he took action to obtain a rigger. However, when he got back to the job site he found that a rigger was there, that PSV 504 was on the module floor and the crane was available. The valve was taken through the module on a push-barrow and lifted up by the crane to the container. Mr Rankin estimated he had been away from the site perhaps 10 minutes.

6.88 Mr Rankin then began work on the PSV in the container. Once the valve was in the container Mr Sutton took the blind flanges down to the job site. He would have carried them individually. Somewhat less than an hour later Mr Sutton returned to the container and confirmed that he had fitted the blind flanges. Mr Rankin did not check this at the job site; it was not his normal practice to do so. Mr Sutton then assisted Mr Rankin with the testing of the PSV. There was a lapse of some 2 or 3 hours between the arrival of the valve in the container and the witnessing of the test certificate by Mr N McLeod, the Occidental QA representative, at 17.40 hours.

6.89 At about 18.00 hours Mr Rankin went alone to the Control Room to arrange a crane to lift the valve back down (Visit 4). There was only one person there. He did not know who this man was, though he believed that he was not the same person as he had spoken to earlier and that he was the "oncoming lead operator". Mr Rankin told him that the PSV was ready to be restored. The operator told him that the crane was not available; he knew this already without having to check by telephone. It was mutually agreed that the PTW should be suspended. The operator retrieved the other 2 copies of the PTW, making 3, and gave them to Mr Rankin. Mr Rankin then suspended the permit. There was no place on the permit for suspension and it was normal practice on the platform to effect suspension by signing 'SUSP' in the gas test column. Mr Rankin said that this is what he did. He had never suspended a permit before and could not remember how he came to know about this procedure. Mr Rankin gave the operator the permit to sign, or perhaps just placed it on the desk. He could not recollect whether the operator signed it. According to normal procedure, Mr Rankin should have checked the job site prior to suspension of the permit, but did not do so. He confirmed to the Inquiry that he considered that he had left the equipment in a safe condition and had complied with the requirements of the Clearance Certificate.

6.90 Mr Rankin then returned direct to the container. There he found Mr Sutton and other persons. Mr Rankin stated that it had been his intention, for his own peace of mind, to inform Mr Smith of the state of the PSV. He and Mr Sutton knocked off and went to the accommodation. They had a wash and then, by chance, in the recreation area, ran into Mr Smith, who had finished his shift; the time would have been between 18.00 and 18.30 hours. Mr Rankin told him, in Mr Sutton's presence, that there was no crane available and the valve was still off. Mr Smith asked if blind flanges had been fitted and Mr Rankin confirmed that this was so.

6.91 There was some conflict between the evidence of Mr Rankin and that of other witnesses. Mr Lynch stated that Mr Rankin's first visit to the Control Room was about 08.30 hours or 08.45 hours. He knew Mr Rankin was the Score foreman and had issued permits to him. There was no possibility of his confusing Mr Rankin with anyone else; he believed he had his name on his cap. Mr Lynch was equally certain that Mr Rankin knew he was the lead production operator and expected to be addressed by him by name, particularly as he had "Joe Lynch" on his overalls. Mr Rankin said he knew A pump was to be given to maintenance and asked if he could have PSV 504. He made this request to Mr Lynch, as lead operator, but Mr Flook was party to the conversation. Mr Lynch was satisfied that Mr Flook knew that Mr Rankin wanted PSV 504 and that if a permit had been issued later, it would have been by Mr Flook. Mr Rankin did not ask Mr Lynch about scaffolding and would not need to, since he could obtain it on request to the scaffolding foreman, who would have a PTW for the whole of C Module. On this visit Mr Rankin did not have a PTW for the PSV 504 overhaul and Mr Lynch sent him to Mr Smith to get one. When shown the recovered PTW signed by Mr Curtis at 07.40 hours, Mr Lynch agreed it was surprising that Mr Rankin did not have it with him; he surmised that the permit might have been in Mr Curtis' desk without Mr Rankin knowing about it. Mr Lynch also stated that Mr Rankin knew that there was other work to be done on A pump.

6.92 Evidence on the removal of PSV 504 was also given by 2 of the riggers involved, Mr J M McDonald and Mr J Rutherford. Mr McDonald stated that he was working in the GCM with Mr Rutherford when about 09.00 hours Mr Sutton came to them and asked for assistance in removing a PSV in C Module. Mr Rutherford went down and he himself followed some time between 10.30 hours and 11.00 hours. When he got there the valve was already on the floor. He assisted Mr Rutherford in taking the PSV along the module to the crane, which took some 20 minutes. By this time the crane was unavailable since the crane driver took his dinner from 11.00 hours to 12.00 hours. They had theirs from 12.00 hours to 13.00 hours. He had no further dealings with the valve. It could have been lifted without riggers by the crane driver any time after 12.00 hours. About 16.00 hours he went down and cleared away a chain block in C Module. Some time about 17.15 hours to 17.30 hours he was told, either by Mr Rutherford or Mr Sutton, that Mr Smith had said the valve was not to go down until the morning, but there was no mention of the crane. It was not uncommon for Mr Smith to terminate work at 18.00 hours to avoid contractor overtime working. He himself had a conversation with Mr Smith about 18.00 hours but no mention was made of the PSV.

6.93 Mr Rutherford, who was on his second trip on the platform, said that he had done a good deal of work in the GCM before becoming involved with PSV 504. He thought in fact that it was afternoon, about 14.00 hours, when he assisted in taking the valve down, though he may have gone and had a look at the site in the morning. He rigged up a sling to take the weight of the valve. The flanges were opened by one fitter working alone. Mr Rutherford lowered the valve first on to the scaffolding and then to the ground. At this point Mr McDonald arrived and moved the valve to the end of the module using the push-barrow, while he took the rigging down.

Handovers concerning removal of PSV 504

6.94 Mr Bollands' evidence shows clearly that Mr Vernon had the intention of starting up condensate injection pump A. Yet Mr Vernon should have been aware that PSV 504 was off. He should have been made aware of this by means of the PTW and this aspect has just been described. He should also have been made aware of it, as should the phase 1 operator, Mr Richard, by the handovers between shifts. As shown in Table 6.1, Mr Smith handed over as maintenance lead hand to Mr Clark. Mr Lynch, lead production operator, handed over to Mr Flook who handed over to Mr Vernon. Mr Grant, phase 1 operator, handed over to Mr Richard. Mr Slaymaker, Control Room operator, handed over to someone unknown, who handed over to Mr Price, who handed over to Mr Bollands. Direct evidence on handovers on 6 July is confined to that of Mr Clark and Mr Bollands. According to Mr Clark, handover between maintenance lead hands normally took place in the maintenance office at about 17.30 hours and was based on a diary of work written up at the end of the shift, together with an A4 pad of notes, a sort of priority list of work, on-going in and planned for the forthcoming shift. Immediately after handover the maintenance lead hand would go to the Control Room and draw out all the PTWs in his name. Mr Clark said he never went through the suspended PTWs, which were held in the Safety Office.

6.95 On 6 July Mr Smith and Mr Clark held their handover meeting at 17.30 hours. Mr Smith spent some time outlining the work planned for the Voith coupling on condensate injection pump A, explaining that the pump was shut down and electrically isolated but that no work had started on it and that the PTW for this work was in the Safety Office. Mr Clark was clear that Mr Smith did not tell him anything about the work on, or PTW for, PSV 504 and that it was not noted in the diary or the A4 pad. It would be normal for the Score supervisor to tell Mr Smith he was taking out a PTW and Mr Clark believed that if Mr Smith had been aware of the PSV overhaul he would certainly have mentioned it in the handover and recorded it on the A4 pad, it being normal practice to record which PSVs contractors were working on. He agreed that if a PSV overhaul had been completed and the valve returned to service during the day-shift, there would be no need to tell the night-shift maintenance lead hand; the important thing was whether the valve had been replaced. He accepted that, with the handover starting at 17.30 hours, Mr Smith could not know about a PTW suspended towards 18.00 hours and, that if he believed the valve overhaul would be complete within the shift, he might not include it in his handover. Mr Clark was categorical that if he had known that PSV 504 was off, he would not have contemplated starting up A pump and that the first he heard of this was in a telephone conversation with the DEn some time after 16 July 1988; he was surprised and shocked to learn this.

6.96 According to Mr Lockwood and Mr Bollands, handover between lead production operators normally took place in the Control Room, commencing about 17.15 hours and lasting some 20-25 minutes. The operators kept notes, not a log, on an A4 pad, and used this as an aide-memoire in the handover discussions. They would also refer to the Control Room operator's log and sometimes, but not always, to the phase 1 operator's log. After handover, at about 17.40 hours, the oncoming lead operator would walk round the platform. About 18.00 hours the lead operator would return and start going through the PTWs. The 2 lead operators did not go through the PTWs together as part of the handover. Before 17.00 hours the PTWs coming in were signed by the outgoing lead operator. If he was not there the PTW could be left on his desk, as described below. After 17.00 hours all incoming PTWs would be handled by the oncoming lead operator. If he was present, he might sign such a permit there and then. He would not start to process the other PTWs until 18.00 hours. A Performing Authority returning a PTW for completion or suspension after 17.00 hours and finding the lead operator unavailable could sign his copy of the PTW, match it up with the other 2 copies and leave them on the desk of the lead operator for him to process.

6.97 According to Mr Bollands, on 6 July Mr Flook and Mr Vernon commenced their handover at 17.10 hours. He stated that he would have expected Mr Flook to know PSV 504 was off and to tell Mr Vernon, but also that Mr Vernon could not have known that the PSV was off because he would have said so and would not have attempted to start up A pump without its PSV. Mr Vernon would have signed off any PTW suspended after 17.15 hours, particularly one suspended at 18.00 hours. Mr Clark stated that Mr Vernon would have told him the PSV was off and tried something else. He knew Mr Vernon well; he was a competent and experienced man and a stickler for detail. Mr Lynch considered that Mr Flook would inform Mr Vernon of the state of the PM work on A pump.

6.98 Mr Bollands also described the normal handover between the phase 1 operators. This would start about 17.15 hours in the Control Room, but at the back of the panels, out of sight both of the lead production operators and the Control Room operators. The basis of the handover was the phase 1 operator's log, which covered only the gas plant. Mr Bollands believed that on 6 July the phase 1 operator's log would have recorded the fact that A pump had been depressurised for maintenance. He was sure Mr Richard knew that he had only one pump available, as evidenced by his prompt reaction when told of the trip on B pump around 21.45 hours. He was also certain that the overhaul of PSV 504 would be recorded in the log and that Mr Grant would tell this to Mr Richard. Mr Grant, who kept a good log, would enter the PSV overhaul, even if the valve was finished and replaced prior to the end of the shift, as the log would record the time when the pump was shut down and the time when it was repressurised. Mr Bollands believed, however, that Mr Richard did not know PSV 504 had not been reinstated as he could not imagine him wanting to restart the pump without its PSV.

6.99 The Control Room operators' handover, described by Mr Bollands, normally began about 17.15 hours in the Control Room and lasted some 15-20 minutes. The basis of the discussion was a log, in triplicate, kept by the Control Room operator, which covered the oil, water injection and produced water plants together with the diesel pumps and the JB turbines. The gas plant was covered not in that log but in that of the phase 1 operator. The oncoming Control Room operator did not read the latter log or have any discussion with the phase 1 operator. Nor did he read the extant PTWs except, when alerted by the lead production operator, those for hot work, since the latter affected the status of the F & G panel. On 6 July Mr Bollands' handover from Mr Price started about 17.10 hours and took about 5-10 minutes. Mr Bollands was not told at handover, nor did he see in the log, anything about maintenance work on, or PTWs for, A pump. In particular, he was not told of the plan to work on the Voith coupling or of the removal for overhaul of PSV 504. In the course of the evening he became aware that A pump was with maintenance, but believed it was for an instrument PM. He said that he would not expect to be told and would not expect that the Control Room operators' log would record the overhaul of a PSV such as PSV 504, and agreed that the system as practised did not allow for such information to be recorded in such a way that the Control Room operator would know. He did not read the phase 1 operator's log that evening.

6.100 Mr Bollands knew Mr Rankin as a Score technician by sight but not by name. He could not remember seeing him in the Control Room between coming on shift and just after 18.00 hours. However, having a PTW signed off or suspended was not a long job and Mr Rankin could have returned the PTW without his noticing.

State of knowledge of the operators

6.101 Against this background, I return to the state of knowledge of the operators. Mr Smith had brought the PTW for the PM to the Control Room just before 08.00 hours that morning. Operations changed over from A pump to B pump and would have set about making the valve isolations and depressurising the pump, preparatory to spading off by maintenance. Mr Rankin stated that Mr Grant seemed to be checking rather than making valve isolations. Mr Seddon did not communicate his intention to defer the PM and proceed only with the Voith coupling work to Mr White until 16.50 hours. Almost certainly the outgoing operators, Mr Flook and Mr Grant, handed over believing that the PM was still on.

6.102 It was the practice for the phase 1 operator's log and handover to include information about PSVs. However, it can clearly be inferred that Mr Richard was not informed by Mr Grant of the state of PSV 504. The fact that the pump was with maintenance may have been a factor in this.

6.103 The handover between Mr Smith and Mr Clark concentrated on the Voith coupling work. It is not clear whether Mr Smith already knew of the decision to abandon the PM or whether he was treating the coupling work as a priority job within the PM. In any event Mr Clark stated that Mr Smith did not tell him PSV 504 was off. Mr Clark agreed that if Mr Smith expected the PSV to be restored on the day-shift, he might well not mention it. The handover occurred before the time when Mr Rankin said he went to the Control Room to suspend the PTW.

6.104 If Mr Vernon was unaware that PSV 504 was off at 21.45 hours, it must have been either because he had no knowledge of the work at all or because he believed the valve had been put back. The persons from whom Mr Vernon could have learnt about the PSV were Mr Flook and Mr Rankin.

6.105 Crucial to this issue is Mr Rankin's last visit to the Control Room, for which I have only his evidence. Mr Rankin stated that the "lead operator", whom he could not identify, told him there was no crane available to lift the PSV. This is difficult to understand, since it was not the function of the lead production operator to deal with the crane. The operator made no telephone call, so that he evidently knew already that the PSV was not to be replaced. Mr Rankin also stated that he suspended the permit by writing "SUSP" in the gas test column, which was the usual practice on the platform. He had never suspended a PTW before and appeared quite unsure how he knew that this was the procedure.

6.106 I am not satisfied that I can rely on Mr Rankin's evidence on this last visit to the Control Room. I have to consider whether he may not have gone back at all. If he did not, and therefore did not return the PTW, Mr Vernon should have detected the absence of the outstanding permit and should have had the work site checked.

6.107 I also have to consider whether if he had dealings with a lead operator it was Mr Flook not Mr Vernon. This would require both that Mr Flook stayed on later than usual and that Mr Rankin's visit was earlier than he thought. According to Mr Rankin, the lead operator seemed to be aware already that the PSV was not to be replaced that night. A natural explanation of this is that, given that he had no confirmation of restoration of the PSV by the time of his own handover, Mr Smith advised the lead operator that if the job was not completed on the day-shift, it should be left to the next day. He was known to be opposed to overtime working by contractors. If it was Mr Flook who dealt with the matter, it was his responsibility to make arrangements to have the work site checked out. Since he himself was going off shift, the simplest way to do this was to advise Mr Vernon.

6.108 I think it much more likely, however, that Mr Rankin did return to the Control Room and that any dealings which he had with a lead operator were with Mr Vernon. His account suggests to me that either he had only minimal communication about the PTW with the lead operator or, more probably, he simply left the permit on the desk. I am not satisfied that the way in which he had filled in the PTW would convey to Mr Vernon that the job was suspended. However, whether the permit showed the job as suspended or completed, it fell to Mr Vernon as the incoming lead operator to have the work site checked. The practice had developed that the lead operator would sometimes sign the permit, whether completed or suspended, before having the work site checked. I infer that by 21.45 hours he had still not had the site checked; with the pump down for maintenance, he could have viewed it as a low priority.

6.109 I conclude that it is probable that the fact that PSV 504 was off was not known to Mr Clark, Mr Vernon, or Mr Richard and that this was due to failures of the handover and in the execution of the PTW systems, which were aggravated by the status of A pump.

Blind flange assembly at site of PSV 504

6.110 Admission of condensate to A pump would cause a leak from the relief line at the site of PSV 504 only if the blind flange assembly at that point was not leak-tight. The flange was a ring type joint (RTJ) flange with a groove on each flange face into which fitted a soft iron ring. A good deal of evidence was heard on this point. Possibilities explored included failure to fit a blind flange at all, inadequate tightening of the bolts, and damage to, or deterioration of the flange, the ring or the bolts. Another possibility considered, arising from uncertainty as to the sizing of the flange, was the fitting of a mismatched blind flange. A possible factor was the physical difficulty of handling these heavy flanges.

Pressure safety valve PSV 504

6.111 Pressure safety valve PSV 504 was supplied as part of the condensate injection pump package by Thyssen Maschinengebau Ruhrpumpen. It was of unconventional design, in that the inlet and outlet connection flanges were not part of the valve body itself but were welded to adapters, which were in turn bolted to the valve body. The valve was recorded in some documents as 4 inch 900 RTJ x 4 inch 600 RTJ, meaning that it was a valve to fit a 4 inch diameter pipe with a 900 lb flange upstream and a 600 lb flange downstream, both flanges having a ring type joint; in other documents it was recorded as 4 inch 1500 RTJ x 4 inch 600 RTJ, meaning that the upstream flange was 1500 lb, the other features being the same. The valve was Class 900 rated to 2160 psi. A full scale model of the valve configuration is shown in Plate 24(a) and a blind flange and ring in Plate 24(b).

6.112 The most recent operating set pressure of the valve was 1750 psi. The operating set pressure had been changed from its original value of 1400 psi, once in 1985 to 1550 psi and again in 1986 to 1750 psi; one reason suggested was to accommodate the higher pressures involved in injection of condensate into the wells.

Flange rating on PSV 504 pipework

6.113 The rating of the flange became an issue initially in that one explanation advanced for a leak at the site of PSV 504 was the fitting of an incorrectly sized blind flange. Subsequently, the rating of this flange also became an issue in relation to the possibility that the blind flange might have been disturbed by an internal explosion caused by compression and autoignition. The evidence on the rating of the flange is given in Appendix G. I have come to no conclusion on the matter. It does not materially affect my views on the possibility of a leak from a less than leak-tight blind flange at the site of PSV 504. The only other matter to which it is relevant is that it leaves open the possibility of rupture if autoignition occurred.

Blind flange practices

6.114 A number of witnesses gave evidence on practice in the fitting of a blind flange. The practice of Score was described by Mr Ritchie and Mr Whalley and by 2 other supervisors, Mr J Tait and Mr A Watt. Other evidence was given by Mr J Pirie, a service engineer with Wood Group Valves and Engineering Services Ltd, Mr R W Barclay, formerly a valve technician with the same company, and Mr A C Bruce, formerly a valve technician with Score. Mr Ritchie gave as reasons for fitting blind flanges: to obtain access to the item concerned; to protect the faces of the pipe flange; to prevent condensation in the pipework; to prevent residual hydrocarbons coming out; and to prevent a leak from the pipework in the event of inadvertent admission of hydrocarbons. Mr Whalley gave the additional reason of keeping debris out but seemed reluctant to acknowledge the function of containing high pressure to which it might be inadvertently exposed. Mr Ritchie said that it would be bad practice and highly unlikely that hydrocarbon would be admitted to the pipework closed by the blind flange. There should be block valves chained shut to prevent passage of fluid and any leak should be very small. If hydrocarbon at pressure were admitted, the blind flange would be expected to withstand a gradual build-up to the static pressure; it would not necessarily withstand a sudden pressure transient, or water hammer. There was always the possibility that a block valve might pass fluid and in this case the pressure between the valve and the blind flange could build up to the line static pressure. This is one of the reasons why the blind flange should be able to withstand that pressure. Mr Ritchie said that the fitting of a blind flange to open pipework was normal practice in the North Sea, and it was the practice of Occidental and of Score. When a PSV was taken out it was Score's invariable practice to fit a blind flange. The blind flange was fitted as soon as possible after taking out a PSV. The exception was where there was a complete shutdown, when often blind flanges were not used. There were no circumstances in which, if a blind flange was fitted, it would not be flogged up. He stated that it was the company's invariable practice that a blind flange should be flogged up. He rejected the suggestion that combination spanners might be used on a flange of the size of that on PSV 504. He agreed, however, that for smaller flanges a combination spanner might be used.

6.115 A demonstration was given by Mr Whalley of the fitting of a blind flange on the PSV 504 rig at the Inquiry (Model E) shown in Plate 24(a). The rig was fitted with a 900 lb RTJ flange on the valve inlet side and a 600 lb RTJ flange on the outlet side. Mr Whalley performed the fitting on the 900 lb pipe flange of a correct 900 lb blind flange and an incorrect 1500 lb blind flange.

6.116 A flange may in principle be tightened by the use of the fingers, or a combination spanner or a flogging spanner and hammer. The tightnesses so achieved are referred to as finger tight, hand tight and flogged up, respectively. Witnesses agreed that a blind flange would not be tightened by fingers alone. There were several who stated, however, that they tended to use combination spanners rather than to flog up or that it was a matter of personal choice. For example, Mr Pirie stated that for joints of 1500 lb or less he used a combination spanner, both for a blind flange and in making up the flange on the valve; this was his personal choice. Witnesses who addressed the question were agreed that a blind flange should not be exposed to high pressure hydrocarbons without a prior pressure test. Evidence was given that in fitting a blind flange the old bolts and the old ring would be used. The possibility was explored of damage to flanges or rings which might lead to a leak. Mr Watt stated that damage to the grooves on flanges did occur and that repair of such flanges was one of the jobs done in the company's workshops. Mr Clark stated that one could not simply look at an old ring and say it was all right and that his expectation that a blind flange would hold system pressure depended on the use of a new ring.

6.117 Mr Grieve gave evidence that on one occasion on Piper, late in 1987 or early in 1988, he had found a blind flange which was loose. This was at the site of one of the discharge PSVs on the first stage of B reciprocating compressor; the valve had been removed for recertification. The blind flange was not incorrectly fitted; it was just lying on top of the pipe flange, with the bolts loose though with nuts on. He went to the container of the contractors, Score, and spoke to them about it. They told him that they had just finished recertification and were going to reinstate the valve. In the course of conversation they also said that it was not common practice in the North Sea to fit blind flanges when removing PSVs. He did not mention it to anyone else.

State of flange on PSV 504 pipework on 6 July

6.118 Mr Rankin stated that it was both standard practice and a Score requirement to fit a blind flange and to flog it up; it could have been an Occidental requirement also. The reasons he gave for fitting a blind flange were the same as those stated by Mr Whalley. He was clear that a blind flange had been fitted to the inlet pipe of PSV 504, although he did not see it fitted and did not inspect it afterwards. He stated that before lunch Mr Sutton prepared the blind flanges and tools, obtaining these items from the container. The tools were combination spanners, flogging spanners and hammer and, he believed, wedges. Mr Sutton did not mention being short of any blind flanges but, if he had been, he would have obtained them from the Occidental flange store on the 68 ft level. After lunch the scaffolding was up and Mr Sutton took the tools down to the job site, making more than one journey; he had no recollection of assisting Mr Sutton. Following his second visit to the Control Room, Mr Rankin went down to the job site and assisted Mr Sutton to break the flanges on the valve. He then went back to the Control Room to arrange the crane, returned to find that the valve was already on the floor and went back up to the container. Once the valve was in the container Mr Rankin busied himself with the valve. Mr Sutton took the blind flanges down to fit them; he would have had to carry them individually. Mr Rankin did not visit the job site again that day. Mr Rankin essentially left it to Mr Sutton to take the blind flanges down and fit them. He did not at the time consider the difficulty of carrying the heavy blind flanges down and lifting them on to the scaffolding. He considered that one man was capable of fitting the blind flanges, though Mr Sutton might have got assistance from a rigger.

6.119 With regard to the size of the upstream flange, Mr Rankin was confident that the blind flanges used were 1500 and 600 lb. He was sure that flanges of this size were in the container. Mr Sutton prepared the blind flanges and tools before the scaffolding was put up. He would know the flange size because he had done PSV 505 and they had available a previous test report indicating flange size. Mr Rankin did not check how many blind flanges Mr Sutton took and did not himself examine the ratings. If a blind flange had been wrongly sized, it would have been obvious and he would have been informed by Mr Sutton who would not have fitted a wrong flange. As far as concerned the tightening up of the blind flange, Mr Rankin regarded the use of combination spanners or flogging up as an individual matter. His own practice was to flog up, which was equally easy, but he could only speak for himself. He had seen Mr Sutton fit blind flanges on Piper before but he could not remember if he flogged them up. As far as concerns 6 July, it was put to him that his second statement of 19 April 1989 included the passage "We were using big combination spanners which would give sufficient torque but there was a flogging spanner on the site and he might have used that also." It was suggested to Mr Rankin that Mr Sutton could well have realised that the work on the PSV would not take long. He may have returned for a blind flange and found the valve in a reasonable condition. He might not have gone to the length of flogging up the bolts. If things went as expected, he would have to start undoing them very soon after. It was also suggested that Mr Sutton might not have put a blind flange on at all, but Mr Rankin rejected this. Mr Rankin had worked with Mr Sutton at least 18 months and regarded him as a competent and experienced workman, which was the reason that he did not go down to inspect his work. In any event, he would have assisted Mr Sutton in putting the PSV back in. A poorly fitted blind flange would be obvious to him. It was not something Score would tolerate. Further testimony on Mr Sutton's competence and conscientiousness was given by Mr Ritchie.

6.120 The other witnesses of the work at the site of PSV 504 were the 2 riggers, Mr McDonald and Mr Rutherford. Mr McDonald's involvement was minimal; he did not go up the scaffolding and he saw neither the fitting nor the state of any blind flanges. Mr Rutherford stated that it was he who did the rigging to remove the valve. There was only one fitter there and he opened the flanges alone, though possibly the bolts might already have been slackened off. He had no recollection of seeing any blind flanges or being asked to assist with them in any way.

6.121 The evidence on whether fitting a 1500 lb flange was a one-man job was to some extent conflicting, but may perhaps be summarised by saying that whilst ideally it would be done by 2 men it could be done by one. Mr Bruce, the Score fitter, had worked with Mr Sutton. He confirmed that he was quite efficient at fitting a blind flange alone, that he would not fit a mismatched flange and that he always flogged blind flanges up; he never cut corners. He agreed that a mismatched flange or finger tight bolts would be detectable and would be severely dealt with. Mr Rutherford was requested to lift the 1500 lb blind flange, shown in Plate 24(b). He was then asked whether he personally would carry such a flange down 50 ft of stairs and replied that he would not, unless there was no alternative, and doubted whether a fitter would; he would call for a rigger.

Leak tests on blind flange assemblies

6.122 The size of leak which might be expected from a blind flange which was not completely leak-tight was explored by experimental leak tests on blind flange assemblies. Assemblies tested included not only assemblies with varying degrees of tightness, but also assemblies with mismatched fixed and blind flanges.

6.123 Two sets of experimental tests on leaks from blind flange assemblies were presented. Mr R Standen, Senior Physicist with Nowsco Well Services Ltd, described tests commissioned by Occidental and conducted by his company. The tests reported were a sample of those conducted, selected on the advice of the Assessors. They were carried out in a marquee on a rig with a fixed flange of 900 lb rating and using both 900 lb and 1500 lb blind flanges. The fluids used were nitrogen (or nitrogen/helium mixture), water and carbon dioxide, the latter being a surrogate for condensate. The pressure aimed for, and achieved in most tests, was 650 psi. The main variables investigated were the fluid, the blind flange rating, the number of bolts, the ring and the degree of tightness. The degrees of tightness were finger tight, hand tight and flogged up. A video of the tests was shown and a still from this video is reproduced in Plate 26(b); the video included sound recordings. The tests showed that with a properly matched blind flange and ring hand tight or flogged up there was no leak and that even with a mismatched 1500 lb flange, with 4 bolts rather than 8, or with the ring missing, the leak flow with bolts hand tight or flogged up was negligible. Leaks were obtained, however, with flanges which were finger tight or slack. Some of the leaks were partial circumferential leaks, and thus oriented in a particular direction. Asked to explain this, Mr Standen referred to tests involving a 1500 lb blind flange on the 900 lb fixed flange. In such tests the fitter had tended to hang the blind flange on and fasten the 2 top bolts first, so that these bolts were perhaps tighter than the others. He was asked whether he would expect a properly matched flange finger tight to show a directed leak. It was his feeling that finger tightening might give a flange which was not uniformly tight. A set of measurements of bolt stretch was also presented. Using a torque-indicating wrench 8 bolts were tightened first from finger tight to hand tight and then from finger tight to flogged up, the torques being 250 ft lb and 430-440 ft lb, respectively, and measured on just 2 bolts in each case. The increase in bolt length was measured for the 8 bolts, numbered 1-8, starting at the 11 o'clock position and going anti-clockwise. For hand tight the increases were 0.06, 0.14, 0.08, 0.02, 0.08, 0.04, 0 and 0.38 mm respectively, and for flogged up 0.16, 0.14, 0.10, 0.44, 0.24, 0.24, 0.08 and 0.22 mm respectively. In these results, therefore, the hand tight bolts were less tight on the underside and there was considerable variability of tightnesses. Attempts were made to produce leaks which gave strong sounds, particularly tones. Sounds started at low pressures, tens of psi, and varied with the pressure. A sound of 121 dBA with a 7500 Hz tone, an almost pure whistle, was produced by a leak of 400 scfm of nitrogen from a 900 lb blind flange with 8 bolts finger tight. A test conducted with a Metaflex gasket, not included in the report but done with the express purpose of inducing a noise, gave a squealing sound.

6.124 Mr R A Davie, Senior Consultant with YARD Ltd, Consulting Engineers, spoke to tests commissioned by the Contractors' Interest conducted by the National Engineering Laboratory (NEL) and witnessed by YARD. These tests were conducted in 2 phases, the first conducted by NEL at the Wood Group facilities at Peterhead and the second by NEL at their own laboratories at East Kilbride. They were carried out on a rig with a 1500 lb fixed flange using a 1500 lb blind flange. The fluids used were air and water and the pressure up to 670 psi. The main variables investigated were the fluid, the number of bolts, the ring and the degree of tightness; no tests were done on mismatched flanges. Again a video of the tests was shown. The degrees of tightness were finger tight and flogged up, which corresponded to measured torques in the ranges 1.7-9.1 Nm and 274-656, respectively, and arbitrary intermediate values of 109 and 347 Nm. The torque corresponding to the enhanced finger tightness obtained by applying a spanner lightly and casually corresponded to a torque of about 50 Nm. These tests too showed that with a matched blind flange flogged up there was no significant leak even with 4 or 2 bolts rather than 8 or with the ring missing. In fact there was no significant leak in any tests where the bolt torque was more than 50 Nm. Leaks were obtained, however, with finger tight bolts. At a pressure of about 450 psi the leak flow of water with a ring and 8 bolts finger tight was about 65 kg/min and that with a ring and 4 bolts with a torque of 50 Nm about 4 kg/min. Measurements were made of the displacement of the blind flange as a function of applied pressure of air for different ring and bolt configurations and bolt tightnesses. At a pressure of 670 psi with a ring and 4 bolts finger tight the displacement was about 0.43 mm and with 8 bolts it was 0.22 mm. The equipment used in the tests was new. Mr Davie was questioned on the possible effects of equipment which had suffered deterioration, but he tended to discount this. He did not think there would be any significant difference between an old and a new ring, though he had not studied that aspect. Mr Davie also pointed out that there are 2 types of ring used in an RTJ, an octagonal ring and an oval one. That used in his work was the octagonal ring, as specified for the flange on Piper. These air and water leak tests were analysed by Dr D A McNeil, Senior Scientific Officer at NEL, for the cases with and without a ring, to obtain estimates of the equivalent hole diameters and associated leak flows at a pressure of 46.3 bara, for the finger tight condition only. With the ring and with bolts finger tight he made the estimates shown in Table 6.3.

6.125 What I principally take from this evidence is that a blind flange which is hand tight or flogged up will not give a leak of the size sought, short of gross damage or deterioration, but that one which is finger tight could do so.

Scenario of leak at site of PSV 504 through a blind flange assembly which was not leak-tight

Nature of the 2-stage leak

6.126 Continuing with my first scenario of a leak at the site of PSV 504 through a blind flange assembly which was not leak-tight, I now turn to the sequence of actions which might have caused a leak. I remind the reader that the leak pattern which I am considering is a gas cloud containing some 45 kg of hydrocarbon within the flammable range, arising from a 2-stage leak, in the second stage some 110 kg/min lasting some 30 seconds and in the first stage perhaps some 4 kg/min. I note, however, that in the first stage a leak as low as 1 kg/min would be sufficient to give a C3 alarm in 30 seconds.

Scenarios for the 2-stage leak

6.127 The fourth and sixth reports presented by Drs Richardson and Saville dealt with the leak rates obtainable at A pump for different GOV states, given suitable orifices in the blind flange. These were spoken to by Dr Saville and Dr Richardson, respectively. The most straightforward way in which a leak might occur is for the GOV to be opened, thus admitting condensate to the delivery pipework, and to remain open. The size of the assumed orifice may be defined in terms of its equivalent diameter, the leak flow being proportional to the square of the diameter. At the condensate pressure of 46.2 bara the large, second stage leak sought, a leak with a leak rate of 110 kg/min, would be given by an orifice 8 mm (actually 7.8 mm) equivalent diameter.

6.128 For the initial small leak a semi-continuous gas leak of 4 kg/min would be given by a variety of combinations of orifice diameter and gas pressure. These include an orifice of 10 mm orifice and 5.3 bara; one of 8 mm and 8.3 bara; and one of 3.4 mm and 46.2 bara. The jagging times to give these pressures are some 0.4, 0.6 and, by extrapolation, about 2.6 seconds, respectively.

6.129 A 2-stage leak could have arisen from various permutations of actions at the GOVs of A pump. One such pattern of actions is that perhaps 2 minutes before the initial explosion the GOV was opened by jagging and then closed before the relief line had filled with liquid, giving a small leak, and that some 30 seconds before the explosion it was opened and stayed open, filling the relief line with liquid and giving a larger leak. The order of leak envisaged is in the second stage some 110 kg/min from an orifice of about 8 mm equivalent diameter and in the first stage one of some 4 kg/min. If the orifice were 8 mm in this first stage also, the pressure required would be 8 bar, but in fact the final 8 mm orifice would be the result of the full pressure of 46.2 bara, so that in the first stage the orifice would be smaller and the pressure greater, though it is difficult to quantify this. The evidence on the actions of the operators at the pumps has already been described. Mr Grieve did not observe Mr Vernon work the push-pull button on A pump. However, either Mr Vernon or Mr Richard could well have jagged the GOV before Mr Grieve arrived. Having reconnected the air line to the GOV, it would be a natural action to give a short pull to confirm movement of the valve. If the electrical de-isolation of A pump had then been effected, the second opening could have been completed in a few seconds and the valve would have remained open. It is worthy of note that when Mr Grieve first arrived at the 68 ft level, Mr Vernon was beside the A pump GOVs. When Mr Young first arrived, Mr Vernon was again beside these GOVs.

Observations on this scenario

6.130 The scenario under consideration is that of a leak at the site of PSV 504 through a blind flange assembly which was not leak-tight. I have already given my views on a number of aspects of this scenario and can be brief at this point. I find the scenario thus far entirely credible. Mr Vernon had the intention and the opportunity to admit condensate to A pump. A natural sequence of actions to effect this admission would give rise to a 2-stage leak. The scenario does require, however, that the blind flange assembly was not leak-tight, for which there is no direct evidence. On this aspect of the credibility of the scenario I defer further discussion until I have considered the other scenarios.

Scenario of leak at site of PSV 504 due to autoignition or other effects consequent on admission of condensate

6.131 Several other scenarios which might account for a leak from the site of PSV 504 were also explored. There were 3 which were postulated on the admission of condensate, namely:

1. Autoignition
2. Shock loading
3. Brittle fracture

whilst the 4th was:

4. Over-pressurisation by methanol injection.

All 4 scenarios were considered by Drs Richardson and Saville in their fifth and third reports. The fifth report dealt with the above 4 scenarios and was spoken to by Dr Saville. It concluded that all but autoignition could be dismissed. The third report, presented by Dr Richardson, addressed further the question of autoignition. In this work frequent use was made of 2 computer programs, PREPROP and BLOWDOWN. The first was used to calculate thermophysical properties of mixtures by an extension of the principle of corresponding states, the second to simulate the depressurisation of a vessel.

Admission of condensate

6.132 In their fifth report, Drs Richardson and Saville gave estimates of the conditions which would occur in the pump system, initially at atmospheric pressure, if condensate at 46.2 bara were admitted through the suction valve GOV 5005. Opening of GOV 5005 would give an initial flow velocity of 133 m/s. If this valve was opened without the interruption inherent in jagging, pressurisation would be essentially complete after some 2 seconds, with the valve still only about 30% open. The BLOWDOWN code was used to determine the temperatures in the gas phase after compression. For the case of compression of air under adiabatic conditions the temperature in the gas space would attain a value of about 500°C. Dr Saville stated that this temperature would be much reduced if the gas space contained a large proportion of hydrocarbon or if conditions were not adiabatic so that there was appreciable heat transfer to the wall. He said that each of these features could reduce the temperature increase by a factor of roughly 2. Assuming that the pump system was initially filled with air, the authors calculated for this case the temperatures shown in Fig 6.6. Compression of the air would lead to a rise in temperature, which would reach almost 270°C (520°F) at the end of pressurisation. The effect of the pressure letdown would be to cause the condensate to flash off, forming vapour and liquid, with the liquid temperature falling to provide the latent heat of vaporisation of the vapour. For a letdown from an upstream pressure of 46.2 bara to atmospheric pressure in the pump system there would be a temperature drop to about -26°C (-15°F), but this would bottom out at about 0.12 seconds, as shown in Fig 6.6. If instead the GOV was jagged, the temperature reached by the gas would depend on the period of the jag. It was estimated that for jags of 0.5, 0.75 and 1.0 seconds duration, the maximum temperatures attained by the air would be 203, 220 and 240°C, respectively. In all cases except the first the maximum temperature would be reached on the first jag.

Autoignition

6.133 If a flammable mixture had accumulated in the relief line from the pump, sudden admission of condensate would cause compression of this mixture and could possibly result in ignition. Such autoignition would be similar to that which occurs in a diesel engine, where ignition is effected not by a spark plug but by compression, although the temperatures attained would be much lower. For ignition to occur, there would have to be a flammable mixture in the system. In other words, there would need to be ingress of air, which would depend on the extent of any openings to atmosphere. The evidence was that the flange at PSV 504 had been open for about an hour. There were also other possibilities. For example, if the valve used to vent the pump to flare had been left open, condensate vapour, being denser than air, would continue to stream out of this valve, drawing air in at the top through the flange at the site of PSV 504. It was not known how long the pump vent valve might have been open nor whether this coincided with the period when the flange was open. As far as

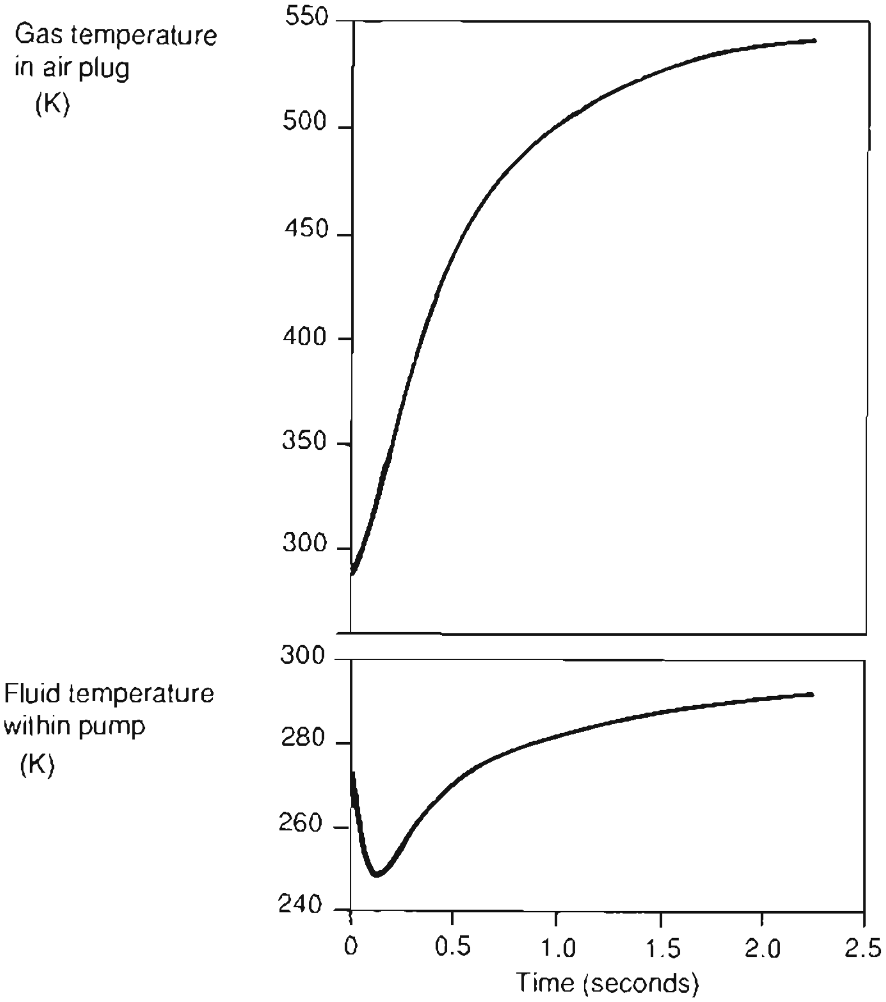


Fig. 6.6 Estimated temperatures of gas (air) and liquid on admission of condensate through GOV 5005 into condensate injection pump A system.

concerned entry of air into the open flange, there was an 11 inch horizontal section from which condensate vapour would readily flow out. If the penetration of air were then by molecular diffusion, it would be very slow, about 1 m/h, but any disturbance, whether of wind velocity or temperature or something else, would increase the rate of diffusion. It was put to Dr Saville, and he agreed, that the vapour from condensate would be rich in methane and so that the gas in the pipe would be buoyant and that air might be drawn in this way. The report considered a mixture of condensate vapour and air with the air content 95%, as a worst case in the sense that the gas temperature after compression would be high and more favourable to autoignition. It was estimated that for pressurisation by jagging the temperatures of the air in the relief line would be in the range 200–270°C. This range of temperatures was compared with published data on autoignition temperatures for the paraffin series of hydrocarbons, showing that those of pentane and above lie in or below this range. Dr Saville pointed out that the scenario envisioned involved a multi-component mixture and also that it differed from the situation in which the published data would probably have been determined, in respect of factors such as vessel geometry and pressure. The conclusion in this report, therefore, was that it was an open question whether autoignition could occur. The authors were not able to say what effect autoignition would have. Dr Saville was asked whether an autoignition scenario could explain a leak giving gas alarms some time before the initial explosion as well as the latter, but he was unable to help. He was asked whether he would expect the flame from an autoignition to pass through the rupture, thus giving on the outside an ignited leak, but he was unsure. It was put to him that if autoignition occurred such as to rupture the pipework, it would be expected that someone in the area would hear it, and he agreed. The objection was raised that there did not seem to be a history of autoignition incidents. Dr Saville replied that compression ignition incidents were really quite common, though not necessarily offshore, and perhaps more often in the past. He pointed out that it would be normal practice to purge with nitrogen. The third report by Drs Richardson and Saville, concerned exclusively with autoignition, was presented by Dr Richardson. This dealt in greater detail with the probability of autoignition and with its effects. The report acknowledged the assistance received by the authors from Dr J F Griffiths, of the School of Chemistry at the University of Leeds, and Mr I A Smith, a consultant. The process of combustion is a complex one and is influenced by a large number of factors. It is convenient for practical purposes to characterise it by features such as autoignition temperatures (AITs) and to treat these as if they were properties, but this is an oversimplification. AITs give a ranking of the reactivity of the substance with oxygen and this ranking is relatively insensitive to the conditions, but the absolute value of the AIT is sensitive. Factors affecting the temperature at which compression ignition may occur, which were discussed in the report, were fuel composition; fuel-air ratio; container volume and geometry; initial pressure; fluid motion; and wall temperature. Some of these factors tend to lower and others to raise the AIT. As far as concerns the specific scenario considered, the high pressure would be a factor tending strongly to decrease the AIT and the fluid motion a factor tending to increase it, but to an unknown degree. Dr Richardson thought the latter effect would be in tens rather than hundreds of degrees. The report concluded that it was not possible to predict whether, for the scenario postulated, autoignition would have occurred. The situation was too complex and experimental work would be required. Asked about air ingress, Dr Richardson said he had little problem in envisaging that sufficient air might have entered to give a flammable mixture.

6.134 Although they were unsure whether autoignition would occur, the authors nevertheless investigated the explosion pressure which would occur if it did. There was some doubt about the composition of the vapour which would exist in the pipe. One possibility was that it would be close to that of condensate. Another was that there might be left in the pump a pool of heavy ends which would slowly evaporate. Two vapour mixtures were therefore investigated, condensate and a heavy end mixture. The authors used the PREPROP code to determine the pressure resulting from an explosion. They calculated that if ignition did occur, then assuming an adiabatic explosion of a stoichiometric mixture, containing some 3-4% of hydrocarbon, initially at 46.2 bara in the fixed volume of the system, the resultant pressure would be 293 bara for a condensate mixture and 297 for a heavy end mixture, or in round figures 300 bara.

6.135 Next the report addressed the question of the effect of such an explosion on the relief line. It considered the effect on the pipe and, for a blind flange, on the flange itself and on the bolts and ring. The detailed results of this analysis are given in Appendix G. They show, assuming a worst case explosion pressure of 300 bara, that a properly made up 1500 lb blind flange assembly would not fail, that a properly made up 900 lb blind flange assembly might possibly fail by failure of the flange itself, that it was possible to find a number of modes of improper assembly which could lead to failure, and that the flame would only propagate to the outside if the hole were relatively large. It was also concluded that an improperly made up blind flange assembly might fail if it had rather fewer than 8 bolts fitted loosely; many fewer than 8 bolts fitted tightly; grossly undersized bolts; or mismatching flanges. The authors drew attention to the effect of pipe whip due to an explosion, but stated that analysis of this was outside their expertise. Dr Richardson agreed that such analysis would require detailed knowledge of how the pipework was restrained.

Shock loading

6.136 The fifth report by Drs Richardson and Saville also dealt with other ways in which failure of the condensate injection pump system might occur. Sudden admission of condensate into the relief line might possibly lead to a shock loading severe enough to cause rupture. If the delivery valve, GOV 5006, was open and the suction valve, GOV 5005, was opened so as to admit condensate into the pump system, a mass of condensate would travel through the system until stopped. The maximum possible pressure on a blind flange at the site of PSV 504 may be determined by assuming that it received the full force of the plug of condensate. Taking the initial flow velocity of 133 m/s obtained by opening of GOV 5005 and a condensate density of 300 kg/m^3, the pressure on the flange caused by this impulse would be 53 bar, which added to the existing system pressure of 46.2 bara would give a total pressure on the flange of about 100 bara.

6.137 In practice the pressure exerted on the flange would be less than this because it would be most unlikely that the fluid would maintain this flow rate through the pump and line and because the first fluid to contact the flange would be gas moving ahead of the liquid and being compressed by it. It was Dr Saville's judgement that by the time the condensate reached the flange it would have little momentum left. The maximum allowable pressure for a 900 lb flange assembly was 150 bar (2160 psig) and for a 1500 lb assembly 250 bar (3600 psig). The conclusion reached was that given a properly made up flange shock loading could not have led to a leak. Dr Saville agreed, however, that if the bolts had not been properly tightened, the flange might have been dislodged sufficiently to permit some degree of leakage. Another possibility considered was a rupture due to unrestrained movement of the relief line. The effect was compared by one counsel with the whip effect when water is admitted into a fire hose. Dr Saville had not studied this, but he re-emphasised that there would be a change in flow as the condensate passed through the pump, referring to an order of magnitude reduction; he was not prepared, however, to rule out the possibility of pipe whip.

Brittle fracture

6.138 The chilling effect consequent on the sudden admission of condensate might conceivably give a temperature low enough to result in brittle fracture of the relief line. For a pressure letdown from an upstream pressure of 46.2 bara to atmospheric pressure in the pump system the instantaneous temperature drop would be to about -26°C (-15°F), as shown in Fig 6.6. This temperature would last, however, for less than a second, too short a time to cause any significant fall in the temperature of the metal. This temperature was compared with the safe lower operating temperature of most carbon steels of -20°F. It was concluded that the temperature drop attendant on admission of condensate could not have led to a leak caused by brittle fracture.

Over-pressurisation by methanol injection

6.139 The last of these scenarios was over-pressurisation of the relief line by methanol injection. The methanol supply was from one head of the methanol injection pump and the methanol would be delivered at a pressure of 230 bara (3320 psig) and a flow of 0.5 litre/min (8 US gal/h). There was some doubt as to the location of the methanol injection point on the condensate injection pumps. It was shown on a drawing as on the delivery line, but Mr J Drysdale, an operator, remembered it as on the suction line. Following pressurisation of the condensate injection pump A it would have been normal, to prevent hydrate formation, to begin methanol injection in the pump before starting it up. It was assumed that GOV 5005 and GOV 5006, the suction and discharge valves, would be closed during this operation. The worst case would be where the pump, its inlet and outlet lines and its pulsation dampeners, unprecharged, were full of condensate at 46.2 bara (670 psi) and 286 K (55.9°F). The volume of the system was estimated as 0.4m^3 and the mass of condensate as 200 kg. The rise in pressure resulting from methanol injection was predicted using the PREPROP code. The 2 extreme cases for heat transfer between the condensate liquid and the metal walls were considered, namely no heat transfer (adiabatic conditions) and perfect heat transfer (isothermal conditions). The results showed that the methanol delivery pressure of 230 bara would be reached after 37 and 52 minutes for the adiabatic and isothermal cases, respectively. Given this fairly long time, Dr Saville said that he would expect the system to approximate more closely to the isothermal case. The maximum allowable pressures of a 900 lb flange assembly would be reached within between 23 and 32 minutes and that of a 1500 lb assembly within between 40 and 54 minutes. If the pulsation dampeners had been precharged to their mid-position prior to methanol injection, the remaining halves of the 2 dampeners would give a volume to be filled of 76 litres and pressurisation would take of the order of 2½ hours. It was concluded that assuming methanol injection began between 21.45 hours and 21.50 hours, there was insufficient time for over-pressurisation to take place and that it was most unlikely that this was the cause of the leak.

Observations on autoignition and other variants

6.140 Of the mechanisms considered for rupture of the blind flange assembly on the relief line or the line itself, only autoignition emerges as a possibility and that only if the flange was 900 lb rating. The occurrence of autoignition is necessarily postulated on the admission of condensate to the relief pipe by jagging the suction GOV so that the liquid completely fills the pipe. A 2-stage leak might occur if an initial jag of the GOV led to autoignition and rupture of the blind flange assembly to give a hole and the GOV were then closed after this initial jag and later opened so that it remained open. In the first stage the leak rate would initially be comparable to that in the second stage. Then, depending on the precharge pressure of the pulsation dampeners, it would on the figures given by Drs Richardson and Saville subside within some 6-25 seconds. The wind tunnel tests do not give sufficient information to decide whether an orifice large enough to give the required leak rate in the second stage would give only a single low gas alarm in this first stage.

Hydrate formation and methanol injection

6.141 At various parts of the plant there was potential for the formation of, and blockage by, hydrates. In accordance with standard practice methanol was injected at selected points to prevent this, as shown in Fig J.8. The quantities of methanol required in phase 1 operation were an order of magnitude greater than in phase 2 and the platform was advised accordingly. It emerged in the course of the evidence that conditions, ie methanol concentration and temperature, at the JT valve, PCV 721, were of particular significance.

Experience of hydrates on plant

6.142 Hydrate problems were sometimes experienced on Piper and evidence on this was heard from several witnesses. Mr Grieve remembered a problem occurring on a single occasion perhaps a couple of years earlier when the molecular sieve driers had become saturated with water. This lasted 2 or 3 days and affected the condensate injection pump 2 or 3 times. The pump did not trip but either ran rather noisily or did not pump anything at all. In his statement to Occidental he described this type of situation in the following terms:

> "There is no visible sign that the hydrate is there; it's just by the pump itself; you get a sort of knocking noise from the pistons themselves. It's very difficult to tell, it's the sort of thing that somebody decides that that's what they reckon it is. They shut the pump down, they zero vent it, leaving lying to zero vent for 5-10 minutes, shut it again and give it a start, it'll run away with no problems at all."

Mr Henderson stated that hydrate problems on the condensate injection pumps were few and far between. Generally the blockage occurred on the suction rather than the discharge side. The usual symptom was that the pump would tend to speed up and there could be a knocking of the valve chest. The remedy was to shutdown, vent off and recommission. Mr Clark said that the pumps might run well for a period and then there would be a number of trips. He agreed that when this occurred it would tend to be due to process conditions. He could not think of anything other than hydrates which would cause such repeated trips. Mr Carey stated that they did not have much damage to equipment from hydrates; it was normally blockages in pipes. He referred in his statement to Occidental to blockages on PCV 723A, B. Mr J E Cotter, the phase 1 operator on nights until 4-5 July, stated that he had had no trouble with hydrates on his last tour.

Methanol injection

6.143 Operation in the phase 1 mode required that different quantities of methanol be injected. Calculations to determine these quantities were made by Mrs E A Paterson, a young chemical engineer in the Facilities Engineering Department. On 23 March 1988 Mrs Paterson, then using her maiden name, Mortimer, sent an internal memo to Mr J Bryce and Mr P J Cosgrove, specifying the quantities of methanol to be injected. This memo stated that areas where hydrate formation was most likely were the JT valve, the JT flash drum inlet, the condensate pumps and the second stage reciprocating compressor suction scrubbers, and specified methanol injection rates of 26, 23, 8 and 3 US gal/h, respectively, at these points. These quantities were determined using the method of Campbell given in *Gas Conditioning and Processing* and included a 5°F safety factor. The memo noted that according to the Occidental Production Chemical Treatment Handbook the maximum injection capacity of the main methanol pump to the JT valve was 23 US gal/h and thus less than the recommended rate. It proposed that additional methanol capacity should be provided at the JT valve and that there should be a back-up injection system at this point. The use of the Williams pumps was suggested, though the wording implies their use for the former rather than the latter purpose. On 6 July heads D and F of the main methanol pump were both connected up to supply methanol to the JT valve. Although both operators and management were examined at some length on the methanol supply to the JT valve and JT flash drum, there was no suggestion that the Williams pumps had been brought into use. The amount of methanol required for phase 1 operation was much greater than for operation in the phase 2 mode; 1300 as opposed to 100 US gal/day. Mr Grieve stated that the operators were fully aware of the need for these higher injection rates; he himself had seen a copy of the 23 March memo. If anything, the operators were going in for overkill.

6.144 According to Mr Grieve, early in the evening of 5 July a leak developed on the seal on head D of the methanol pump; the leak was small but liable to get larger and a repair was carried out. The whole pump was shut down for some 5 minutes. Head D was shutdown for a rather longer period, but Mr Grieve's evidence on this was variable, ranging from an hour in his statement to Occidental to 15-20 minutes. In this statement Mr Grieve estimated that about 100 gallons of "injection rate" would have been lost, but he was unable to explain this figure. A further interruption to the methanol supply occurred on the afternoon of 6 July. Evidence on this was given by the fitter involved, Mr J B Russell. At about 14.00 hours that day he was working on the system renewing a drain valve on the methanol storage tank; this job was covered by a PTW which was recovered. He noticed that head F was leaking and informed the maintenance department. At 16.00 hours the leaking head was shut down for repair. It was not handed back to production until about 20.00 hours, so that it was down for 4 hours. According to Mr Russell, the pump head was checked by Mr Grieve and put back into operation. Mention was also made in evidence of work on a non-return valve on one of the methanol lines. Mr Grieve believed that an NRV was fitted on the hose from the methanol pump to the JT valve during the day. He stated that on 6 July he came on duty at 17.30 hours and was made aware of the work on the pump; he believed there was an entry in the log. He did not, however, have a clear recollection of the events. He could not remember reinstating the head after repair. He was reluctant to accept that the pump head was off for as long as 4 hours or that the work extended into the evening. Asked about the possible effect of a loss of methanol supply to the JT valve, Mr Grieve was unable to say how long it would take for such an effect to show up - whether it was a matter of minutes, hours or days.

6.145 Evidence on the pumping capacity of the individual heads on the main methanol pump, which was recovered and stored at Peterhead, was given by Mr R Williamson, an engineer from the pump manufacturers, Bran and Leubbe (UK) Ltd. The stroke position indicators on the pump were plastic and had been destroyed by heat. After some initial difficulties due to seizure of the main drive motor, it proved possible to free the system sufficiently to rotate the drive shaft and observe the full forward and reverse stroke cycle of each pump head. The stroke lengths were then determined and the corresponding theoretical liquid volumetric flows were determined. These were 21.8, 7.6, 0, 19.9, 7.3 and 18.0 US gal/h for heads A-F, respectively. Thus interruption of the methanol supply from head F would cut off 18.0 US gal/h and leave only the supply of 19.9 US gal/h to the JT valve.

Temperature at JT valve

6.146 The temperature of the JT flash drum in phase 1 operation given in Fig 4.12 of the Petrie Report was 40°F. In the initial process quantities flowsheet (PSK-A1-1229-0) for phase 1 operation on 6 July produced by Occidental after the disaster the temperature of stream 200 downstream of the JT valve was shown as 49.7°F (9.9°C). A revised quantities flowsheet (PSK-A1-1229-1), given in Table J.1, spoken to by Mr M R Clark, Chief Process Engineer of Occidental, gave this stream temperature as 52.5°F (11.4°C) and that of stream 210 entering the JT flash drum as 55.6°F (13.1°C). The temperature of this latter stream, which would also be that in the drum itself, was higher because of the addition of the warmer condensate in stream 320 from the condensate suction vessel. Mr Clark explained that the figure of 55.6°F was based on the last entry in the Fiscal Metering Log Sheet for 5 July, but acknowledged that that entry referred to the temperature at the outlet of the condensate injection pumps and that since there was a rise in temperature between the drum and the outlet of these pumps, the temperature in the JT flash drum would have been lower, but he considered that the temperature rise of 4.5°F shown on the flowsheet might have been estimated on the high side. Assuming it to be correct, however, on the basis of the log the temperature in the JT flash drum would be some 51°F (10.6°C) and that at the JT valve some 48°F (8.9°C). Evidence was also given of the temperatures at the JT valve actually observed on the plant. The log for 5 July stated that the JT flash drum temperature was 40°F and had been down to 28°F. Later entries in the log showed a rise in temperature. Mr Henderson that day noted that the JT flash drum temperature was 48°F. This, however, was before the startup of the third centrifugal compressor. Mr Clark believed that bringing in the third compressor would have tended to raise the JT flash drum temperature. According to Mr Bollands, the plant conditions should have remained steady on 6 July after this compressor had been returned to service on the evening of 5 July.

Hydrate formation at JT valve

6.147 This evidence indicates that on 6 July there almost certainly was an interruption of the methanol supply from head F to the JT valve between 16.00 hours and 20.00 hours and that the temperature downstream of the JT valve could well have been no more than 50°F (10°C) on that evening, thus creating conditions favourable to hydrate formation. Evidence on whether hydrate would in fact form under such conditions was given by Drs Richardson and Saville in their first and eighth reports, presented by Dr Richardson and Dr Saville respectively. Drs Richardson and Saville calculated that at a temperature of 50°F the methanol in the aqueous phase required to prevent hydrate formation was 15% w/w. This corresponded to a methanol injection rate at the JT valve of 19.9 US gal/h. This flow equalled that to the valve during the interruption of methanol supply.

6.148 Additional evidence on the equilibrium conditions for hydrate formation, on the rate of formation and on the behaviour of hydrates was given in work commissioned by the Inquiry and spoken to by Dr H K Johnsen, Managing Director of Petreco, Stjordal, Norway. Dr Johnsen carried out a number of experiments on hydrate formation and behaviour under conditions typical of those on Piper. All the tests were done using a wheel-shaped flow simulator. Condensate was formed in the wheel by admitting a suitable mix of gases and was then brought to equilibrium at the required pressure and temperature by rotating the wheel. Water was then admitted and the behaviour of any hydrates formed was observed. The first series of tests investigated hydrate formation under conditions representative of downstream of the JT valve, downstream of the JT flash drum, and within the condensate injection pump. The third series dealt with hydrate formation due to decrease in temperature. The second and fourth series were concerned with hydrate dissolution by increase in temperature and by methanol addition, respectively. Three tests in the first series were concerned with conditions downstream of the JT valve. In particular one test simulated the conditions which may have occurred at the JT valve on partial loss of methanol on 6 July. In this test with 15% w/w methanol in the aqueous phase at 50°F (10°C) and 639 psia (43.5 bara) hydrates formed rapidly at the valve, about a quarter of the water being converted to hydrates. After 40 minutes all the water had converted to a hydrate slurry. Dr Johnsen considered that the conditions at the JT valve, with water being sprayed into an atmosphere of hydrocarbons, was a close to ideal situation for hydrate formation. On the basis of this work Dr Johnsen estimated that some one third to one half of the water at the JT valve would be converted to hydrate during the period of reduced methanol supply. He also estimated that the flow rate of water at the JT valve was about 130 litres/h, making some 500 litres over a 4 hour period, and that this would yield some 250 kg or more of hydrate. In a test in the fourth series, involving the effect of raising the methanol concentration, at 34°F (6.1°C) and 604 psia (41.1 bara) with 10% w/w methanol sticky hydrates formed. When water with 20% w/w methanol was injected the hydrates formed a slurry which flowed.

Hydrate behaviour in condensate system

6.149 Dr Johnsen thought it probable that hydrate formed at the JT valve would adhere loosely to the JT flash drum and along the pipework leading to and from the condensate booster pumps. This pipework was 10 inch on the suction and 8 inch on the discharge side of these pumps; the pressure rise across them was only 35 psi, from 635 to 670 psia. He expected water and hydrates to accumulate in parts of the pipework which were not horizontal and in particular he expected such accumulation in an upward pointing bend after the booster pumps. It was his expectation that on resumption of the full methanol supply to the JT valve the hydrates formed would become more mobile. He envisaged that they would begin to move from the JT flash drum and that they would pass relatively freely through the condensate booster pumps. The hydrates would then enter condensate injection pump B in which they would be raised from 670 to 1100 psia. Since water is relatively incompressible, the temperature rise would be small compared to the pressure rise so that the conditions at the pump discharge would be much more favourable to hydrate formation. He envisaged that a compacted hydrate would form at the discharge of the pumps and would block the discharge line. He thought that the timescale over which this movement of hydrate might occur could well correspond to the period which elapsed between the resumption of full methanol flow to the JT valve and the trip of B pump at about 21.45 hours. On the basis of these studies, Dr Johnsen postulated a scenario in which the trip of B pump at that time was caused by hydrate blockage, the relief valve opened but also blocked with hydrate, the pump over-ran and generated a high pressure and the relief valve ruptured.

6.150 Dr Johnsen was asked what experience there was in the offshore industry of hydrocarbon leaks caused by hydrates. He stated that he had never read anything in the literature on such cases; it was the sort of thing which was not publicised. He said that he had heard of instances of rupture due to dislodging of hydrate plugs in large bore pipes; he later referred to maybe a couple of cases, but could not put a date to them. He had not heard of cases of rupture due to dislodging of plugs in small bore pipes or due to over-pressure behind a hydrate blockage. The Inquiry was the first time he had assisted an investigation of an incident which may have been caused by hydrates.

Scenario of leak at or near PSV 505 due to hydrate blockage

6.151 The basic scenario is that condensate injection pump B delivery line was blocked by hydrates, that the relief line also became blocked by hydrates, and that the latter line was over-pressurised and ruptured. The scenario was put forward by Mr Sylvester-Evans, but its detailed development was due to Dr Johnsen. A further account of the Johnsen scenario was given by the Crown and a version of it was favoured by Score. The versions of this scenario actually advanced by Dr Johnsen are not as clear as they might be. However, he appeared to hypothesise that the rupture occurred either at the initial trip or during an attempt to re-start the pump. The version favoured by Score was that the rupture occurred during an attempt, but not the final attempt, to re-start the pump. There are therefore 2 cases to consider, rupture at the initial trip or rupture at a re-start. It is common to both versions that hydrate formed at the JT flash drum and was carried forward. It passed through the condensate booster pumps and through B pump but blocked on the delivery side. This blockage occurred first on the pipe to the MOL, which is the pipe where there is flow. The delivery pressure rose, PSV 505 opened and condensate flow occurred in the relief line.

Rupture at initial pump trip

6.152 In the first version, case 1, the relief line too became blocked by hydrates at the PSV during the initial trip. The pump over-run was enough to cause over-pressure and rupture at the valve. The rupture orifice plugged with hydrate, which then slowly melted, giving first the initial alarm and then, as the final melting occurred and the hole grew rapidly larger, the final group of alarms. Mr Vernon evidently made at least one attempt to re-start B pump before coming up to the Control Room to get A pump reinstated. Mr Grieve took part in a further attempt to re-start B pump. It is not known how many attempts Mr Vernon made before Mr Grieve arrived, so there may have been some additional efforts between the first and last attempts at re-start. In this version these attempts at re-start are of secondary importance. At most they may have created high pressures again in the relief line and aggravated the leak. In particular, the last re-start attempt may have finally dislodged the last bit of hydrate.

Rupture on pump re-start

6.153 In the alternative version of this scenario, case 2, at the initial trip, flow but no blockage occurred in the relief line. However, during an attempt, but not the final attempt, to re-start the pump the discharge was over-pressurised and again PSV 505 opened. This time the hydrates plugged the PSV and rupture occurred. The rupture orifice itself plugged with hydrate, which then slowly melted, giving first the initial alarm and then, as the final melting or dislodgement occurred and the hole grew rapidly larger, the final group of alarms. It was suggested by Score that this final increase in leak size occurred as a result of (i) the admission of suction pressure due to the opening of the GOVs during the final attempt to re-start the pump; (ii) the generation of discharge pressure due to the actual attempt to re-start the pump; (iii) melting of the hydrate plug; or (iv) a combination of these. These explanations of the final, increased leak seem equally applicable to the first version (case 1).

Relief line

6.154 The tenth report by Drs Richardson and Saville, spoken to by Dr Saville, addressed the burst pressures of the B pump relief line and of PSV 505 itself, shown in Fig J.9. They found that the weakest point was the flanged joint on the body of PSV 505 and that the failure pressure of this joint was 250 bar.

Pump trips

6.155 No mention has been made so far of the trips on the pump. Those which appear most relevant are those for high pressure, pump overload, lube oil system and pump vibration. The pump overload trip needed to be re-set at a point away from the 68 ft level. It is not known what caused the initial trip on B pump, but Mr Bollands said that Mr Vernon seemed to think it might be the high pressure trip, though the latter also mentioned something about oil, perhaps lube oil, near the pump. Whatever the trip was, it was evidently not such as to inhibit attempts to re-start B pump. This seems to argue against pump overload. Dr Johnsen hypothesised it was the HP trip activated by high discharge pressure due to hydrate blockage.

6.156 As far as concerns over-pressurisation of the pump, there were 2 trips which should have prevented this, the HP trip and the pump overload trip. However, the pump overload trip may have been set at a relatively high value. According to Dr Johnsen, the pump motor was likely to have been drawing some 70-80 kW of its total capacity of 368 kW and he understood that it was likely that the overload setting would be close to the latter rating. In this case it is conceivable that even with the pump pumping against a discharge pressure rising to 250 bar instead of its normal discharge pressure of 75.8 bara the overload trip might not operate immediately. The HP trip should have operated to shut the pump down on high discharge pressure before the PSV opened. It was set 50 psi below the PSV set pressure. Given a gradual rise in discharge pressure and accurate setting of both devices, this should have been enough to shut the pump down before the PSV opened. But with a sudden blockage and very rapid pressure rise it is possible that the PSV would lift before the pump was fully stopped. This would be the more likely if there were errors in the setting of the HP trip or PSV, or both, which brought the setting of the HP trip above that of the PSV. PSVs had lifted to relieve pressure on a number of occasions. The assumption made by Dr Johnsen was that on the occasion when the over-pressure causing rupture occurred, the HP trip blocked with hydrate and so could not prevent the rise in pressure, which led to the opening of the PSV, the flow of condensate in the relief line, and the blockage in, and rupture of, the line. Score, on the other hand, assumed that the HP trip operated correctly, but not fast enough to prevent the above effects.

Pump power train

6.157 For this scenario to be valid, therefore, it must have been possible for the pump to continue pumping for a sufficient period to cause the discharge pressure to rise to at least 250 bar. Dr Johnsen stated that the pump weighed about 3.3 tonnes and he estimated that the rotating part would weigh perhaps 2 tonnes. It would therefore have an appreciable inertia. The volume of the relief pipework from the discharge of the pump to the PSV was some 160 litres and the volume displaced per revolution of the pump some 10 litres. Dr Johnsen was sure that even 2 revolutions of the pump would create a very high discharge pressure.

6.158 The pressures which might have been attained if pump over-run occurred were estimated in the ninth report by Drs Richardson and Saville, spoken to by Dr Saville. Fig 6.7 gives the pump discharge pressures as a function of the number of revolutions of the pump and shows that a pressure of 250 bar would have occurred after less than 1 revolution of the pump. At the normal pump speed of 100 rpm, this pressure would have been reached in about 0.6 seconds, or at the minimum speed of 40 rpm in 1.5 seconds. The pressures estimated assume that nothing happens to prevent such pressure rise. Dr Saville mentioned as points to consider whether the pump pistons or valves would withstand the pressures or the drive fracture. He agreed that it would also be necessary for the hydrate plug to hold, but stated that he had experience of plugs of particulate matter withstanding 2000 bar, albeit in different sized pipe.

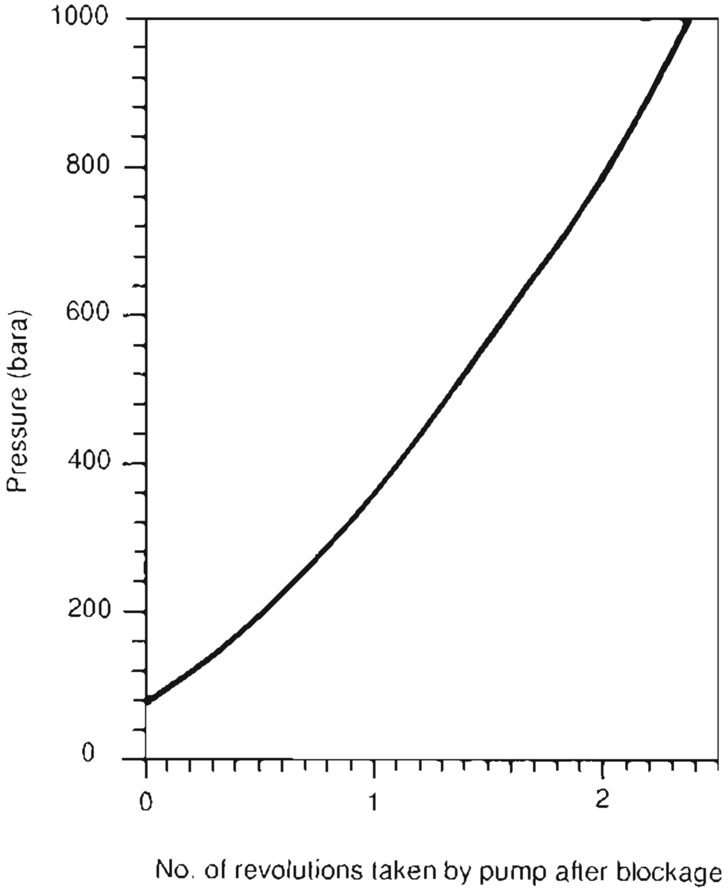


Fig. 6.7 Estimated pressure rise in condensate injection pump B discharge pressure with no pressure relief.

6.159 The possibility of pump over-pressure was addressed by Mr Skidmore. He considered what would happen in the following 4 cases if the pump delivery and relief lines were blocked: (i) case 1, pump re-start with torque converter healthy and a minimum pump speed of 40 rpm; (ii) case 2, pump re-start with converter locked; (iii) case 3, pump running and converter healthy; and (iv) case 4, pump over-running after a stop signal and converter healthy. He argued that in the first case the converter would stall and that in the second the motor would trip on overload. The third implied failure of protection by both the HP trip and the PSV. The upper bound of the torque, with the converter vanes fully open, corresponded to a pump discharge pressure of 356 barg (5160 psig). He agreed that a high JT flash drum level would imply a higher than normal converter vane setting. In the fourth case he believed the torque transmitted would fall away very rapidly.

Observations on this scenario

6.160 I now give my observations on the scenario of a leak in the relief line to or at PSV 505, confining myself at this point to the question of whether it is credible. There is clear evidence that there was an interruption of the supply of methanol to the JT valve, of the order of 4 hours, starting about 16.00 hours and ending about 20.00 hours. The temperature of stream 200 at the JT valve could well have been 50°F or below. At this temperature the loss of methanol would almost certainly have resulted in the formation of large amounts of hydrate at the JT flash drum. The passage of this hydrate through to the condensate pumps could well have been delayed so that it manifested itself towards 21.45 hours that evening. The hydrates could have passed through the condensate booster pumps and condensate injection pump B and then blocked first the delivery line to the MOL. If the HP trip did not operate first, PSV 505 would have opened and condensate would have flowed through the relief line. The HP trip might have failed to operate first because it was blocked by hydrate but it seems at least equally likely that the setting of the HP trip and PSV 505 might have been sufficiently in error for the relief valve to lift first. It is clear, however, that B pump did trip eventually and that Mr Vernon was uncertain of the cause of the trip. It is probable that it was the HP trip which activated. It is less likely that the trip was on pump overload, since this would have inhibited further re-starts until cleared at a point away from the 68 ft level.

6.161 Either on this occasion or on a subsequent attempt to re-start B pump the opening of the PSV and flow of condensate through the relief line could have carried forward hydrate which then blocked the line. The likely point of blockage would then be PSV 505, both because this seems to have been the point most likely to block and because, given the hypothesis of a leak, it was the weakest point. When this blockage occurred the pump would trip. However, it would continue to rotate for a period of uncertain though very short duration. Given that both delivery and relief lines were blocked, the discharge pressure would rise very rapidly and 1 or 2 revolutions would be sufficient to cause the PSV to rupture. The occasion on which the pump motor and pump would unarguably have high rotational speeds is the initial trip. Moreover, the vane setting of the torque converter might well have permitted the transmission of power to the pump, especially given a high level in the JT flash drum. It is less certain what speeds would be attained in the subsequent attempts to re-start the pump, and converter stall is more probable.

6.162 A leak pattern consistent with the gas alarms observed by Mr Bollands, with the noises heard in the workshop and with the sudden departure of Mr Richard could be generated by a leak which was initially small but which increased in size so that by the last 30 seconds it was substantial. Such an increase might be caused by melting of the hydrate plug, or during the final attempt to re-start the pump, by admission of suction pressure through the GOVs or by the pressing of the start button.

6.163 There is no direct evidence that there was hydrate blockage and over-pressure at PSV 505, but there is evidence that conditions could well have been conducive to hydrate blockage. Such blockage might explain the behaviour of the pump system and a rupture consequent on pump operation. I cannot rule out on the available evidence that one or other of the sequences of events which the versions of this scenario require took place.

Scenario of leak at reciprocating compressors

6.164 The other leak scenario proposed in the Petrie Report was carryover of liquid into the reciprocating compressors resulting in damage and a leak (Scenario B). A meeting of technical experts chaired by the Assessors was held to clarify the issues and a report was presented by Mr C D Plummer, Chief Engineer of Atkins Oil and Gas Engineering Ltd. The scope of the work was to explore the possibility of ingestion of liquid into the compressors; it did not address the consequences if this had happened. The report tackled the problem from 3 angles:

1. The back-up of liquid in the time available.
2. The physical possibility of ingestion.
3. The probability of failure of the devices which should have prevented ingestion.

The equipment which would fill with condensate on cessation of pumping from the JT flash drum was taken as the drum itself, the second stage suction scrubbers and the interconnecting pipework. The condensate suction vessel was excluded because it was controlled at a higher pressure than the JT flash drum and even back-up of the liquid in the latter would not overcome this pressure differential. The total volume of the JT flash drum was 18.05m^3 and the volumes at normal operating level and at high level alarm were 3.02m^3 and 6.14m^3, respectively. Those of the 2 suction scrubbers were 1.1m^3 each and that of the pipework was 2.58m^3. Following the evidence given, the state of the plant was taken to be normal phase 1 operation up to 21.40 hours (case 1), then operation with the reciprocating compressors unloaded and on recycle (case 2), then as this last case but with only one centrifugal compressor running (case 3). In the last 2 cases the flow of lift gas would stop and the gas would be flared.

6.165 Process flowsheet simulations were done using a computer package and reasonable agreement was obtained for the base case given in the original process quantities flowsheet (PSK-A1-1229-0). For this base case of normal operation (case 1) the total condensate production rate was taken as 8,800 bbl/d with the contribution from the condensate suction vessel being 4,218 bbl/d, or 0.482 m^3/min, and the rest coming through the JT valve. For case 2 the total condensate production was 3,146 bbl/d, or 0.381 m^3/min, this being the reduced rate from the condensate suction vessel with no contribution from the JT valve, after the last of the lift gas had worked through the system. For case 3 the total condensate production was 2,185 bbl/d, or 0.265 m^3/min. The average total condensate production during transition from case 1 to case 2 was 3,682 bbl/d, or 0.432 m^3/min, and that during transition from case 2 to case 3, 2,558 bbl/d, or 0.30 m^3/min.

6.166 Starting with the JT flash drum at its normal level, the times to fill the JT flash drum, suction scrubber and interconnected pipework were calculated as 19.7 min, 52.1 min and 74.7 min for cases 1-3 respectively. Two further cases were also investigated, based on the evidence of events on the night. In the first, case 4, it was assumed that the condensate injection pump tripped at 21.50 hours, that the reciprocating compressors were unloaded and recycled at 21.54 hours, that 2 centrifugal compressors tripped at 21.55 hours and that the initial explosion occurred at 22.00 hours. In the second, case 5, these events were assumed to occur at 21.45 hours, 21.50 hours, 21.55 hours and 22.00 hours, respectively. In both cases 4 and 5 the unloading and recycling of the compressors was assumed to occur after the JT flash drum had reached its high level alarm. Utilising the condensate flows from cases 1-3 for the appropriate periods gave the volume of condensate in the JT flash drum at 22.00 hours as 8.97m^3, 50% full, for case 4 and 11.7m^3, 65% full, for case 5. The use of the revised quantities flowsheet (PSK-A1-1229-1), which included the water contents of the streams, was investigated; its effect was to reduce the total condensate production rates, that for normal operation being 7,500 bbl/d, and thus to increase the times to fill the drum. The conclusion from this work was that there was insufficient time for liquid back-up to occur. This agreed with Mr Grieve's evidence that just before the initial explosion the level reading for the JT flash drum was somewhere around the 90% mark; it had not reached 100% (a full-scale, or 100%, reading on the level indicator was reached well before the drum was full). Mr Plummer stated that these timings were taken on instruction. He agreed that on timing the crucial issue was the time which elapsed between the trip of the condensate injection pump and the unloading and recycling of the reciprocating compressors. The possibilities of passage of liquid from the JT flash drum before it was full due to droplet carryover or foaming were investigated but discounted. The gas flow with the reciprocating compressors on recycle would be low and not conducive to carryover. It would be normal for fine liquid droplets to pass into the compressors and they would cope with this throughout their working life. The possibility of preferential filling of suction scrubber A due to the pipework arrangement was also considered, but discounted.

6.167 Another argument advanced was that the conditions at the reciprocating compressors when on recycle were such as to make it physically impossible for liquid to pass into them. A computer simulation was carried out to predict the suction and discharge pressures and temperature of the compressors when on recycle, recycle being through GOVs 903 and 905, but not PCV 746. The analysis indicated that the recycle would occur in a system which was effectively closed. The suction pressure would have risen from about 635 psia to about 730 psia and the discharge pressure fallen from about 1735 psia to about 750 psia. The rise in pressure on the suction side would cause the NRV on the line from the JT flash drum to close, while on the discharge side both the NRV to the gas lift well and PCV 945 would close as the pressure fell. Compression of the gas in this closed system would cause its discharge temperature to rise until the machine tripped on high discharge gas temperature.

6.168 With liquid backing up the gas space in the JT flash drum would be compressed and with continued inflow of gas the pressure would rise within about 10 minutes to 670 psia, equalling that in the condensate suction vessel. This pressure rise would be countered, however, by the action of DPCV 723 which would open to relieve the pressure, thus preventing the pressure from rising above the suction pressure of the compressors. If liquid backed up so that it entered the line to DPCV 723, the valve would open and discharge condensate to flare; there were several mechanisms by which this might occur, but they all had this effect. Failure of this valve was possible, but given that its action had been checked that day and that it would be open just before the compressors were unloaded, coincident failure was unlikely.

6.169 There were devices which should have functioned to prevent liquid being ingested into the compressors even if it had backed up. There was a level control valve on each of the suction scrubbers, though the offtake line was only one inch. More significantly, there was on each scrubber a high level trip which would trip the compressor.

6.170 Mr Plummer concluded that ingestion of liquid into the reciprocating compressors would not have been possible. Counsel to the Inquiry indicated that in view of this evidence and of the fact that it had not been challenged at the meeting of technical experts, further evidence on this scenario would not be led.

Other leak scenarios

Scenarios reviewed by Mr Sylvester-Evans

6.171 Difficulties perceived in the scenarios of a leak at the PSVs led in the early stages of the Inquiry to an exploration of other possible leak sources. This work was described by Mr R Sylvester-Evans of Cremer and Warner. He did not deal with the 2 scenarios put forward in the Petrie Interim Report (Scenarios A and B), but did address other scenarios given in the Petrie Final Report. He outlined 8 other scenarios, C-J, broken down into some 30 sub-scenarios, summarised in Table 6.4. He illustrated the scenarios by reference to Figs J.8 and 3.4. The aim of the work was to produce a fairly comprehensive list of scenarios. The scenarios were not purely theoretical but had some link with the information available at the time, which included a hazop study, past equipment failures and process conditions that night. The evidence was confined to a review of the scenarios and of the underlying assumptions. It did not deal with their likelihood and did not attempt to rehearse previous evidence.

6.172 The account which I give here of the scenarios is necessarily a simplified one. In general terms, scenarios were favoured which fitted a low lying leak of condensate at the east end of C Module and the gas alarm sequence, with the first alarm in zone C3. The genesis of scenario C was evidence on hydrate blockages in the recycle lines of the centrifugal compressors and on failure of a differential pressure tapping on these machines together with the fact that off-loading of the reciprocating compressors and tripping of the centrifugal compressors would place a load on the various pressure control and depressurising valves. Evidence that there had been leaks on the centrifugal compressor suction and discharge scrubbers underlay scenario D. Failures of pipework had occurred on the reciprocating compressors due to vibration and fatigue and gave rise to scenario E. The origin of scenario F was evidence that there had been a failure of a flexible hose on the fuel gas line in the turbine compartment of a centrifugal compressor on 16 May 1988 and of a tapping on the pipework of compressor A on 13

June 1988, as well as repeated gas alarms on the compressors. Scenario G was suggested by evidence that in phase 1 operation the gas pipeline to Claymore was being topped up using high pressure gas from Tartan and on maintenance activities on PSV 524/1,2. Scenario H was concerned principally with leaks downstream of condensate injection pump B arising from the evidence on the activity at this pump just before the initial explosion. The possibility of low temperature brittle fracture of the JT flash drum resulting from sudden depressurisation was identified in a hazop study carried out in 1986 by Occidental and gave rise to scenario I. The various leak scenarios associated with maintenance activities in the GCM were comprehended in Scenario J.

6.173 Some of the sub-scenarios involved blockage of a pipe by ice or hydrate or isolation by closing a valve, followed by exposure of the upstream section to a high pressure which the pipe was not designed to withstand; these included C1, C2, D3, E2, H5, and I2. Others involved the dislodging of an ice or hydrate plug and consequent mechanical damage to the downstream pipework; C1, E1, E3, E4, G2, H2, H3 and I4 were of this type. One version of one of these sub-scenarios, scenario H2, is the third scenario which I considered above. Formation of ice or hydrates at some of the points envisaged in Scenarios C-J was addressed in the 7th report of Drs Richardson and Saville, spoken to by Dr Saville. They assumed methanol addition at the prescribed rates, but commented on the effects of loss of methanol. They also considered the potential for low temperature brittle fracture in the sense that pipework might fall to −20°F. They found that there was potential for formation of ice or hydrates downstream of PSV 1000A and downstream of DPCV 723A,B, unless there was sufficient methanol in the vapour to suppress it, which could not be assessed; downstream of the centrifugal compressor recycle valves 201A, 202B, 203C, probably, and downstream of the first stage reciprocating compressor recycle valves GOV 902, 904; and downstream of the drain valves on the lines on the centrifugal compressor discharge scrubbers and on the second stage reciprocating compressor suction scrubbers, with potential for brittle fracture in both cases. Another set of sub-scenarios involved the existence of an inherent defect and its activation by the events leading up to the initial explosion; C3, D2, E1, F2, F3, and G3 fell into this category.

6.174 Common difficulties with these scenarios were that they tended to involve a number of assumptions, such as presumed failure of instruments or actions of operators, and that the associated leak did not fit well in respect of its location, its timing or the gas alarm pattern.

Scenarios involving reciprocating compressors

6.175 A report on possible leaks from the reciprocating compressors was given by Dr K E Bett of Imperial College. One possibility was a fatigue failure of the pipework on one of the compressors. There had been one fatigue leak and one fatigue crack on the compressor systems in the first half of 1988. Whilst he could not discount entirely a leak prior to the unloading and recycling of these machines, he considered it highly unlikely. It might be argued that vibration could be worse when the compressors were unloaded and recycled, but there was no evidence for this and on the basis both of his experience and of theoretical considerations, he would not expect it.

6.176 Dr Bett also considered the possibility of stud bolt failure. 7 failed stud bolts were discovered on No 1 cylinder yoke/frame extension flange on A machine in February 1988 and 5 failed stud bolts at a similar location on No 3 cylinder of B machine in June 1988. These were fatigue failures. On each occasion all the stud bolts at the flange where the failures occurred were replaced. All other bolts were retorqued to establish that they had not cracked or lost their pre-tension. When the failures occurred on A machine, no check was made on B machine. Dr Bett considered the condition a serious one and failure to check the other machine a serious omission. However, he thought it highly unlikely that such stud bolt failure was the cause of the leak on 6 July.

Conclusions as to the cause of the leak

6.177 The evidence before me at the Inquiry explored a large number of possible scenarios. I have to consider whether or not I am satisfied that a particular one was the explanation for the leak and hence for the initial explosion. For that purpose I apply the ordinary standard of proof in civil cases - proof on a balance of probabilities. In the present case there is no direct evidence as to what happened. Accordingly proof is dependent upon inference from the evidence; and the inference must be a natural and reasonable one. This involves among other things that I have to consider whether a particular scenario is or is not consistent with the evidence; whether it provides a credible explanation for the observed events; and whether there is enough factual evidence from which to draw the inference that it was the explanation, as opposed to being a mere possibility or a matter for conjecture.

6.178 The scenarios which were described by Mr Sylvester-Evans of Cremer and Warner explored a wide range of explanations for my consideration. I will put to one side for the moment the explanation based on hydrates in the relief line on B pump and deal with the rest. Many of those scenarios were devised by adopting an assumption that what had occurred in a previous incident had happened again; and to that extent each had a credible element. However, each posed a difficulty in the way of acceptance partly because of the number of assumptions which required to be made as to the failure of equipment or the actions of operators before a leak was produced; or because it was inconsistent with evidence as to matters such as the location of the leak and the pattern of the gas alarms. Even more fundamentally none of these scenarios had its origin sufficiently founded in the events on the evening of 6 July. For these reasons after considering the whole evidence I regard them as no more than theoretical possibilities. I make the same observations in regard to the scenarios considered by Dr Bett.

6.179 Coming to the events of 6 July I accept the evidence that ingestion of condensate liquid into a reciprocating compressor did not occur. Accordingly I rule out the scenario which was based on this having happened.

6.180 I consider next the scenario of a leak from a blind flange at the site of PSV 504. This scenario involves quite a short series of events, namely the admission of condensate to A pump, followed by a leak from the blind flange.

6.181 As regards the first of these events there is no direct evidence that Mr Vernon took this action. However, he showed a clear intention to start A pump. He had a strong reason for doing so. He had sufficient time and was in the correct place to do so. His actions at the pump were consistent with his attempting to start A pump. There was probably no physical impediment in the way of mechanical or electrical isolation which would have prevented him from doing so.

6.182 In regard to the leak, there is no direct evidence as to how it was brought about. However there are a number of important considerations:

(i) The evidence of the wind tunnel tests and explosion simulation pointed to a leak in the region in which PSV 504 and PSV 505 were situated.

(ii) My conclusion, based on the evidence as to the gas alarms and the wind tunnel tests, that there was a 2-stage leak might appear to introduce a complication. However, I have come to the conclusion that it provides support rather than a difficulty for the scenario. It seems to me quite likely that an operator having re-connected the air line to the GOV would try it out by giving the GOV a short jag. This would account for the initial stage of the leak. The second stage would be due to subsequent and longer opening of the GOV. Further the timing of the 2 stages of the leak fits reasonably well with the evidence which points to Mr Vernon's opportunity to open the GOV for A pump.

(iii) In the light of the evidence of Drs Richardson and Saville the flow rates of escaping condensate which would be required to account for the explosion would be consistent with the results of the GOV being open for a period of about 30 seconds, given a hole size at the site of PSV 504 of equivalent diameter of some 8 mm. The evidence of the leak tests showed that a blind flange which was only finger tight could give the required flow rate and would be consistent with a hole of that size. Further a finger tight configuration appears to be one of those most likely to give rise to the noises which were heard shortly before the initial explosion.

6.183 At this point it is necessary for me to consider on the other hand the evidence given by Mr Rankin that Mr Sutton told him that he had fitted blind flanges - which was in accordance with the PTW - and the evidence given by Mr Rankin that he would have expected Mr Sutton to make a leak-tight joint. However, as I have noted earlier in this chapter, I found Mr Rankin's evidence to be unsatisfactory on a number of points; and on one it is in conflict with that of Mr Lynch, the lead production operator. Mr Rankin appeared to have total recall of all his actions in regard to the PTW, including the procedure for its suspension, but no recall as to the persons with whom he dealt. I am doubtful as to the reliability of his evidence as to what he expected Mr Sutton to do and what Mr Sutton said to him. I bear in mind that Mr Rankin did not check the work site before suspending the PTW, as was required by the PTW system. Accordingly he did not see what Mr Sutton had done.

6.184 Earlier in this chapter I have recounted the evidence on normal practice in fitting a blind flange. However, the circumstances on 6 July were somewhat unusual. From the time when the PTW was issued until nearly the end of the day-shift A pump was to be the subject of a full planned maintenance. If the pump, having been shut down and vented, was to be isolated for that purpose it might well be thought that it was unnecessary to replace PSV 504 immediately and that the blind flange on the pump side of the site of PSV 504 need not be made leak-tight. (I note in passing the preferred method of isolation for a planned maintenance was to drop out a spool piece and fit only the live end of pipework with a fully tightened blind flange.) A number of witnesses gave evidence without contradiction that Mr Sutton was a competent and careful fitter. If he had left the blind flange on the pump side of the site of PSV 504 only finger tight when it should have been flogged up, the difference would have been easily discoverable; on the evidence it might well have led to his dismissal. If therefore Mr Sutton left a blind flange only finger tight it is likely that this was for a particular reason. It may be that he was given to understand that it was unnecessary to make up the joint fully but that evidence of this has been lost as a result of the death of a number of the personnel who were on the day-shift. I may add that for him to fit the blind flange finger tight would still serve a useful purpose in that it would prevent dirt from entering the relief line. In these circumstances I do not regard the hypothesis of a finger tight blind flange as improbable.

6.185 I have examined an alternative type of explanation, which is that the blind flange assembly at the site of PSV 504 ruptured following the admission of condensate due to events such as autoignition, shock loading, brittle fracture or over-pressurisation by methanol injection. I have rejected all of these except autoignition. This cannot be ruled out but I regard it as unlikely. It depends upon the fulfilment of a series of assumptions for which there is no direct evidence. Further the assumed explosion was not heard by any witness.

6.186 So far as concerns the scenario of a leak from the relief line at or near PSV 505, there is clear evidence of a considerable loss of methanol supply on the evening of 6 July. The JT valve had experienced a low temperature on the previous day. Accordingly process conditions on the night of 6 July might well have been conducive to formation of hydrates which passed into condensate injection pump B and caused blockages on the discharge side. Over-pressure of this pump could well have occurred on the initial trip given the particular converter vane setting which seems quite likely and a failure of the high pressure trip which could have occurred from several causes including trip setting or hydrates. This scenario requires that the melting of hydrates at the rupture point was gradual and did not give rise to a gas alarm until some 10 minutes later. Converter stall appears to present a greater difficulty for other versions of this scenario. All versions depend upon a complex train of events and involve a number of assumptions which cannot be substantiated in evidence. On the evidence I do not rule out this scenario but consider it to be unlikely.

6.187 In the whole circumstances I have come to the conclusion that on a balance of probabilities the leakage of condensate was from a blind flange assembly at the site of PSV 504 which was not leak-tight.

Observations in regard to the permit to work system and the shift handover

6.188 It is clear in my opinion that Mr Vernon would not have attempted to start condensate injection pump A if he, or for that matter Mr Clark, had known that PSV 504 was not in place. From the evidence I conclude that this was due to a failure in the transmission of information under the permit to work system and at shift handover.

6.189 Information as to the removal and non-replacement of PSV 504 should have been included in the handover between Mr Smith and Mr Clark both for the effective prosecution of the work on the platform and as a matter of good safe practice. Mr Smith did not mention the PSV work to Mr Clark and had not recorded it in the maintenance diary or on the A4 pad, as he should have. Mr Smith knew that the overhaul of PSV 504 was under way. He had had no contact with Mr Rankin during the day. He should have assumed that the work was incomplete and so informed Mr Clark. Mr Clark was in general critical of the PTW and handover systems. In his own words: "It was a surprise when you found out some things which were going on."

6.190 The handover to Mr Vernon himself was not deficient even if it contained no information on the overhaul of PSV 504. Mr Vernon knew that A pump was with maintenance and had been electrically isolated for the planned maintenance or for the repair of the coupling. The overhaul of PSV 504 was information which it was reasonable to expect him to be informed of by his operators if events required him to know. It is evident that he did not learn this from Mr Richard, the phase 1 operator. It was the practice to record the overhauls of PSVs in the phase 1 operator's log. The handover between phase 1 operators was based on going through that log. I infer that Mr Grant failed to inform Mr Richard that the PSV had been removed and not yet replaced, which he should have done, notwithstanding the fact that the pump was with maintenance.

6.191 In any event it is necessary to examine why Mr Vernon failed to become aware of the work on PSV 504 from his involvement with the permit to work system. According to Mr Rankin, when he suspended the permit at 18.00 hours, he spoke to the lead operator. At that time the lead operator could only have been Mr Vernon. I have already expressed my views on Mr Rankin's reliability. I am not satisfied that a conversation between Mr Rankin and Mr Vernon about the suspension of the permit took place. In any event, even without a discussion with Mr Rankin, Mr Vernon should have known of the overhaul of PSV 504 because at the end of the day-shift the permit should have been suspended as the work was incomplete. This should have involved Mr Vernon signing the permit and having the job site checked by one of his operators. It is evident Mr Vernon failed to have the job site checked and accordingly failed to ensure that the site of PSV 504 was left in a safe condition over-night.

6.192 I should add for the sake of completeness that I do not consider that the handover to Mr Bollands was deficient. By 21.45 hours he knew that A pump was with maintenance. It was not necessary for him to know the details of any maintenance work which was being undertaken.

6.193 As I have stated earlier, prior to signing and leaving the PTW for the PSV work for suspension Mr Rankin should have inspected the job site which on his own evidence he did not. That would be sensible and safe practice in any PTW procedure. However, before acting as a Performing Authority Mr Rankin had received no training in the detailed operation of the PTW system on Piper either from Occidental or from Score.

6.194 I consider that it is of some importance to know whether these failures were merely isolated instances or form part of a wider pattern of deficiencies in the permit to work system and in handovers between shifts. As part of the background to the disaster I examine these matters further in Chapter 11.

Observations on methanol injection

6.195 Although I have concluded that the failure of methanol supply and the possible consequent formation of hydrates was not the cause of the leak, it is clear that the maintenance of adequate methanol injection was important to the safety of the platform and that it was not achieved. It was recognised by Mr J L MacAllan, the Production and Pipelines Manager, and Mr J Bryce, the Production and Pipelines Superintendent, that when the platform's operation was changed from phase 2 to phase 1 the only operational problems which might ensue would result from the gas stream being wet rather than completely dry as in phase 2 production. It is clear from Mr MacAllan's evidence that it was realised that this had implications for safety on the platform. To offset this and the known consequent potential to form hydrates they decided that methanol needed to be injected at various points in the process, and in particular prior to the pressure letdown over the JT valve. They commissioned a study of the rates of injection required at different points. This was carried out by Mrs E A Paterson (then Ms Mortimer) of the Facilities Engineering Department. In a memorandum setting out her results she stressed the importance of methanol injection being continuous and suggested that a back-up injection system should be made available. In the result the former was not achieved and the latter was not provided. The memorandum did not contain any guidance as to what should be done if the injection failed as such an operational problem was beyond her experience.

6.196 While Mr MacAllan could not recall seeing the memorandum, it is clear that it was sent to the management of the platform and that the process operators who were responsible for the methanol injection system received a copy. There was no evidence to indicate that the operators were given any instructions as to any special action to be taken if the methanol injection failed. Mr MacAllan's evidence was that it would be a matter of concern if methanol was not injected for several hours at the critical point upstream of the JT valve and that in such an event, while there was a lot of methanol being injected elsewhere, he would expect to shutdown part of the process operation.

6.197 It is clear that continuous injection of methanol was critical not only to the smooth operation of the platform but more importantly to its safe operation. The fact that this was not achieved was due, in my view, to the inadequate instructions to the operating staff who should have been given clear guidance as to what to do in the event of the failure of any part of the injection system. Such guidance could have set out the action to be taken, even a simple instruction to report immediately any failure to the platform management would have guarded against the dangers inherent in hydrate choking. I consider that there was no fault on the part of the operators and leading hands involved as they did not have the technical background to assess the risks consequent on a failure in the methanol injection, particularly as their previous experience was that hydrate chokes could be cleared easily. However, it seems to me that those who were responsible for the management of the platform, both onshore and offshore, failed to give adequate instructions to guard against an eventuality which had safety as well as production implications.

Table 6.1 - Some Piper production and maintenance personnel on shift on night of 5 July and on 6 July 1988

	Night (5/6)	Day	Night (6/7)
A—Production			
Lead production operator	C Lockwood(a)	J Lynch/(b) H E G Flook	R A Vernon
Control Room operator	G Bollands	J M Slaymaker/(c) A N Other/ R L Price	G Bollands
Phase 1 operator	-(d)	P J Grant	R M Richard
Phase 2 operator	E C Grieve	M J Groves	E C Grieve
Oil water operator	- -	J B Kirby D A McWhinnie	A R C Bremner G M Rennie
B—Maintenance			
Maintenance lead hand	A G Clark	W H Smith	A G Clark

Notes:

(a) Mr Lockwood left the platform on 6 July.

(b) Mr Lynch was relieved by Mr Flook about 10.00 hours and then left the platform.

(c) Mr Slaymaker was relieved about 10.00 hours by someone unknown and then left the platform. Mr Bollands did not know who this person was; he believed it would have been one of the operating team but probably not the lead operator. This unknown person was relieved by Mr Price about midday.

(d) Dash indicates that no evidence was taken.

Table 6.2 - Details and results of FLACS code simulations

Case	1	2	3	4	5	6
Type of fuel	NG	NG	C	NG	C	C
Mass of fuel (kg)	173	173	186	80	186	46
Location of ignition source	X	Y	Y	X	Y	Z
Proportion of module filled by flammable mixture (%)	50	50	50	30	50	ca.12
Wall behaviour	FL	FL	FL	FL	FX	FL
Over-pressures (barg)						
P1	0.43	0.55	0.69	0.11	1.54	0.196
P2	0.43	0.63	0.76	0.15	1.70	0.251
P3	0.39	0.63	0.77	0.19	1.58	0.295
P4	0.34	0.67	0.77	0.19	1.48	0.234
P5	0.37	0.51	0.62	0.10	1.89	0.176
P6	0.37	0.60	0.70	0.15	1.88	0.235
P7	0.35	0.70	0.72	0.17	1.60	0.255
P8	0.37	0.72	0.84	0.19	1.62	0.257

Notes:

(a) See Figs 5.1, 6.4 and 6.5

(b) NG = Natural gas; C = condensate

(c) FL = wall fails; FX = wall fixed, does not move

(d) In cases 1-5 the firewall failure pressures were taken as for the B/C firewall 0.138 bar and for the C/D firewall 0.25 bar. For case 6 the corresponding pressures were taken as 0.10 and 0.12. A version of case 6 was also run with the former set of wall failure pressures. For this latter case the pressures P1-P8 were, respectively:-

0.219; 0.269; 0.314; 0.261; 0.23; 0.302; 0.31; 0.288.

Table 6.3 - Estimated gap size, orifice diameter and condensate flow for certain conditions of blind flange assembly on PSV 504

No of bolts	Gap size (mm)	Equivalent orifice diameter (mm)	Estimated flow (kg/s)[a]
8	0.072	6.79	1.46
4	0.11	8.39	2.22
2	0.188	11.0	3.82

Note:

(a) Flow of condensate at a pressure of 46.3 bara.

Table 6.4 - Summary of leak scenarios reviewed by Mr Sylvester-Evans

No.	Description of scenario
A B	see note (a) below
C	Release from failures of piping associated with pressure control valves or centrifugal compressor recycle or depressurising valves in C Module
C1	Hydrate or ice plug in various pipework locations
C2	Blockage and over-pressure of vent header
C3	Inherent defect in centrifugal compressor pipework
D	Failure of condensate piping or centrifugal compressor discharge scrubbers located at east end of C Module
D1	Low temperature brittle fracture of centrifugal compressor discharge scrubber boot or pipework
D2	Inherent defect in condensate pipework triggered by tripping of compressors
D3	Over-pressure of or mechanical damage to drain line to oily water system
E	Release from failures of pipework associated with reciprocating compressors, due to causes other than liquid carryover from the suction scrubber
E1	Inherent defect in small bore pipework on reciprocating compressors
E2	Over-pressure of or mechanical damage to drain pipework of reciprocating compressor suction scrubbers
E3	Dislodging of ice or hydrate plug in condensate pipework from second stage reciprocating compressor suction scrubbers to condensate knockout drum
E4	Dislodging of ice or hydrate plug downstream of reciprocating compressor recycle GOVs 902 and 904
F	Releases within enclosures of centrifugal compressors and turbines
F1	Failure of seal oil system
F2	Failure of tapping or flange
F3	Failure of fuel gas flexible coupling
G	Release from Claymore pipeline system located in west end of C Module
G1	Liquid slugging at PSV 524 or in downstream pipework
G2	Dislodging of hydrate plug downstream of PCV 501
G3	Inherent defect in pipework
G4	Isolation and over-pressure of flare header downstream of PSV 524
H	Release from failures of condensate piping in C Module other than those associated with condensate injection pump A
H1	Liquid slugging downstream of PSV 505
H2	Over-pressure or mechanical damage to pipework downstream of PSV 505
H3	Dislodging of hydrate plug downstream of condensate injection pump B
H4	Over-pressure of PSV 505 or downstream pipework due to methanol injection
H5	Isolation or blockage by ice or hydrate plug and over-pressure of vent or drain pipework
H6	Dislodging of hydrate plug downstream of LCV 724
I	Release from failure of condensate or relief piping associated with JT flash drum or relief piping associated with condensate suction vessel
I1	Depressurisation and rapid repressurisation of JT flash drum leading to low temperature brittle fracture
I2	Over-pressurisation or dislodging of ice or hydrate plug or liquid slugging downstream of DPCV 723A and B
I3	Inherent defect in transmitter tapping of DPCV 723A and B
I4	Dislodging of ice or hydrate plug downstream of PSV 503A and B.
J	Release into C Module associated with maintenance activities ongoing in GCM
J1	Leak from passing isolation valve ignited by hot work, causing explosion which then caused larger leak
J2	Release from vessel or pipework not fully freed of hydrocarbons
J3	Repressurisation of section of pipework between Valves 1 and 2 which had been opened to form a double block and bleed arrangement

Notes:

(a) Scenarios A and B, which were not considered by Mr Sylvester-Evans, are the 2 scenarios given in the Petrie Report:

A - A gas release from condensate injection pump A system

B - Liquid carryover in to the reciprocating compressors causing damage and a gas release

(b) For GOVs 902, 904; PSV 524; PCV 501; DPCV 723 see Fig J.8. LCV 724 was the level control valve on the line from the condensate suction vessel to the condensate knockout drum. PSV 503 was the pressure safety valve on the condensate suction vessel.

Chapter 7

The Escalation of the Disaster

Introduction

7.1 In this chapter I will consider the physical events and actions which followed the initial explosion and may have had a bearing on the series of fires and explosions which led to the destruction of Piper Alpha. I will also discuss the effect of events on the platform systems. While this study will draw on the evidence given by eye-witnesses and others, the description of what happened to personnel on the platform is postponed to Chapter 8. A discussion of the effectiveness of external fire-fighting is included in Chapter 9. The present chapter will also discuss the response on other installations to what was happening on Piper.

From the initial explosion to the rupture of the Tartan riser at 22.20 hours

Evidence given by eye-witnesses

7.2 The evidence given by eye-witnesses on the initial explosion was described in Chapter 5. Captain Clegg on the *Lowland Cavalier* and Mr Flaws, Mr Murray and Mr Miller on the *Tharos* all saw the flames associated with this explosion. As already described, within a matter of seconds Mr Miller also began to take photographs, the first being that shown in Plate 14(a). Mr Miller estimated that he took this photograph some 5-10 seconds after the initial explosion, although the smoke plume shown in it is already well developed, which suggests a rather longer time lapse of the order of perhaps 15 seconds. The photograph shows a fireball coming out of the west face of B Module at a time when there was already a fire there. Although he was unaware of it at the time, it also shows what appears to be flaming at the north face of the platform. Thereafter Mr Miller took a series of photographs over a short period in quick succession. In the following 3 photographs (Plates 14(b), 15(a) and (b)) the fireball is shown as subsiding. Flames appeared temporarily below the 84 ft level. Those and subsequent photographs (Plates 16(a) and (b), 17(b) and 18(a)) taken by him show that the fire in B Module developed rapidly and strongly. In some of them flames could be seen in C Module. Some show flames apparently south of the line of the firewall between A and B Modules and behind the heat shield. Flaming at the north face of the platform was shown until the 13th photograph when the view was obscured by smoke. On close examination it appears that the flaming was at the 121 ft level. The fire does not appear to have taken hold at the 68 ft level until the 19th photograph (Plate 18(a)) when flames become clearly visible below the west side of B Module. From the time when the fire started in B Module thick black smoke streamed northwards from B Module progressively engulfing the upper parts of the platform which lay in this direction. The timing of the photographs taken by Mr Miller is discussed below.

7.3 A number of survivors who were on the dive skid below the 68 ft level observed oil running down the MOL immediately after the initial explosion. Mr MacLeod, the diving superintendent, described this increasing to the point where there was "a vast amount of oil" dropping down and the dive skid was "an inferno".

7.4 About 22.15 hours the jib of the west crane fell into a lowered position resting on the heat shield.

7.5 In connection with what happened in this period it is important to note that photographic and other evidence shows that the fire in B Module was still burning strongly at about 22.50 hours.

The outbreak of fire in B Module

7.6 It is clear from the evidence, such as that provided by Mr Miller, that the initial explosion was followed without apparent delay by a fire in B Module. This was a significant fire before the fireball occurred and for the first 20 minutes it was the principal fire on the installation. The expert evidence which I describe below makes it clear that missiles generated by disintegration of the firewall would have had more than enough energy to rupture small pipework on the oil system in the module.

7.7 Dr D D Drysdale, a Lecturer in the Fire Safety Engineering Unit of the University of Edinburgh, gave evidence as to his interpretation of these conditions in the light of the evidence of eye-witnesses and the available photographs. It is clear that the fuel for the fire in B Module must have been crude oil. According to Dr Drysdale stabilised crude oil on Piper contained about 7% of light ends. An ignited leak of this oil would give flames both from the flashing vapour (for which he used a round figure of 10%) and from the resulting pool of oil. He suggested that the fire might have been due to a rupture in the 4 inch condensate line in B Module before it joined the MOL, the rupture being either upstream or downstream of the non-return valve (see Fig J.8). In the latter case the rupture would release condensate in the normal direction of flow and also crude oil from the MOL in the reverse direction. In the former case oil would not be released from the condensate line unless the non-return valve had failed to function properly. He said that such malfunction was not uncommon. I accept his evidence that rupture of the condensate line at either place could explain the subsequent fire.

7.8 The explanation put forward by Dr Drysdale gains support from the evidence given by Dr R A Cox, then of Technica Ltd. He considered the damage which could have been caused by projectiles generated by the disintegration of the firewall between B and C Modules in the event of an explosion in C Module. He estimated the energy requirement to cause pipe collapse as 164 kJ for the 20 inch MOL. The 4 inch condensate line had 2 sections of different strengths:- (i) the short piece between the non-return valve and the MOL and (ii) the piece which comprised the remainder of the pipe and which had thicker walls. Dr Cox estimated the pipe collapse energies for these 2 sections as 2.9 kJ and 5.79 kJ, respectively. He gave the energy required to break off small bore pipework as of the order of 0.05 kJ. He obtained the kinetic energy of the projectiles from their velocity as estimated from the dynamic pressure pulse derived from the TNT equivalent explosion model. Although he also gave results using other models, which tended to yield higher kinetic energies, this method, which he called the gas velocity method, was his preferred approach. He considered the range of possible projectiles, including panel bolts, small and large panel frames or portions of these and the door in the firewall; and 3 explosion scenarios namely (i) case 1, 100% fill of natural gas and edge ignition; (ii) case 2, 25% fill with natural gas and edge ignition; and (iii) case 3, 50% fill with propane and central ignition (see the 2 Technica cases, T1 and T2, and the DEn case 3 in Table 5.1). The kinetic energies obtained for the large fragments were in the range of 18-40 kJ, 3.3-8.5 kJ and 77-161 kJ for cases 1-3 respectively. Making an allowance for the efficiency of energy transfer from the fragment to the target to take into account factors such as the orientation and relative stiffness of the projectile, Dr Cox proceeded on the assumption that if the ratio of the fragment energy to pipe collapse energy exceeded 5, the pipe collapse was probable. He concluded that bolt projectiles would not cause pipework failure in B Module; that the smaller fragments would not cause failure of the 20 inch MOL and were unlikely to cause failure of the 4 inch condensate line; that the larger projectiles were unlikely to cause failure of the MOL; that, depending on the case considered, these larger projectiles might cause the 4 inch condensate line to fail; and that all of the panel and door projectiles were capable of breaking off small bore pipework. He thought failure of the 4 inch condensate line was to be expected for cases 1 and 3. For case 2 it was possible but not probable. I note from the above figures that the fragment kinetic energies in case 3 were higher than those in case 1, that in the former the gas was propane and ignition was central and that these factors more than compensate for the smaller module fill. I expect that there would be a similar effect as between case 2 and the scenario considered in the explosion simulation with 12% fill propane and central ignition which has been described in Chapter 6.

7.9 A detailed analysis of failure modes for the 4 inch condensate pipe was given by Dr A C Palmer of Andrew Palmer and Associates Ltd, Consulting Engineers, who described 10 possible modes of pipe deformation and the energy required in each case to rupture the pipe. In his opinion the most likely mode was denting by an edge, or formation of a deepish dent by impact with a very sharp knuckle at the end of the dent. Another quite likely mode would be dynamic puncturing, or a gouge penetrating the wall to such a depth that, with the aid of the internal pressure, it created a crack. He calculated the energies required to give these 2 failure modes of the pipe as 26 and 7 kJ, respectively. The latter, being a dynamic mode, also required a higher velocity of at least 40m/s. He did not himself make estimates of the velocity or kinetic energy of the firewall fragments but compared the values which he had estimated for the various failure modes with those given in the Technica study. He thought that pipe rupture was probable with the kinetic energies given for cases 1 and 3 above, and possible but less probable for case 2. He accepted that the velocities given in the Technica study were maximum velocities and that projectiles striking the pipe close to the firewall were less likely to have reached their maximum velocity than those striking it further away. With regard to the efficiency of energy transfer he emphasised that this was highly variable and described circumstances where the energy available to rupture the pipe might be half the kinetic energy of the fragment. One potential projectile which received greater emphasis in Dr Palmer's study was the door in the firewall. He calculated that with an applied force equivalent to 0.4 bar over-pressure and at a distance of 1.5m, which was that from the wall to the section of pipe parallel to it, the velocity of the door would be some 40m/s and its kinetic energy some 150 kJ, the latter initially increasing linearly with distance. Dr Palmer did not suggest a particular part of the 4 inch condensate line as being especially likely to suffer rupture. He did believe, however, that the probability of a fragment striking the pipe was quite high. He said "We are talking about a large wall with a pipe very close to it and the wall becoming fragments of different sizes, some of them perhaps quite large with the pipe only 5 feet away. My judgement is that in that situation impact would be quite likely. It is not to be thought of like throwing balls at a coconut-shy. It is something much closer in than that."

The occurrence of the fireball

7.10 The first matter to be considered is the timing of the fireball which depends upon the timing of the photograph in Plate 14(a). Mr Miller believed that he took that photograph within 5-10 seconds of the initial explosion and, though pressed, he held to that view. Various attempts were made to use the length of the plume of smoke to determine the time which must have elapsed before the photograph was taken. However this is complicated by uncertainty as to whether the whole plume is in the photograph and by the fact that the wind at the time would blow the plume not due north but approximately north-east. From the evidence I estimate that the photograph was probably taken some 15 seconds after the initial explosion.

7.11 Dr Drysdale estimated that the fireball shown in the photograph had a vertical dimension of 33m and a horizontal dimension of 23m. Using a standard model relating the diameter of a fireball to the mass of the fuel and taking a diameter of 28m he obtained for the mass of fuel a figure of 112 kg. He advanced the hypothesis that the fireball was consistent with a full-bore rupture of the condensate line either upstream or downstream of the non-return valve already mentioned. In the event of such a rupture the contents of the line between PCV 511 and the point of rupture would have been released. The total amount of condensate in the line between PCV 511 and the MOL was about 125 kg. The initial discharge rate would be about 500 kg/s. The flash fraction in this instance would be about 40% which would give a rapid evolution of vapour resulting in the ejection of virtually the whole of the contents of the section of the line concerned within 1-2 seconds. The eruption of the fireball would have been accompanied by some over-pressure, although this would have been very much less than that associated with the initial explosion. As stated above, the fireball was shown to decay in the second, third and fourth photographs taken by Mr Miller which he said he took at intervals of about 2-3 seconds.

7.12 It is obviously necessary to consider why the fireball did not appear at the same time as the fire in B Module. This raises the question whether there were 2 separate releases or not. Dr Drysdale dismissed the possibility that the rupture of the condensate line was caused by over-heating of the line due to fire in B Module on the ground that there was not enough time for this to occur. He looked instead for any non-normal events which might be taking place at this time and identified the closing of ESV 208 on the MOL and the run-down of the MOL pumps. ESV 208 was a 20 inch valve and on the rule of thumb that such a large valve closes at a rate of about 1 inch per second its closure time would be about 20 seconds. In the light of the events described it appears to me to be likely that the condensate line was damaged by a missile sufficiently to leak a significant amount of oil. Dr Drysdale put forward as one possible failure mechanism initial damage to the line, causing a partial rupture, with subsequent full-bore rupture on closure of ESV 208 and/or as the MOL pumps ran down. Factors which might have contributed to the total rupture were heating of the line, perhaps from a jet flame from the leaking oil, and vibration resulting perhaps from the state of the pipework after the initial explosion. The fireball, which I have estimated to have occurred about some 15 seconds after the initial explosion, would then have been the result of this rupture. I accept this sequence of events as a credible explanation.

7.13 Dr Drysdale explained that the running of oil down the MOL may have resulted from oil being sprayed on to the MOL during the time when the fireball was occurring. Alternatively it was due to a leak from above ESV 208 which decreased when the valve closed. Dr Drysdale also stated that the fireball would have caused burning gases to spread from the existing fire in B Module. The flames which appeared temporarily on the 68 ft level at the time of the fireball appear to have been forced down to that level by over-pressure in B Module.

The extent and duration of the fire in B Module

7.14 Dr Drysdale was of opinion that the weight of evidence was against flaming in C Module immediately after the initial explosion. If Mr Flaws was correct in his evidence that he saw flames to the left of the west crane, this may have been a jet fire at the site of the initial leak, but assuming that the inventory was limited the leak and the jet flame would be diminishing. Some of the later photographs taken by Mr Miller show flames in C Module (eg Plate 18(a)). In Dr Drysdale's view these almost certainly emanated from the fire in B Module through a breach in the firewall. If there had been a separate fire in C Module, flames would have issued from the module merging with those in B Module to give a continuous "wall" of flame. What appeared to be flames at the base of the derrick above A Module were interpreted by Dr Drysdale as reflection, perhaps from the flare, rather than flames as there was no indication at that point of flame through the heat shield immediately below. He also expressed the opinion that the flames on the north face were an extension of the fire in B Module. The phenomenon of flame extension is well known in buildings where fire gases which are rich in products of partial combustion such as carbon monoxide emerge from a fully developed room fire, pass along the ceiling of a corridor and on meeting a stairwell or an opening to atmosphere burst into flame. In the present case the gas stream would also be rich in volatile hydrocarbons. Dr Drysdale discounted the alternative possibility that the fire was at the diesel tanks above the 121 ft level since both the storage site and the quantities stored made that improbable. His hypothesis was that the hot gases passed from B Module through a breach in the firewall into C Module and thence to the north face. He had some difficulty in identifying the precise path taken beyond C

Module. However, he noted that fire damage had occurred to the cabins at the north-west corner of the ERQ, which was consistent with there having been a prolonged external fire at that point. Further the area of the north wall of the ERQ which was to the west of the air intake duct had been exposed to temperatures in excess of 900°C. The hot gases would be driven by buoyancy, wind and any over-pressure in B Module. They would tend to be channelled by the I-beams in the roof of B and C Modules. During their passage through C Module they would undergo some rather inefficient combustion with the air beneath. The photographs taken by Mr Miller show that the west end of C Module was masked by smoke apparently within tens of seconds of the initial explosion. This would have obscured the view of any hot gases passing through C Module. It was suggested that any hot gases passing into C Module might well find outlets to atmosphere other than on the north face, on reaching which they would burst into flame. This might explain other flaming observed at the periphery of the platform. Dr Drysdale also expressed the view that the extension of the fire to the 68 ft level which was shown in the 19th photograph taken by Mr Miller might indicate that oil leaking on to the deck of the 84 ft level had started to spill over the collar of the deck penetration where the MOL came up from the 68 ft level. The continuing overflow would have allowed a pool to be established on the deck in parts of the 68 ft level exposing the Tartan riser to intense heating for at least 10 minutes. Survivors had also described a fire at the drums of rigwash stored near the riser. If the 2 fires were initially distinct, it is probable that they soon merged.

7.15 Following the fireball, the fire in B Module would have been fed by oil issuing from the system and spreading out over the deck of the module, giving rise to a pool fire. Estimates of the burning or regression rate of the fuel on the pool surface were given by Dr Drysdale. For pools in the open the burning rate depended on the pool diameter and approached a limiting value asymptotically. He quoted a value of 0.08 kg/m^2 per second for this limiting burning rate. For small confined pools increases in burning rate had been recorded which exceeded those for similar pools in the open by factors of 5 or 6 but for the large pool envisaged in the present case this factor would probably be much less. With a confined pool the burning rate was increased by radiation of heat back to the pool from the enclosure. In the case of B Module conduction of heat through the deck would also tend to increase the heat received by the pool. On the other hand the effect of the grating in the module would be to reduce the amount of radiation received by the pool surface. Taking such features into account he gave an estimate for the burning rate of 0.16 kg/m^2 per second. The main source of fuel in the process plant was in the separators, which he estimated at 50-55 tonnes. At the above burning rate and assuming that the pool contained some 50 tonnes and that some 5 tonnes of oil did not enter the pool but went down the drains, pool areas extending to 50, 100, 150 and 200m^2 would burn for 104, 52, 35 and 26 minutes, respectively, neglecting any fraction flashing off immediately on release, or 94, 47, 32 and 23 minutes, respectively, after allowing for a flash fraction of 10%. There was thus enough oil in the separators to maintain a fire in B Module up to 22.50 hours provided that the pool area did not exceed about 100m^2. He considered, however, that the pool was larger than that. Making the assumptions that the deck plates were sloped from a high ridge at the centre of the module towards the open drains under the MOL pumps and that the eastern limit would be defined by the penetration of the MOL through the deck plates, he estimated a minimum pool area of 150m^2 (10m x 15m) and making the assumptions that there was a collar 5 cm high to prevent normal spillages running down the MOL and that the deck plates were sloped at an angle of one degree, he obtained an estimate of 200m^2 for the maximum pool area. He adopted the value of 150m^2 for the probable area of the pool. These considerations led Dr Drysdale to postulate that the pool fire in B Module was also fed from another source. Possible sources were the wellheads and the MOL. Accepting the evidence of an Occidental investigation of the wellhead valve which showed that the valve had closed, he concluded that it was probable that ESV 208 did not achieve a tight shutoff and that oil leaked back from the MOL. He drew attention to photographic evidence of an intense fire near the location of the MOL. An alternative explanation was that the fire caused over-heating and at least partial fracture of the MOL. As will be seen from what follows the Tartan riser is believed to have ruptured after being subjected to an oil pool fire for some 10-15 minutes. I should add that once the Tartan riser had ruptured, the jet flame from that riser would have enhanced the heat input to, and the burning rate of, the pool fire, a point which strengthens Dr Drysdale's contention that the pool was not fed from the separators alone.

7.16 The available data on the oil pipelines in the network between Piper, Claymore and Flotta were examined by Scientific Software - Intercomp (UK) Ltd in Annex 9 of the Petrie Final Report, spoken to by Mr I R Ellul. It is clear that due to the limited amount of information and uncertainty as to its accuracy it is difficult to draw a clear conclusion. With the aid of a computer model Mr Ellul simulated for each pipeline what might occur in the event of - (i) no leak; (ii) a 10% leak; and (iii) a 20% leak in the MOL at Piper. The predicted results were then compared with the graphs of the measured pressures in the oil lines between 21.00 hours on 6 July and 06.00 hours on 7 July. Mr Ellul stated that the comparison of the predicted results with the readings for the Tartan oil line suggested no leak. The comparison with the readings for the Claymore line suggested a 10% leak. Nothing could be taken from the comparison in the case of the Flotta readings due to the low pressure in the oil line which allowed gas to be liberated from the oil and made the readings unreliable. Mr Ellul concluded that the results suggested a low probability of a significant leak of oil from the oil export line at Piper until at least 23.15 hours when Claymore shut down and depressurisation of the line commenced at Flotta. A "significant" leak meant a leak of about 10%. He explained that he was only able to say that there was a low probability of such a leak as he considered that the validity of the Claymore readings was undermined by the way in which the graph fell away sharply at 23.30 hours, which on one view fitted a "no leak" better. However at such low pressures his programme was not necessarily accurate. He agreed that if the pressure on the Claymore model had not fallen away so sharply at 23.30 hours he would have had no reason for coming to any other view than that the Claymore readings suggested a 10% leak at Piper, and he agreed that further inaccuracies in the computer predictions might be produced due to the scarcity of information for 23.30 hours. He accepted that his findings were consistent with a leak having occurred as a matter of probability.

7.17 In the light of the evidence I draw the following general conclusions:-

(i) The fire in B Module which followed immediately after the initial explosion was fuelled by crude oil which was released as a result of the 4 inch condensate line in B Module being ruptured by projectiles generated by the disintegration of the B/C firewall which was due to the initial explosion.

(ii) The fireball which came from the west face of B Module did so about 15 seconds after the initial explosion and was due to the rupture becoming full bore as a result of the pressure of crude oil.

(iii) The fire in B Module extended through a breach in the B/C firewall into C Module and thereafter appeared on the north face of the platform. As a result of the spillage of crude oil from the pool which was providing fuel for the fire in B Module, the fire was extended to the 68 ft level.

(iv) The crude oil came not only from the inventory on the platform but also from the MOL as a result of ESV 208 not achieving a tight shutoff.

The rupture of the Tartan riser at 22.20 hours

7.18 It is clear from the evidence of survivors and photographs that at 22.20 hours there was a second major explosion which engulfed the platform in a sudden and massive intensification of the fire. Its effects were immediately felt on vessels several hundred metres away as well as by personnel at the base of the platform. It is clear that this was due to the rupture of the Tartan riser.

7.19 The riser came up from the seabed between legs B5 and B4. Just below the 68 ft level it bent over to a horizontal run in a southerly direction where it was suspended from 3 pipe hangers. Between legs B3 and B2 it entered a right-angled bend towards the east and thereafter inclined upwards, penetrating the 68 ft level deck plating and connecting into the main pipeline shutdown valve ESV 6 upstream of the pig receiver. The riser had a diameter of 18 inches and a wall thickness of 1 inch. The steel grade was API 5LX-X60. Its coating was paint. Its flanges were RTJ A105.

7.20 Dr Richardson, who has been referred to in Chapter 6, gave evidence as to the analysis of flows in the gas lines between Tartan and Piper, MCP-01 and Piper, and Claymore and Piper. In his second report with Dr Saville he calculated the gas inventories in the various lines prior to the initial explosion and with the assistance of computer models attempted to predict the likely rate of depressurisation of each line, based on the start time and capability of each facility which would match the resulting pressures measured in the lines. From their calculations they were able to conclude that at least one of the Tartan gas import or MCP-01 gas export valves on Piper appeared to have shut at about 22.00 hours. Indeed, the data available to them were consistent with all Tartan gas import and MCP-01 gas export valves on Piper having shut at about that time, although he could not say whether they had shut tightly or not. It appeared that until 22.20 hours all the lines were intact. At that point it appeared likely that the Tartan to Piper line ruptured at Piper. The line then had an inventory which he estimated at 18 MMSCF. All the information of which he was aware implied a full bore rupture. Over about one minute 7% by mass of the gas would have left the line; in a further 23 minutes about 80%. The time for depressurisation to essentially atmospheric pressure was about 60 minutes, although the mass flow may have been rather higher. Pressure measurements at Tartan seemed to him to indicate that depressurisation was in fact completed in 55 minutes after 22.20 hours. This was subject to any small amounts taken off by Tartan itself.

7.21 Mr M R Clark, Chief Process Engineer of Occidental, prepared an estimated inventory of hydrocarbons as at 22.00 hours, which included the residual hydrocarbon content in C Module when depressurised in an emergency shutdown of phase 1 operation. The time taken for the major flows of hydrocarbons to reach the flare would be 5 minutes, after which there would be a slow boil-off of the small amounts of heavier hydrocarbons. This period was based on experience on Piper that neither the reciprocating nor the centrifugal compressors retained significant pressure for periods beyond that time. After blowdown the largest inventory of hydrocarbons would be the 1200 barrels of diesel in the diesel storage tanks.

7.22 Dr Cox undertook an investigation of the failure times of the Tartan riser due to varying heat loads. He calculated the rate of heating of the riser under different conditions and estimated the time at which the critical failure temperature would be reached. His best estimate of the likely range of heat fluxes was 100-200 kW/m^2. He considered a number of failure mechanisms, out of which the governing mode of failure was likely to be high temperature reducing the pipe steel strength to below the hoop stress induced by internal pressure. That failure would probably occur within the temperature range of 580-700°C. A number of heat transfer mechanisms were considered, of which the significant ones were heat gain due to radiation and convection from the fire; heat loss to surroundings by radiation; and heat loss to stagnant gas within the pipe. The critical section of the pipe for heat transfer was that immediately upstream of ESV 6 where the fire burned most fiercely and a pool of burning oil could have collected underneath. At a typical heat flux level of 150 kW/m^2 the exposure time to failure of the riser would be of the order of 7-18 minutes. This would be consistent with the timing of the observation of the large eruption of fire. Dr Drysdale also gave evidence that the most likely mode of failure of the Tartan riser was failure under hoop stress due to internal pressure caused by over-heating. He described the fire resulting from the rupture of the riser as an impinging jet fire. The question was raised as to why the MCP-01 riser did not rupture about the same time as the Tartan riser. Dr Drysdale was not able to offer an explanation for this other than the fact that the former was slightly further to the north than the latter.

7.23 Dr Cox was aware of the practicability of applying fireproofing to pipework. He agreed that this type of coating could have made a difference to the time during which the pipe retained its integrity, depending on the thickness of the coating. He said that he was fairly sure that "one could extend the survival time of a pipe of this sort by something of the order of a small number of hours perhaps, or one hour, two hours, three hours but only of that very very approximate sort of figure". If the pipe had been protected by a deluge which itself survived the fire, it could have survived indefinitely so long as the deluge continued. I should add that, as was stated in Chapter 3, the automatic operation of the deluge system on the 68 ft level had been switched off before the disaster because of the carrying out of welding work in connection with the Chanter riser. In any event the deluge system was disabled by the initial explosion (see para 7.65). The existing deluge system in the area of the 2 risers was a foam system, which suggests that it was primarily suitable for extinction of fires rather than cooling of equipment. There was no evidence as to whether if the system had come into operation at the time of the initial explosion, it would have been able to provide the protection for the Tartan riser which was envisaged by Dr Cox.

7.24 In the light of the evidence I draw the following general conclusions:-

(i) The major explosion at 22.20 hours was caused by a full-bore rupture of the Tartan riser immediately upstream of ESV 6 as a result of the high temperature created by a pool fire beneath it.

(ii) The rupture gave rise to an impinging jet fire and to the depressurising of the Tartan gas pipeline in 55-60 minutes.

(iii) Rupture of the riser could have been delayed by fireproofing for a substantial period, perhaps 1-3 hours, and by a cooling deluge system which came into operation after the initial explosion for an indefinite period. In the light of evidence which I heard in Part 2 of the Inquiry and which I discuss in Chapter 19, I recognise that there are certain disadvantages in fireproofing.

Subsequent explosions and the disintegration of the platform

7.25 At about 22.50 hours there was a further violent explosion, the vibration of which was felt 1 mile away. Debris was projected 800m from the platform. The men who were on the helideck of the platform were forced to jump off and the FRC from the *Sandhaven* was destroyed and 2 of its crew killed while engaged in the rescue of personnel from the platform. This is likely to have been due to the rupture of the MCP-01 gas line at Piper on the downstream side of its emergency shutdown valve. The pig launcher for that line was a short distance to the north of the pig receiver for the Tartan line. From there the MCP-01 line went west, running under the 68 ft level, then turning north and then eastwards towards the A3 leg, where it turned north again and ran towards the A4 leg, where it took a vertical turn down towards sea level. From his examination of the records Dr Richardson expressed the view that the gas line to MCP-01 appears to have been intact until 22.50 hours when it started to be depressurised, apparently as a result of a full-bore rupture at Piper. At that time the inventory in the line was 51 MMSCF. Depressurisation was complete within about 5 hours. Support for the interpretation of a rupture at 22.50 hours is provided by the recording at MCP-01 of the pressure in the line. After 22.50 hours there was a sharp tail-off in pressure. By 24.00 hours one half of the pressure had been lost. This could not be accounted for by flaring alone but must have been largely due to a rupture.

7.26 Following the explosion at 22.50 hours the collapse of the structure of the platform started at the 68 ft level below B Module. About 23.15 hours the western crane collapsed from its turret. It is probable that the jib and cab fell into the sea. This was as a result of the continued deterioration of the area around B Module due to riser fires. Shortly thereafter there was a major structural collapse in the centre of the platform. The deteriorating condition in the area of B Module caused the drilling derrick to collapse towards the north-west corner, the top section falling across the pipe deck. The structure of the platform had already taken a slight tilt to the east. This was followed by a sudden collapse of the pipe deck. According to Mr Letty, the master of the *Tharos*, shortly after beginning to pull back from the platform at about 23.18 hours, there was "an enormous explosion on the platform", which he believed to be "the biggest of the night". This was probably caused by the failure of the Claymore gas riser. Some witnesses said that the collapse of the pipe deck was associated with an explosion while others did not distinguish it in this way. The collapse was much more serious than the first and was to the west. Both this and the first tilt caused equipment to fall and injure or trap men in the White House. It caused the structure of the White House and the OPG workshop (both of which were on the pipe deck) to fail and force many of the men out, although some were trapped or engulfed by flames at this point. When the men came out, they discovered the pipe deck had collapsed to the west at an angle of up to 45° and was split from east to west along the line of the south face of the SPEE Module. The collapse also caused structural failure in the support of the ERQ which tipped to the west. It is also probable that it then crushed and destroyed the LQW. This conclusion was advanced by Mr D M Tucker, a Fire and Loss Consultant of Tucker Robinson, Consulting Scientists, who examined the ERQ at Flotta after its recovery from the seabed. He indicated that slide marks in the kitchen of the ERQ could be explained by a tip to the west which could only occur if this tip destroyed the LQW or if the LQW had already gone. There was no evidence of any prior collapse which would have destroyed the LQW. Although the LQW was made of more combustible materials than the other modules, the explanation that it had been destroyed by fire could be discounted because of the amount of unburnt wreckage from it. Accordingly it appears correct to conclude that the LQW was destroyed when the ERQ tipped to the west in the same structural collapse that caused the derrick to fall and the pipe deck to collapse. This would account for the fact that survivors saw wreckage from the LQW in the water. Mr Tucker also concluded that the ERQ would have fallen into the water at about this time. The basis for this view was the lack of fire damage to the west and south faces of the ERQ, which suggested that they were shielded from fire and smoke until the ERQ fell (see Plate 22(b)). In addition smoke ingress into the ERQ through doorways from the LQW was more consistent with small fires in the LQW and not with the LQW being fully ablaze or absent.

7.27 In the light of this evidence I consider that it is more likely that the rupture of the Claymore riser contributed to the structural failure of the centre of the platform rather than having been caused by it. The Claymore pig launcher was situated at the 68 ft level in the north-west corner of the platform. From the pig launcher the riser turned vertically downwards in the western half of the north face and maintained that direction to sea level. Dr Richardson noted that there had been an apparent depressurisation of the Claymore pipeline at 23.00 hours. At that time the inventory in the pipeline was about 10 MMSCF. According to evidence given by personnel on Claymore depressurisation of the pipeline started at Claymore at 23.00 hours through FCV 970, which was a choke valve of 6.25 inches diameter. This evidence was not available to Dr Richardson. Accordingly he was unable on the information available to him to determine whether the depressurisation had begun at Piper or at Claymore. However, he did say that he would have expected the pressure at Claymore to have dropped more rapidly than was shown in Fig 9.5 of the Petrie Report (Fig 7.3) if depressurisation at Claymore accounted for the total effect.

7.28 The explosion which took place when the Claymore riser ruptured contributed to the accelerating deterioration in the condition of the platform which followed. Mr Letty said that by 00.15 hours the north end of the platform had disappeared completely. However, the log of the *Tharos* stated that at 00.45 hours "The Piper accommodation module over-turned into the sea." This was probably the AAW, the only module remaining on the north end of the platform at that time. Mr Tucker found that the AAW (see Plate 23) had suffered much more extensive fire attack than the ERQ with heating predominantly from the south. He also said that it had tipped over on to its north face and remained there for a period of time. It could not have tipped over to the north until the LQW had gone. Eye-witness accounts indicate that the north end of the platform collapsed slowly. Once the centre had fallen out of the platform the AAW would have been subjected to extreme heating on its south face, certainly from around 23.30 hours. The description of the AAW bending over towards the sea could have been due to its falling over into the space left by the LQW before sliding into the sea at the north-west corner of the platform. Mr Letty also confirmed that by 00.15 hours the fire was mainly from the surface of the sea, a highly pressurised fire, like a Bunsen burner. This indicates that burning gas, under pressure, was coming from one or all 3 of the gas risers which by then had been severed by falling equipment and structural debris from the modules and the north end of the platform. Plate 21 shows the broken end of one of the risers ablaze the next morning. Mr Letty also described a pool of burning oil, about 100 ft across, in the vicinity of the MOL riser.

Extended flaring

7.29 Photographic and other evidence shows that there was significant flaring and venting on Piper after the initial explosion. In particular the high pressure flare, shown just before the initial explosion in Plate 13, continued to burn with a clean, constant flame until the explosion at about 22.50 hours. If the shutdown systems had worked correctly, then depressurisation of the production facilities would have been expected to occur long before this time. The low pressure flare was extinguished about 10 minutes after the initial explosion but after several minutes it began to emit a strong vapour plume. About 10 minutes after the initial explosion a vapour plume was also seen coming from an atmospheric vent on the east flare boom. This plume lasted beyond 22.20 hours but disappeared before either the high pressure flare or the low pressure plume ceased.

7.30 An interpretation of the photographs of the flaring was provided by Mr P C A Watts, Chief Process Engineer, Kaldair Limited, who were the suppliers of the flare tips. On his interpretation the flow of gas through the high pressure flare prior to the disaster was about 20 MMSCFD. During the blowdown the rate was 60 MMSCFD through the high pressure flare and 4 MMSCFD through the low pressure flare. Photographic evidence showed a rise to a peak of 240, falling to 160 MMSCFD. Thereafter there was a rapid reduction in the high pressure flare, with some dark smoke, which would be induced by the carryover of liquid droplets or an increase in the molecular weight of the gas or a combination of both. This was followed by a steady period of flaring for about 45 minutes at 60 MMSCFD until the explosion at 22.50 hours. At some time during this period the low pressure flare went out and was replaced by a steamy plume. The high pressure flare showed the burning of clean gas free from liquid or heavy ends. The flare would be smoky only if there was a low gas pressure and flow combined with either gas of molecular weight greater than 60 or with liquid carryover in excess of about 50% w/w.

7.31 Mr R J Smyllie, Senior Engineer, Cremer and Warner, estimated that 200-300,000 SCF had flared off in a period of 3 minutes after the initial explosion. This excluded gas coming from the source of the continuous background flaring of 60 MMSCFD over that period, which was equivalent to 125,000 SCF. He said that after the flare subsided the smoke might have been due to the burning of gas with a significant increase in heavy ends or even a hydrocarbon liquid carryover. The source was most likely to be the JT drum and the production separators. He said that a large proportion of the gaseous inventory on the platform (220,000 SCF plus 25-30,000 SCF from the centrifugal compressors) must have been consumed very shortly after the first explosion in order to fuel the observed 240 MMSCFD peak flow. In fact the volume of hydrocarbons estimated to have flared off in the first 3 minutes was consistent with the gaseous and flash gas inventories that existed on the platform at the time of the explosion. The remaining oil and condensate inventories left after depressurising were not sufficient to supply the high pressure flare for a prolonged period. Further had these been a major contributor a smoky flame would have been expected. However, the remaining hydrocarbon inventories could have produced a small continuous flow by way of the fail-open PCVs if fires in the vicinity generated sufficient heat to drive off gases. The high pressure flare could be expected to reduce to a minimum flow within a relatively short time of an ESD.

7.32 As regards off-platform sources Mr Smyllie said that the probability of a combination of valve failures allowing gas to come from a well was small. Moreover, such a source would give a smoky flame. He ruled out gas lift since the isolation valves were found to be closed. Turning to the gas pipelines, the lack of change in the flare before and after the event which affected the Tartan pipeline at 22.20 hours indicated that that line was not the source. He considered that the mass balance carried out by Drs Richardson and Saville showed that there was no major leak at ESV 956 on the MCP-01 pipeline. Thus by process of elimination he was drawn to the conclusion that the source of the gas was the Claymore pipeline. This pipeline contained Tartan gas which would not give a smoky flame. For the Claymore line to be the source the gas would have had to pass through the ESVs at the pig trap; then through one of a number of intermediate routes; and finally through a PCV or PSV to flare. He considered a path through ESV 501, PCV 501 bypass and PCV 945.

7.33 I consider each of these routes in turn. PCV 945 was a fail-open valve. Dr Cox expected that this valve and the other PCVs to the flare would have gone to the open position due to action of the PESD. With regard to the path through the PCV 501 valve set Mr Smyllie's preferred route was through the bypass. However, although the PCV itself was near reciprocating compressor B the bypass was at some height up and fairly inaccessible. Evidence of normal practice was that on loss of 1 or 2 centrifugal compressors the phase 1 operator would open the manual block valves on either side of PCV 501 but that until the third compressor was lost no action would be taken to open the PCV itself. Mr Bollands said that Mr Richard would know what to do but he would have had no time after the tripping of the third centrifugal compressor to open the PCV. However, PCV 501 was a fail-open valve and Dr Cox stated that he could envisage that damage caused by the accident might cause such a valve to open. I think it probable that the block valves were opened and regard it as more probable that the PCV opened as a result of the explosion than that the bypass was already open. As far as concerns the path at the pig trap, MOV 502 and ESV 503 were normally closed and are unlikely to have been the route. It is much more probable that ESV 501 failed to close fully. The ways in which this might have happened were explored with both Mr Smyllie and Dr Cox. Mr Bollands stated that he did not press the buttons to close the gas pipeline ESVs. According to Dr Cox ESV 501 would therefore only have closed if there was a loss of the 120V AC supply. As described below, he believed that the D Module 120V AC supply was lost. Even if it had not been lost, the cable for ESV 501, which was separate from that for ESV 6 and ESV 956, might have been damaged even if the UPS was intact, thus effecting the closure of ESV 501. However, if local damage to the valve occurred it might not have closed fully. As regards the low pressure flare Mr Smyllie's interpretation was that it was due to the blowdown from the third centrifugal compressor and the deoxygenating towers. The vapour plume was thought to be the result of steam generated within a number of vessels as a result of fires burning in their locality. As regards the atmospheric vent, his interpretation was that the plume was most likely to have come from the 3 inch diameter centrifugal compressor skid blowdown line, possibly due to a fracture or a passing valve. I should add that the Claymore gas pipeline could be "topped up" with Tartan gas through the "Gas to Claymore" (GTC) valve and that during phase 1 operation the dry Tartan gas was being used in preference to the wet Piper gas for topping up the line. Such a topping-up operation could have been going on at the time of the initial explosion. However, Mr Smyllie's argument against Tartan gas being the source for the extended flaring still stands. Moreover, the record at Tartan of the Tartan line gas pressure showed that ESV 6 on that line at Piper closed when that platform shut down at 22.00 hours.

The response of other installations

7.34 It has been shown earlier in this chapter that the amount of crude oil which fuelled the fire in B Module could not be wholly accounted for by the inventory of crude oil on Piper at the time of the initial explosion; and accordingly must have come partly from the MOL, either by reason of the failure of ESV 208 to close completely or by reason of a fracture of the MOL itself. The MOL at Piper formed part of a system into which 2 other installations, Claymore and Tartan, normally pumped crude oil; and in which the onshore terminal at Flotta normally maintained a back pressure (see Fig 3.1). It was therefore appropriate to discover whether anything could have been done at any of these other installations which would have had the effect of reducing the amount of crude oil discharging at Piper and so reducing the consequences which flowed from that. It has also been shown earlier in this chapter that the disaster at Piper was hastened by the successive rupturing of the gas pipelines connecting Piper with Tartan, MCP-01 and Claymore. Accordingly it was appropriate to discover whether anything could have been done elsewhere to prevent or defer such events taking place.

Stopping the production of oil

7.35 Claymore continued the production of oil until about 23.10 hours. About 10 minutes earlier steps were begun in order to carry out a controlled shutdown. This type of shutdown was chosen in order to avoid problems with the compressors at Claymore. An emergency shutdown would have taken immediate effect. At Tartan between 22.30 and 22.45 hours steps were begun to shut down oil production. Wells were shut down in stages between 22.55 and 23.23 hours. The last step was the closing of the main export valve at 23.52 hours. Once again this was a controlled shutdown. The reasons given in evidence were the risk of generators not automatically switching over to diesel so that the operators would be faced with a "black start" situation; and the containment of full pressure in vessels and flow lines from satellite fields. An emergency shutdown would have taken immediate effect. Before oil production was shut down on Claymore the terminal at Flotta had shut down a stabilising train and a gas plant as a result of indications that Piper had shut down production and information from Claymore that an explosion had taken place at Piper and that personnel were being evacuated. Between about 23.15 and 23.25 hours Flotta was instructed by Occidental to effect the depressurisation of the pipeline from Piper. This was carried out after Flotta had verified that Claymore and Tartan had both ceased production. The normal back-pressure of 220 psi, which was equivalent to 16 bar, had been reduced to 6 bar at 00.20 hours and 0.7 bar at 07.00 hours.

Depressurisation of the gas pipelines

7.36 The depressurisation of the gas pipeline from Tartan to Piper was instructed on Tartan between 22.30 and 22.45 hours. This took until 23.20 hours to set up, the last step being the opening of the export gas valve ECV 54. As will be explained below, it was then found that the pipeline contained virtually no gas pressure which was capable of being measured at Tartan. The depressurisation of the gas pipeline from Piper to MCP-01 was carried out at MCP-01 starting just after 23.00 hours. This pipeline normally contained about 60 MMSCF. The flaring capacity at MCP-01 was 2.6 MMSCFD. The depressurisation of the gas pipeline between Piper and Claymore was instructed on Claymore about 23.00 hours and took about 5 minutes to set up. Depressurisation was carried out through FCV 970. In addition after 24.00 hours gas was taken through the separators to the low pressure flare. It is uncertain how quickly this pipeline lost pressure. According to Mr J Davidson, Operating Superintendent on Claymore, a pressure of 400 psi was reached in about 4 hours, whereas the trend record for this line given in the Petrie Report, which was based apparently on readings taken on Claymore, showed that this pressure was reached after about 45 minutes. The pressure records for all 3 gas pipelines are given in Figs 9.1, 9.3 and 9.5 of the Petrie Report and are here reproduced in Figs 7.1-3.

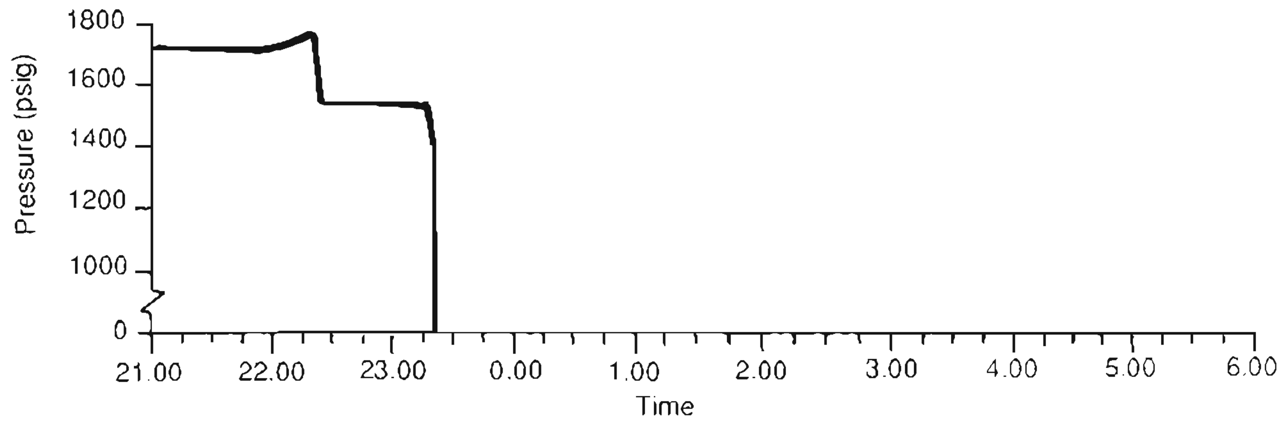


Fig. 7.1 Trend record of the Tartan gas export pipeline pressure on 6/7 July.

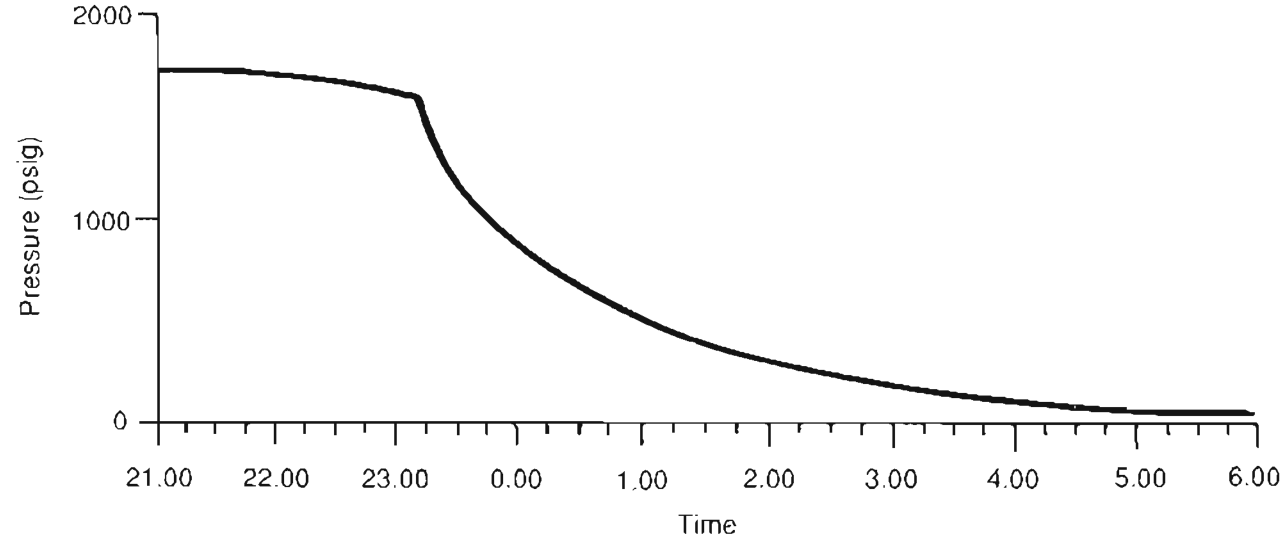


Fig. 7.2 Trend record of the MCP-01 gas import pipeline pressure on 6/7 July.

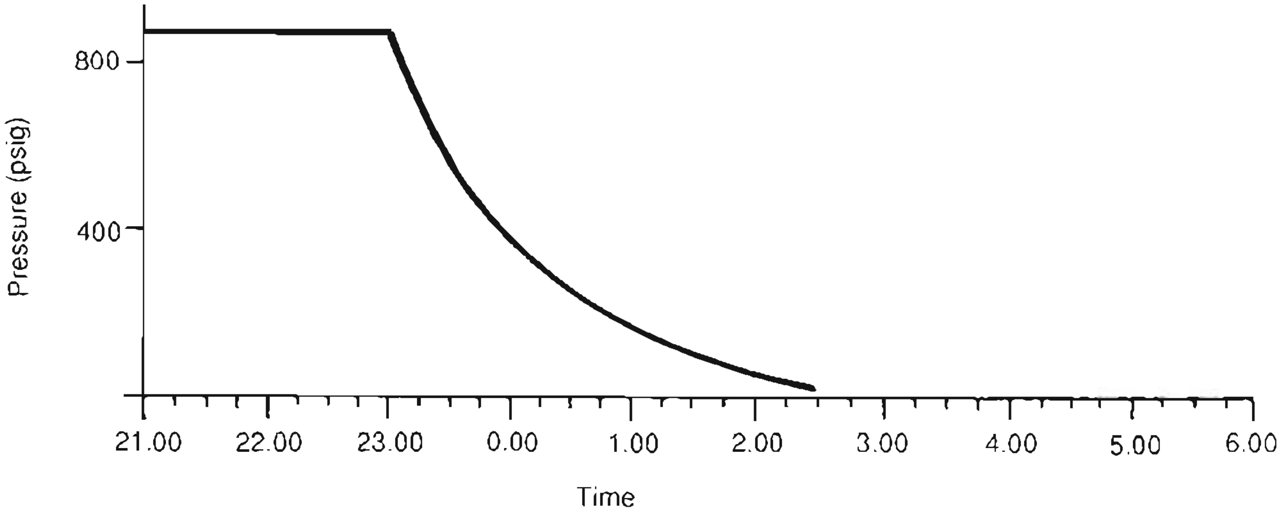


Fig. 7.3 Trend record of the Piper-Claymore gas pipeline pressure on 6/7 July.

The response on Claymore

7.37 Shortly after 22.00 hours the OIM on Claymore, Mr S B Sandlin, was told that there had been a mayday due to fire and explosion on Piper. At that time Piper could not be seen from Claymore. The OIM said in evidence that he treated the matter as a major emergency but thought that it could be controlled on Piper. He and Mr Davidson tried to telephone Piper but without success. The OIM said that he had not been unduly concerned about this as platforms such as Piper had the ability to isolate themselves and to control communications through the OIM in the event of an emergency. After hearing of a second mayday the OIM instructed the standby vessel of Claymore, the *Nautica*, to proceed to Piper. He also telephoned Mr J Bryce, Production and Pipeline Superintendent, who was his immediate superior, in order to report what he knew. There was very heavy traffic on radio channels. The information available on it was unclear and confusing. The most reliable source of information was the *Tharos*. Mr Davidson was told by the *Tharos* on VHF that there had been an explosion on Piper and that there was a fire on its west side, with a large volume of black smoke blowing over the helideck from the east side. This was about 22.15 hours. Mr Davidson told the OIM of this and said that he wanted to shut down the MOL because of the risk of oil being released on Piper in the area of the fire as a result of heat failure. It was known by then that Piper had shut down production of oil. Having found that the pressures in the pipelines were stable, the OIM decided that production should be continued.

7.38 Arrangements were made for the pressures in the pipelines to be monitored and any change reported. It was then discovered that the telemetry system providing information from other installations had failed. As a result operators had to note what was shown on the pressure gauges for the gas pipeline and look at the chart recorder in respect of the oil pipeline. At 22.20 hours the telephone system failed when the OIM was attempting to telephone Occidental's Emergency Control Centre. At 22.20 and 22.30 hours Mr Davidson again raised the shutting down of production with the OIM. At the latter time he had heard from the *Tharos* of fire spreading and people being in the water. From the helideck he could then see a glow coming from the direction of Piper. The OIM continued to maintain production as he did not think the position on Piper would be beyond the control of its fire pumps.

7.39 Following the failure of the telephone system at 22.20 hours the OIM spent a considerable number of minutes trying to get in touch with Occidental's Emergency Control Centre by means of the satellite system. There is disagreement among the witnesses as to when this communication was established. According to Mr Davidson it was between 22.50 and 22.55 hours, whereas Mr A G McDonald, Occidental's Head of Telecommunications in the North Sea, gave the time of 22.38-22.40 hours, which he said he had logged at the time. The OIM himself said that he spoke first to Mr Bryce and then to Mr Bryce's superior, Mr J L MacAllan, Production and Pipeline Manager. It appears likely that the latter conversation took place at about the time period mentioned by Mr Davidson. By the time of this conversation Mr Davidson had on 2 further occasions suggested to the OIM that production be shut down. Throughout the time since monitoring of the pipeline pressures had begun no report had reached the OIM of any drop in those pressures. The OIM said that he spoke to Mr Bryce in order to establish a communication link; and to Mr MacAllan "for mutual information". Mr Davidson said in evidence that when the OIM was in conversation with Mr MacAllan he (Mr Davidson) got a further report from the *Tharos* of a massive explosion in which Piper was enveloped in flames. (This is plainly a reference to the explosion at 22.50 hours.) He said that at this he shouted across the radio room to the OIM to get him to ask Mr MacAllan if Claymore should be shut down. It seemed to him that the OIM was asking Mr MacAllan for instructions or advice. The OIM's account was that he was not consciously consulting Mr MacAllan or anyone else; it was for himself to decide when to shut down. When Mr Davidson shouted about a major deterioration at Piper, he realised that the situation was uncontrollable and he decided to shut down production. Mr MacAllan said that he asked the OIM about the position with regard to production and the pipelines. When the OIM told him that Claymore was still on line he instructed him to shut down production, blow down the gas line to Piper, and get in touch with Tartan by way of VHF in order that Tartan should shut down production and start blowing down the gas pipeline between Tartan and Piper. His reaction to hearing that Claymore was still on line was "a certain degree of anger", which he explained as a reaction of impotent frustration. He himself called Texaco, the operator of Tartan, to impress on them the urgency of having the gas line to Piper blown down as quickly as possible. He also made arrangements for Flotta to depressurise the oil pipeline and for Total to blow down the gas line to MCP-01. These courses of action were followed. From the evidence it appeared that this was the first time at which Claymore had been in touch with Tartan since 22.00 hours. According to Mr McDonald, there was no technical reason to prevent Claymore calling Tartan earlier, ie by means other than the omnibus telephone system.

7.40 The OIM explained that his decision to continue production was based on the maintenance of pipeline pressure and on a limited knowledge of the situation on Piper "albeit appearing to get worse but still not indicating to me that a major disaster was in the making". He relied on his own judgement and knowledge of what was written down. He was referred to para B.4.4.1 of Occidental's Pipeline Operating and Emergency Procedures Manual, which states:- "If it is immediately clear that a major problem exists such as the rupture of the pipeline or a serious incident at the platform, shutdown of the platform or the whole system will be initiated by the affected platform. Each location can only initiate automatic shutdown of its own systems so it is vital to inform the other locations of the situation and of the need for action so that they can initiate their own shutdown actions. The objective will be to reduce pressure in the pipeline as quickly as possible and to halt the outflow of product from the pipeline in the event of a rupture ...". He knew that in the event of a pipeline rupture the amount of oil or gas would be such as to provide a very considerable source of fuel for the fire on Piper. He would have shut down and vented if he had received word from Piper to do so or if he had known the situation to be as extreme as it was. He was also referred to para B.4.4 which states "... in relation to the pipeline and pipeline contents the priority is to reduce pressure and stop flow into the pipeline by stopping gas compression and closing the main line valves. This may be to reduce pressure acting on damage (sic) sections or to minimise the quantity of gas escaping if the pipeline is ruptured." He said that at the time he had no indication that there was any gas escaping from the Claymore pipeline. The indications were that that pipeline was secure and pressure was reducing gradually through normal usage. The OIM had not required to shut down Claymore at the time of the emergency on Piper in 1984. He also said that if Mr Davidson or anyone junior to him had felt that the platform should have been shut down, they could very easily have done so without any fear of repercussion from himself or Occidental. However, he agreed that Mr Davidson had indicated that he was deferring to him. "He gave his reasons for wanting to and with my experience and knowledge and information at hand my choice was to continue production."

Tartan

7.41 After hearing about the mayday the OIM, Mr J Leeming, looked in the direction of Piper, some 12 miles distant, and saw "a red envelope of flame" projecting from its north side just below the modules. He realised that something serious had happened. Mr M D Moreton, the Production Supervisor, was instructed to monitor pressure on the gas pipeline to Piper. The OIM spoke on the telephone to his superior in Aberdeen. Between 22.10 and 22.20 hours Mr Moreton discovered that the telemetry system had frozen as from 22.00 hours, with the result that only information from Tartan was updated on the VDU display. He tried without success to call Piper and Claymore on the omnibus system. Production was maintained in the belief that Piper was also doing so. However, over a period of 10-15 minutes he noticed an increase in the pressure of the gas pipeline to Piper which indicated to him that the import valve on Piper had shut. At about 22.15 hours he decided, in accordance with instructions from the OIM, to shut down the export compressors and close ECV 54. He did so for the purpose of stopping a rise of pressure in the gas pipeline. If he had not done so, the gas compressor would have tripped in due course. The closure of ECV 54 is in accordance with the procedure to be followed in the event of a serious emergency on Piper. Mr Moreton did not at that stage consider depressurisation of the gas pipeline. After the closure of ECV 54, which was recorded as being at 22.25 hours, Mr Moreton was told of a large explosion on Piper. He looked in the direction of Piper and saw a fireball. He then noticed that there had been a sharp drop in the pressure of the gas pipeline between 22.20 and 22.25 hours. He thought this odd, discussed it with someone else but could not explain it. He did not associate it with the large explosion on Piper although "it is apparent now". It should be added that the OIM was unable to explain why, if the decision to close ECV 54 was taken prior to the explosion on Piper at 22.20 hours, it took as long as until 22.25 hours for ECV 54 to be closed.

7.42 The pressure chart for the gas pipeline to Piper showed a horizontal line after 22.25 hours. Neither the OIM nor Mr Moreton nor Mr K Roberts, the Facilities Engineer on Tartan, were aware that the sensor for the chart was upstream of ECV 54 and that accordingly the chart was presenting a false picture as to the pressure in the gas pipeline. There was a pressure gauge downstream of ECV 54 but this was not normally monitored. Later on the OIM instructed Mr Moreton to depressurise the gas pipeline to Piper. The last step in this process was the re-opening of ECV 54 at 23.20 hours. According to Mr Moreton the process was started about 22.45 hours. Until then "everyone was to some extent in some degree of shock as to what had happened over there, and trying to find out what was happening and what had happened". According to the OIM the process took over 45 minutes. "On this particular night I think personnel were suffering from shock, so they would be additionally cautious in what they did, so maybe it took a little longer than expected". While the process was going on, a message was received from Claymore asking Tartan to depressurise the gas line. This refers, of course, to a result of the conversation between Mr MacAllan and the OIM on Claymore. As stated above when ECV 54 was opened, it was found that the pipeline had already depressurised. On Tartan depressurisation had been designed to supply fuel and sweet gas for operations. A heat exchanger and a 2 inch pipe restricted the flare discharge to 10 MMSCFD. The gas in the gas pipeline was 20 MMSCF. Accordingly total depressurisation of the pipeline would normally have taken at least 2 days. Initial venting would have been at the rate of 500,000 SCF per hour. There was no way in which depressurisation could have been speeded up beyond this rate.

7.43 The OIM also instructed Mr Moreton to shut down oil production. He said he did so because of the escalating situation at Piper. It is not clear when this instruction was given. According to Mr Moreton it was given at the same time as he instructed depressurisation. According to the OIM it was in the region of 22.30-22.40 hours. The last step in this process was the closing of the main export valve at 23.52 hours. During this process a further message was received from Claymore asking Tartan to shut down oil production. It appeared from the evidence that due to problems with VHF radio transmissions Tartan had been unable to initiate contact with Claymore at any earlier stage of the disaster.

7.44 Mr Moreton said that his general approach had been to estimate the seriousness of the incident. He had assumed Piper's fire-fighting equipment was working and that the incident was being tackled. It did not occur to him that the closing off of crude oil production could affect the fire on Piper. He agreed that as regards gas, the major threat to Piper was not Tartan's production but the pent-up capacity of the gas pipeline. He said that at no time had his employers pointed out that fact to him or discussed it in management meetings or the like. The OIM's general approach was that he had hoped that the situation on Piper could be contained. He had not thought that Tartan crude oil was fuelling the fire. He had considered that there might be some sort of check valve to prevent oil back-flowing to Piper, since Claymore had not stopped production. Until ECV 54 was opened he was not aware of gas from the Tartan line escaping and fuelling the fire on Piper. The pipeline contained about 20 MMSCF as compared with a production rate of about 30 MMSCFD of gas. Accordingly the amount which would be put into the pipeline during an hour would be relatively small compared with that which was already contained within the pipeline. Asked whether at the stage when ECV 54 was closed he thought that the gas in the pipeline might escape and fuel the fire on Piper, he said "I cannot recollect that consideration specifically, but yes, I suspect I had considered that". He thought that being aware of the potential catastrophe of a rupture at either end of the pipeline "was not something that perhaps you would think about. Maybe, if you had a morbid mind you may dwell on that subject". However, he said he thought that the production staff including Mr Moreton would certainly have been aware of the potential reservoir within the pipeline and the effects of a rupture. An increase in the depressurising rate at Tartan had been discussed in the past "but not really gainfully". The blowdown rate of 500,000 SCF per hour was to evacuate any contaminated gas near Tartan. A fast rate of blowdown was not necessary for that purpose. He did not believe that depressurisation of the pipeline was ever considered for emergency purposes.

7.45 During the evidence there was some discussion of para 5.2 of the Emergency Procedures Manual for Texaco Submarine Pipelines, which refers to a "serious incident on Piper or Claymore platform (no Tartan oil or gas line damage)". One of the steps stated is that "Piper closes valve on incoming riser from Tartan causing gas process shutdown at Tartan". Corresponding to this is the step "Claymore closes valve on incoming riser from Tartan causing process shutdown at Tartan". The manual is inaccurate in respect that owing to the compressibility of gas a closure at Piper would not cause an immediate gas process shutdown at Tartan. It would take over an hour for a closure to have this effect. As regards Claymore the procedure described was unknown to either Mr Davidson or the OIM of Claymore. Further Mr Davidson said that Claymore would not close the valve on the incoming riser from Tartan until Tartan had said that they had shut down. What was stated was contrary to practice and not sensible. The OIM said that he would rather have not closed the valve without reference to Tartan in the first instance.

MCP-01

7.46 Shortly after 22.00 hours Mr J Burns, the Shift Supervisor, was called to the Control Room after the mayday had been received. He found that it was possible to telephone the shore. However the telephone links to Tartan and Piper did not work, nor did the telemetry from them. It was decided that in the absence of any indication that the flow from Tartan or Piper had been interrupted MCP-01 should continue as it had been. Pipeline pressures were monitored. No noticeable change in pressures was seen until 22.50 hours when there was a sharp drop. Since the pressure of the gas arriving from Piper required to be slightly higher than the gas which was compressed at MCP-01, MCP-01 would have required to shut down the line from Piper in such circumstances. However they received a telephone call from Occidental to blow down the line from Piper. This process began shortly after 23.00 hours. By 24.00 hours the gas pipeline from Piper had lost about half its original pressure. This loss could not be accounted for merely by flaring but must have been largely due to rupture at Piper. The blowdown facility at MCP-01 was not designed to blow down the line from Piper but could be used to do so. The flaring capacity was 2.6 MMSCFD, whereas the pipeline from Piper contained 60 MMSCF. At a later stage the shore provided MCP-01 with the working frequency of Tartan on VHF and contact was made between MCP-01 and Tartan at 01.30 hours.

Observations

7.47 As regards shutting down oil production, there was no physical reason why it could not have been done earlier than it was done at Claymore and Tartan as part of a controlled shutdown. This would have caused an almost immediate reduction in the flow of oil which was fuelling the fire in the centre of the platform. In so far as the fire on the 68 ft level was fed by an overflow of oil from the 84 ft level any reduction might well have had a significant effect on the fire threatening the Tartan riser. If oil production had been shut down before 22.20 hours, this would probably have delayed the rupture of the Tartan riser. It is not possible to say that it would have prevented it.

7.48 It is more problematic what shutdown would have achieved after 22.20 hours and in particular what its effect might have been on the timing of the rupture of the MCP-01 and Claymore risers, since by then the intense heat of the burning gas from the Tartan riser was added to the fire. On that particular point I am not able to reach a conclusion. However, any delay in shutdown contributed to the amount of smoke and heat which was generated by pool fires.

7.49 The OIM on Claymore had full authority to shut down oil production and was under no constraint from management in this respect. His suggestion that Mr Davidson or his juniors might have shut down production had they felt that this should be done was unrealistic. Mr Davidson repeatedly made his point of view clear to the OIM but clearly deferred to him for his decision. The OIM was well aware of the serious consequences of oil discharging at Piper near the seat of any fire. His attitude at the time was that there was an insufficient basis for him taking the step of shutting down oil production. Making all allowances for the benefit of hindsight, I consider that he should have shut down earlier than he did, at the latest after the rupture of the Tartan riser at 22.20 hours. By then and despite difficulties in regard to radio messages he had received first-hand information of a major fire on Piper which could then be seen to be ablaze. At the same time the telephone system had failed, presumably as a result of the major explosion at 22.20 hours. At that stage any confidence or hope which he had previously entertained that the fire on Piper was controllable should have been severely shaken. It seems to me that it was not enough for him to rely on lack of evidence of actual rupture of a pipeline. The risk of rupture was too serious in its consequences. The OIM appears to have persisted after 22.20 hours in attempts to exchange information with the Occidental Emergency Control Centre. From the evidence I conclude he was reluctant to take the responsibility for shutting down oil production. The shutting down of oil production at Claymore was a direct result of instructions which Mr MacAllan gave to the OIM.

7.50 As regards Tartan, I am surprised that it did not occur to Mr Moreton or the OIM that the continued production of oil by Tartan could affect the fire on Piper; and that the OIM could only speculate as to the existence of a check valve which would prevent oil back-flowing to Piper.

7.51 As regards the depressurisation of the gas pipelines between Piper and Claymore and Tartan it is clear that even if this had been undertaken at an earlier stage than it was it could not have had any material effect on the fire at Piper, having regard to the fact that the capacity of each platform to flare off gas was extremely small compared with the enormous quantity of gas contained within the length of pipeline in each case.

7.52 The strong impression with which I was left after hearing the evidence as to the response of Claymore and Tartan was that the type of emergency with which the senior personnel of each platform was confronted was something for which they had not been prepared. Both Mr Moreton and Mr Leeming said that they had not undertaken any pipeline exercises for anything on the scale of Piper. Occidental witnesses provided confirmation of this in the case of Piper and Claymore. Mr G Richards, one of the OIMs of Piper, said that a scenario in which it was assumed that one of the platforms was knocked out had never been considered by him or discussed by the OIMs. Mr A Bodie, the Offshore Safety Superintendent, said that he had never been involved in joint procedures between the different platforms. Mr R M Gordon, Manager of the Loss Prevention Department, said that the Department had never been involved in discussions with other platforms as to the collation of procedures. Mr A D McReynolds, Vice-President of Operations, said that he had never been involved in a scenario which involved the knocking out of one of the platforms. In my view if there had been adequate and regular practising of the type of response which should be undertaken in the event of a major emergency involving fire or explosion on one of the three platforms, much of the misunderstanding, delay and indecision on Claymore and Tartan would have been avoided. In this way safety in a wide range of possible scenarios would have been enhanced. Much of the existing procedures for Claymore and Tartan seems to have been based upon the assumption that the means of communication between the platforms would remain capable of being used. For example, in para B.4.3.1 of the Pipeline Operating and Emergency Procedures Manual which applied to Claymore it was stated "in all cases rapid communication and notification of actions to the four Control Rooms is essential so that the necessary actions can be taken quickly to minimise the consequences". Mr Davidson stated that he had not taken part in any exercises for rapid communication and notification in the case of an emergency. In any event if exercises had been undertaken in which it was assumed that the ability to communicate was wholly or partly affected, this would have provided a clearer basis for decision-making. Mr Davidson and other Occidental witnesses such as Mr Bodie and Mr MacAllan did not realise that a failure on Piper might affect the omnibus telephone link to the other platforms, although this was appreciated by Mr McDonald, Occidental's Head of Telecommunications.

Effect on platform systems

7.53 A number of eye-witnesses provided evidence of their own observations from which it was possible to determine to what extent the platform systems had been affected by the initial explosion. In addition evidence was given by Dr Cox on this subject in the light of the evidence of eye-witnesses and an understanding as to layout and operation of the platform systems. Subject to my comments below I accept the conclusions at which Dr Cox arrived. His study proceeded upon the assumption that the initial explosion took place in C Module. An air-hydrocarbon gas cloud expanded on combustion by a factor of about 7. Given that the gas cloud before ignition was towards the east end of the module the explosion pressure would be higher at that end. It was probable that the firewalls were severely damaged at the centre of the module and at its eastern end. With the destruction of the firewalls between C Module and B and D Modules along most, if not all, of their length much of the movement of gas would be into those modules, where it was reasonable to expect heat effects and projectile impacts. His overall conclusion was that all the critical systems either suffered considerable direct damage or were rendered inoperable due to loss of power. This was only to be expected where there was no design for blast resistance. However, there could be cases where equipment was robust enough to withstand the effects of an explosion. Disablement of equipment might have been avoided due to a variety of reasons such as distance from the centre of the explosion, the existence of a back-up battery power supply or the operation of fail-safe systems.

Electrical power

7.54 There was a considerable body of evidence as to the immediate or early loss of electric light. At the time of the initial explosion the lights went out at once in the diving area, the Mud Module, the oil laboratory and the GCM. In all these areas except possibly the last the emergency lighting came on. Witnesses spoke of the loss of power to machinery in the first 2 areas. The lights also went out in the Control Room and the Mechanical Workshop, which remained in darkness. The Control Room was severely damaged and the ceiling of the Mechanical Workshop fell in so that the lighting in both may have been completely disabled. On the other hand some time after the initial explosion light and power were still available in the drilling area. In the accommodation the normal lighting stayed on for a period and then failed. The emergency lighting came on for some 10-15 minutes and then itself failed, leaving lighting only in areas where a back-up from battery packs existed. As regards the process alarms in the Control Room and the platform general alarm system the evidence was conflicting as to whether or not they were disabled.

7.55 It was Dr Cox's view that the initial explosion probably resulted in immediate loss of electrical power from both the normal and emergency 440V switchboards, although it was not certain which elements in these systems had failed. However, he believed that the drilling 440V switchboard had continued to supply power for some minutes. The main generators might have been lost due to damage to the machines themselves, to their diesel supply, to trips caused by damage to the switchboards or to vibration trips. A cable to the 13.8 kV switchboard and a cable to and a transformer for the 4.16 kV switchboard, both at the east end of D Module mezzanine level, were probably damaged. Likewise a cable to and a transformer for the main 440V switchboard, located just to the west of the 4.16 kV switchboard, probably suffered damage. He considered that it was very probable that the emergency 440V switchboard, which was located next to the C/D firewall, would have been severely damaged. The emergency generator itself was unlikely to have been damaged given its location in the north-west corner of D Module. However, its diesel fuel supply, which ran from the 107 ft level through C Module, could well have been. Moreover, the damage to the emergency 440V switchboard could have caused the emergency generator to trip out. Probably the drilling generators in the diesel module escaped damage at this stage. Loss of the emergency switchboard would cut off the normal 125V DC and 120V AC supplies. As for the D Module UPSs Dr Cox considered that the evidence pointed strongly to the conclusion that the 120V AC UPS was damaged, but he believed that the 125V DC UPS survived for some time. The latter was in the DC room at the north-west corner of D Module mezzanine level. The former was in the same room but on the south wall and 10 ft nearer the C/D firewall. He adduced as evidence of the loss of the 120V AC UPS the absence of process alarms. As evidence of the survival of the 125V DC UPS he pointed to the operation of emergency lighting. On this assessment, accordingly, the 125V DC UPS was the only power supply in D Module which was not disabled. He considered that due to their position the 125V DC and 120V AC supplies in the Utility Module were unlikely to have been damaged. There was no evidence of changeover to the Utility Module UPS supplies.

Process alarms

7.56 There was conflicting evidence as to whether there was a supply of electrical power to the process alarms in the Control Room. Mr Bollands said he was fairly sure that the mimic panel was still intact but he could not be sure if there were lights on. The JB generator panels seemed to be all right. Mr Ferguson, who entered the Control Room after the initial explosion, said that the control panels were still in place but he could not remember any lights on them. On the other hand Mr R F Carey, an instrument technician, said that when he entered the Control Room there was definitely an alarm light with a sound on the far side of the room.

7.57 Dr Cox pointed out that the power for the main control panel annunciators was from 125V DC and 120V AC supplies in the DC room. These annunciators were relatively near the C/D firewall. On the basis of the evidence of Mr Bollands and Mr Ferguson he concluded that the process alarms were not functioning. This could have been due to damage to the panels themselves or to the 120V AC UPS or cabling. His conclusion was that it was unlikely that the process alarm panel was functioning after the initial explosion. This is the only conclusion to which Dr Cox came about which I have any doubt, in view of the evidence of Mr Carey.

Public address and general alarm systems

7.58 A number of survivors spoke of hearing an alarm. This was anything between 10 and 40 minutes after the initial explosion, according to their differing accounts. Some of them described it as sounding like an alarm for the abandonment of the platform. On any view it did not last for more than about 30 seconds. Mr Jennings said that when he was in the Radio Room some 10-15 minutes after the initial explosion he heard an alarm coming from a loud speaker in the Radio Room. He thought that it must have been on the UPS system as otherwise he would not have been able to hear it. This speaker had a microphone by which a message of abandonment could be broadcast throughout the platform. However, Mr Kinrade, the Radio Operator, was not able to say if this tannoy was working after the initial explosion. Mr Bollands described a survivor trying to activate an alarm on the west side of the platform but to no effect. The UPS should have provided power for this to sound.

7.59 Dr Cox said that in view of the conflicting eye-witness evidence the status of these systems could not be confirmed. What was heard was not definitely identified. The sound could have been due to telephones or other alarms and perhaps from such things as the operation of the halon system. The main amplifiers in the Communications Room and main reception could have survived, as well as the microphone in the Radio Room and the main reception. The microphone in the Control Room was near enough to the C/D firewall to have a significant probability of damage. Loudspeakers in some parts of the platform may have been damaged. The power supply was from the D Module 120V AC UPS with back-up from the Utility Module 120V AC UPS, changeover being manual. The former UPS and cable may well have been damaged and there was no evidence that manual changeover was effected. If on the other hand electrical supply was available the various alarms heard could have been alarms initiated by actuation of, or damage to, manual alarm points or other field equipment. Dr Cox took the view that probably the 120V AC UPS failed. His general conclusion was that the public address and general alarm systems were most likely to have been not operative due to loss of power supplies.

Communication systems

7.60 Some of the internal telephones on the platform were still working after the initial explosion. For example, Mr B C Barber, the diving superintendent, was able to telephone the Radio Room from the dive module. A number of witnesses described a telephone call received at the drill floor from the Bawden workshop on the 107 ft level, some 10 minutes after the initial explosion. A call was received in the Radio Room from the Occidental Materials Office in Submodule D about 5 minutes after the initial explosion. One of the survivors described the OIM making a telephone call to the Radio Room from the accommodation. Radio communication in the platform was still possible by means of hand-held radios. As regards radio communication between the platform and elsewhere Mr Kinrade, the Radio Officer, was not able to say to what extent the radios in the Radio Room were damaged by the initial explosion. He was able to send out a mayday a few minutes after that explosion, then a 2-tone alarm and an abandon platform message, all on 2182 kHz (which was not audible on the platform). Mr Jennings described the standby Radio Room as being inaccessible due to smoke and heat. When he reached the Radio Room 10-15 minutes after the initial explosion he found the room deserted and very hot. Over the SOLAS radio, which was battery powered, he heard the *Tharos* relaying the mayday. This radio was not linked to the tannoy. Communications to and by other platforms have been described earlier in this chapter. On the day of the disaster MCP-01 was "host" to the tropospheric services. From the evidence it is clear that the whole telemetry system failed at the time of the initial explosion. The omnibus telephone system also failed at that time, but the 3 line of sight systems continued to operate. Until about 22.20 hours both Claymore and Tartan had telephone contact with the shore by the line of sight systems via Piper into the MCP-01 tropospheric link. However, Tartan could not establish telephone contact with Claymore, whilst Claymore made no attempt to contact Tartan. After 22.20 hours Claymore and Tartan lost this link with shore. Sometime later Claymore established a telephone link with shore via satellite. When MCP-01 came to use the telephone links with Tartan and Claymore it found them dead. Later in the evening radio links were established. Claymore's call to Tartan about 23.00 hours was by VHF radio. MCP-01 also made contact with Tartan by VHF after obtaining the Tartan radio frequency from shore. At no point was any platform able to contact Piper. Flotta found the land line dead; MCP-01 obtained only a burring sound; and Claymore apparently got through but heard the telephones ringing unanswered. Mr McDonald attributed the "dropping" of the telemetry system just after 22.00 hours to damage in the Control Room, where the telemetry equipment was situated.

7.61 Dr Cox pointed out that the platform telephone exchange was powered by the D Module 120V AC UPS but had its own internal battery UPS. The radio systems were supplied from the normal and emergency 440V switchboards with battery back-up for the HF ship-to-shore radio. Since the normal and emergency 440V supplies and probably the 120V AC UPS (all in D Module) were lost at the initial explosion only those communications systems with battery back-up would have been available, namely the telephone systems, line of sight systems, the HF ship-to-shore radio and hand-held radios. He referred to the evidence of survivors that there was a partial availability of the main telephone and sound powered systems but also that some extensions were not working. The line of sight systems between Piper and Tartan and between Piper and MCP-01 were still operating at that time. The ending of the telemetry links at the initial explosion was probably due to damage to the telemetry equipment in the Control Room. His conclusion therefore was that after the initial explosion communications were probably confined to elements of the telephone system, the line of sight systems, the HF ship-to-shore radio and hand-held radios.

Emergency shutdown and depressurisation systems

7.62 According to the evidence Mr Bollands pressed the PESD button shortly after the initial explosion. He said that it appeared to him to be intact. In any event he expected the system to have shut down before he pressed it. A number of survivors were aware of a silence after the initial explosion which they associated with a platform shutdown. At the same time some survivors noticed an increase in flaring which would have been consistent with the blowdown of pressure vessels and process pipework.

7.63 Dr Cox considered that the ESD system was activated. The use of the PESD button in the Control Room opened the pneumatic loop directly and was not dependent on electrical power. Further it was probable that the pneumatic ESD loop, which passed through several process areas with high potential for damage, was in fact damaged sufficiently to depressurise it. Due to its location in A Module the wellhead hydraulic ESD system should not have been damaged. The PESD would result in shutdown of all the wells, the separators and their inlet valves, ESVs 37, 38 and 39, the gas processing equipment and the oil pumps. The gas processing plant was probably depressurised by way of compressor shutdown and loss of instrument air to the relevant pressure control valves. The pipeline ESVs not part of the ESD system probably closed due to loss of the 120V AC UPS power supply. It was also possible that the cables were damaged. The cable to ESV 501 and that to ESV 6 and ESV 956 were separate but both were vulnerable to damage. However, it was possible that local damage to pipeline ESVs occurred through damage to the valve, the actuator or the small bore pipes supplying the actuator, thus preventing full closure. I have already considered this aspect in my earlier discussion of the extended flaring.

Fire detection and protection systems

7.64 As regards gas alarms it has been recounted above that Mr Carey said that when he was in the Control Room there was definitely an alarm light on with a sound on the far side of the Control Room. On the other hand Mr Bollands said that he could not see the fire and gas panels because of smoke. As regards the fire-water system it is clear that it never came into operation. A mere trickle came out of the sprinklers at the dive module and the gondola, which was slung under the 68 ft level. Apart from this no water came out of sprinklers or the deluge or water hoses. Mr R A Vernon, lead production operator, and Mr R Carroll, safety operator, put on breathing apparatus sets and endeavoured to reach the fire pumps in D Module in order to start them manually. However, due to the fire they could not get near them.

7.65 Dr Cox stated that the fire and gas panels, which were near the firewall between C and D Modules, could easily have been damaged by the initial explosion. Power supplies could also have been damaged. The water pumps were near the same firewall and therefore might be likely to have been damaged, especially in view of the likelihood that there was greater damage at the east side rather than the west side of D Module. It was also probable that no power was available for the electrically operated pumps. The fire main on the production deck ran along C and D Modules near the firewall between them and also near the firewall between A and B Modules. The energy required to crush the fire main, which was 16 inches in diameter, was much less than the estimated kinetic energy of some of the larger debris from the firewalls. The smaller branches could be broken even more easily. The fact that Mr Vernon and Mr Carroll were unable to reach the fire pumps due to heat and smoke, along with the considerable damage to the Control Room, suggested that the fire pumps had been damaged. The main was unlikely to be intact even if the pumps could have been started. His general conclusion was that it was very likely that the fire pumps and the smaller fire main branches were severely damaged by the initial explosion so that fire-water was not available. Moreover, there was probably no capability to distribute it.

7.66 While I have no difficulty in accepting the conclusion that the initial explosion had these effects on the fire-water system, it was also clear from the evidence that at the time of the initial explosion the diesel fire pumps, which formed an important part of the fire-water system, were not on automatic but on manual mode, with the result that even if these pumps had not been rendered inoperable by the initial explosion, they would not have come into operation automatically but would have required manual intervention. Accordingly there would have been the risk that these pumps were not started at all or started after some delay. Moreover, the evidence also raised questions as to whether the deluge system in C Module would have functioned fully, in view of evidence as to a long-standing problem of blockages in the nozzles of that system. These matters were explored further in evidence. They are discussed below in Chapter 12.

7.67 In conclusion it is convenient to note a submission by the Trade Union Group that there had been a breach of Reg 9(2) of the Fire Fighting Equipment Regulations in respect that the fire pumps were not "situated in different parts of the installation". This submission was not well founded. The written guidance provided by the DEn, which is consistent with Reg 9(2), clearly took the line that what mattered was separation for the purposes of fire protection. Thus it was stated that there should be "a minimum of 2 pump units so arranged that a fire in any part of the installation will not put both pump units out of action." The arrangements in regard to the fire pumps on Piper, which are described in Chapter 3, could not unreasonably be regarded as satisfying that objective, and were apparently approved by the DEn or its agents for that purpose. What neither the regulation nor the DEn nor Occidental took into account was the risk of wholesale disablement by explosion. It was also submitted that it was arguable that there had been a breach of Reg 9(3) in respect that, having regard to the limit of endurance of their protection against fire, the pumps were not each "capable, once activated, of operating automatically for 12 hours". This submission was misconceived. The provision in question is concerned with operating capability as opposed to protection.

Chapter 8

The Effects of Events on Personnel

Introduction

8.1 In this chapter I will set out a description of the events on the platform as they affected the personnel on board. I will also compare the intended procedure for a major emergency with what happened on the evening of 6 July; and consider whether despite the fire and explosions more might have been done to save lives. My description of events is of necessity based on fragmentary evidence owing to the large loss of life. The description of what happened to survivors will continue to the point where they left the installation; their rescue will be described in Chapter 9. As regards the cause and circumstances of the deaths of the deceased, the present chapter should be read along with Chapter 10.

Personnel on board at 22.00 hours on 6 July

8.2 At 22.00 hours there were 226 personnel on board the installation (see Fig 3.11). 62 persons were on night-shift duty.

8.3 The remaining 164 persons were off duty. It appears correct to infer that by far the greatest number of them were in the living quarters at 22.00 hours. However, it is known that a few were working in the offices or were about to return from finishing overtime. Further, although they were officially off duty, 10 of the personnel were on 24 hour call. These were the OIM; the safety supervisor and the medic; the acting maintenance superintendent; the offshore projects superintendent and the offshore contracts supervisor; the drilling supervisor and the drilling platform superintendent; and the acting operations superintendent and the acting deputy operations superintendent.

Occidental's system for control of a major emergency

8.4 The system is set out in Occidental's Emergency Procedures Manual and was described in evidence by Mr G Richards, the back-to-back OIM, and other witnesses. Under that system a major emergency is defined as one requiring the mobilisation of the response teams and key personnel and possibly external support. An example of such an emergency is the occurrence of a fire or explosion which involves the need to evacuate the installation. Under the system it was the duty of personnel at the site of an incident to activate the general emergency alarm or telephone the Control Room or the Radio Room. The operator in either of these rooms then notified the OIM and personnel are sent to investigate and report back.

8.5 The OIM was expected to proceed to the Radio Room and exercise control from there. On his instructions the Duty Communications Operator at the Occidental Emergency Control Centre in Aberdeen and other agencies would be informed. The OIM was to remain in charge of the platform throughout the emergency. He was responsible for ensuring the shutdown of the process and drilling operations, the direction of fire-fighting and damage control, the evacuation of non-essential personnel, and the evacuation of diving personnel. He was to discharge these responsibilities by co-ordinating the work of key personnel from the Radio Room. He was also to maintain liaison with the Onshore Emergency Controller and his team.

8.6 The OIM was the person who had the ultimate responsibility for deciding whether the platform should be abandoned and if so by what method. In the event of a major emergency the first objective was to ensure that non-essential personnel were taken off the installation before conditions deteriorated. If it appeared that evacuation might be necessary the OIM was responsible for alerting Occidental's Communication Operator in Aberdeen. He was to ensure that contact was made with the Duty Doctor if medical assistance was required. He was to consult with or advise the Onshore Emergency Controller on the evacuation of non-essential personnel. He was to contact the standby vessel and call other installations, shipping and helicopters in the area for assistance if that was necessary; and advise the coastal radio and Coastguard that evacuation was taking place. Following an emergency on the installation on 24 March 1984 Occidental reviewed and modified their emergency procedures. One of the changes which was made was the institution of an Emergency Evacuation Controller (EEC) and his team which included the helicopter landing officer and the lifeboat coxswains. Their function was the evacuation of non-essential personnel. They assembled at the reception area where the EEC directed the arrangements for evacuation in consultation with the OIM. If the OIM summoned helicopter transport, which was the preferred method of evacuation, the EEC was to ensure that the helideck was operational and that groups of personnel were called up from the lifeboat muster stations where they had assembled. (It may be noted that as the result of drills on the installation personnel were familiar with the practice of proceeding to their lifeboat stations from which one lifeboat complement at a time was called to the reception area as if for evacuation by helicopter.) Information on the state of evacuation was to be broadcast under the instructions of the OIM. If as a last resort evacuation by lifeboats was essential, the OIM was to give the instruction 3 times on the public address system. If the evacuation was to be total, the OIM had to ensure the complete shutdown of the platform; and the standby vessel and Occidental's emergency control centre were to be informed before transmissions were closed down. The lifeboat coxswains were responsible to the OIM and the EEC for all operations concerning the lifeboat stations and were to await instructions from the OIM on the public address system before allowing personnel to board the lifeboats.

8.7 Also according to Occidental's system the Operations Superintendent was to go to the Control Room to assess the extent of the emergency and determine priorities. He was to co-ordinate plant shutdown to a safe status and fire and damage control in production areas. It was his responsibility to maintain contact with the emergency teams and keep the OIM informed as to plant status and emergency action. He was also required to ensure that the other pipeline users were kept informed of the situation. The "assigned mechanic and electrician", whose names were shown on a notice board, were required to report to the electrical workshop and start up and run the emergency diesel pumps (for pumping fire-water) and SOLAR generator "as required" (in accordance with para 6.2.7 of Occidental's Emergency Procedures Manual). The safety supervisor was to co-ordinate fire and damage control with the superintendents, advise emergency teams and keep in touch with the Radio and Control Rooms. Safety operators were assigned to each of the emergency teams. These emergency teams were 3 in number and each normally had 6 members. An Occidental team was made up of personnel from the Maintenance Department with a leading hand in charge. A second team was made up of personnel employed by Bawden International with a toolpusher in charge. A third team was made up of personnel employed by companies in the Wood Group with a supervisor in charge. The Bawden team was to muster at the White House on the pipe deck. The other two teams were to muster at the Electrical and Mechanical Workshops in D Module. These teams were to remain on the installation to deal with any fires, depending on the extent and location, until there was no further hope of control. The Drilling Superintendent was responsible for closing down the wells.

The response to the emergency

8.8 In the event the system was almost entirely inoperative and little command or control was exercised over the movements of personnel.

8.9 Mr D H Kinrade, the Radio Operator, stated in evidence that the OIM came into the Radio Room which was situated above D Deck of the ERQ a few minutes after the initial explosion. He was wearing a survival suit. Mr Kinrade did not think that he had a portable radio with him. The OIM instructed him to send out a mayday call because of the explosion and fire. Mr Kinrade then sent out a mayday call asking for assistance. He used the international distress frequency of 2182 kHz. This was about 3-5 minutes after the initial explosion. At that stage the OIM had said nothing to him about evacuation. He did not seek to use the public address system on the installation or instruct Mr Kinrade to use it. Mr Kinrade did press the button and blow into the microphone for the public address system but found it difficult to tell whether it was still working. Public address could also be achieved by means of the use of the internal telephone system but Mr Kinrade did not establish whether this was working. The normal procedure would be for the radio operator to establish whether the radio equipment was damaged and to await instructions from the OIM. Depending on those instructions he would have established a telephone circuit with the Occidental office in Aberdeen; established contact with the standby vessel and the *Tharos* by VHF radio; and used the public address system to instruct personnel on board the installation. However, the OIM left the Radio Room without giving any further instructions or stating what were his intentions. (I should add that Mr Kinrade said that the telephone for communication with the Occidental office had come off the bulkhead, but he did not know if it was still operable.) The OIM had been gone "a matter of seconds when he came running back" in what appeared to Mr Kinrade to be a state of panic. He told Mr Kinrade that the access to the Radio Room was on fire and full of smoke. Mr Kinrade told him that in that case they had to get out and could use an escape hatch for the purpose. Mr Kinrade took out 3 life-jackets, one for the OIM, one for himself and one for a telecommunications engineer who was also in the Radio Room at the time. The OIM instructed Mr Kinrade to broadcast a message on the same frequency as before that the platform was being abandoned. He did not say what kind of abandonment. Mr Kinrade set off a 2-tone alarm signal in order to discourage other radio traffic on the frequency and broadcast that the platform was going to be abandoned. He said that he himself was panicking and the message was haphazard. The OIM made no specific attempt to call in helicopters from the *Tharos* or elsewhere; or to communicate with vessels around the installation; or with the shore or other installations; or with personnel on Piper. As stated above it appeared that the OIM did not have a portable radio with which to communicate with senior personnel who had such radios. It would not have been possible for him by using facilities in the Radio Room to make contact with such radios. Mr Kinrade added that while he was in the Radio Room a telephone call was received on the FILO's telephone from Mr E Duncan in the Materials Office to the effect that he was trapped there because of fire and asking if the other radio operator could go with keys to enable him to get out of that room into the adjoining telecom room at the west end of Sub Module D. This was possibly about 5 minutes after the initial explosion. After broadcasting the second message Mr Kinrade along with the OIM and the engineer left the Radio Room. By this stage flames could be seen coming up the east side of the platform and coming out of the east crane.

8.10 There is reason to think that the evidence given by Mr Kinrade as to the messages sent out by him was not entirely accurate. According to the record of messages picked up by Wick radio from Piper on 2182 kHz, which I accept as being an accurate record, the following messages were heard:-

> At 22.04½ hours: "Mayday (repeated) .... explosion and fire on the oil rig on the platform and we'll (sic) abandoning abandoning the rig". The record notes that radio interference was being experienced at this time. This message was acknowledged at 22.05 hours.
>
> 22.06 hours: "Mayday (repeated) .... we require any assistance available any assistance available we've had an explosion and er a very bad explosion and fire er the Radio Room is badly damaged".
>
> 22.08 hours: "Mayday (repeated) .... we're abandoning the Radio Room we're abandoning the Radio Room we can't talk any more we're on fire."

There are a number of possible explanations for these inconsistencies and in particular in regard to whether Mr Kinrade broadcast at the outset that the installation was being abandoned. Apart from the obvious explanation that Mr Kinrade's memory has become confused, one possibility is that he broadcast a message that was not picked up by Wick radio. However Mr Kinrade said clearly that he had sent out no mayday before sending out one 3-5 minutes after the initial explosion. Another is that the first message picked up by Wick radio was in fact 2 messages that appeared to run into one because of interference. The third is that Mr Kinrade was still in the process of sending out the first mayday when the OIM returned to the Radio Room and told him to send out a message about abandonment of the installation. It is unnecessary for me to choose which of these explanations is the correct one. While I accept that the record kept by Wick radio as the reliable account of the messages sent out I have no difficulty in accepting the substance of the rest of Mr Kinrade's evidence.

8.11 Mr M H G Jennings, the FILO, who had been in the cinema at the time of the initial explosion went to the dining-room on D Deck of the ERQ and telephoned the Radio Room. He spoke to the telecommunications engineer who told him that Mr Kinrade was putting out a mayday call. He suggested that Mr Jennings check the Standby Radio Room which was in the AAW. Mr Jennings found that that room was inaccessible on account of smoke and heat. When he reached the Radio Room about 10-15 minutes after the explosion it was deserted and very hot. Over the SOLAS radio, which was battery powered, he heard the *Tharos* relaying the mayday. From a loudspeaker he heard an alarm.

8.12 From the evidence it is possible to gain some insight into the limited extent to which there was an organised response to the events that had so suddenly and so quickly overwhelmed the installation. The EEC, who was Mr J Heggie, and at least part of his team assembled at the reception area. Both Mr Heggie and Mr N McLeod, who was second in command, had portable radios. Mr A H Mochan, who was another member of the team gave evidence that Mr McLeod and another volunteered to put on breathing apparatus and look for a way of escape out of the doors from the reception area to the helideck (see Fig J.7(d)). They returned in about 10 minutes saying that things were "pretty desperate". It was known that Mr R Carroll was in the area of the Control Room and in touch with Mr Heggie by portable radio. He and Mr Vernon, lead production operator, put on breathing apparatus and made an unsuccessful attempt to reach the fire-water pumps in order to start them. However they found that they could not approach them owing to the smoke and flames. Owing to the conditions the emergency response teams were unable to reach their respective muster points. However it appears that a number of small groups of men, wearing fire-fighting clothing and breathing apparatus, made a series of excursions out of the upper levels of the ERQ in order to see whether there was any safe route available. These may well have been members of one or other of the emergency response teams. The safety supervisor, Mr A Wicks, was also seen wearing breathing apparatus and apparently looking for a way out. In the event none of these brave efforts led to anything. At no time was there any organised exodus from the accommodation. Access to the lifeboat muster stations was at all times out of the question because of the presence of smoke and flames. Likewise the smoke and flames would have made it impossible for any helicopter to land on the helideck. Persons such as Mr Mochan spent a considerable amount of time searching for a means of getting out of the accommodation. There were no facilities in the ERQ to assist the OIM or other senior personnel to assess the situation outside; or determine the status or action of any of the emergency systems.

8.13 I have set out above a brief account of whatever traces there may have been of the coming into operation of any system for coping with a major emergency on the evening of 6 July. Later in this chapter I will come to the situation which developed in the living quarters and the way in which a number of survivors made their escape from it. However in attempting to set out the whole picture it is appropriate at this point to turn to the various groups of personnel who were at work at 22.00 hours. As will be seen a number of them never reached the accommodation but were able to make their escape from the installation. Others reached the accommodation; and from that point onwards the story of their escape is bound up with the larger number of personnel who had been in the living quarters when the initial explosion occurred.

Personnel working on the 68 ft level and below; and in D Module

8.14 At the time of the initial explosion 7 divers were on or near the dive skid below the 68 ft level and one was working underwater at -50 ft depth. The diving supervisor was in the gondola at the 58 ft level and 6 other diving personnel, including Mr S R MacLeod, the diving superintendent, and Mr B Barber the Occidental diving representative, were working in or near the dive complex on the 68 ft level (see Fig J.6). Immediately after the initial explosion these levels were progressively affected by fire and the dropping of oil and debris from above. The smoke which at first was light rapidly became dense. These personnel were efficiently and intelligently led and their orderly evacuation owes a lot to the presence of mind of Mr MacLeod and Mr Barber, the latter of whom perished later when making his escape to the sea. In accordance with normal procedure the diving personnel assembled at the dive complex. Steps were taken to recover the diver who was submerged. After a brief period in a decompression chamber he joined the rest of the personnel in making their way to the north-west corner of the platform on the 68 ft level. It had been intended that they should muster at their lifeboat station on the 107 ft level but the smoke was so dense that they were unable to reach a higher level than the 68 ft level. Before the diving personnel set out from the dive complex the Radio Room had been unable to give any advice to them as to which route they could take. By the time that the last of them, including Mr MacLeod, left the dive complex the dive skid was, in his words, "like an inferno". Accordingly by the time this group reached the north-west corner it was impossible for them to retreat to the area from which they had come. Dense black smoke was being blown along the platform in a north-easterly direction. The north side of the platform was wholly enveloped in smoke. Their only means of escape was to go down to sea level. It was impossible by then for them to use the internal stairways from the 68 ft to the 20 ft level. They reached the 20 ft level by means of a knotted rope attached to the 68 ft level which was reached by use of the navigation platform located a short distance below that level. They were joined in this means of escape by 4 riggers who had been working on the 68 ft and the 20 ft levels; by 7 personnel from the Mechanical, Instrument and Electrical Workshops in D Module; by Mr Clark and Mr Bollands from the Control Room; and by Mr Young from the 68 ft level. Two of these personnel fell off the rope into the sea on their way down to the 20 ft level. The explosion at 22.20 hours forced one of them to jump off the navigation platform into the sea and others to jump off the 20 ft level. Apart from these personnel a further rigger who had been working on the 40 ft level jumped off the 68 ft level into the sea. Mr Grieve who had been on the 68 ft level in the area of the condensate pump jumped off the same navigation platform. It remains to mention the chemist, Mr M R Khan, who was working alone in the oil lab on the 68 ft level. He walked directly to the 20 ft level by means of a stairway at the southern end of the platform.

Personnel working elsewhere

8.15 As was shown in the earlier chapters the initial explosion took place in C Module and was followed rapidly by a crude oil fire in B Module. The survivors included no one who had been present in A, B or C Modules at the time of the initial explosion. Apart from the obvious conclusion which can be drawn from the initial explosion and the subsequent fire and explosion no specific account can be given of what happened to such of the personnel on duty as were working in any of these modules at 22.00 hours.

8.16 As regards the other working areas, 10 of the personnel who had been working there survived the disaster. Of these 10, 6 were employees of Bawden International. The initial actions of the shift drilling crew indicated a well organised response to the initial explosion. Having ensured that the drilling equipment had been secured the

Bawden employees from the drill floor crossed the pipe deck as a group and formed around the entrance to the Bawden offices on B Deck under the instructions of the toolpusher, Mr J L Gutteridge. The main body of drilling personnel then made their way to the galley on D Deck in order to muster there (see Fig J.7). Mr Gutteridge stated in evidence that it was decided that this should be done because it was already apparent to him that he could not muster the Bawden emergency response team at the White House on the pipe deck because of the smoke. However, 2 of the Bawden personnel having talked together decided that it was not worth while for them to wait in the smoke at the accommodation and made their way back to the drill floor where the air was clear. They then decided that their best course of action was to get down to the 68 ft level at the south-west corner of the platform, from which they jumped at the time of the rupture of the Tartan riser at 22.20 hours. Meanwhile Mr Gutteridge and others checked the Bawden living quarters for any men who were off duty and investigated to see if any of the exits from the accommodation were passable before going to the galley. The remaining 4 personnel consisted of Mr Mochan and Mr Kinrade, who have been mentioned already, and 2 personnel who had been engaged on work on the GCM and made their way to the accommodation.

The accommodation

8.17 The remaining 20 survivors were in the ERQ at the time of the initial explosion. 7 were in the cinema on C Deck. One was in the television room next to the cinema. 12 were in cabins (1 on A Deck; 7 on B Deck; 3 on C Deck; and 1 on D Deck). As has been mentioned already, after the initial explosion there was no announcement of any kind made by the public address system and no alarm, whether a general or an abandon platform alarm, was sounded. However, from the time of the initial explosion none of the survivors had been in any doubt that a major emergency had occurred and that the platform would require to be evacuated. Along with others in the living quarters they made their way to the higher levels of the accommodation (see Fig J.7). A large number of them began to assemble in the galley. There was no evidence that this was the result of any positive actions on the part of anyone in a position of authority. Varying estimates of their numbers were given in evidence. One witness estimated their number as being in the region of 100. Mr Mochan said that the EEC's team were advised by those who were outside the accommodation to keep people as calm as possible until a way out could be found for them. At first conditions were not too bad. There was still emergency lighting and the smoke in the atmosphere was light. It is clear that personnel were waiting in the galley for a helicopter to arrive to take them off. However after the emergency lights went out panic set in. The smoke was becoming much worse and beginning to affect the personnel. It seemed that the opening of doors was the main source of the increasing smoke. The deteriorating conditions forced the men to crawl along the floor at low level in order to escape the worst and use wet towels as make-shift face masks. The smoke was gradually incapacitating its victims both physically and in their thought processes. Some hoped that the *Tharos* might be able to take them off. At 22.33 hours the following message on channel 9 VHF was received by the *Tharos*: "People majority in galley area. Tharos come. Gangway/hoses. Getting bad."

8.18 From the evidence it is clear that the personnel in the galley received no further instruction than to wait for a helicopter to take them off. There were no instructions as to what to do or where to go. A number of survivors said that in the galley no one was in charge or giving instructions or advice; and that there was confusion. Mr Jennings said that he was carried by the crowd into the dining-room where he could see flames coming up the north face of the platform. The OIM was trying to calm everyone, saying that the mayday had been put out and that the whole world knew they were having problems. It was already obvious to the witness (who was a FILO) that a helicopter could not land safely on the platform. Another survivor described the OIM trying to make a telephone call in the galley. After the call the OIM said that he had made a distress call to all shipping and helicopters in the area. The OIM did not give any other instruction or guidance. One survivor said that at one stage people were shouting at the OIM and asking what was going on and what procedure to follow. He did not know whether the OIM was in shock or not but he did not seem able to come up with any answer. The witness thought that it was a safety officer who said that a mayday had been sent out and that a helicopter would be there in an hour. Nobody was giving any orders. Another survivor said that the OIM came into the galley and just generally asked if there was contact with the Control Room. He was told "no, no contact". After a further explosion quite a few started to panic, screaming for someone to make a decision. It was fairly obvious that there was not much of a decision to be made ie he had to get out of there. Another survivor said that when there was panic and shouting, no one seemed to be taking charge. Another survivor described the OIM as standing on a table in the centre of the galley. He supposed that he was trying to assume some kind of command. This was virtually impossible due to panic, commotion and heckling. The witness said to the OIM that he was in charge and to get them out of there. The OIM told him to calm down. He told him that 4 men were outside with breathing apparatus trying to find an escape exit. The OIM spoke 4 times into a radio in order to make contact with the men but got no answer. People were now crouching down in the dining-room in order to avoid the smoke as far as possible.

8.19 Following the rupture of the Tartan riser at 22.20 hours a number of personnel in the accommodation and especially those on D Deck reached a point where they decided individually or in groups that they had to find a way out. In a few cases they had a particular destination in mind but in most cases the main aim was to get out of the accommodation. Some left the galley because there was no point in staying there. Others realised that if they did not get out they were going to die there. Others took the view that they had nothing to lose by at least attempting to save themselves. A particularly graphic account was given by Mr J M McDonald, a rigger. He asked the Occidental lead production operator, Mr A Carter, for instructions but found that he was delirious. He then said in evidence:

> "I just said to myself 'get yourself off'. I got my pal Francis, and I got him as far as the reception, but he would not go down the stairs because he says 'We have done our muster job; they'll send choppers in'. I said to Francis 'I've tried to speak to Alan Carter; Alan Carter cannot talk to me, Francis. There's something drastically wrong on this rig. We'll have to get off'. Francis would not go, and he just slumped down. Anybody that knows the rig and the reception next to the bond, he slumped down there. That was as far as I could get him."

A large number of people apparently made no attempt to leave the accommodation. From the evidence it appears that there were a number of reasons for this. Some waited in the hope of a helicopter coming. Some stayed because they had been told to wait there and had received no other instruction. Some would not have remained there if they had known the full gravity of the situation which threatened the platform. Others remained because they simply did not know what else to do. There was no systematic attempt to lead men to a means of escape from the accommodation.

Escape from the accommodation

8.20 While conditions were deteriorating in the accommodation and in particular in the galley area on D Deck of the ERQ small groups of personnel were searching for a safe way of getting out of the accommodation. A number of drillers were aiming to reach the drill floor. Most had no objective other than getting out of the accommodation and in doing so they took whatever opportunities presented themselves. There was no organised escape. If leadership occurred in these escapes, it arose by individuals joining those who seemed to know their way around. A number of the survivors said that it was only their familiarity with the platform which saved them. One of these was Mr McDonald to whom I referred in para 8.19. Making use of advice which he had heard on a training course he used his initiative and found out that the wind was blowing from the south after he had got out of the accommodation. He used his knowledge of the platform to make his way to the drill floor and from there to the south-west navigation platform from which he descended by means of a hose before dropping into the sea. It is impossible to state the total number of personnel who were able to leave the accommodation. Of those who did 28 survived. They left behind them at least 81 personnel in the accommodation. Many of them were not familiar with the platform outside the accommodation. This was the total number of bodies which were later recovered from the accommodation, as will be explained in Chapter 10.

8.21 Personnel found that they could escape from the accommodation at a number of levels and exits (see Fig J.7). On D Deck they escaped through the door which led from reception to the helideck; through the double doors in the storeroom adjacent to the kitchen; and through the double doors on the east side of the dining-room. From this level a number of them made their way down to the pipe deck, whereas others climbed up on to the level of the helideck (see Fig J.5). 10 survivors escaped from D Deck and made their way in one or other of these directions. 7 of them reached the level of the helideck. When they were there, 4 of them were forced to jump into the sea by the explosion at 22.50 hours. The distance from the helideck to sea level was approximately 175 ft. The remaining 3 then made their way down the outside of the south face of the accommodation to the pipe deck. 7 of the survivors escaped at C Deck from the accommodation, using the double doors of the recreation room which were adjacent to the construction and drilling tea huts. One of them, Mr Kinrade, made his way up to the level of the helideck where he too was forced to jump into the sea. The remainder made their way downwards towards the pipe deck. 11 survivors escaped by the door on B Deck which was adjacent to the Bawden Office. These included Mr Gutteridge and 4 other drillers who were familiar with the means of access to the accommodation at that point. From this door these survivors and others made their way to the pipe deck. Having reached the pipe deck a number of survivors who were mainly drillers made their way to the drill floor and across it to the navigation platform at the south-west corner of the 68 ft level where they climbed down a hose from which they dropped 15-20 ft into the sea and swam to leg B1 at the south-west corner of the platform. 2 survivors made their way to the drill floor and down to the oil lab on the 68 ft level where, after throwing a life raft overboard, "which failed to inflate" they climbed down a rope and entered the sea. One survivor headed for the south-east corner of the platform and used a rope in order to descend from the navigation platform at the 68 ft level. At that corner he reached the base of leg A1 where he stood until he was forced off it by the explosion at 22.50 hours. Another survivor crossed to the drilling derrick and climbed on to a roof beside it and facing south. He remained there until he was forced to jump off as a result of the same explosion. The remaining survivors who had reached the pipe deck sheltered for a time in the White House, which was the drill store, and the OPG Fabrication Workshop on the north side of that deck. At the time of or shortly after the damage to that deck which occurred as a result of a series of explosions (described in para 7.26) they attempted to get off the platform by jumping from the level of the pipe deck which was approximately 133 ft above sea level. 15 survivors made their escape from the platform in this way and through intense heat. 13 made their way along pipes on the collapsed slope of the west side of the pipe deck and jumped off. One went along a beam beside the SPEE Module on the north side of the gap which had opened in the pipe deck; and one ran along a cat-walk, probably on the east side of the platform, and jumped off.

8.22 A number of the survivors who jumped off the platform from a great height commented that they had been led to believe that it was very likely to prove fatal. In that connection the Emergency Response Handbook provided by Robert Gordon Institute of Technology (RGIT) to those undertaking training in survival has, since the disaster, highlighted the advice that it is recommended that persons seeking to escape should get down if possible to a height of 10m before going into the water: but that if a person is in a "no alternative" situation at whatever height and is forced to step off, he will have to do so. It was also noteworthy that when jumping into the water survivors followed their training by holding their nose with one hand; and holding down their life-jackets with the other arm in order to minimise the risk of breaking their necks when they hit the water. Some also adopted the expedient of curling themselves into a ball in order to minimise impact injury.

Summary of escape from the platform

8.23 Since the bodies of 30 of the personnel from Piper have not been recovered it is not possible to determine how many of the personnel from Piper escaped alive from the platform. As regards those whose bodies have been recovered, it will be seen from para 10.19 that in 14 cases the deceased died during or after an escape from the platform. A total of 61 of the personnel from Piper survived the event. Their evidence was heard at the Inquiry. In the light of the account which I have given in the preceding paragraphs and which is based on that evidence it can be seen that they escaped from the platform in the following ways:-

27 descended by rope from a navigation platform below the 68 ft level to the 20 ft level.
1 walked down by stairways to the 20 ft level.
7 climbed down a rope or hose from the 68 ft level or a navigation platform below it and dropped into the sea.
5 jumped off the 68 ft level or a navigation platform below it.
1 jumped off a roof beside the derrick.
15 jumped off at the level of the pipe deck (133 ft).
5 jumped off at the level of the helideck (175 ft).

8.24 Of the 61 survivors, 39 (including 34 contractors' personnel) had been on night-shift duty. The remaining 22 (including 21 contractors' personnel) had been off duty. These numbers may be broken down by categories of work as follows:-

Category	*On duty*	*Contractors*	*Off duty*	*Contractors*
Operations	3	1	—	—
Drilling	6	6	4	4
Maintenance	8	5	5	4
Marine & Underwater	19	19	—	—
Offshore Projects	2	2	12	12
Inspectorate UK	1	1	1	1
	39	34	22	21

This may be compared with the table of the total complement (Table 3.2) and the breakdown of the numbers of the deceased in para 10.20. It may be noted that 63% of those who had been on night-shift duty survived the disaster; whereas only 13% of those who had been off duty did so.

Life rafts

8.25 The capsules in which the life rafts were contained were situated on the 68 ft level (see Plate 12(b)). It was intended that they should be launched overboard after the pin which secured the straps holding the capsule in place had been removed. One end of a painter line was attached to the platform at the point of launch and the other end was attached to a mechanism inside the capsule for operating a gas cylinder. When the capsule was launched, its fall caused a length of the painter line to be pulled out of the capsule. Once the capsule had reached the sea a further length of the painter line required to be pulled out of the capsule until the end of the line was reached. At that point a further pull or tug would cause gas to discharge from the cylinder and the life raft to inflate. The length of painter line which was used on Piper was twice the distance between the 68 ft level and sea level. This length was in accordance with the length prescribed by the SOLAS convention. However, while the convention applies to ships and mobile installations, it does not apply to fixed installations. Accordingly it would have been open to Occidental to arrange for any length of painter line so long as it was of appropriate length, ie long enough to allow for the distance between the 68 ft level and sea level together with a nominal margin and an allowance for tidal effect. The length of painter which required to be pulled out was marked on each capsule. However it was not shown on a pictogram which was displayed at the launching point for the guidance of those intending to put a life raft into operation.

8.26 A number of the survivors who had assembled at the north-west corner of the 68 ft level kicked a life raft capsule overboard but were unable to inflate the life raft. One witness said that the painter line had been pulled out "to the bitter end". It was, he said, "a ridiculous long amount to pull". Several witnesses said that the painter line was pulled out to the extent that it was taut and the life raft was being pulled out of the water. Following these efforts the life raft drifted under the jacket and the line became wrapped around a leg of the platform. The attempt to inflate the life raft was then abandoned. Mr P G Jeffery, Consultant Engineer, of Plessey Assessment Services, carried out an examination on 31 January 1989 of a number of life rafts which had been recovered after the disaster, including the life raft to which I have referred above. It had been recovered partially inflated. At the time of his examination it had been deflated. He found that the valve head of the cylinder showed that the cylinder had been operated. This was confirmed by removing the operating head cover and examining the mechanism. There was no evidence of malfunctioning on any of the operating heads. Mr Jeffery also found that there was no sign of fire damage or oil contamination on the life raft. The survival packs were complete and the sea anchors secured. There was a tear in the boarding ramp consistent with fouling after inflation. The container had a split and some signs of charring and oil residue. He said that it appeared that wave action had caused the life raft to inflate. The pull required for this purpose would have been between 12 and 30 lb. He had carried out a functional test of a life raft which had been recovered from Piper still in its capsule. In this case it had been found that the painter which was considerably frayed was fully extended although inflation had not taken place. Only a sharp tug was required to cause this life raft to inflate. It did not fully deploy, apparently because the survival equipment container had become displaced in the life raft chamber, probably during recovery, and as a result the cord securing the container had become snagged around the buoyancy chambers. It could have been deployed manually. As regards the evidence given by the survivors Mr Jeffery suggested that there was confusion as to what was happening at the time. The witnesses were not clear as to what had to be pulled out of the capsule. As the painter line was pulled out of the capsule it would appear taut. Wave action could give the impression that the life raft was being lifted out of the water. He suggested that either the painter had not been fully extended or that it had not been pulled hard enough. However, if anyone could lift the life raft, which weighed 400 lb, out of the sea it would be expected to inflate. As regards the maintenance of the life rafts, the Merchant Shipping (Life-saving Appliances) Regulations require that inflatable life rafts be serviced annually at an approved service station. Records of the servicing of all the life rafts on Piper had been provided and checked against the serial numbers noted in the last survey of life rafts by the DoT in February 1988. The installation records and servicing certificates accorded with the survey certificate. In those circumstances Mr Jeffery found no evidence of any general failure in maintenance which might throw light on the incident. In that state of the evidence I am not able to come to any definite conclusion as to the cause of the non-inflation of the life raft from the north-west corner of the 68 ft level. Despite the fact that survivors described the life raft in graphic terms as being lifted out of the water I am inclined to think that in the circumstances of the emergency confronting them they may, quite understandably, have thought that they had reached the point at which they had done everything to inflate the life raft when in fact this was not so. The fact that the painter line was twice the length of the distance between the 68 ft level and sea level might well have made it more difficult for them to cause inflation.

8.27 It was clear that a number of those who assembled at the north-west corner of the 68 ft level had never been shown the location of the life rafts nor how to launch and inflate them. Some survivors did not know how long was the painter line which required to be pulled out of the capsule after it had landed in the sea. Others thought it was considerably shorter than it was. I will return to the matter of safety inductions in Chapter 13.

8.28 In the course of making their escape from the platform 2 of the survivors had kicked a life raft capsule at the south-west corner of the platform but had made no attempt at inflating it as it was seen to be moving under the platform. (It may be noted that this life raft was at the time obscured by scaffolding boards. Mr B M Goodwin, one of the 2 survivors, said that he would not have known of its presence if he had not carried out maintenance on it before the disaster.) This life raft was also recovered after it had inflated of its own accord. It was covered in oil, badly burned and damaged apart from the underside of the floor. This was consistent with it having drifted under a spray of hot or burning oil. There was no evidence that any attempt had been made to use any other life raft on the platform.

8.29 Mr Goodwin also gave evidence that some months before the disaster and shortly before an inspection - which may have been the DoT inspection in February 1988 - he had found that the lever which was intended to be used to make the capsule drop into the sea was seized as a result of salt spray. The same applied to most of such levers at that time. It did not, however, prevent the capsules from being kicked overboard. He had managed to loosen the lever and had reported their state to the safety department. Mr G G Robertson, safety supervisor, said that 2 levers on the west side of the platform had been reported as seized but were found to be operable after maintenance had been carried out. He said that the life rafts were checked monthly by the safety department. There was no evidence before the Inquiry that at the time of the disaster any of the levers were seized or that their maintenance was deficient.

Life-jackets

8.30 The life-jackets used on Piper were of the standard non-inflatable type which was passed over the head and had flotation compartments at the front and back. They were fitted with a whistle and had reflective strips to made them visible. Each person on board was allocated one for his own use which was kept in his cabin. Supplementary life-jackets were kept at lifeboat muster stations but these were fewer in number than those kept in the cabins. A number of life-jackets kept in reserve in a box at the north-west corner of the platform proved insufficient to meet the demand from the survivors who had arrived there. They had, of course, been unable to return to the accommodation to collect their own life-jackets. A number of survivors criticised the type of life-jacket. It was said that they were too bulky for narrow spaces, for wearing with breathing apparatus, for climbing down knotted ropes and for wearing while swimming. It was said that they could get water-logged and did not always keep the face of the wearer out of the water. Some bodies had been seen dressed in survival suits and wearing life-jackets but face downwards in the water. It was also pointed out that orange was an unsatisfactory colour for life-jackets since many other objects likely to be seen in the sea were of the same colour.

The later examination of the accommodation

8.31 In November 1988 the ERQ and the AAW were recovered from the bed of the sea adjacent to the remains of the platform jacket and transported to Flotta. Mr D M Tucker, Fire and Loss Consultant, gave evidence as to his findings following an examination of these parts in the accommodation in November 1988 at Flotta. His evidence throws further light on what happened inside these modules during the course of the events which I have attempted to describe above from the point of view of the personnel who were there.

8.32 As regards the ERQ he found that there was evidence of severe external attack by fire on its east and north sides (see Plate 22(a)). There was little evidence of attack by fire elsewhere save at the north-west corner where windows on the north face had broken and there had been some limited spread of fire into the end cabins on the lower 3 decks. The west and south elevations had been protected by adjoining and adjacent structures (see Plate 22(b)). The underside of the ERQ appeared to have suffered relatively little fire attack. Paint on the helideck was increasingly damaged towards its south-eastern corner. In general the fabric had been fairly successful in withstanding the effect of heat. On the other hand, he found that smoke, hot gases and some flame had spread into the reception area on D Deck through a door-way from the LQW and the door on the south side which gave access to the helideck. It was not possible to say which was the more important route. This was consistent with prolonged exposure to a layer of very hot smoke spreading in from these directions. He said that conditions in this area would not have been survivable for long. However, closed doors leading off from the reception area had protected the rooms beyond. Smoke and gases had been able to spread to rooms which were near the reception area and the kitchen storeroom by way of voids in the ceiling. On the other hand walls and other barriers had prevented them spreading by this route to the plant room, stair enclosure and dining-room. There was no evidence that the ventilation system had been a major route. The ventilation air intake dampers were found to be closed. They were designed to be activated by high temperature but not by smoke so that closure must have been due to heat from the fire. The ventilation fans would have stopped on loss of power so that air was no longer drawn in. (It appears therefore to have been the fortuitous loss of power which prevented smoke being drawn in by way of the ventilation system, at least until the inlet dampers closed on account of the heat.) He found that a fire-resisting door between the reception area and the staircase had been held open by a hook. (This was apparently because the reception area was both a general thoroughfare and an emergency control centre.) As a result hot, dense smoke had spread into the passage between the reception area and the dining-room and stairwell. The door from the passage to the dining-room had been open briefly from time to time. There was no major route of smoke ingress to the dining-room but it could reach that area through gaps around the door, when the door was opened and through the kitchen and ventilation system. Some smoke could have entered the kitchen from the storeroom by way of ceiling voids or extract trunking. The kitchen and the dining-room showed moderate smoke damage but no heat damage. He thought that judging by smoke deposits conditions there would have been survivable in the short term. There would have been enough oxygen in the ERQ as it was not totally enveloped in flames, especially on its south side. Accordingly in the light of his examination of the ERQ it was possible that some of the deceased might still have been alive in those rooms when the ERQ fell into the sea. Mr Tucker noted that the ERQ was more substantial and more insulated than the AAW. Its sprinkler system was intact and would have operated if it had been activated. Its operation would have washed out some of the particles and possibly some of the toxic products from the smoke and so prolonged the conditions in which personnel could have survived. To minimise smoke ingress and prolong survival the fire doors should have been kept shut. The closing of the door between the reception area and the stairs, which was a self-closing door would have reduced the ingress of smoke to the dining area possibly by a significant amount. As regards the other levels he found that smoke conditions would have been in general survivable in the cabins. On C Deck he found that its north corridor had been affected by a spread of smoke and hot gases from the LQW. Smoke damage to cabins had occurred where their doors had been open. In A and B Decks there was only slight smoke damage. As regards both C and B Decks there was no significant evidence of the spread of smoke from the AAE.

8.33 As regards the AAW Mr Tucker found that there had been severe heating of its external faces and roof (see Plate 23). This module had been subjected to considerably more fire than the ERQ and possibly for longer. However, it was less able to withstand a given level of fire. The external copper piping of the sprinkler mains especially on the south side, had melted. This probably would not have happened if water had been flowing through it. As regards internal damage this was more severe than in the case of the ERQ. He took the view that it was unlikely that anyone who had been trapped in it would have survived even before this module fell into the sea.

Heat conducted through the external walls had damaged most of its rooms. Fire and hot gases had come through the external doors. Hot gases and smoke had also entered it through the ventilation trunking and some of the extract trunking. All of the sprinkler heads appeared to have been activated by heat. Mr Tucker said that the AAW did not have true fire dampers. However the later evidence of Mr G H Bagnall, a lead maintenance technician with Occidental, satisfied me that it had 4 fire dampers. Only one of them was found to have been fully closed. The remainder varied between fully and partially open.

8.34 The above evidence of Mr Tucker satisfied me that unlike the AAW the ERQ would have been able to provide within the galley area on D Deck and in cabins on its lower levels a survivable atmosphere for some time after the initial explosion. As far as the ERQ is concerned it is clear that the fire dampers operated successfully and that the ventilation system was not a major cause of the ingress of smoke. That ingress was due primarily to the temporary or permanent opening of doors in the path of the smoke which accelerated the deterioration of conditions to the point where personnel were overcome by its effects. It is also clear that if greater discipline over the opening of doors had been exercised and in particular if the fire-resistant door had not been pinned back this would have prolonged the conditions in which personnel were able to survive in the galley area. It is probable that that door was hooked back to ease the movement of personnel. That was the interpretation which was given by the back-to-back OIM, Mr Richards.

The actions of the OIM

8.35 After reviewing the evidence which I set out in this chapter it is necessary for me to consider what view I should take of the conduct of the OIM. He was the person who was primarily responsible for the taking of decisions for the safety of those on board the installation. He must have known that the conditions of fire and smoke were such that access to the lifeboats and access to a helicopter were out of the question. Further, I cannot see how he could have taken the view that there was any prospect of either form of access becoming practicable. After the initial explosion the fire which broke out in B Module spread rapidly and extensively. He must have known that virtually every emergency system on the installation had been rendered ineffective and that Occidental's system for response to emergencies on board was crippled from the start. Conditions in the galley were initally tolerable but within about a quarter of an hour after the initial explosion were deteriorating to the point where personnel were being overcome. In face of all this it is unfortunately clear that the OIM took no initiative in an attempt to save life, even if it was that the personnel should choose the lesser of two evils by getting out of the accommodation as quickly as possible. It is clear that a considerable number of those who had been in the accommodation realised that there was no point in staying to die. It was better to get out of the accommodation whatever lay beyond that. Meanwhile those who remained in the accommodation in expectation or obedience succumbed to the effects of smoke and gases which came from the extensive crude oil fire on the production deck and below. There was only one way in which those who were in the accommodation could escape certain death there and that was to get down to sea level by whatever means were available. It is, of course, impossible to say how many would have survived in this way. The risks of death were considerable. However, in my view the death toll of those who died in the accommodation was substantially greater than it would have been if such an initiative had been taken, even allowing for the speed and voracity of the disaster which was engulfing the platform.

Chapter 9

Rescue

Introduction

9.1 In this chapter I will describe the offshore and onshore response to the disaster and the way in which the survivors were rescued. Following a general account I will explore in more detail a number of aspects which caused difficulties or led to criticism.

Vessels in the area of Piper Alpha

9.2 The Emergency Procedures Regulations require that within 5 nautical miles of every offshore installation when it is manned there is to be present a standby vessel ready to give assistance in the event of an emergency on or near the installation. On the evening of the disaster Piper was attended by the *Silver Pit*, a converted trawler, as its standby vessel (SBV) (see Plate 11(b)). She was on close standby about 400m north-west of the platform, with a fast rescue craft (FRC) swung out ready to be launched. The FRC was an HT 24, diesel-driven water-jet boat, capable of accommodating 3 crew and 12 survivors. It was capable of a speed of 25-30 knots. It had no fixed radio on board. The *Silver Pit* was certified as having space available for 250 survivors, with a minimum manning of 9 persons. In addition to the FRC, the *Silver Pit* also carried a smaller inflatable craft for the use of the crew in accordance with the requirements of the DoT, called a DOTI boat. For 300 survivors she would have required to have 2 FRCs: and would then have been exempt from the requirement to carry a DOTI boat.

9.3 About 550m off the west face of Piper and with her stern square on to the platform was the *Tharos*, which was owned by the Occidental Group (see Plate 11(a)). The *Tharos* was a semi-submersible vessel which was designed to have a number of functions including that of a fire intervention vessel. She carried equipment for fire-fighting and well killing; a hospital with emergency facilities for 22 persons; accommodation for 224 men and crew; and a gangway for access to installations. She had on board a fast rescue craft which was jet driven and could be launched by crane and accommodate 18 men. She also had a helicopter which could take 12 passengers, but was not equipped with a winch for rescue purposes. The *Tharos* was designated as the support vessel for major emergencies in the sector of the North Sea in which Piper was situated. However on the day of the disaster she was at Piper in connection with work on the installation at Piper of a pipeline which was to carry hydrocarbons to Piper from the satellite Chanter field. At the time of the initial explosion she was holding her position by means of 3 anchors set to the south and west and was ballasted at a draught of 15m.

9.4 The *Maersk Cutter*, a supply vessel, which was acting as an anchor handler for the *Tharos* was about 1 mile off the north-east corner of Piper. This vessel was fitted with fire monitors and was able to act as a rapid intervention vessel (RIV). She was capable of discharging 10,000 tons of water per hour with a range of up to 140m.

9.5 The *Lowland Cavalier* lay 25m off the south-west corner of the platform and with her stern facing it. She was engaged in trenching operations for the pipeline between Chanter and Piper. At the time the trenching equipment was on the seabed and over the pipeline track.

9.6 In response to the mayday a number of vessels involved in offshore work came to the scene in order to assist. I do not intend to give a description of the part played by each of them. But at this stage I would mention the following vessels which figure in the narrative which follows. The *Sandhaven* was on standby duty at the Santa Fe mobile drilling installation which was 4½ miles from Piper. She was a converted supply vessel, and was more manoeuvrable than a converted trawler such as the *Silver Pit*. She had a crew of 8. Her FRC was an Atlantic 21, which had a petrol-driven engine. It had a crew of 3 and was capable of a speed of 30 knots, 3 times that of the parent vessel. The *Sandhaven* also carried a DOTI boat. At the time of the mayday the *Loch Shuna* was sailing with supplies for the Kingsnorth UK installation. It diverted from this journey, arriving on the scene at about 22.50 hours. It had an FRC of the Atlantic 21 type (see Plate 12(a)). The *Loch Carron*, a supply vessel, was heading for the Marathon Brae installation. It also was diverted, arriving on the scene at 03.00 hours on 7 July. Her FRC was a petrol-driven Fletcher type in which the fuel was stored under the deck. Part of the hull was hard and there was a flotation collar.

9.7 During the disaster a large number of FRCs which had been launched from different vessels, took part in the search for and recovery of survivors and the dead. (Plate 12(a) shows a FRC of the Atlantic 21 type.) According to information collected by Mr A D M Letty, master of the *Tharos*, 11 FRCs were involved, so far as had been recorded.

9.8 The Piper platform was located at 58° 28'01" North, 00° 15'36" East. It was 120 miles north-east of Aberdeen. According to the log of the *Tharos* the following weather conditions were noted as at midnight on 6/7 July: Wind 160-170°, 10-15 knots. Maximum wave height 3m. Visibility 10+ miles.

Maritime search and rescue

9.9 The responsibility for initiating and co-ordinating civil maritime search and rescue in the United Kingdom part of the continental shelf (UKCS) rests with HM Coastguard on behalf of the DoT. The co-ordination of search and rescue operations is achieved through a number of maritime rescue co-ordination centres (MRCCs), including one at Aberdeen which is responsible for a region within which Piper was situated. The MRCC at Aberdeen was fitted with a comprehensive telecommunications system which included a 24 hour radio watch on the international distress frequency, channel 16 (VHF). The International distress frequency of 2182 kHz was manned on their behalf by British Telecom International which had permanent liaison arrangements with the MRCC. For the purposes of search or rescue offshore the coastguard relied on the facilities provided by Ministry of Defence helicopters through rescue co-ordination centres (RCCs), one of which is situated at Pitreavie near Edinburgh; the DoT search and rescue helicopter at Sumburgh and other facilities such as Nimrods and warships that may be available. The MRCC at Aberdeen has private telephone lines to most oil companies and to the RCC with which it has close operational links. The RCC is not responsible for co-ordinating the rescue effort but for supporting the coastguard with airborne assistance. The RCC at Pitreavie controls the movements of search and rescue aircraft at 7 bases which have at least 1 unit on permanent standby. At night Wessex helicopters are on 1 hour standby, whereas the Sea King helicopters are on 45 minutes standby, with the exception of those at HMS Gannet at Prestwick where the period is 90 minutes. Nimrod aircraft, which are maintained at Kinloss, are on 1 hour standby.

9.10 It is well recognised that, as part of an efficient system of search and rescue at sea, it is essential that there should be an on-scene commander (OSC) to monitor and co-ordinate developments in detail. According to the Offshore Emergencies Handbook prepared by the DEn and circulated to all operating companies and agencies which may be called upon to deal with major emergencies involving offshore installations:

> "The OSC will normally remain the OIM of the stricken installation, or the master of the vessel in distress, unless the seriousness of the emergency or loss of communication demands otherwise. As soon as a decision is made to abandon an installation/vessel the role of OSC must be devolved to another. Depending on circumstances, this may be the OIM of a nearby platform, the master of a safety, supply or specialised vessel, or the captain of a suitably equipped aircraft. Hard and

> fast rules cannot be laid down and a decision must be based on the nature and scope of the emergency and the type of facilities and expertise immediately available. As time is critical the master of a standby vessel, for example, could assume OSC initially before relinquishing to the master of a more sophisticated vessel with better communication and equipment as soon as one becomes available ..." (Annex A, paras 8.3-5).

The Handbook also states that the MRCC, after consultation with the operator, may designate another vessel or aircraft to assume the role of OSC. The functions of the OSC may be summarised, according to the Handbook, as executing the plans of the search and rescue mission co-ordinator, which may be the MRCC; modifying those plans as required to cope with changing on-scene conditions; assuming operational co-ordination of all units assigned by the co-ordinator; establishing and maintaining communications with the co-ordinator; submitting situation reports at regular intervals to the co-ordinator for action; establishing and maintaining communication with all facilities performing search, rescue or similar operations; providing initial briefing and search instructions to such facilities; receiving and evaluating sighting reports from them; co-ordinating and diverting surface facilities or helicopters and aircraft to evaluate sightings; and obtaining the results of search as each facility departs the scene. It is also envisaged that as the process of search and rescue progresses any surface vessels may join in the search for survivors. The most suitable may be appointed to be the co-ordinator surface search (CSS), for which the Merchant Ship Search and Rescue Manual (MERSAR) provides an outline of duties and details procedures and techniques. The Handbook also emphasises the importance of liaison between the MRCC and the operator. It states that:

> "In a major incident effective rescue action will demand the integration of facilities directly or immediately available to the operator with those made available to, and under the co-ordination of the MRCC. Regardless of whether search and rescue mission co-ordination rests with MRCC or the operator, during any search and rescue incident offshore it is vital that close liaison is maintained between the MRCC and the emergency control organisation of the operator ..." (paras 5.1-2).

The provisions made by the Handbook for the co-ordination of search and rescue are broadly similar to those issued by the International Maritime Organisation (IMO) and embodied in MERSAR to which I have referred above.

General narrative of search and rescue

9.11 In immediate response to the initial explosion the FRC of the *Silver Pit* was manned and launched at about 22.02 hours. Two minutes is the normal time for manning and launching. The FRC went in towards the north-west side of the platform, with the *Silver Pit* following. At about 22.05 hours the FRC crew had picked up the first survivor from the platform, who had walked down stairways to the 20 ft level. The FRC thus began a number of trips between the platform and its parent vessel.

9.12 At about 22.02 hours the *Lowland Cavalier* broadcast a mayday. She moved back to about 60m from the platform in order to allow her work-boat to be launched. It was launched about 22.14 hours. Later in the evening the *Lowland Cavalier* also launched one of her lifeboats.

9.13 In response to the initial explosion the crew of the *Tharos* manned their emergency stations and her master took charge of the movement of the vessel. Generators for the fire pumps were started as additional engines were brought on line. The *Tharos* started moving towards the platform at about 22.05 hours. This process involved paying out her anchor cables in a controlled manner. It took about half an hour for the vessel to reach a close range from the platform. The process was made longer by the fact that the vessel's thrusters cut out from time to time due to an overload on the supply of power. At 22.11 hours her helicopter was airborne. Two minutes later the pilot reported to the vessel that Piper's helideck was obscured by smoke. No flames were visible on the east side of the platform. As from 22.03 hours the *Tharos* was in communication by satellite with Occidental in Aberdeen.

9.14 By the time of the rupture of the Tartan riser at 22.20 hours the FRC of the *Silver Pit* had picked up 2 additional loads of men from the north-west corner of the platform near B4 leg and was making its way towards the *Silver Pit*. The heat of this explosion blistered the paintwork of the *Silver Pit* and damaged her DOTI boat. The work-boat of the *Lowland Cavalier* picked up 2 men who had fallen into the sea from the rope at that corner. When this boat was heading towards the south-west corner to pick up more men a fireball forced its crew to get into the water for shelter. After it had passed, the men to whom the boat was heading were no longer to be seen. By 22.20 hours about 22 survivors had left the platform. Thereafter most, if not all, of the survivors reached safety by being picked up in the sea, either by an FRC or by one of the larger vessels.

9.15 The master of the *Tharos* did not make any announcement that he had assumed the role of OSC but effectively acted in this role from the outset. He expected that the coastguard would know of his vessel's capabilities. At 22.18 hours he instructed vessels in the vicinity to launch their FRCs. At that time the *Tharos* launched her own. At 22.15 hours the jacking out of the fire boom which supported the gangway had started. The crane was being racked in order to fit the fire monitor which operated from it.

9.16 The mayday which had been broadcast by the *Lowland Cavalier* was picked up by Wick radio, after which the MRCC alerted the RCC. At 22.19 hours the RCC instructed RAF Kinloss to scramble a Nimrod. This Nimrod became Rescue 01. Its main use was as a flying communications platform, handling the signals from the helicopters and reporting back to the RCC on HF transmission. It could remain on station for 8 hours. At 22.20 hours the RCC was told about the messages from Piper that the platform was being abandoned. At 22.22 and 22.28 hours Sea King helicopters, R137 and R131, took off from Lossiemouth and Boulmer respectively. The first of these helicopters had been recalled from going to participate in a mountain rescue.

9.17 At about this time the RCC was in discussion with MRCC and the Royal Navy as to the possibility of support being given by the Standing Naval Force Atlantic (STANAVFORLANT) which at this time was at 50° north 3° east. Maritime HQ advised that this force, including helicopters, was available if required. The MRCC took the view that this would be a valuable asset and asked the RCC to request that it proceed to Piper with all speed. There was some conflict in the evidence as to when the MRCC expressed this wish to the RCC but it was not later than 22.35 hours. It then lay with the Royal Navy to make contact with the naval force with a view to diverting it to Piper. It appears that radio communications with the force took some time to be achieved.

9.18 The *Maersk Cutter* had been made ready for fire-fighting within about 3 minutes of the initial explosion. The master estimated that her fire monitors were being deployed on to the platform after about 10 minutes. The vessel was then about 150-160 ft off the south-east corner of the platform. The monitors were being aimed at the level of the drill floor. By about 22.30 hours 3 of her 4 monitors were in use, discharging at the rate of 7500 tons of water per hour. She continued to discharge water at this rate until about 00.15 hours. She did not launch her FRC as it was decided that she should concentrate on her primary function of fire-fighting. She also used her searchlight to point out survivors in the water.

9.19 The FRCs were continuing to pick up survivors (see frontispiece); the last of those who were to reach the *Silver Pit* were more seriously injured than those who had reached her earlier. Her FRC picked up a number of more seriously injured survivors who were holding on to an upturned lifeboat. They were taken to the *Silver*

Pit with the exception of one man who was so injured that he required to be taken on to the *Loch Shuna*.

9.20 In the meantime preparations had been made for the *Tharos* to open her fire-fighting monitors. The master's intention was to deploy them in such a way as to create a cascade of water on to the platform rather than jets. The latter would have run the risk of causing injury to survivors. The intention was to open the monitors in sequence. However the opening of the first discharge valve of a fire pump did not occur until 22.31 hours when 6 fire monitors began to deliver water under the correct pressure. This was some 14 minutes after that pump had started. Normally it would have taken about 2 minutes from the starting of a fire pump to the opening of its discharge valve. The reason for the difference was that too many monitors had been opened shortly after the starting of that pump, with the result that there was insufficient pressure for the discharge valve to be opened. Fire-water did discharge briefly and weakly from the monitors which had been opened. Instructions were given that all the monitors were to be shut except for one which was used in order to bleed off air. The discharge valves of the other fire pumps were opened at 22.35, 22.39 and 22.52 hours. Although there was a substantial delay in the cascade coming into operation, which can be put at approximately 12 minutes, it does not appear that this made any practical difference to conditions on the platform. I accept the master's evidence that at 22.31 hours the cascade was not yet close enough to reach the platform. However, I must point out that the cascade proved to be of assistance not merely to those on the platform but also to the rescue vessels and those in the water. At 22.41 hours the spray which provided a heat shield to the *Tharos* was put on. By 22.45 hours the *Tharos* was 60-70m off the west face of the platform and the monitors were being deployed on to it. The master's intention had been to deploy the gangway on to a landing on the west face of the 83 ft level of the platform (see Fig 9.1). The fire boom supporting it could only be extended slowly. It would take 5 minutes to be extended 2 ft and 75 minutes to reach a minimum usable length of 30m. At 22.33 hours the *Tharos* received the radio message from Piper: "People majority in galley area. Tharos come. Gangway. Hoses. Getting bad." By 22.50 hours the *Tharos* was about 50m from the platform. By that stage a number of survivors on the platform were feeling the benefit of the spray from her monitors, in particular in giving some alleviation of the intense heat and dense smoke. This was particularly the case for those who reached the pipe deck and the helideck. The spray was also giving some cooling to fast rescue craft, such as that of the *Silver Pit*, which were continuing to penetrate extreme conditions of heat in their search for survivors in the water. However at this stage the landing position where the master intended to place the gangway was completely obscured by smoke and flames. The tremendous roaring made by the ignition of gas from the Tartan riser made communications difficult. In those circumstances the *Tharos* was unable to land her gangway on the platform. However lines and baskets together with life-buoys had been deployed over her aft end. One of the survivors was successful in swimming from the platform to the *Tharos* which he reached at 22.40 hours. He climbed up a fixed ladder on one of her stabilising columns.

9.21 At about this time a number of additional search and rescue aircraft became airborne. At 22.45 hours the Shetland coastguard helicopter (R117) took off. At 22.51 hours a second Sea King (R138) took off from Lossiemouth. At 22.55 hours the Nimrod, Rescue 01, took off from Kinloss.

9.22 By the time of the rupture of the MCP-01 riser at 22.50 hours approximately 39 survivors had left the platform. Shortly before it occurred the FRC of the *Sandhaven* had picked up 4 men from the south-west corner of the platform and had turned back to pick up 2 additional men. All of them had probably reached that corner by descending from the drill floor. At the moment of the explosion the FRC was entangled with ropes which had been used in the escape. The explosion destroyed the FRC and killed all its occupants with the exception of the crewman Mr I Letham. The fireball associated with the explosion partially engulfed the *Tharos*, and her master gave orders

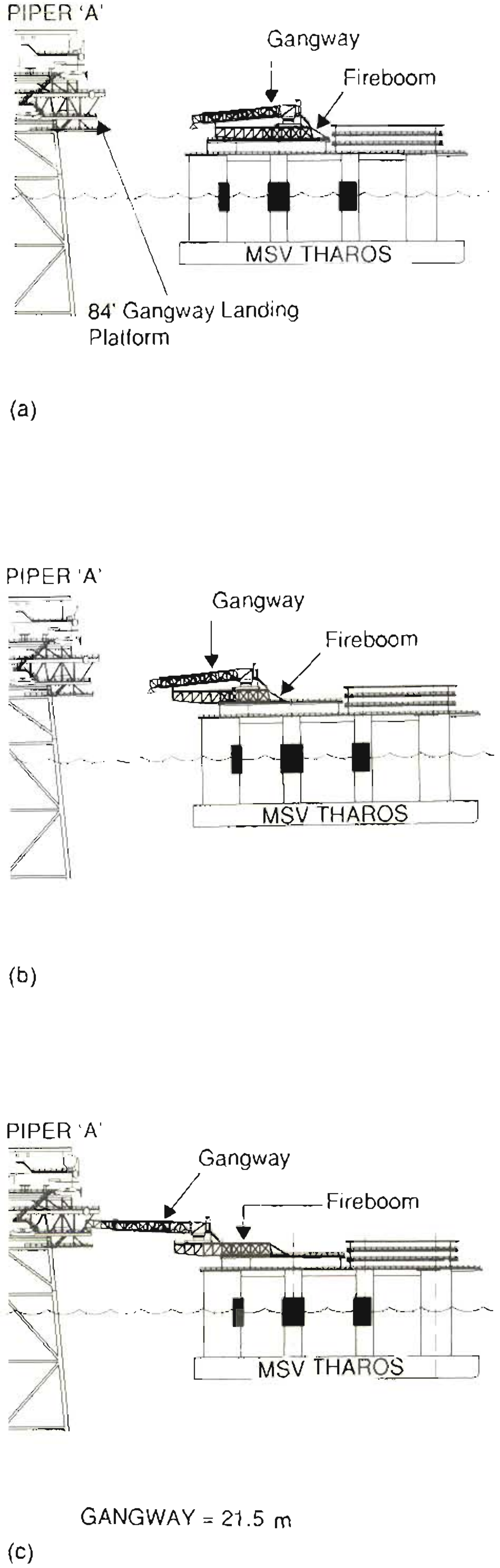


Fig. 9.1 The *Tharos* gangway: (a) gangway fully retracted; (b) gangway partially extended; and (c) gangway fully extended.

that the vessel move back to a distance of 100m from the platform so that the position could be assessed. I should add that at a later stage in the evening a further explosion damaged the hull and engine of the FRC of the *Silver Pit*. However it was able to rescue a further 5 persons before it lost power and stayed barely afloat. Its occupants were later rescued by the *Maersk Cutter* after it had ceased fire-fighting.

9.23 At 22.56 hours MRCC made direct contact with the Occidental Emergency Control Centre. At 23.06 hours a direct radio link was created between MRCC and the *Tharos*, which had commenced moving back towards the platform at 23.05 hours. MRCC formally requested the master of the *Tharos* to assume the role of OSC. Mr Letty instructed the *Loch Shuna*, which had pulled up to the west of the platform, to co-ordinate the surface search and rescue. As OSC he thereafter made periodic reports on the situation to MRCC.

9.24 At 23.13 hours the *Silver Pit* was alongside the *Tharos* so that 3 of the more seriously injured survivors could be transferred to her. At 23.18 hours the *Tharos* was advised by MRCC or Occidental to pull back from Piper due to the possibility of hazard from the presence of hydrogen sulphide. Her master ordered that the vessel move back about 200m. Other vessels in the vicinity received similar advice. At this stage men who had jumped off the level of the helideck and the pipe deck were being picked up by FRCs, such as those of the *Silver Pit* and the *Loch Shuna*; and also by larger vessels such as the *Silver Pit* and the *Maersk Logger*. Vessels were instructed to bring survivors to the *Tharos* in view of its hospital facilities. They were brought aboard mainly by the use of a crane and basket.

9.25 At 23.27 hours the Nimrod aircraft reached the area of Piper, having already assumed the functions described above. Three minutes later the first search and rescue helicopter, R137, reached the *Tharos*, where the *Maersk Leader* was unloading survivors. This was followed by the arrival of helicopters R117, R138 and R131 at 23.44, 23.48 and 23.53 hours. Arrangements were made for helicopters to be refuelled at the Claymore platform. The first helicopters on the scene were used to evacuate non-essential personnel from the *Tharos* to other platforms from which additional medics were brought back. This process started at 23.38 hours. The worst casualties were brought to the *Tharos* by helicopter from the *Silver Pit*. Other helicopters took part in the search for survivors. Casualties continued to be brought to the *Tharos* at least until about 00.26 hours. The seriously injured were accommodated in the sick-bay, and the others in the helicopter hanger. The master of the *Tharos* explained in evidence that, apart from the risk of hydrogen sulphide, there were a number of additional reasons for his pulling the *Tharos* back to the extent that the platform was no longer within the range of her monitors. Soon after his moving back there was little left of the platform. Further he wanted to pull back sufficiently far to ensure that helicopter operations were not compromised by the heat of the fires on the platform.

9.26 At 00.40 hours the *Tharos* pulled back a couple of hundred metres and turned off the heat shield. At 00.43 hours command of the surface search and rescue was passed from the *Loch Shuna* to the *Lowland Cavalier*. By 01.19 hours there were 21 injured men in the sick-bay of the *Tharos*. By then a team from Aberdeen Industrial Doctors had arrived at the *Tharos* and were at work there. At 02.00 hours the Offshore Specialist Team from Aberdeen Royal Infirmary arrived at the *Tharos* with a considerable amount of medical equipment. It was found that the injuries sustained by the survivors were in general external and internal burns, carbon monoxide poisoning, bruises and some fractures. The efforts of the medical team were directed to stabilising the condition of those who had been seriously injured pending their being taken to hospital in Aberdeen. At 01.13 hours the Nimrod advised that no further helicopters were required to give assistance. At 02.02 hours all fire-fighting was stopped, and all ships were instructed to participate in the current search of the area around the platform.

9.27 At 02.26 hours the first helicopter left the *Tharos* for the shore with casualties and medics on board. All the casualties were to be taken to the Aberdeen Royal

Infirmary. This helicopter arrived at the infirmary at 03.30 hours. Medical care was provided on most of the flights to Aberdeen, apart from one which carried the walking casualties. At 04.00 hours the *Tharos* resumed control of surface search and rescue from the *Lowland Cavalier*. Her deputy OIM set up a search and rescue pattern with the use of MERSAR. By this stage 45 vessels or more were in the vicinity of the remains of the platform. At 07.29 hours the *USS Hayler* arrived at the scene, her commander (who was the Commodore of the NATO force) having become OSC.

9.28 By 08.15 hours 63 personnel (including the surviving member of the crew of the FRC of the *Sandhaven* and one survivor from Piper who subsequently died) had been landed on shore. Aircraft were used to search the area of the platform until the afternoon of 7 July. The search by vessels continued until 22.45 hours on that day.

The method of rescue of the survivors

9.29 Of the 61 survivors from Piper a total of 37 survivors reached the *Silver Pit*, 29 of them having been picked up by her FRC and the remaining 8 by the vessel directly. Nine men who had been picked up by FRCs were taken to the *Tharos*. Seven were taken to other vessels. Seven survivors were picked up directly by other vessels, in particular by the *Maersk Logger*. As stated above one survivor reached the *Tharos* by swimming out to it.

The co-ordination of search and rescue

9.30 It is clear that from the outset this was threatened by poor communications and a failure in the procedures which were intended to secure a prompt, well-informed and efficient response. Mr J P A Wynn, who was Search and Rescue Mission Co-ordinator at MRCC until relieved by the Deputy Regional Controller, stated that for almost an hour after the initial explosion all that they knew was that there had been an explosion on Piper. They needed to know the nature of the incident, the number of persons on board, the intentions of the OIM, the weather on scene, the communication facilities, the available life-saving facilities, the vessels available in the area and other information. Without that information they had to assume the worst, that all had abandoned the platform by whatever means. Reference was made to Sec 3 of the Offshore Emergencies Handbook with which the witness was familiar. This sets out the information which the "OIM/shore base" should report to, *inter alia*, the MRCC "in the event of a fire becoming, or in danger of becoming, uncontrollable". He assented to the description of the first hour as "an hour of chaos". Mr Wynn explained that the international frequency of 2182 kHz, which was the only frequency available for direct contact with Piper, was controlled by Wick radio station "so we could not interrupt it willy-nilly". MRCC concentrated on seeking information from Occidental and asking the coastal radio station to try to establish communications with either the *Tharos* or the *Lowland Cavalier* which could provide MRCC with more information as to what exactly was happening. However the distress frequency was cluttered with traffic. Mr Wynn commented that:

> "In the North Sea with its many rigs, platforms, support vessels, aircraft and fishing vessels and so on, the response to a distress message is often out of all proportion to the assistance required. The relay via the coast radio station is unwieldy and inefficient. Vessels offered assistance on a continuous basis and inhibited us gaining vital information from on scene. Queries and suggestions received by the coast radio station are really destined for the Search and Rescue Mission Co-ordinator at the Coastguard Rescue Centre. However, the coast radio station operator had little time to consult with Aberdeen MRCC and we think could be therefore pressurised into making decisions which are not really his responsibility."

He advocated communications by VHF as the ideal method for controlling search and rescue operations. The Aberdeen Search and Rescue region was unique among those in the United Kingdom in respect of the much higher activity from 100 to 150 miles from the coast. This was an area of high disaster potential because of the existence of large numbers of drilling rigs, fixed installations and associated vessels and aircraft employing many thousands of men.

> "Without the benefit of VHF coverage offshore and because of our limited facilities regarding medium frequency equipment, and the present procedures whereby the coast radio station controls the distress frequency, Aberdeen MRCC was put at a severe disadvantage and we were not able fully to co-ordinate the initial rescue phase effectively and provide on-scene the executive authority that is required. I am talking of the first hour or hour and a half or so of the incident."

According to the witness it was not until 22.56 hours that the Occidental Emergency Control Centre was fully manned and the MRCC was able to obtain information from that source as to what was involved in the incident at Piper. MRCC was then told that the approximate number of persons on board Piper was 220; that the platform could not be completely evacuated at the time; some persons were in the water; that all communications to Claymore and Piper had been lost; and that there was one satellite link to the *Tharos* which Occidental wished to maintain and did not want to put through to anywhere else. The use of the satellite link would have provided earlier knowledge of the scale of the disaster. However, the witness clearly stated that this would not have affected the way in which MRCC in fact responded to the emergency. According to the witness the radio link between MRCC and the *Tharos* was eventually established by Wick radio. MRCC would have designated the master of the *Tharos* as OSC at an earlier stage had they been able to make contact. Liaison officers from Grampian Police and Occidental eventually arrived at MRCC, the latter after MRCC had made a second request for attendance. The witness was questioned about exercises carried out with oil companies in order to test emergency procedures. These were usually on the basis of a slow build-up. A scenario on the scale of Piper had not been considered. For the future the initial reaction of MRCC to an incident would remain unchanged, namely mobilising the rescue services until they got more information.

9.31 Mr E R Kerr, a Radio Officer who was in charge of radio telephones at Wick radio station, which was part of the maritime section of British Telecom International, gave evidence as to the receipt of the mayday from the *Lowland Cavalier* and the series of wireless messages received on 2182 kHz from Piper. The mayday was telexed to the coastguard, RCC and Lloyd's between 22.12 and 22.17 hours; but owing to the number of calls from vessels offering assistance he was unable to broadcast a relay until 22.26 hours. His first contact with the *Tharos* was at 22.13 hours when the vessel sent a message that it was 500m off the west face of Piper and that a helicopter was on the way. He passed that information to the coastguard. Contrary to the evidence given by Mr Wynn, Mr Kerr said that as far as he recollected Wick radio had not been involved in setting up any direct link between MRCC and the *Tharos*. Further there was no entry in any of the logs to this effect. He suggested that the link was through Stonehaven radio which dealt with day-to-day communications with the *Tharos*. If the coastguard had wanted a direct link Wick radio would have called the *Tharos* on 2182 kHz and asked the vessel to transfer to a working frequency so that the vessel could communicate with the coastguard. He did not recollect any particular difficulty in communicating with the *Tharos* that night apart from possibly later on when there may have been occasions when the radio operator on the *Tharos* did not respond immediately, perhaps because he was busy with other communications.

9.32 Squadron Leader G D Roberts of the RCC stated that very little information had been received by the RCC during the first hour after the initial explosion. The first indication of the extent of its seriousness came from the Nimrod aircraft at 23.27 hours. When the first helicopter took off it had no information as to how significant the incident was or what it would be required to do when it reached the scene. As regards the naval force it seemed to be surprising that it took as long as it did for them to arrive on the scene. However, it did not appear that life had been endangered by this lapse of time. In the circumstances I decided not to pursue further enquiries into it.

9.33 As stated earlier in this chapter from an early stage after the initial explosion the master of the *Tharos* carried out the work of an OSC; he said in evidence that he supposed that it was at the back of his mind that he was in fact in command of the emergency. The master of the *Silver Pit* said that he had assumed that the *Tharos* would provide the OSC as his vessel was directly involved in rescue work. However, it does not appear that Mr Letty, let alone Occidental, informed the coastguard that he had assumed this role. He was not familiar with the Offshore Emergencies Handbook, but he considered that most merchant mariners would be familiar with MERSAR. He took the view that the main importance of the *Tharos* on the night of the disaster was as an operations control centre. She was in radio communication by VHF with all the vessels and aircraft in the area, as well as with Occidental and in due course the coastguard. However in the area of instructions and communications a number of criticisms were expressed in the Inquiry. The diving superintendent, Mr S R MacLeod, who assisted the rescue effort after he had reached the *Silver Pit* stated that the *Silver Pit* managed to make radio contact with the *Tharos* informing them that there were 7 seriously injured people there needing immediate medical attention. He was told to stand by but nothing happened for an hour. Contact was then made by the *Silver Pit* directly with a helicopter which removed the worst cases. *Tharos* had been contacted 3 times and on each occasion the *Silver Pit* was told to stand by. The radio channels were busy and chaotic but those on the *Silver Pit* felt that they were being ignored. Another witness from the diving team, Mr J Barr, said that there were no clear instructions for the *Silver Pit* until the Nimrod aircraft came on the scene. The master of the *Loch Carron* advanced a number of trenchant criticisms which were not otherwise borne out in the evidence. He said that as his vessel was proceeding to Piper his crew were aware of a great deal of radio traffic without proper co-ordination. He was familiar with the concept of on-scene command but there appeared to be no effective command at that time. By the time that the vessel arrived on the scene there was some form of command but it was difficult to get proper instructions as to what part they could play in the rescue. The ships were too far apart and there was no real communication with whoever was organising the search. He said that it did not show good foresight to be transferring survivors between vessels before taking them to the *Tharos*. He expressed the view that it was not practicable for the master of a standby vessel or a supply vessel to act as OSC as there was far too much for the crew of each of them to do.

The recovery of survivors from the platform and the sea

9.34 The events on the night of the disaster proved beyond any doubt the importance of FRCs in a case in which men are forced by a major emergency to take to the sea to save their lives. The work for which they are normally used in conjunction with a standby vessel is the recovery of men who have fallen overboard from the platform. For that type of rescue speed of response is essential. On the night of the disaster the FRCs showed also how they could be used to get close to the platform even when the fire was raging. Conspicuous bravery was shown by the crews of these FRCs who repeatedly exposed themselves to danger. I would mention in particular the crew of the fast rescue craft of the *Silver Pit*, under their coxswain Mr J P McNeill, who showed an extraordinary example of cool courage in the face of extreme hazard; and the crew of the fast rescue craft of the *Sandhaven*, all of whom but Mr I Letham perished at the time of the rupture of the MCP-01 riser as I have described above. Through the efforts of the various FRCs 45 of the 62 survivors were directly recovered, either from the platform or from the sea immediately around it.

9.35 The weather conditions for the use of rescue craft in the recovery of survivors were fortunately favourable during the evening of 6 July. However the Inquiry heard that it is practicable for FRCs to be used for the recovery of survivors in wind speeds up to 35 knots, and that such craft can be used in a force 9 gale. The real limitation lies in whether the craft can be safely launched from or recovered by the parent vessel. It was said that the launching of the FRC of the *Tharos* would not have been hazardous for the crew until the wind reached force 8; whereas the Captain of the *Loch Carron* said that launching was difficult in winds of more than force 5. His view was that launching and recovery procedures were inadequate.

9.36 The Inquiry heard some criticism to the effect that more FRCs could and should have been put into use. A particular instance was the FRC on the *Maersk Logger*, the crew of which, it was said, appeared to be too busy dealing with survivors to launch it. I do not consider that the evidence at the Inquiry bears out this criticism. I have already recorded that at about 22.18 hours the master of the *Tharos* instructed vessels in the vicinity of the platform to launch their FRCs. There was also evidence from the master of the *Silver Pit* that sometime within the first half hour after the initial explosion he sent a message on the radio for shipping to put out their rescue boats. Subject to the instructions received from the vessel in charge of the search and rescue operations, it was for the master of each vessel to use his facilities to the best advantage. I do not consider that there was any evidence of failure in this respect. The master of the *Loch Carron* also referred to difficulties experienced in communications between FRCs and the parent vessel and advocated the adoption of a helmet containing a radio, such as is used by the RNLI. Other evidence supported the installing of fixed radios in the FRCs.

9.37 Some witnesses said that FRCs should be better protected against explosion either by being diesel powered or by having the fuel tanks located under the deck. However it is clear that neither of these things would have made any difference to the fate of the FRC of the *Sandhaven*. Other evidence suggested that the crew should be better protected against fire and debris.

9.38 The method for recovering survivors and for transferring them to other vessels was not ideal. In the circumstances survivors had to be dragged into the FRCs as quickly as possible. It was said that it was difficult to put men aboard a vessel from an FRC in seas over 4 ft. While these factors did not cause any problems at the outset when the survivors were relatively uninjured, they caused distress when the more seriously injured survivors were being handled.

9.39 A number of FRCs broke down during the course of the evening. At one point the FRC of the *Tharos* appeared to lose power and headed back to the parent vessel where it was lifted out of the water for attention to the fuel supply. The FRC of the *Sandhaven* moved in to take its place. Had this problem not occurred the FRC would probably have remained at the platform picking up survivors. It was subsequently used to transfer survivors from the *Silver Pit*. The coxswain of the FRC of the *Loch Shuna* gave evidence that for some time its engines had not been working well, although attempts had been made to rectify this. During the evening the crew found that the engines were not fully operable.

9.40 During the evidence as to the recovery operation the Inquiry heard that problems were caused by vessels having to investigate orange-coloured objects in the sea in mistake for life-jackets. The use of a specific colour for life-jackets was advocated.

The Silver Pit

9.41 According to her master the allocation of a particular vessel for standby duties was a matter for agreement between her owners and operator. The deployment of the vessel was decided by the OIM of the installation, with whom the master had no more than radio contact. Until the time of the disaster he had seen the role of his vessel in terms of ordinary evacuation procedures or the rescue of men who had met with an accident.

The conduct of the master and crew

9.42 At an early stage in the evidence given by the survivors there were a number of criticisms which I must examine at this point. The navigation of the vessel in its approach to survivors in the water was criticised. It was said that the master found it hard to approach the survivors while taking care not to let the propeller come close to them. The wind and tide often made the vessel drift away. Although the vessel appeared to be trying to stop up-wind of the survivors and drift down-wind towards them it was never actually coming alongside them. In my view these comments arose out of the lack of manoeuvrability of the vessel both in itself and in the condition in which it was on the night. I am satisfied that the master was doing his best in what were difficult circumstances. A number of witnesses complained of a lack of co-ordination or leadership on board the *Silver Pit*. The master appeared to be over-worked and needed someone to back him up. The demands on the crew were more than they could meet. Much of the organisation, initial assistance, care and transfer of the injured was undertaken by the diving team among the survivors who were more familiar with the sea than the others. It was also said that those who endeavoured to operate the VHF radio did not appear to know the correct procedure. In considering these complaints it is only right to bear in mind that the crew of the *Silver Pit* consisted of 9 persons; consisting of the master, mate, chief engineer, second engineer, cook and 4 deckhands. The master was constantly on the bridge. The chief engineer was in the engine room. The second engineer was acting as medic and was in the sick-bay. The cook was supplying hot soup and tea for survivors. The mate was giving help where he could; and the deckhands formed the crew of the FRC. The master and crew of the *Silver Pit* found themselves confronted with a situation in which on the one hand the vessel required to take part in the rescue of survivors and supporting its FRC for that purpose; and on the other hand to deal with 37 survivors, a substantial number of which were seriously injured. I agree with the view which a number of survivors and others expressed that the crew showed great courage in maintaining a position close to the platform and that they did their best to cope with the handling of the survivors. On the other hand it is clear that for the actual job which they had that night the crew were seriously under-manned. Further, I consider that the crew should have been better trained in order to have the technical and practical skills required for responding to an emergency situation, and in particular one involving large numbers of survivors for which their vessel was theoretically able to provide accommodation. In saying that I do not place any responsibility for those deficiencies on the master.

Inherent capability for the rescue of survivors

9.43 The difficulty in the manoeuvring of the *Silver Pit* was due mainly to her inherent characteristics. Converted trawlers have good sea-keeping qualities with low freeboard, open deck space and large internal space. Against that, they are old and of limited manoeuvrability because of having single screw propulsion. If thrusters have been added, as in the case of the *Silver Pit*, they tend to be under-powered and of use mainly in the harbour. Their restricted visibility and high windage makes it necessary to approach survivors drifting down-wind, beam on, which is a slow process. The master is the only person on the bridge. Hand steering is normal. The *Silver Pit* was a typical converted trawler. Its weak bow thruster did not prove very effective when turning up to the wind. At the time of the disaster it worked in any event for only 5 minutes before breaking down. Unfavourable comparisons were made between converted trawlers such as the *Silver Pit* and larger and more modern vessels, such as supply vessels, which are used for the purpose of standby duties. These would have been preferable because of their larger size, greater manoeuvrability with the assistance of thrusters and better behaviour in rough weather. Vessels such as the *Silver Pit* were described by some witnesses in evidence as being no more than "a token gesture" by operators, "a necessary evil" in order to satisfy the legal requirement for a standby vessel. I am entirely satisfied that in the above respects the *Silver Pit* was essentially unsuitable for the purpose of effecting the rescue of survivors. I am also satisfied that this led in a number of instances to distress and delay in the process of recovering survivors.

The state of the vessel

9.44 In a number of significant respects the state of repair of the *Silver Pit* left much to be desired:

(i) The searchlight was not working. There were no searchlight bulbs on the vessel and the master believed that the wiring might also have been defective. The master had discovered this after the vessel had sailed. He had had 2-3 hours notice of sailing and clearly relied on the owners as regards the state of maintenance of the vessel. The normal procedure for the reporting of an item was to put it on a list before the vessel came into port. The master said that there was a lot of repair work on those vessels. "They are old ships and they do tend to have a lot of breakdowns". In place of the searchlight the crew used an Aldis lamp to try to locate persons in the sea. The lighting could not in any event cover the full 360° around the vessel.

(ii) As stated above the bow thruster ceased to function about 5 minutes after the initial explosion.

(iii) When an attempt was made to open a gate in the side of the vessel the gate fell off.

(iv) An unsuccessful attempt was made to start the DOTI boat. This boat had no facilities to start it and was unserviceable. In any event there were no davits for launching it. (However it should be pointed out that in evidence the master and mate said that they did not consider that this inflatable boat was suitable for launching even if it could have been started. Its vulnerability would create additional risks to those who are picked up. The heat from the fire on the platform had caused blisters on the flotation sections which could be punctured so causing the boat to sink.)

Facilities for the reception and treatment of survivors

9.45 Difficulties were encountered in getting survivors, especially those who had been badly burned, on board. Scramble nets had been placed on the sides of the vessel but they were not properly secured and sagged into the water. Although there was adequate assistance from those on the vessel it was an agonising experience for the injured to clamber up the nets. The ropes attached to the life-rings were of unsuitable length and diameter for rescuing survivors in the water. There was only one boat-hook available. The movement of injured men on the vessel also caused difficulty and distress. In particular it was difficult to get injured men past some of the bulkheads and into the forecastle where there were mattresses. It was also difficult to get stretchers up and down stairs to the aft deck for evacuation by helicopter. Some of the men were in agony when they were moved. From this evidence it was plain that the layout of this converted vessel was by no means satisfactory for the reception and handling of the injured.

9.46 The second engineer who was acting as medic on the night of the disaster had undergone a 2-day certification course of first-aid approved by the DoT. He had also attended a course on the care of survivors which was approved by the DoT. It should be added that at least 2 other members of the crew had undergone the first-aid course. The medic was continuously at work attending to the injured. His performance won well-deserved praise. He was assisted by members of the dive team who helped in moving the injured and attending to those in shock and with severe burns. The medical supplies on board were in accordance with the requirements of the DoT. However, the medic found that they were not adequate in respect of supplies for the treatment of burns such as bandages. There was no saline drip. Further the sole pain-killers on board were a personal supply of paracetamol which the medic had with him. In the master's cabin in a locked box was a supply of morphine. However there was only enough for a few injections. Only the master could administer it and he could not leave the bridge. As a result the morphine was not used. One survivor explained that in view of his injuries the FRC which held him had been lifted out of the water and on board. He was then taken below on a stretcher which tilted on the way. Although he had a crushed vertebra and a broken leg the only pain-killers he could be given were the paracetamol tablets. He was taken by helicopter to the *Tharos* and given medical treatment there. It was also found that there were insufficient warm clothes, blankets and hot drinks. Problems and distress were encountered in the movement of men by stretchers to the *Tharos*. The medic did not know that a more suitable type of stretcher for this purpose was stowed at the forward end of the vessel. The most seriously injured men had been put in cabins and it was extremely difficult to manoeuvre them in and out.

The inspection of the Silver Pit by the Department of Transport on 21 December 1987

9.47 The *Silver Pit* was inspected by Mr E Hutchison, a Nautical Surveyor in the Marine Directorate of the DoT, on 21 December 1987 under the Merchant Shipping Act 1970. At that time the *Silver Pit* had been granted a certificate for operation as a SBV until 11 May 1988 but the Chief Surveyor had information that the vessel was not in a position to fulfil that role. At the time of his inspection the vessel no longer had a launching davit on the starboard side for the FRC, which was not on board, and difficulty was being experienced with the hydraulic mechanism for the operation of the port davit. This had led to the vessel returning to port. The reason for the collapse of the starboard davit had been two separate weld failures. Mr Hutchison also found that 4 types of lights on the vessel were absent or inoperative. The master and the company's representative were informed that it was proposed to recommend withdrawing the certificate of suitability. Some of the deficiencies were rectified on the day of inspection and a letter of compliance was issued with some of the deficiencies outstanding.

9.48 Mr Hutchison said that the deficiencies in the vessel which were said to be present on the night of the disaster were not present at the time of his inspection. He would have expected to pick them up. For example at the time of his inspection the searchlight was working. He confirmed that the vessel should have had a working searchlight and that the DOTI boat should have been maintained in a condition so that it could be launched immediately.

The Tharos

9.49 The presence of the *Tharos* on the evening of the disaster was fortuitous. So too was that of the anchor haulers such as the *Maersk Cutter*. There was no legal requirement for the availability of a vessel for fire-fighting, let alone rapid intervention for that purpose. The *Tharos* and the *Maersk Cutter* were unable to arrest the development or reduce the intensity of the fire on Piper. It was abundantly clear from the evidence that fire-fighting with water has no effect on a fire which is fed by gas escaping under high pressure from a riser. The master of the *Tharos* also said in evidence that when it came to the well-kill operation in the aftermath of the disaster he was personally surprised by the lack of effect which the fire monitors had on the wellhead fires which were relatively small in comparison to the fires on the night of the disaster. Following discussion with 'Red' Adair they agreed that the only effective method of extinguishing large hydrocarbon fires was to remove the source of combustion. On the other hand numerous survivors spoke of the beneficial effect of the spray from the *Tharos* monitors in providing some cooling and keeping down smoke. One of the survivors said that had it not been for the *Tharos* spray he did not think that he would have been able to get out on to the pipe deck and hence escape from the platform. The *Tharos* also had a valuable role as a communications centre and as a place for the reception and treatment of survivors. However during the survivors' evidence a number of criticisms of the *Tharos* were advanced and to these I must now turn.

Criticisms of the Tharos

9.50 It was said that the *Tharos* should have been brought into action more quickly. To increase its speed its anchor cables should have been cut. In any event her dynamic positioning system should have been used in conjunction with 2 of her anchors in order to enable the vessel to be manoeuvred close to the platform. It was also pointed out that initially the spray from her monitors fell a long way short of the platform and then died down. Her heat shield should have allowed her to come in close to the platform where the gangway should have been deployed for rescuing personnel from the platform. She did not stay close to the platform for long enough to fight the fire, and moved away when men needed to be picked up from the water. If she was unable to rescue men directly from the platform they should have been told to get off. Instead some waited for her to come in; while others vainly attempted to attract her attention by waving towels. One of the survivors said "If they had said they could not get in to help us some of the guys in the accommodation would have found their own way out."

9.51 In connection with this evidence I was reminded of the radio message received by the *Tharos* at 22.33 hours: "People majority in galley area. Tharos come. Gangway. Hoses. Getting bad." My attention was also drawn to a number of statements about the capability of the *Tharos* in Oxy Today, No 15, which was issued by the Occidental Petroleum Corporation in 1981. This publication contains a number of statements about the *Tharos* including the following:

> "Like a semi-submersible rig, the *Tharos* has great stability in rough seas. Sophisticated dynamic positioning permits it, by virtue of a computer link to 4 motors, to remain on station, perhaps over a damaged pipeline section while maintenance is being carried out, or beside an oil production platform during an emergency. .... Primarily the vessel is designed to fight fires, kill wild oil wells and provide support and hospital facilities during any offshore emergency. Its water cannon can throw 40,000 US gallons of water per minute over a horizontal distance of 240 ft. A 62 ft bridge enables personnel to walk on to a stricken installation to work on a fire or blow-out. .... About 20,000 gallons of water a minute can be piped to a platform to assist any fire-fighting teams which are still aboard in the event the platform's own water pumps happen to be shut down .... In the event of a platform evacuation, communications with the shore, standby vessels, helicopters and HM Coastguard would be sustained from a protected communications center which carries radio, telephone, telex and computer links."

In the same publication 'Red' Adair, who is described as having helped in the design of the *Tharos*, is quoted as saying that for fighting offshore fires "the Tharos is the best solution to date. Second to having a stable platform, powerful water cannon are needed to keep a flaming platform cool and protect the platform from literally melting away." The editor of the *Oil and Gas Journal* was quoted as saying that "the people on the Claymore and Piper fields can certainly now sleep a little bit more safely at night." A number of survivors said that the Tharos could not do what it was claimed it had been designed to do. The vessel was referred to as "the most expensive white elephant in the North Sea".

The capability of the Tharos

9.52 It is clear that the *Tharos* was designed to fulfil a number of functions, one of which was that of a fire intervention vessel. The others, as described in his evidence by Mr K R Wottge, Occidental's Facilities Engineering Manager, were the functions of a diving inspection/construction vessel, an intermediate lift crane barge, a construction support floatel, a first-aid/hospital vessel and a well-kill/plugging support vessel. The master of the *Tharos* said in evidence that she had never been designed to be a rapid intervention vessel, which normally was a supply vessel with a fairly high speed and fitted with fire monitors. Her intervention would be expected to take place after the initial evacuation of personnel by lifeboats, helicopters or a standby vessel. He pointed out in that connection that the high volume of water which the vessel was capable of delivering could not be used when personnel were still on the platform because of the risk of causing injury to them as well as structural damage to the platform. During the course of the evidence it was also pointed out that the gangway, which had been fitted to the fire boom after the 1984 incident, was made of aluminium and accordingly was unsuitable for deployment in close proximity to an intense hydrocarbon fire.

9.53 While I have no difficulty in accepting the evidence which I have referred to in the last paragraph as reflecting the real sense in which the *Tharos* was able to act as a fire intervention vessel, I am left with a clear impression that there was misunderstanding as to what it was capable of doing in the face of an outbreak of a major hydrocarbon fire no more than 500m away from it. This was reflected in the evidence of survivors and in the evidence as to the radio message received by the *Tharos* at 22.33 hours. The master rightly decided not to persist in his attempt to land the gangway on the platform. He said in evidence that he did not hear of the message received from Piper at 22.33 hours until about 1-1½ hours later, but it is clear that this did not influence his decision. I doubt whether it would have been practicable for the *Tharos* to have sent a message which was capable of being received by those who were in the accommodation after that time. However the OIM on Piper should have known what was the true position and disabused those who waited of their mistaken hopes.

The movement of the Tharos

9.54 The response of the *Tharos* to the initial explosion was immediate. Control was switched from the forward to the aft control room. The chief engineer went to start the fire pumps; and the positioning operator was instructed to commence moving the vessel towards the platform. As stated earlier, she started moving at about 22.05 hours. Having regard to the way in which she was anchored and the depth to which she was ballasted her potential speed was much less than her normal transit speed and amounted to about 2½ knots. However this was not attainable in the comparatively short distance through which the vessel travelled towards the platform. The automatic positioning system kept the vessel heading square on to the west face. Manual adjustments were made to port and starboard to allow for the effects of wind, tide and anchors. One of the first mates had the responsibility of keeping the correct tension on the winches which were paying out the anchor cables. As stated earlier, thruster phase-out was occurring from time to time as the maximum power generated was not quite sufficient to keep all systems functioning. This reduced the speed of the vessel from time to time but did not affect the pumps or winches. The vessel proved difficult to manoeuvre near the platform because of the effect of the anchor cables, the bad visibility caused by the spray and the smoke blowing over the platform. The master had considered jettisoning the anchors but decided that this would take too long, although precautions had already been taken to provide equipment ready to cut the cables if required. Likewise there was not enough time to set up the dynamic positioning in the way suggested by one of the survivors. Taking into account the inherent characteristics of the vessel I am satisfied that there was no fault as regards the speed with which the vessel approached the platform. Further I do not consider that there is any good ground for criticism of the master for his decision, in the exercise of his responsibility for the vessel, to pull back from the platform in face of the explosion at 22.50 hours.

Fire-fighting from the Tharos

9.55 It was clear to me from the evidence that the crew immediately responded to the initial explosion by making preparations to fight the fire. All the pump motors were lined up by 22.05 hours. There was however a delay of about 12 minutes in the cascade coming into operation, for the reason set out earlier in para 9.20. While this made no difference to the time at which the cascade was brought to bear on the platform and the personnel who were still on it, this must have reduced the relief and protection given to the rescue vessels and those in the water between the *Tharos* and the platform. This appears to have arisen from an over-enthusiastic attempt to bring the monitors into operation. It was stated in evidence that the monitors were tested every month. However proper training in the procedures should have ensured that the monitors were not allowed to discharge prematurely. This is a matter which could have been, and no doubt since the disaster has been, put right. I should add for the sake of completeness that difficulty was encountered with the starting of one of the fire pumps. However I accept the evidence which was given that this of itself played no part in either delaying or reducing the amount which the *Tharos* was able to cascade.

9.56 The Inquiry heard that from the stage when the *Tharos* was able to bring her cascade to bear upon the platform the crew had difficulty in judging where the spray was landing to the extent that another vessel was asked to report to the *Tharos* where the spray was landing. It was suggested that this evidence suggested of itself lack of training in the use of the monitors. However I interpret it as indicating the difficulty was caused by the obscuring effect of the fire and smoke on the platform. I see no grounds to find fault with the manner in which the cascade was used.

9.57 It was also suggested that a rapid intervention vessel (RIV) should have been on the scene. This ignores the fact that the *Maersk Cutter*, although it was in attendance as an anchor handler for the *Tharos*, was immediately involved in the use of its monitors on the east side of the platform. In any event her fire-fighting capability made no difference to the intensity or escalation of the fire. Accordingly in the case of the Piper Alpha disaster the presence or absence of an RIV was irrelevant.

The care and treatment of the injured

9.58 The Inquiry heard certain criticisms relating to the transfer of the injured to the *Tharos*. It was said that it was a long time before the injured who required medical attention were taken there; and that the basket and crane method of transfer from vessels to the *Tharos* was not suitable for those who were injured. On board there was, according to Dr Strachan, Director of Aberdeen Industrial Doctors, a degree of confusion in the sick-bay, with almost as many helpers as there were casualties. Mr A Matheson, Senior Consultant in the Accident and Emergency Department of Aberdeen Royal Infirmary, who headed the Offshore Specialist Team, said that though there had been a degree of confusion, the medical arrangements had gone as smoothly as could reasonably have been expected. I accept that this was so.

Occidental and Grampian Police

9.59 At 22.03 hours the *Tharos* informed Occidental in Aberdeen that there had been an explosion on the platform. This information was received by the Occidental Communications Officer who initiated a cascade call-out system in accordance with the laid down procedure. He also initiated a lesser call-out which was carried out by security guards at the security lodge. For this purpose the information given to the guards was that a major emergency had occurred offshore. At that time it was the practice that no further detail should be given to or issued by them. This series of calls was completed between about 22.12 and 22.21 hours. The first call in this was to police headquarters. The call was made on a dedicated direct exchange line between the security lodge and the police. The call was received by the police at 22.08 hours. The security guard who made the call followed the normal procedure by informing the police that a major emergency had occurred offshore. The police officer concerned then used the same line to telephone back to Occidental to authenticate the first call. This was a standard procedure in order to eliminate the risk of a hoax call.

9.60 In response to the cascade call-out senior Occidental personnel arrived at headquarters and manned an Emergency Control Centre there. Mr J L MacAllan, the Production and Pipeline Manager, was the first to arrive at 22.21 hours. Mr J B Coffee, as Vice-President Operations was the Onshore Emergency Controller. However as he had only recently been appointed to take responsibility for operations in the North

Sea he had to rely on the advice of senior personnel in co-ordinating the response. He was supported by the Vice-President Engineering, and the managers of the Production and Pipeline, Transport, Marine Operations, Loss Prevention and Drilling Departments. Mr MacAllan made a series of attempts to make contact with Piper and Claymore without success. He was eventually able to speak to the OIM of Claymore by the satellite system and had a conversation with him, as I stated in para 7.39. A plan was devised to send a team to the *Tharos* to assist in fire-fighting and rescue. The team, which included members of Grampian Fire Brigade, was flown out to the *Tharos* at 04.40 hours on 7 July but when they arrived they found that there was little left of the platform. In the light of the evidence which I heard I have no reason to consider that there was any material failure in Occidental's procedures for calling out senior personnel: or that Mr Coffee's lack of experience affected the security of emergency facilities.

9.61 The next step which the police were to take in carrying out contingency plans for emergencies was to send an inspector as a liaison officer to the emergency control centre of the operator. However it appears that this was delayed as a result of a desire to obtain more information as to the nature of the emergency. According to the evidence of Chief Inspector I Gordon who was concerned on a full-time basis with offshore emergency procedures and the contingency plans of the police and operators, the police tried to telephone Occidental 2 or 3 times between 22.20 and 22.40 hours but found that there was either no answer or the line appeared to be engaged. However, according to Occidental's Head of Telecommunications in the North Sea, Mr A G McDonald, the dedicated line to the security lodge was manned by a guard during this period. Numerous other telephone lines passed through the public exchange, but these had all been monitored and in every case but one the call had been answered. There was one additional dedicated line but that was in an office at the Occidental headquarters which was for the use of the police liaison officer when he arrived. Between 22.20 and 22.40 hours no attempted calls to Occidental headquarters were recorded in the police log. They would have been recorded in the police teltag system but a print-out was not available to the Inquiry as evidence since the records were destroyed some 6 months after the disaster. In these circumstances I am not satisfied that the police used the dedicated line or that there was any neglect on the part of Occidental in responding to any call from them at this stage.

9.62 In the meantime the police received telephone calls from the media asking them for confirmation of reports of an explosion on Piper and saying that the coastguard had informed them that they were not able to take press calls at that time. According to the contingency plan the coastguard should inform the police of an incident immediately and the police should be informed as to the installation involved, the nature of the incident and the casualties. It is obviously important that the police should have such information at an early stage. The police called the coastguard on a direct line and were told that the coastguard was busy and would call back in a few minutes. When the coastguard did not do so the police called the coastguard again. This was about 22.40 hours. At that stage the police were advised by the coastguard that they had received reports of an explosion on Piper. There were no reports of fire or casualties but it was said that a Nimrod and at least 6 helicopters had been scrambled in an effort to evacuate personnel from the platform. At this stage Mr Gordon became involved and a sergeant of Grampian Police, who was more readily available, was sent to Occidental headquarters to provide liaison with Occidental and establish the facts. At the same time another police officer was sent to the coastguard as a liaison officer.

9.63 At about 22.55 hours the police set up a major incident room for casualty enquiries, which was served by 12, later 24, telephone lines. The state of confusion as to what had happened prevailed even after 23.00 hours. At 23.10 hours when Chief Inspector Gordon spoke to Mr D A Miller, Occidental's Security Manager, who was then with the sergeant serving as the liaison officer, Mr Miller advised him that he had been told that "it was a diving accident", in response to which Chief Inspector Gordon said that he was rather surprised if this was the case as the police had been told by the coastguard that a Nimrod and at least 6 helicopters had been scrambled. At 23.20 hours the coastguard provided more information about the disaster to the police, as a result of which the police called out trained casualty documentation teams. At 23.47 hours the first information on casualties reached the police. After midnight the Occidental liaison representative arrived at police headquarters. At 00.45 hours the police received from Occidental a list of the persons who had been on board Piper. This was not entirely accurate as it included 7 persons who had moved from Piper to the *Tharos* some hours before the disaster. Further, the list was not in a form which was entirely helpful in respect that the names were arranged alphabetically within the companies represented on the installation. The significance of these points can be appreciated when it is understood that one of the tasks of the police was to advise the next of kin of any person who has died and to advise if a person has been injured. In the course of the night the police required to deal with numerous enquiries from relatives. Police officers were sent to Aberdeen airport and the helipad at Aberdeen Royal Infirmary where the uninjured and the injured, respectively, were landed by helicopter. Details of the passengers and their medical condition were relayed to the incident room at police headquarters. Police officers from the Grampian and other forces were sent out to advise the next of kin of the deceased. This was done within 24 hours of the incident. The tasks undertaken by the police were considerable. The Inquiry heard that 174 officers of Grampian Police were involved in work arising out of the disaster during the first 24 hours after it began.

9.64 Since the disaster the police and operators have given further consideration to emergency communications and procedures. This has resulted in a booklet prepared by the police and approved by the United Kingdom Offshore Operators Association Ltd (UKOOA) in July 1989. In accordance with that procedure the police will send a liaison officer to the operator on being informed of a "major offshore emergency". However in the light of the reasons set out in the booklet as to why the police require to be told of the nature and location of incidents it is hoped by the police that in future operators would give more information than that.

Chapter 10

The Causes of Loss of and Danger to Life

Introduction

10.1 In this chapter I will describe and comment on the recovery and examination of bodies of the deceased. I will give my findings as to the medical causes of death where these are ascertainable. I will also set out my conclusions as to factors which contributed to the deaths of the deceased and the risks to which the survivors were exposed in the disaster.

The recovery of bodies of the deceased

10.2 Late on 6 July rescuers recovered an injured person from Piper who later died from his injuries in hospital on 19 July. On 7 July the bodies of 15 deceased persons from Piper were recovered by various vessels from the surface of the sea at and around the remains of the platform; and the bodies of 2 members of the fast rescue craft of the *Sandhaven*.

10.3 In the period after 7 July the Marine Department of Occidental was responsible for the location and recovery of bodies, in addition to the examination of the platform jacket and the identification of debris on the seabed. At the time of the disaster the *British Magnus* was on its way to carry out underwater survey work, including the use of remotely operated vehicles (ROVs), for which it was then fully equipped. As a result of the co-operation of BP, Occidental were successful in obtaining the services of this vessel for the initial survey and recovery work. A series of side scan sonar sweeps and ROV excursions around the platform were carried out. Surveys were carried out in grids of $10m^2$, with the intention of attempting to cover each square twice. As a result of this work between 10 and 29 July a further 27 bodies from Piper were recovered from the seabed.

10.4 On 4 August the *British Magnus* was demobilised in order to proceed to her original work for BP. On 8 August the *Seaway Condor*, a diving support vessel, took up the survey work which had previously been done by the *British Magnus*. As from 10 November 2 fishing vessels, the *Heather Sprig* and the *Janeen*, were used to trawl in a wider area for debris and any human remains which had not been located previously. Arising out of this work 4 bodies were recovered between 15 August and 17 October; and a further 6 between 31 October and 22 November 1988.

10.5 The last body to be recovered from the seabed was found on 2 June 1989.

10.6 Early on in the survey work the ERQ and the AAW of the platform's accommodation had been located in the seabed. The ERQ was resting upside down. It was also found that the LQW was in a disintegrated condition on the seabed. It was found that the ERQ contained a considerable number of bodies. In September 1988 7 bodies were recovered by divers from its galley. Preparations were made for the lifting of the ERQ and the AAW from the seabed. This involved a difficult operation and called for considerable resources of equipment and manpower. On 10 and 15 October 1988 the AAW and the ERQ were raised from the seabed. Thereafter they were taken to the Occidental terminal at Flotta for examination. Later in October and in November 1988 a total of 74 further bodies were recovered from the ERQ, 70 from D Deck and 4 from A, B and C Decks. No bodies were found in the AAW.

10.7 From the above it will be seen that 16 of the deceased from Piper were recovered from the surface of the sea; 38 were recovered from the seabed; and 81 were recovered from the ERQ. 30 persons from Piper remain missing and should be presumed to have died on 6 July as a result of the disaster.

10.8 Appendix H to this report contains a schedule of information relating to the deceased, including the 2 members of the crew of the fast rescue craft of the *Sandhaven*. That schedule sets out information as to the recovery of the body of the deceased where this was achieved. In the case of those missing and those recovered from elsewhere than the wreckage of the accommodation it sets out the last known whereabouts of the deceased in the period from about 22.00 hours on 6 July in the light of the evidence available to the Inquiry.

10.9 It was found that of the 135 bodies from Piper which were recovered, 66 were wearing survival suits; and of the 81 recovered from the accommodation 42 were wearing them. As regards life-jackets, the position is unknown in regard to the bodies which were recovered on 7 July, apart from one case in which a life-jacket is known to have been worn. As regards the remaining bodies it was found that a life-jacket was worn in 19 cases.

10.10 In his closing submissions Senior Counsel for the Trade Union Group criticised Occidental's effort with regard to the recovery of bodies in a number of respects. His remarks were directed to the evidence given by Mr D J M May, Senior Engineer for Pipelines and Structures in Occidental's Marine Department. He submitted that when the *British Magnus* was demobilised on 4 August 1988 the search was not complete because during the 4 weeks since the disaster there were, in the words of Mr May, "too many things to do and not enough things to do them with". The *British Magnus* was not replaced with a comparable vessel but with the *Seaway Condor* which was not only a less well equipped vessel for such a search but was required in any event to assist in the recovery of the accommodation quarters. This created, in the words of Mr May, "a conflict of goals". Accordingly the *Seaway Condor* could not be released to concentrate on the search for bodies. Counsel submitted that his criticisms were supported by the fact that only a few bodies were recovered between the demobilisation of the *British Magnus* and the start of the trawling operations and by the fact that the results of the trawling operations demonstrated that there were further bodies which could be recovered. He went so far as to suggest that it was possible that more bodies would have been recovered "had the search been continued with the same concentration, expertise and facilities as was provided in the first 4 weeks". However, the evidence shows that the *Seaway Condor* continued the type of search in which the *British Magnus* had been involved. Mr May gave evidence that Occidental had equipped that vessel to standards which were practically equivalent to those of the *British Magnus*. The reference by Mr May to "too many things to do and not enough things to do them with" was in the context of the practical difficulties which had been experienced in carrying out surveys with the ROVs, which initially required to be done on an *ad hoc* basis. His reference to a "conflict of goals" arose from the fact that at the time Occidental wanted to recover the ERQ as they knew that it contained bodies which they could not otherwise recover. They also suspected that there were bodies in the AAW. He also pointed out that the work required to recover the ERQ precluded survey work in the area of the ERQ and a large area around it. This meant that Occidental could not survey the most important area on the seabed which the *British Magnus* had not surveyed. It is also reasonably clear from the evidence that as a result of the combined work of the *British Magnus* and the *Seaway Condor* a large area surrounding the platform was surveyed, and in most instances twice. At the time when the trawlers were put into operation there was no obvious deficiency in the scale of the work which had been done with a view to the recovery of bodies. That was not inconsistent with their realisation that it was possible that further bodies might be recovered in the trawling operation which was to cover a still wider area. In my view the criticism of Occidental in these respects was misconceived. I do not consider that Occidental failed to take any steps which they should reasonably have taken in the light of the information available to them and the whole work of survey and recovery in which they were involved.

The Post-mortem Examination of Bodies

10.11 Appendix H sets out the principal cause of death, where that has been ascertained, of those whose bodies were recovered. In paras 10.11-10.18 they are identified by the numbers shown against the names in that Appendix. The deceased from Piper and the *Sandhaven's* fast rescue craft were examined by a team of pathologists under Dr W T Hendry, then Head of the Department of Forensic Medicine in the University of Aberdeen, with the exception of the deceased (No 14) who was recovered alive on 6 July but died later from extensive burns; and the deceased (No 84) whose remains were recovered on 2 June 1989.

10.12 As regards the bodies recovered at sea on 7 July 1988 the post-mortem findings were as follows. The 2 members of the crew of the FRC (Nos 10 and 146) were found to have died by drowning. They also showed patchy superficial burning of the face. As regards the 15 deceased who had come from Piper, 8 of them had apparently died during an attempt to escape from the platform. Of that group 5 (Nos 28, 53, 64, 99 and 109) had died by drowning, showing also superficial burns of the face, possibly sustained by contact with burning oil in the water. The remaining 3 (Nos 40, 95 and 131) had died by chest injury, essentially fractures of the ribcage combined in varying degrees with injury to the lungs, heart and liver. In Dr Hendry's opinion, those injuries were typical of the result of impact with water after a descent from a considerable height when the victim struck the water in other than a feet-first attitude. The remaining 7 deceased had apparently died on board from the effects of the fire. Of this group 6 (Nos 4, 22, 27, 49, 122 and 156) had died from the inhalation of smoke and gas. This finding was based on the presence of a sooty deposit in the airways and confirmed by analysis of blood samples for the presence of carbon monoxide which is the most important toxic gas produced in fires. In these cases the carbon monoxide content varied from 71% to 89% saturation of the blood. In the case of fire victims it is usually accepted that a level of 50% or greater indicates that death was essentially the result of the inhalation of smoke and gas. In 4 cases there were varying degrees of post-mortem heat injury, 3 showing major post-mortem injury. In the seventh case (No 67) there was evidence of both significant inhalation of smoke and gas and a necessarily fatal open abdominal injury along with post-mortem heat damage. The injury in that case was consistent with the victim striking, or being struck by, a penetrating object.

10.13 Of the 27 deceased whose bodies were recovered from the seabed between 10 and 29 July, 4 of them (Nos 33, 43, 73 and 141) had apparently died during an attempt to escape from the platform. In each case it was considered that they had drowned. This diagnosis was not based upon positive evidence to that effect because the bodies had been exposed to pressure at depth. It was presumed in the absence of injury and heat damage, together with a low blood level of carbon monoxide. The remaining 23 deceased had died apparently on board the platform. 14 of this group (Nos 26, 66, 68, 98, 105, 114, 127, 134, 140, 144, 145, 157, 161 and 163) had died from inhalation of smoke and gas, the levels of carbon monoxide in the blood varying from 63% to 93%. Several of them showed minor heat damage and some degree of injury. 2 of the deceased (Nos 162 and 164) presented severe damage by heat and were regarded as having died in the fire. 3 (Nos 19, 44 and 152) had a blood level of carbon monoxide varying from 43% to 47% and were regarded as having died from inhalation of smoke and gas. The remaining 4 deceased (Nos 45, 56, 75 and 160) were found to have suffered major visceral injuries involving the heart or a main vessel, 3 showing signs of the inhalation of carbon monoxide, in one case at a level of 48%. These injuries suggested that the victims had sustained impact following motion as in a fall or projection by blast.

10.14 Of the 4 bodies recovered between 15 August and 17 October the first 2 presented difficulty of interpretation due to greater post-mortem change. As the samples of blood which were taken from them were seen to be decomposed it proved necessary for them to be sent to the Department of Forensic Medicine and Science, Glasgow University, where more sophisticated laboratory equipment was available. As a result of analysis by that equipment it was found that in one case (No 104) there was a 72% concentration of carbon monoxide which confirmed death had occurred by inhalation of smoke and gas. In the other case (No 39) a result could not be obtained. Accordingly all that could be said was that the latter victim died in a fire since the remains showed only post-mortem heat damage and no injury. The third body (No 72) which was found showed no evidence of primary injury or heat damage. The carbon monoxide level was later found to be 86%, which confirmed death by inhalation of smoke and gas. The fourth body (No 154) was the subject of a presumptive diagnosis of death by drowning because there was no evidence of heat damage to the body or injury and the carbon monoxide level was only 17%.

10.15 As regards the 6 bodies recovered between 31 October and 22 November 1988, death was ascribed in 4 cases (Nos 42, 121, 130 and 133) to the inhalation of smoke and gas, the blood carbon monoxide levels varying from 21% to 84%. There was no evidence of injury. In the fifth case (No 7) there was no evidence of burning or injury and it was considered that death had been due to drowning. In the last case (No 38) there was insufficient material on which to base an opinion.

10.16 In the case of the body which was recovered on 2 June 1989 (No 84) it was found that there was insufficient material on which to base an opinion as to the cause of death.

10.17 All of the bodies which were recovered from the galley of the ERQ in September 1988 showed post-mortem change but no sign of injury or heat damage. The diagnosis of the cause of death depended almost entirely on the results of the blood analyses which were later received from Glasgow University. In 3 cases (Nos 54, 107 and 126) the relevant levels varied from 39% to 69%. It was considered that death in these cases was due to the inhalation of smoke and gas. In a further 2 cases (Nos 15 and 86) the levels were 22% and 21%. It was interpreted that they also had most probably died from inhalation of smoke and gas. In the remaining 2 cases (Nos 91 and 147) the cause of death was not ascertained because the relevant level was reported as being only 13%.

10.18 As stated earlier 70 bodies were recovered from D Deck of the ERQ at Flotta (Nos 1, 2, 3, 5, 8, 11, 16, 17, 18, 20, 21, 23, 25, 31, 32, 34, 35, 36, 37, 46, 47, 48, 50, 51, 52, 57, 63, 69, 70, 71, 76, 77, 78, 79, 81, 82, 85, 87, 88, 89, 90, 92, 94, 97, 100, 101, 102, 103, 106, 110, 111, 112, 116, 117, 119, 120, 123, 128, 129, 132, 135, 137, 138, 142, 148, 151, 155, 159, 165 and 166). It was found that in general they were remarkably intact and well preserved in comparison with those recovered from the seabed, despite the long post-mortem interval. Evidence of fire damage was seen in only 10 cases and this was limited to localised post-mortem lesions. There were minor post-mortem fractures in 10 cases. A single body (No 151) had sustained major crush injuries after death. In almost every case there was evidence that the victim had inhaled smoke and gas. Analyses of samples of blood and muscle at Glasgow University showed the presence of carbon monoxide in each case, the level in the blood in 56 cases varying from 24% to 93% and the level in the muscle varying in 19 cases from 24% to 83%. In 45 cases a level of 50% saturation or more was obtained. In only 7 cases was the carbon monoxide level less than 30%. Dr Hendry expressed the opinion that the variation in the carbon monoxide blood levels might be explained in some cases by the possible loss of carbon monoxide over a period of time in decomposing or stored blood. On the other hand he said that it had been recorded that carbon monoxide might be formed in the tissues of a submerged body but that this was only minimal in the case of blood specimens. Those considerations apart, he said that it was a well recognised fact that in fatal fires some of the victims were found to have low levels of carbon monoxide in the blood. Those deaths were usually attributed to a deficiency of oxygen or an excess of carbon monoxide in the atmosphere or to a rapid rise in body temperature in a very hot environment. Other toxic gases such as hydrogen cyanide might have been implicated but they could not be detected after any delay. Taking into account all those factors his belief was that it was reasonable to conclude that all the victims in the ERQ died in an irrespirable atmosphere, just as two thirds of them undoubtedly did. It was quite clear that not one of them died by burning. In November 1988 the remaining 4 bodies which had been taken from

Decks A (Nos 41 and 139), B (No 59) and C (No 113) of the ERQ were examined. The findings in these cases were similar to those in the case of the deceased recovered from D Deck. The levels of carbon monoxide in the blood varied from 30% to 65%. No injuries were found but in one case localised post-mortem heat damage had occurred.

10.19 In the light of these findings, which I accept in their entirety, it can be seen that the cause of death was ascertained in the case of 131 out of the 135 bodies from Piper which were recovered. The principal causes of death may be summarised as follows:-

11 of the deceased died by drowning

11 of the deceased died from injuries, including burns

109 of the deceased died from the inhalation of smoke and gas (79 of them having been recovered from the ERQ)

It may be noted that in a total of 14 cases (11 drowning, 3 injuries) the deceased died apparently during or after an attempt to escape from the platform. In all other cases the deceased died on, or apparently on, the platform. Death was caused by burn injuries in only 4 cases.

The deceased from Piper

10.20 Of the total of 165 deceased persons from Piper 23 (including 17 contractors' personnel) were on night-shift duty on the evening of 6 July. The remaining 142 (including 116 contractors' personnel) were off duty. The latter number includes 10 who were on 24 hour call (see para 8.3). These numbers may be broken down by categories of work as follows:-

Category	*On duty*	*Contractors*	*Off duty*	*Contractors*
OIM	—	—	1	—
Safety	1	1	4	1
Operations	4	2	12	3
Drilling	11	11	27	26
Maintenance	5	3	22	12
Marine & Underwater	1	—	9	9
Offshore Projects	—	—	43	42
Materials	1	—	1	—
Inspectorate UK	—	—	2	2
British Telecom	—	—	3	3
Kelvin Catering	—	—	18	18
	23	17	142	116

It may be noted that 37% of those who had been on night-shift duty died in the disaster; whereas 87% of those who had been off duty did so.

Summary of conclusions

10.21 In the light of the evidence which I have considered in this and the previous chapters I am able to state my conclusions in summary as follows:-

(i) All those named in Appendix H died as a result of the disaster. They died on 6 July 1988, with the exception of No 14 who died on 19 July 1988.

(ii) In the case of 133 out of the 135 bodies of personnel from Piper which were recovered it was possible to ascertain the principal cause of death, which was as set out in Appendix H.

(iii) In the light of the findings as to the principal cause of death it should be inferred that in 14 cases the deceased died during or after an attempt to escape from the platform; and that in all other cases the deceased died on, or apparently on, the platform.

(iv) The disaster was the result of a series of events which were set in train by an initial explosion in C Module. In paras 6.177-187 I set out my conclusions as to the cause of that explosion. In paras 6.188-192 I made observations as to failures which led to this. This is subject to my further observations in Chapter 14 as to the management of safety.

(v) The series of events included (a) a crude oil fire which generated heat and dense black smoke which engulfed the accommodation from the outset; (b) a series of explosions; and (c) massive and prolonged fires fuelled by gas under high pressure following the ruptures of the Tartan and MCP-01 risers.

(vi) The development of the crude oil fire and the damage caused by it were greatly assisted by the fact that the initial explosion had destroyed or disabled the active fire protection system.

(vii) The size and duration of the crude oil fire and the heat and smoke generated by it were exacerbated by the fact that the Claymore and Tartan platforms did not shutdown production sooner than they did.

(viii) The ruptures of the Tartan and MCP-01 risers were on the upstream and downstream sides of the respective emergency shutdown valves, thus rendering these valves ineffective for the purpose of isolating the platform from the inventories of the pipelines.

(ix) The death toll among those in the accommodation was greater than it would have been if the OIM had given instructions that personnel should abandon the accommodation and attempt to escape from the platform by whatever means they could.

SECTION THREE: BACKGROUND TO THE DISASTER

Chapter 11

The Permit to Work System and Shift Handovers

Introduction

11.1 Chapter 6 of this report has already examined the working of the permit to work system and the handover from the day to the night-shift on 6 July. The exploration of these matters led to the revelation of a number of serious deficiencies of which those on 6 July were merely specific instances. In this chapter I will set out some of the more salient shortcomings, together with a brief account of an earlier fatality which is relevant to the discussion. In Chapter 14 I will examine the way in which Occidental management discharged their safety responsibilities in regard to the permit to work system and handovers.

The permit to work system

11.2 A permit to work system is a formal written system which is used to control certain types of work which are potentially dangerous. Within that system the permit is a formal written means of making sure that potentially dangerous jobs are approached and carried out with the use of appropriate safety procedures. It is an essential part of a procedure to ensure that the work is done safely. Safety in this context means the safety not only of those carrying out the work but also of those who may be affected by the carrying out of that work. An examination of the system as it prevailed on Piper for a substantial period up to the time of the disaster raised a number of general questions. It is convenient to set out the results of that examination by reference to the questions which follow below.

Was the Occidental procedure complied with?

11.3 In order to ensure that an effective permit to work system is achieved in practice it is essential that operating staff work exactly to the written procedure which has been developed by the management of the company. The Occidental written procedure was contained in their Safety Procedures Manual, which was a working draft issued in September 1987 in replacement of an earlier manual. So far as the permit to work procedure was concerned the same content but in a slightly different format appeared in a Work Permit Booklet which was produced in 1985 as an up-date of the earlier procedure. However, the evidence at the Inquiry demonstrated that in a number of significant respects this procedure was habitually or frequently departed from. From the evidence a number of examples may be given as follows:-

(i) The procedure required by section 3.2 that the Performing Authority take the permit to the Approving Authority in person, but this was often not done in practice.

(ii) An examination of a number of permits to work, which appeared to be typical of recent practice, showed numerous errors in completion of various details which are required under the procedure, such as errors in regard to signatories, the description of work, the carrying out of gas tests, the effecting of electrical isolation and the affixing of red tags, the insertion of dates and times, the completion of declarations and certificates, the deletion of inapplicable alternatives and the details of extensions, suspensions and safety precautions.

It may be noted at this point that Reg 3(3) of the Operational Safety, Health and Welfare Regulations requires that a permit to work should specify "The work to be carried out, the precautions which have been taken to ensure that the work is carried out safely, any particular procedures to be followed or particular equipment to be used or worn, the period for which the permit is to continue in force and the name of the person to whom it is issued."

(iii) Occidental procedure required by section 3.1 that the precise nature of the task should be set out on the permit by the Performing Authority. It will be recalled from Chapter 6 that when Mr White, the maintenance superintendent, signed the permit for PSV 504 he entered the number and location of the valve on the permit. This necessary information had not been included by Mr Rankin, the Performing Authority.

(iv) Section D10 of the permit form asked "Is there any other work which may effect (sic) this work?" (see Fig 3.9). This section was seldom used. At most it might be ticked but no detail supplied as to the work or its effect.

(v) Section 3.3 of the procedure provided that the Designated Authority was to mark section E of the form showing the protective equipment required, stating "These are not suggestions, they are demands to ensure the personal safety of the people performing the work ..." On the other hand at a safety meeting on Piper in September 1987 those who were present were reminded that the responsibility for completing that section was that of the Performing Authority. However this was not brought to the attention of Mr C Lockwood, an experienced lead production operator, who explained the working of the permit to work system at an early stage in the Inquiry.

(vi) Contrary to the written procedure multiple jobs were undertaken on a single permit. A particular example of this was provided by the permit issued in March 1988 in respect of the refurbishment of both PSV 504 and 505 which were attached to the pipework of different condensate injection pumps.

(vii) Contrary to the written procedure the Performing Authority's copy of the permit was frequently not displayed at the job site. It was not uncommon for the Performing Authority to keep it in his pocket, as Mr Rankin did.

(viii) When Performing Authorities returned permits to the Control Room shortly before the end of the day-shift they would sign off all copies of the permit and leave them on the desk of the lead production operator for his subsequent attention. This was contrary to Occidental procedure which required the Performing Authority and the Designated Authority to meet. This deficient practice had developed because the lead production operators were engaged in their handover at this time. It will also be recalled from Chapter 6 that the evidence of Mr Rankin was that before returning to the Control Room to suspend the permit at 18.00 hours he did not inspect the work site. This also was contrary to the Occidental procedure. It was, of course, contrary to good practice in that as supervisor he failed to ensure that the work was in a safe condition to be left overnight.

(ix) Designated Authorities would regularly but not always sign off permits both for completion and for suspension prior to having the job site inspected. This was contrary to Occidental procedure at section 3.5. Mr Lockwood agreed that this was an example of a number of fairly casual aspects to the permit to work procedure. According to Mr Rankin's evidence the lead operator accepted the permit for suspension without first inspecting the job site and satisfying himself that it was in a safe condition.

(x) Suspended permits were filed in the Safety Office overnight. However, Occidental procedure by section 3.6 required Designated Authorities to retain the suspended permits. It followed that unless he was involved himself in suspending a permit a night-shift lead production operator would not know which permits had been suspended and accordingly what equipment had been isolated for maintenance purposes.

These examples serve to demonstrate that the operating staff had no commitment to working to the written procedure; and that the procedure was knowingly and flagrantly disregarded.

Were practices in the permit to work system unsafe?

11.4 It is not unreasonable to proceed upon the basis that the specific provisions of the Occidental procedure were devised with the intention of achieving the safety objective to which a good permit to work system should be directed. Accordingly each of the above departures from the written procedure represented a departure from safe practice. In any event it does not take much imagination to appreciate that they had in them the potential for causing accidents. However the unsafe aspects of the system can be further demonstrated by the following examples:-

(i) Apart from the case where it had been planned to carry out a major shutdown, there was no consistently used system for affixing a tag to an isolation valve which had been closed as part of the isolation of equipment for maintenance where the tag warned that the valve should not be opened. Unlike the practice of locking-off for electrical isolation, there was no consistent practice of physically locking-off isolation valves which had been closed in order to prevent their being opened inadvertently. Even where equipment had been locked-off, there was nothing to tell an operator what was the reason.

(ii) Where the work under one permit could affect the work under another there was no cross-referencing of the two permits. Reliance was placed on the memory of the Designated Authority. As stated above section D10 of the permit might be ticked but no further detail was supplied. Further, the system of filing active permits in the Control Room according to the location of the equipment meant that work affecting associated equipment on different levels would not be filed together.

(iii) At shift changeover lead production operators would not review or discuss the active or suspended permits. Accordingly there was a gap in the system of communication.

(iv) Suspended permits were not kept in the Control Room but in the Safety Office, apparently on the ground that there was not enough room in the Control Room to display them there. A lead production operator could be aware of a suspended permit if it was one of those permits which came to him for suspension during the period of three quarters of an hour before he officially came on shift. But it could be unknown to him if it had been suspended days before or earlier on the same day before he arrived in the Control Room for the handover. Mr Lockwood stated that he would not look at the suspended permits in the Safety Office when he came on shift; and there is no evidence of such a practice. On the other hand Mr A G Clark, a maintenance lead hand, said that he would check suspended permits. The correlation of suspended with active permits was made more difficult by the fact that in the Safety Office suspended permits were not filed according to location but according to the trade involved. This made it difficult for any supervisor to check readily which equipment was isolated for maintenance.

(v) For significant periods there were large numbers of suspended permits in the Safety Office, some of which had been suspended for months. In February 1988 it was found that 124 permits to work were outstanding. The safety staff accepted the need to reduce this number and to police the system but no procedure was instituted to bring about any improvement.

(vi) There appeared to be no system for ensuring that fire and gas panels were reactivated as soon as the need for locking them off had ceased. The reactivation depended upon whether action was taken by either the Control Room operator or the Designated Authority and in either case whether he knew that the work for which the fire and gas panels had been locked off was either completed or suspended.

Faced in cross-examination with the proposition that in many ways merely lip service was paid to the permit to work system and that in reality communication was relied upon either by word of mouth or by habit Mr Lockwood replied "That is correct. The communication was very good. That is the only thing I can say in defence of the system. Communication between the people working on the operations and the maintenance was very good." Whether that was generally the case I am unable to judge, as this would go far beyond the province of this Inquiry. However in my view such an approach put too high a premium on informal communications. On 6 July the permit to work system failed to prevent the night-shift staff from embarking on the recommissioning of the A condensate injection pump while its PSV was missing from the system. Such a failure can well be understood against the background of the informal and unsafe practices which I have outlined above.

Was there adequate training in the system?

11.5 In order to have an effective permit to work system it is essential that the personnel who are required to operate the system are thoroughly trained in all its aspects. This applies particularly to those who are to act as Designated Authorities and as Performing Authorities since the safe execution of maintenance work is their responsibility.

11.6 As regards Occidental personnel who were to act as Designated Authorities it is clear that Occidental provided no formal training in the permit to work system. Thus Mr Lockwood required to pick up the practice from watching others carrying out the function of Designated Authority. This also applied to other personnel on the platform. While training "on the job" no doubt has a part to play in the full training of personnel in positions of responsibility for safety, I consider that it should not be the sole or primary means of training. It suffers from the crucial weakness of perpetuating or accumulating errors.

11.7 The contractors who worked on Piper could be divided into 3 groups:- (i) long-term contractors, such as heating and ventilation technicians; (ii) specialist contractors, such as Score (UK) Ltd; and (iii) short-term contractors, such as those working for a few weeks on major overhauls. Personnel from the first and second of these groups were in practice expected to operate the permit to work system as Performing Authorities. It will be recalled from Chapter 6 that on 6 July 1988 Mr Rankin was acting as Performing Authority in relation to the permit to work for the overhaul and recertification of PSV 504. It is clear that to a large extent Occidental placed the responsibility of ensuring that contractors' employees were familiar with the permit to work system on the contractors themselves. According to Mr A C B Todd, maintenance superintendent, under whose authority maintenance contractors work, Occidental organised no training for contractors' employees in regard to the permit to work system. In his view the long-term contractors would be familiar with the system. As I stated in para 6.81, he said that when Mr Rankin came to his office on 28 June he asked him if he knew the PTW system. Mr Rankin said he was happy with it and knew how to work it. Mr Todd did not probe to determine whether this was the case.

11.8 In para 13.5 I will refer to the safety induction at which the permit to work system was "explained". However, in the light of Mr Patience's evidence, this appeared to be no more than a reference to the existence of a permit to work system; and a statement of the types of work for which the different kinds of permit were intended. "Newcomers" to Piper were provided at the heliport with copies of a small Safety Handbook prepared by Occidental for Piper and Claymore in May 1987. This contained information on 3 pages relating to the permit to work system. However a comparison between its statements and the system as it was in fact operated on Piper demonstrated a number of significant differences, some of which could have important implications for safety. The Safety Handbook stated incorrectly that:- (i) there were 4 different types of permit; (ii) that written application for a permit to work was submitted to the OIM (this was the case on Claymore); (iii) that on receipt of a permit the person responsible for carrying out the work was to personally inspect the work site (whereas in practice he was expected to do so before obtaining the permit, in order to ensure that there was no problem in proceeding with the work); (iv) that on completion of the work or at the expiry of the time written on the permit the person responsible for carrying out the work was to state when returning the permit that "normal operations may safely be resumed at the work site" (whereas no such statement was contained in the "clearance certification" on the permit to work form or was a necessary implication of the returning of the work permit). In these respects the handbook was dangerously misleading. At this point I note that in giving evidence on behalf of the Wood Group, Mr W H Carr, a Director of the John Wood Group PLC and Wood Group (Engineering) Ltd, stated that their clear understanding from Occidental was that the permit to work system was fully dealt with in the platform induction procedure and the Safety Handbook. The only other written guidance as to training in the permit to work system was contained in a set of notes issued by the OIM and safety supervisor on Piper to the discipline supervisors and charge-hands in or about 1987, a copy of which was produced at the Inquiry. This included a section on permits to work. After providing some guidance as to the work for which, and the procedure by which, a permit was obtained it stated "Prior to commencing any task, supervisors are to ensure that all conditions of the permit are strictly adhered to. On completion and/or suspension of the permit, the job site is to be cleared and made safe." This fell a long way short of what should have been provided, namely a systematic and consistent set of training notes explaining in relation to the permit form the full and exact responsibilities of the Performing Authority and the safety implications of full compliance with laid down procedure.

11.9 In the result I consider that the training required to ensure an effective permit to work system was operated in practice was not provided.

Was the operation of the system adequately monitored?

11.10 An essential aspect of any permit to work system is the monitoring and auditing of the operation of the system in practice. By the former I mean checking on a routine basis by platform personnel. By the latter I mean the planned examination of the system at infrequent intervals by personnel who are not responsible for the operation of the system. I will leave over auditing to Chapter 14.

11.11 The monitoring of the permit to work system on Piper was carried out almost entirely by the safety organisation. The lead safety operator considered that it was one of his duties to check whether the formal permit to work procedure was being complied with. This was confirmed by the platform safety supervisor, who personally joined in this activity although there was no laid down procedure as to how it should be done. The faults which he personally found were limited in number and importance and he said that he had no concerns about the system. Mr Todd said that he had taken no action to monitor the permit to work system in the 12 months prior to the disaster. Mr R G Sneddon, an operations superintendent, considered that compliance with the procedure was an important aspect of safety but said that the system was being operated in a proper manner in 1988 and that he was not aware of any problems. Mr A Bodie, the Safety Superintendent who was based on the shore, did not investigate the working of the system or discuss it with the lead operator. His department, the Loss Prevention Department, did not help personnel on Piper to be acquainted with the permit to work procedure. He had no feedback about problems with permits to work.

The written procedure

11.12 A number of comments can be made on the adequacy of the written procedure itself, but I should not be taken as indicating that in all other respects the procedure was satisfactory. The points which I would mention are as follows:-

(i) The procedure makes no reference to methods of isolation and in particular does not set out a system of tagging and locking-off of isolation valves which have been closed or opened as part of making equipment safe to work upon. While Occidental's general approach to the isolation of equipment for maintenance is set out in another section of their General Safety Procedures Manual there is no mention of either tagging or locking-off. Without these added precautions there is a real risk of inadvertent operation of a valve which is critical to safe isolation.

(ii) The procedure does not mention the need to cross-reference permits where one piece of work may affect another. Without this there is a danger that on completion of one task isolations which are critical to another piece of work may be removed.

(iii) The procedure does not draw attention to the danger which is involved in the recommissioning of suspended maintenance work.

(iv) Reg 3(4) of the Operational Safety, Health and Welfare Regulations provides that:-

> "It shall be the duty of the person to whom any work permit has been issued, on the work to which it relates being completed or ceasing to be carried on by him:-
>
> (a) to sign thereon a declaration that the work which he has carried out has been properly performed and either completed or ceased to be carried on and that the equipment affected by the work has been left in a safe condition; and
>
> (b) to deliver the work permit to a responsible person."

The form of permit used by Occidental included a "clearance certification" which was to be signed by the Performing Authority, making a declaration in the following terms:

> "I declare that the work for which this permit was issued is now completed/suspended, that all men have been withdrawn: and that all tools have been removed and that obstructing objects do not remain."

It does not appear that the permit contained a declaration by the Performing Authority which satisfied para (4). In particular it did not contain a declaration that the equipment affected by the work had been left in a safe condition.

End of shift handovers

11.13 In Chapter 6 I found that the handovers between phase 1 operators and maintenance lead hands on the evening of 6 July 1988 were materially deficient in that they failed to include communication of the fact that PSV 504 had been removed for overhaul and had not been replaced. Was this an isolated case of the failure to transmit evidence as to maintenance which had a critical bearing upon whether it was safe to operate equipment which was part of the gas plant? It should be noted that there were no written procedures for handovers. Mr Lockwood had never experienced problems as a result of inadequate handover and considered communications between process and maintenance staff to be very good. What was written on the lead production operator's pad and communications at handover was left to his discretion but this did not present problems. Mr Lockwood's own practice, which he thought others followed, was to look at the operators' logs to check what was going on. Maintenance work was not always set out in the logs which were kept by operators. It was only if it affected an important piece of machinery so that it would not be available to be operated.

11.14 However, this evidence should be taken in conjunction with that of Mr Clark, who had worked on Piper since 1977. On the one hand he agreed that the whole plant and platform was run in a professional manner. He felt that those who were employed on the platform did their utmost and took a pride in what they did. Safety was improving continually. There were quite a few meetings at which complaints were put forward and, if it was practicable, the complaint was dealt with. On the other hand it was his view that there should be a written procedure as to the amount of information which should be transmitted between personnel as to the work that was being done. "There were always times when it was a surprise when you found out some things that were going on." At a seminar held at the head office of Occidental in Aberdeen in early 1988 he had criticised the way in which the permit to work system was applied. "I thought it was high time it was upgraded and more specific." He had also criticised the lack of communication of information. "I just said that it was totally inadequate and it left a great need for rewriting." He said that nothing had really come from this seminar by 6 July. Asked whether he had felt this in the years leading up to 1988 he said "We had made an issue of it and we had discussed what we felt we wanted between the people on the platform. We had approached the OIM about getting something done with the permit system. We discussed it with him for quite some time and the permit system was altered but, again, when it came, it was not what we wanted." Right from the beginning he had also been critical of the method of communication. He could not see any reason why his suggestions could not have been carried out. As far as the permit to work system was concerned it was open to interpretation. "Everybody had their own idea of how the permit system should be applied and it sort of changed week to week and crew to crew." He criticised the way in which a permit was extended. "At the end of the day-shift, when it was cancelled, the night-shift would take it back out and just put "extension" on the back of it, which was not the way it was supposed to work." What annoyed him more than anything was permits not being properly carried through. "With permits, there was such a great difference between them and that should never have been." The majority of the maintenance department and also contractors were critical both of the communication methods and the permit to work system on Piper. These comments, which I have no reason to think were other than well-founded, underline the grave shortcomings in Occidental's approach to potentially dangerous jobs.

The Sutherland fatality

11.15 On 7 September 1987 Mr F Sutherland, a rigger employed by an offshore contractor was killed in an accident in A Module. This accident and what arose out of it has a significant bearing on the discussion of the adequacy of Occidental's attention to the quality of its permit to work system and handover procedure.

11.16 On the day of the accident a damaged bearing required to be replaced in a pump on the east side of A Module. It was found that it was impossible to remove the bearing without lifting the motor. For that purpose Occidental's lead maintenance hand on the day-shift obtained the assistance of riggers before handing over to his night-shift counterpart. Occidental's mechanical technicians on the night-shift decided to depart from the method of lifting which had been proposed by the day-shift and decided that clamps should be attached to overhead beams for the purpose of assisting in the lift. This was not discussed with the night-shift lead maintenance hand. In order to attach a shackle and sling to the beams Mr Sutherland climbed on to a panel which formed part of a canopy over the pump. The panel shifted from its support on one side and Mr Sutherland fell off sustaining injuries from which he later died. A number of points should be noted for present purposes:-

(i) According to a note made by Mr R D Jenkins, a DEn Inspector, whose work will be referred to in more detail in Chapter 15, the one and only permit which had been issued in respect of the work was to "check and repair the thrust bearing". The lifting of the motor and the replacement of the bearing were not mentioned. One of the conclusions of the Occidental Board of Inquiry into this accident was that "The expansion of the original scope of the work to the extent that it required the raising of the motor did not alert the supervisor to the additional measures that might have been taken to ensure the safe conduct of the new workscope." In those circumstances it might reasonably be said that if a further permit to work had been applied for this would have ensured that attention was given to the precautions to be stated on the fresh permit and taken at the time when the work was being carried out. Following the fatality Occidental were prosecuted under secs 3(1) and 33(1)(a) of the HSWA for failing to conduct their undertaking in such a way as to ensure, so far as was reasonably practicable, that persons not in their employment who might be affected thereby were not thereby exposed to risks to their health and safety. The complaint, to which they pleaded guilty on 17 March 1987, set out a specification of the manner in which they had failed to supervise the job including "No new permit was taken out to cover the installation of said lifting gear and other necessary work". Mr G Richards, the back-to-back OIM, agreed in evidence that the permit to work should have been extended but took the position that this did not contribute to the accident. This was not identified as a problem at the time. He agreed that if work had been restricted the crew would not have reached the stage where the accident happened. But, according to him, an additional permit would not have played a key part. A permit stated precautions, not the method of carrying out the work. While I appreciate that distinction it does not in my view follow that the absence of a further application for a permit to work had no bearing on this accident. Once again, it seems to me that the Occidental approach left too much to be settled as the work went along.

(ii) The complaint to which Occidental pleaded guilty also specified "inadequate communication of information from the preceding day-shift to the night-shift". A number of witnesses from the production and maintenance sides on Piper said in evidence to the Inquiry that no changes were made to handover practice after the fatality or Occidental's plea of guilty. There was no awareness of any weakness in or criticism of communication at handover. Mr Bodie, who was a member of Occidental's Board of Inquiry into the Sutherland fatality, was not made aware of the terms of the complaint to which Occidental had pleaded guilty or asked to reconsider the report of the Board in the light of those terms. The report was a production before the Inquiry and contains no examination of the adequacy or quality of the handover between the maintenance lead hands. Nonetheless, Mr Bodie said that he concluded that there was no contribution from the handover.

(iii) The fatality to Mr Sutherland had a number of sequels, one of which was the issuing of a memorandum by Mr J L MacAllan, Occidental's Production and Pipeline Manager, to all OIMs dated 24 September 1987. In this memorandum he emphasised, *inter alia*, that persons filling out permits should be encouraged to be more specific and detailed in the job description. As an example he said that it would not be sufficient to state "change gas head". The permit should read "erect scaffold, change gas head, dismantle scaffold". This advice reinforces the terms of the Occidental written procedure for permits to work. However, it was apparent that this advice was not followed. One example of this was provided by the permit which related to the refurbishment and recertification of PSV 504 and 505 in March 1988. The instruction "isolate as required" was inadequate.

(iv) Another sequel to the fatality was the issuing of a memorandum dated 21 October 1987 to rigging and other supervisors. This referred to the assessment of the job by the rigging foreman and the raising of permits for certain categories of lift. However the evidence given by riggers at the Inquiry was that they would give assistance without their foreman being involved. Mr Richards said that he had checked with the rigging foreman that "everything was going to him". He was unaware that personnel who needed rigging would simply approach a rigger, as apparently happened at the time when preparations were made for the removal of PSV 504 on 6 July 1988. Once again it appears that although action was taken in a certain respect after the Sutherland fatality it did not have a lasting effect on practice.

Chapter 12

The Operability of the Fire-Fighting System

Introduction

12.1 In para 7.66 I accepted the conclusion that the failure of the fire-water deluge system was likely to have been caused by the effect of the initial explosion on the fire pumps and at least the smaller branches of the fire-water main. In this chapter I am concerned with considering the importance of the fire-water system and the extent to which it would have been operable on Piper even if the initial explosion had not had either of the effects. In para 13.18 *et seq* of the next chapter I will discuss training for fire-fighting and other duties.

The importance of the fire-water deluge system

12.2 In a memorandum dated 24 May 1985 to Mr P G Clayson, then Occidental's Safety Superintendent, Mr K R Wottge, Occidental's Facilities Engineering Manager, made the statement that:

> "We certainly concur with you that the fire-water system is critical to platform safety and must be maintained in a peak operating state at all times."

In this he was entirely correct. The basis of Occidental's approach to fire protection was that fire could be controlled on Piper before heat damage occurred to pipework, pressure vessels or structural members. Mr Wottge explained in evidence that in B Module Occidental anticipated primarily an oil fire. It was recognised that they could have difficulty in closing off any oil leakage. The deluge was therefore designed to deliver foam, sealing in the flames and knocking down the fire. In C Module it was assumed that the gas inventory could be shut down and vented to flare in a short period of time. The removal of the fuel source would prevent the fire continuing for long enough to cause any structural damage. He agreed that the isolation of the fuel source and the deluge system were the critical aspects of fire-fighting capacity on Piper. Apart from its effect in sealing in the flames and knocking down the fire it provided cooling to pipework, pressure vessels and structural members, so preventing escalation. The deluge was effective to control a fire in C Module because pressure was significantly reduced after the first minute of blowdown to flare and was virtually depleted after 5 minutes. The fire would be controlled by a combination of the deluge, monitors at each end of the module and the use of fire-hoses. Piper had not been originally designed in order to provide cooling for structural members, apart from the effect which the water curtain should have had on the firewalls. However the overall effect of the deluge would be to decrease the intensity of heat. As regards the removal of the hydrocarbon inventory to flare in the case of a gas fire in C Module Mr Wottge appreciated that it was essential that this take place as quickly as possible. This was underlined by a passage in his memorandum dated 18 March 1988 to Mr J L MacAllan, Occidental's Production and Pipeline Manager, in which he said:

> "This is especially critical on Piper since we have no structural fireproofing as on Claymore and all structural members are highly stressed. Structural integrity could be lost within 10-15 minutes if a fire was fed from a large pressurised hydrocarbon inventory."

Mr Wottge observed that it was very difficult to fight or put out a high pressure fire with any kind of water system. In any event, as Mr Clayson and Mr J S Henderson, the Commandant of the Offshore Fire Training Centre at Montrose, observed, the extinguishing of a large gas release may exacerbate the situation by allowing a gas cloud to grow and then find another source of ignition with devastating results. In the case of a gas fire the fire-water is used to cool the surrounding area until the fuel can be cut off. The need to ensure that the fire-water system was maintained in a peak operating state at all times was, if anything, increased by the fact that on Piper unlike

Claymore there was no structural fireproofing, and in particular fireproofing of the structural members associated with the production modules, such as the diagonal trusses, the upper and lower chords and the deck beams connecting the modules to each other. The fireproofing material which had been used on Claymore was mandolite, a cement-like material.

The operability of the diesel fire pumps

12.3 On the evening of 6 July the diesel fire pumps had been switched from automatic to manual mode in accordance with the practice followed on Piper during any shift in which diving was to take place beneath the platform. I will examine the practice below. I will first examine the implications of this for the fire-fighting capacity and what would have been involved in any attempt to start those pumps.

The implications for fire-fighting capacity

12.4 Until such time as the diesel fire pumps had been started the fire-water system on Piper would have had to depend on the output of the 2 electric pumps. These pumps were kept in continuous operation, even during an emergency shutdown. According to Mr A Bodie, Occidental's Safety Superintendent, these pumps could feed at least one module and a couple of monitors. However, the amount of deluge required depended upon the areas from which there was a demand for fire-water. It is clear that in a substantial emergency the fire-fighting capacity on Piper was severely handicapped if the diesel fire pumps were out of action.

Starting the diesel fire pumps

12.5 Under the arrangements for the starting of the diesel fire pumps which had prevailed at least from 1983-84 it was possible for the Control Room operator to start the pumps when they were in the automatic mode by operating a switch in the Control Room. Accordingly if one of the pumps did not come into operation automatically when it should have done so the operator could ensure that it was started. If on the other hand the diesel fire pumps were switched to the manual mode there was an alarm light for each pump in the Control Room showing that the pump was in that mode. However, in order to start the pumps when they were in the manual mode it was necessary for someone to go to the control panel which was adjacent to each pump in D Module in order to operate a switch to start the pump. The process of starting would have taken 1-3 minutes. Mr Bodie pointed out that in accordance with Occidental's Emergency Procedures Manual at 6.2.7 there were an assigned mechanic and an assigned electrician whose duties in the event of an alarm included the starting up and running of the diesel fire pumps. He informed the Inquiry that their names were shown on lists which were posted in the Control Room, the Mechanical Workshop, the Electrical Workshop and provided to the operations superintendent. However, at the beginning of an emergency they could be anywhere on the platform and might take some minutes to reach the pumps, assuming that their route was not impeded by the emergency itself. Further, there was no procedure by which the Control Room operator might ascertain whether they were on their way or had reached the pumps. In theory it was possible for the Control Room operator to go and switch on the pumps. It would take him about 1 minute to reach them. However, as Mr Bollands quite properly pointed out, a Control Room operator would not leave the Control Room unattended and would only go if he could find someone to whom he could delegate his duties. In any event the fact that it was necessary to go to the pumps themselves in order to start them when they were in the manual mode created the danger that the emergency itself might impede access. This was what happened on the night of the disaster when Mr Vernon and Mr Carroll donned breathing apparatus and attempted without success to reach the control panels of the diesel fire pumps in order to turn them on. If, on the other hand, there had been a switch in the Control Room by means of which these pumps could have been switched on when they were in the manual mode this could have made a vital difference to fire-fighting capability so long as the fire-fighting system was not disabled. From the evidence there appeared to be no technical reason why such a switch could not have been provided in the Control Room.

The practice on Piper in regard to the diesel fire pumps

12.6 The practice that the diesel fire pumps were on manual mode during any shift in which diving work under the platform was taking place had been followed during at least 2 or 3 diving seasons during which divers were down for extended periods mainly on the night-shift. In practice, according to Mr Wottge, they were in the water 20-30% of the time in the diving season. Accordingly during the summer period the diesel fire pumps were regularly on manual mode from 18.00 hours until 06.00 hours on the following morning. The Inquiry heard differing evidence as to how the practice had arisen. According to Mr Richards the divers had requested this arrangement. The decision had been made on the platform and been accepted by the beach. On the other hand Mr C J Rowan, Senior Diving Supervisor of Stena Offshore, gave evidence as to a meeting on Piper on 16 April 1988 at which Mr C Seaton, the deceased OIM, had ruled that the practice on Piper was that the diesel fire pumps were to be on manual mode during the whole time that divers were in the water and rejected Mr Rowan's proposal that Piper should follow the same practice as on Claymore, where each of the pumps was left on automatic mode unless a diver was working near its intake.

12.7 In accordance with the practice adopted on Piper a pump status sheet was prepared in respect of each shift. A copy of it was posted in the Control Room and another copy was handed to the diving co-ordinator before the beginning of the shift. The divers would keep in close contact with the Control Room throughout the day. After the pump status sheet had been handed over the Control Room operator was not to alter the status of the pumps without the permission of the diving superintendent, after which the pump status sheet was changed. It was up to the Control Room to decide whether pumps were to be on or off. If a pump was already on manual mode the divers would be warned by a telephone call from the Control Room or by the sounding of an alarm. The divers informed the Control Room, usually by telephone, when they had finished their diving work. At the end of the shift it was up to the Control Room operator to put the diesel pumps back on to automatic mode. Mr Richards said that he had not made it his practice to ensure that this was done.

12.8 A number of witnesses with diving experience gave evidence as to the risk which formed the reason for following the practice on Piper. Mr S R MacLeod, the diving superintendent, described the difficulties which divers could experience through the effects of disorientation, currents and poor visibility. There was the possibility of a problem if a diver was working at the -120 ft level, which was just above the level of the open end of the stilling columns of the pumps. There would be in his view an equal problem whether the pumps were on already or were started up while the diver was working at that level. However a diver should be all right if he kept 20 ft away from an intake. If a diver was working at -50 ft he saw no problem. The diver would be in radio contact with his supervisor and could say when he had finished working in a hazardous area. The supervisor would have a good idea of the state of visibility. As far as he was concerned there were some dives on which there would be no risk posed by the intakes. Mr E T R Punchard, the diving inspection controller, drew attention to an accident on Piper a few years before the disaster in which a diver was injured as a result of being sucked into a pump intake. He would not be happy about working "adjacent to an unprotected intake which was switched to automatic". On the other hand Mr J Barr, the diving supervisor, said that a diver would be aware before diving of the pumps that would be in use. He could safely work on the same level as the pump intakes so long as he was aware of them and could take precautions. If a pump was switched on unexpectedly there would be some risk if the diver was within 15 ft of the intake. However he would know to ensure that his umbilical was nowhere near an intake. About 10-15 ft away from an intake a diver would probably be able to notice the flow. Given the cages around the pump intakes there should be no undue danger. He would not expect disorientation at Piper as the water was quite clear and there was seldom a large reduction in visibility. If there was, this would be readily apparent to those on the surface. A diver should not change levels unexpectedly. He would require to adjust for the difference in the pressure with depth. In the dive control he would know by looking at a gauge what depth the diver was at and he would also check the depth by speaking to the diver. Although, as I have stated above, Mr Rowan sought to establish the same procedure at Piper as at Claymore he appreciated that it was safer for the divers that the diesel pumps should be on manual mode. He was aware of the previous accident at Piper. He felt that a safe distance for divers from the intakes was 10-15 ft.

12.9 The practice of keeping the diesel pumps on manual mode during the time when diving was taking place was noted in June 1983 at the time of a fire protection and safety audit on Piper. At that time the audit personnel, who included Mr Wottge, noted a recommendation that a procedure be adopted to ensure that those pumps were set to the automatic mode when diving was not being carried out near the intakes of those pumps. It appears that despite this recommendation it was left to the OIM to determine the practice which should be followed. Mr Wottge informed the Inquiry that it was only when he heard the evidence at the Inquiry that he realised that the practice of putting the pumps on manual mode whenever divers were in the water had continued to the time of the disaster. Mr Bodie said that he had no problem with the practice followed on Piper, given that fire-water was fed from the utility water main.

The practice on Claymore

12.10 On Claymore there were 2 inlets for pumps at -160 ft, and 20 ft apart, with mesh screen protection below the intakes. A switch in the Control Room could be used to start each pump, whether it was in the automatic or in the manual mode. In practice the pumps were left on automatic except when work was being done near a particular pump intake. In that event only that pump was switched to manual, and for the duration of that work.

Should changes have been made in the practice or intakes at Piper?

12.11 I can appreciate that there were significant differences in the existing configuration of the pump intakes at Piper and Claymore. The intakes at the latter platform were spaced much further apart and accordingly could be separately considered if it proved necessary for the manual mode to be used. At Piper on the other hand it was not unreasonable for both of the diesel pumps to be treated in the same way. On the other hand in the light of the evidence given by Mr Wottge there appeared to be no technical reason why the intakes of one or more of the pumps could not have been moved in a horizontal or vertical position so that they could be separately treated. However, this apparently had not been considered by Occidental. Turning to the period for which in practice the diesel fire pumps were kept on manual mode, it is understandable that an OIM would be attracted to a practice which was simple and did not rely on the exercise of judgement. In my view, however, the practice of keeping the pumps on manual mode throughout shifts in which any diving was taking place inhibited the operability of the pumps in an unnecessary and dangerous way. I was not convinced in the light of the evidence that there was any good reason why the recommendation made by the auditors in 1983 was not followed, so that pumps were set to the manual mode only when diving work was being done in the area of their intakes. The effect of the practice on Piper may be illustrated by reference to the events of the evening of the disaster. Diving operations started at about 18.00 hours after which 3 divers dived to work at the -120 ft level. The last of these divers left the water about 21.00 hours. After an interruption Mr G P Parrydavies dived at about 21.20 hours in order to carry out work at -50 ft. He was working there at the time of the initial explosion and was recovered by the diving personnel. If the diesel pumps had been put back on to automatic mode shortly after 21.00 hours and had been in that mode at the time when Mr Parrydavies was carrying out his work I do not consider that this would have caused any risk of the diver or his equipment being sucked against the intake at the -120 ft level.

The fire-water deluge system

12.12 It is clear that the operability of the deluge system was at least one of the critical elements in ensuring adequate fire protection on Piper. In the light of evidence which emerged at the Inquiry I considered it proper to enquire whether as at 6 July 1988 the deluge system, and in particular C Module, was capable of fulfilling that role.

The operability of the deluge in C Module

12.13 The deluge system was normally tested every 3 months as part of regular maintenance and under the supervision of the safety department. Work on the system was carried out by the maintenance department, unless it involved clearing out or replacement which would be undertaken by the Offshore Projects Group (OPG). Any problems with the system were reported to management through either the Production Department or the Facilities Engineering Department. A routine test in C Module on 14 May 1988 disclosed that 50% of the deluge nozzles were blocked. These comprised 15 in area C1 and 17 in area C2. It proved impossible to improve the situation by removing deluge heads and flushing through the system. The deluge pipework required to be disconnected and cleared by rodding. The state of the nozzle heads was due to the fact that the galvanised carbon steel from which the deluge distribution pipework had been fabricated had been affected by salt water with the result that scale from internal corrosion had caused plugging. The findings on 14 May were immediately reported to the Facilities Engineering Department and it was decided that the distribution pipework in C Module was to be replaced as a matter of high priority. An Authorisation for Expenditure (AFE) was issued for approval on 17 May and approved on 1 June 1988. The engineering package was scheduled for completion on 23 June, following the issuing of a preliminary bill of material to the OPG on 24 May. The disaster came before this planned replacement could be carried out.

12.14 As will be seen below the plugging of nozzle heads with scale was no new problem on Piper. So far as 1988 was concerned the Inquiry heard evidence from a number of other sources as to the state of these heads in the period up to the disaster. The previous routine testing of the deluge system in C Module showed that on 14 February 1988 several heads were blocked in C1 and on 16 February there were at least 25 blocked heads in area C2. At this time the blockages were cleared relatively easily. Mr J S Meanen, a scaffolder, gave evidence that 1 or 2 days before the disaster he had removed bags which had been attached to the heads of the deluge in C Module in order to catch water which was discharged when the system was tested. He found that out of the 10 or 12 bags which he took down 3 or 4 were dry when they should have had water in them. When Mr G G Robertson, safety supervisor on Piper, reported the findings on 14 May to Mr Bodie he pointed out that even if rodding was successful "it is only going to be temporary as the amount of internal corrosion in the system is extensive". When Mr Wottge was asked about the deluge as at 6 July 1988 he said that there would have been plugging and that it was likely or possible that the fixed distribution system did not provide "full coverage". That is an under-statement. In the light of the evidence I consider that it is likely that if the deluge had been activated on 6 July 1988 a substantial number of the deluge heads would have been blocked by scale with the result that they would not have discharged.

12.15 The vulnerability of deluge heads in C Module to blockage was not detected by the Department of Transport (DoT) in the course of the last biennial inspection before the disaster which was concerned, *inter alia*, with the functioning of the fire-fighting equipment of the installation. Mr W P Wood, a ship surveyor in the Surveyor General's Organisation of the Marine Directorate of the DoT visited Piper on 1 and

2 February 1988. He said in evidence that he usually tested "an agreed selection" of the deluges. He asked for certain systems to be tested but did not force his selection as there might be reasons why a particular part of the system could not be tested at the time. On this visit he tested the deluge system in A Module and in the area of the pig launchers for the Tartan and MCP-01 gas lines. He found even distribution and no shadow effect. Two heads were found to be blocked. He understood that they were cleaned out later in the day. There was no apparent corrosion. He chose those areas principally because they were ones which had no pumps or significant control equipment. This could have caused a problem in B and C Modules. Another reason which he had for testing in A Module was that it contained the greatest danger. He had not been to Piper before and had no means of knowing whether the systems which he tested were the same as those which were tested during the last visit by a DoT surveyor. He did not inspect any records as to the testing of the deluge system. At the time of his visit he was not aware of any problem with the deluge system. He did not expect an operator to tell the surveyor about any problems. He expected the operator to rectify any defects. He would not necessarily pick up even "severe problems" in a biennial survey. The system could have been flushed out immediately before the visit or it could have been covered by planned maintenance. If he had found that the deluge system was not operating satisfactorily he would have asked for something to be done about it and would have asked for all the deluges to be tested. If he had found that 10% or more of the system was inoperative he would have discussed the matter with the OIM. If there had not been a quick solution he would have discussed the matter with his office in Aberdeen. If as much as 50% was inoperative he would have wanted the platform to be shut down, although he was unsure of what power he had to insist on this. In the light of what was found by Occidental in May 1988 no fresh certificate would have been issued until matters had been put right. Mr Wood also said that at the time of his visit he was not personally aware that any alterations had been made to the deluge system in the preceding 2 years, although there was documentary evidence before the Inquiry of correspondence between Occidental and the DoT in regard to the changing of heads and the replacement of pipework. The latest part of that correspondence was in March 1987. Since the disaster surveys by DoT inspectors are preceded by a telex to the operator informing them of the visit and giving them ample time to protect equipment against the operation of the deluge.

The previous history of Occidental's actions

12.16 The problem caused by scale plugging the deluge heads was identified by Occidental at least as early as 1984. At that stage Occidental were in no doubt as to the cause of the scale. Their first action was to replace the existing nozzles with ones which had larger orifices. This was begun on a trial basis late in that year. It was, however, appreciated that it might well prove necessary to replace the distribution pipework itself. The memorandum from Mr Wottge to Mr Clayson dated 24 May 1985, to which I have referred earlier in this chapter, demonstrated the extent of the problem at that time. Up to 40-50% of the original type of nozzles had been found to be blocked when the deluge system had been recently tested. The new type of nozzles had shown a definite decrease in plugging. However, Mr Wottge proposed that a specification for the replacement of the deluge pipework should be developed and stated that replacement might need to be done in the longer term if the short-term results were not successful. Preparations were made in July 1985 for the replacement of the distribution pipework in B Module but that project was suspended pending the results of greater experience with the new type of nozzles. By mid-1986 it had become clear that this would not provide a long term solution and the Facilities Engineering Department turned to the replacement of the distribution pipework on a systematic basis. It should be pointed out at this stage that Occidental were encountering no problems with blockage on the 68 ft level as the Kunifer material from which the distribution pipework on that level was made was not affected in the same way.

12.17 On 25 June 1986 an AFE was approved for the replacement of the distribution pipework in B Module with "duplex" quality stainless steel piping. In October 1985

Occidental's partners had given budgetary approval to improvements to the deluge system to prevent further corrosion. In support of the AFE the Facilities Engineering Department had stated on 6 June 1986 that:

> ".... the original deluge distribution pipework is fabricated in galvanised carbon steel and over the years in service salt water has virtually destroyed the galvanising protection of the steel. The resultant internal corrosion scale from the pipework has been causing serious problems of plugging in the deluge nozzle heads during deluge flow tests. This has entailed removal of the heads for cleaning out during the tests but leaves a serious question on how many deluge nozzles could block during an emergency situation. This problem has been getting worse over the last few years and shorter periods between deluge testing is in operation to reduce the amount of corrosion scale that can collect between tests. Larger diameter nozzles have also been installed and tested over an extensive trial period. These larger nozzles have reduced the amount of plugging considerably although not completely eliminating it ....".

In evidence Mr Wottge said that he could not say that the statement that the problem had been getting worse over the last few years was incorrect "but whenever we do AFEs we write a justification: we like to dramatise it a little bit to make it easier for people up the line to approve it". The approach adopted by the Facilities Engineering Department was to complete one module before starting work on the others so that anything learnt in the installation of the first could be designed into the replacements in the other modules. B Module was selected since it contained the highest hydrocarbon inventory. As far as Mr Wottge was aware the problem in B Module was approximately the same as the problem in C Module. The total replacement of the distribution pipework was further supported by a memorandum from Mr Bodie to Mr G F Foldes of the Facilities Engineering Department dated 18 August 1986, which enclosed test results for B and C Modules for the previous 18 months. Mr Bodie stated "These show a consistent pattern of head blockages. I therefore recommend that the replacement of the deluge pipework be carried out to alleviate this problem." In evidence Mr Bodie said that the frequency of testing had been increased in 1985 to every 6 weeks in order to obtain data to justify replacement of the whole distribution pipework. However it was found that this set up a vicious circle as more flushing meant more corrosion. The tests went back to the quarterly basis.

12.18 The carrying out of the replacement of the distribution pipework in B Module was affected by a number of delays. In the first place what was said to be a shortage of draftsmen held up the issuing of the engineering package to the OPG. Mr Wottge said that it was possible that a delay of no more than 4 weeks resulted but he was not sure. The draftsmen were engaged by Occidental on contract and it seems surprising that this situation was not avoided especially as the project was, according to Mr Wottge, accorded "high priority". Mr Wottge also said that there could have been a delay of several months while the stainless steel was being procured. The Facilities Engineering Department forecast that the work of replacement in B Module would be carried out within January 1987; and following installation experience with B Module planned to issue an AFE for the replacement of the pipework in A and C Modules during 1987. In the event, the work in B Module having started in January took until about August 1987 to be completed, although the work was done in parts which in total amounted to a period of the order of 2 months. It should, of course, be pointed out that the work was designed to be done in such a way that only a small amount of the deluge system in B Module was out of action at any given time.

12.19 In the meantime a further AFE was raised and approved for a similar replacement in A Module. When asked in evidence why it was decided simply to replace in A and not in C Module Mr Wottge said "We do not want to be working on half of the deluge system on the platform. You cannot adequately control that. When you replace a deluge system you have to have fire watches, you have to have people out there and our policy has been to de-activate only a small portion of the system at a time." He denied that the fact that the work was done in sequence was related to the question of manpower and expense. "One of the main reasons I had for my recommendations is that in these projects of replacing systems just about every job we do is in a very congested area. It does not always go to plan. We learn by doing the work and we like to incorporate what we learn into a following similar project." He explained that A Module had been chosen on the basis that it had the next highest risk level in an extended hydrocarbon-fed fire which could be fed by a well accident. He said that he did not believe that because an AFE had been written only for A Module that the timing of the replacement in C Module necessarily suffered. "You are looking at a major system in A Module. You cannot just tear down piping in several modules." From mid-1987 his department had worked on the drawings for the replacement in both A and C Modules. He agreed that C Module would still be at risk but maintained that the fire monitors at each end of C Module could supplement the deluge if there were some blocked nozzles. He added "At that time we did not experience massive deluge head blockages. The system was OK for practical purposes." His evidence was that on routine tests "They would find the odd nozzle plugged". This was broadly in line with the evidence of Mr Bodie who added: "The blockages we were experiencing were on the ends of pipe-runs. Deluge systems are not the be-all and end-all. They are a tremendous first-hit system. If deluge systems worked perfectly, there would be no need for firemen. We could see some blockages in the heads and we were taking action to do it, but it was in the ends of heads over at the edges of the modules ..... head blockage over the side of the module does not cause me such great concern as a head blockage in the centre runs. We have other systems to back this up, of course - the fire monitors, and then we go in and fight it by hand." He said he felt confident that the deluge system would work in an emergency. His staff were carrying out the tests and would also have to head the fire teams. They would certainly not let the system slip into a state where it would not work at all, as was proved by the immediate reporting of the difficulties in the following May.

12.20 Progress towards the replacement of distribution pipework in both A and C Modules was also delayed. Problems with the delivery of stainless steel caused the work on A Module to be deferred initially to early 1988. However, in about November 1987 the corporate auditors advised Occidental to consider adding direct spray protection on to structural members as part of the project. Mr Wottge put the replacement of the distribution system in A and C Modules "on hold" and commissioned a study of the viability of incorporating such cooling. Mr Wottge perceived that his main problem, as he put it in a letter to the auditors dated 23 February 1988, was that:

> "Essentially all members on Piper are highly stressed and to assure adequate cooling of these would require an extensive fixed deluge distribution network which would also consume incremental high water rates. If you are aware of any novel structural cooling deluge distribution system, we would welcome information on these or any ideas that you may have. The basic problem that I see is that to provide thorough coverage via fixed nozzles at near ceiling level will require a very extensive costly distribution network."

12.21 This was the state of matters against which the finding of blockages in February and May 1988 should be viewed. It should be noted that what was found in February was not immediately reported by the platform to either Mr Bodie or to Mr Wottge, although the former read later in a report for the month of March that the blockages were "now cleared". Both of them stated in evidence that if they had known of the blockages at the time their reactions would have been the same as they were in May, namely to recommend immediate replacement of the distribution pipework in C Module.

12.22 At the time when hasty preparations were made in May for the replacement of the pipework in C Module it was also planned to proceed with A Module after replacement in C Module had been completed. It also should be noted that Occidental had obtained full budgetary approval from their partners in the previous year for the replacement of pipework in both modules. When the replacement of the pipework in C Module was authorised for expenditure on 1 June 1988 it was noted that a further AFE might follow to cover the cost of any additional steel work cooling that might arise.

12.23 In the Inquiry Occidental were criticised for having deliberately decided to defer replacement in C Module, first in order to give preference to B Module and secondly in order to give preference to A Module. The problem of blockage was no worse in these other modules than in C Module. It was suggested that the piecemeal ordering of deferral of work was due to a desire to save or spread cost. Further the process of replacement was unnecessarily extended by various delays. In the meantime there were no grounds for confidence that the deluge system in C Module would work properly. This is a subject to which I will return in Chapter 14 (at paras 14.47 *et seq*) in the light of the evidence of management witnesses. However at this point I should say that I do not consider that it was unreasonable for Occidental to proceed by taking the replacement of pipework in one module at a time in order to gain experience from the installation. Further, it was reasonable for them to proceed in such a way as to avoid putting the whole of the deluge system in a single module out of operation at any given time. On the other hand the total period from the point at which replacement in B Module was sanctioned to the point where it was completed amounted to approximately 2 years. Should the progress of the design work have been held up by lack of manpower if the project had, and deservedly, a high priority? After the work on B Module was finished shortly after the middle of 1987 should Occidental not have been able to move rapidly into the work of replacing in the other modules? By then they would have known the problems which would be encountered in the course of installation. It would be normal practice for early orders to be placed for the necessary material. Should further work on replacement in A and C Modules have been placed on hold in the light of the auditors' report? The latter did not prevent hasty steps being taken in May 1988 for replacement in C Module. I am also sceptical of the evidence that the actual experience on the testing of the deluge system in C Module prior to February 1988 showed only a few blocked heads. In the light of the long history of the problem which the larger size of nozzles had failed to remove and the statements which were made as to the state of the pipework in June 1986 and in May 1988 I find it hard to believe that in 1988 there had been an unexpected deterioration in the performance of the deluge system.

Chapter 13

Training for Emergencies

Introduction

13.1 During the course of the Inquiry evidence was heard on a number of aspects of emergency training. In this chapter I will be concerned mainly with training which was specific to Piper. What I learnt in the course of the evidence gave cause for concern on a number of points, as will be seen below.

13.2 It was Occidental's policy that personnel who came to work on Piper should have attended the combined fire-fighting and survival course provided by RGIT or an equivalent course provided by another of the 6 centres in the United Kingdom. At the heliport there was a check that such personnel were in possession of the certificates of attendance. Deficiencies were reported by Occidental to the relevant contractors by monthly report. Occasionally someone worked on the platform even although he had not completed the course. For example, 3 of the Wood Group personnel on Piper at the time of the disaster had not taken the course. Supervisory personnel of contractors such as Bawden International required to have completed separate survival and fire-fighting courses, on the basis of their responsibility for the safety of others. Personnel were expected to undertake refresher training 3-4 years after the original training. However to a significant extent this was not the case. Thus of the 14 Wood Group employees who survived the disaster 8 had not received the refresher training which they should have. One cause of this was the waiting list for such training, which has been somewhat eased by the opening of an additional centre in Dundee.

Safety induction

13.3 It was Occidental's intention that "newcomers" to Piper should receive a safety induction briefing on their arrival at the platform. Whether a person was to receive an induction was determined at the heliport from which a telex message was sent to Piper and passed on to the safety personnel there. The period since a person's last visit to Piper which was long enough to make him a "newcomer" for this purpose was apparently 6 months. However it was surprising that a number of the Occidental safety personnel who gave evidence were either mistaken or uncertain as to what the period was. Mr J A Patience, a lead safety operator, could not recall any set period. Mr G G Robertson, who had been a safety supervisor on Piper until shortly before the disaster, thought that the period was a year. Mr R M Gordon, the Manager of the Loss Prevention Department, could not recall whether the period was 6 or 12 months, but believed that it was the latter. This state of the evidence should be considered in conjunction with the evidence of survivors to which I will refer below.

13.4 As I have stated in Chapter 11, "newcomers" to Piper were provided at the heliport with copies of a small Safety Handbook for Piper and Claymore, the current edition of which was issued as from May 1987. This handbook contained the injunction that the possessor should "study it well - it may be your passport to survival"; and at the induction on the platform personnel were told that it was their duty to read it. However it should be noted that the handbook depicted a method of throwing life raft capsules over the rail which did not apply to Piper. It also stated, but in very small print, that there was perhaps 80 ft of line which required to be pulled out before inflation would begin. It also advised "Should the need arise for you to use a life raft, try to board it via scrambling nets, knotted ropes or lower walkways keeping as dry as possible", whereas scrambling nets had been removed from both Piper and Claymore in the early 1980s.

13.5 On arrival at the platform personnel who were to receive an induction were collected by safety personnel after they had been given the number of their cabin and the number of their lifeboat. A lead safety operator, such as Mr Patience, would normally give the induction after obtaining details from the "newcomers" of their names, job titles, employers and courses attended. It did not appear that any particular format was laid down for safety personnel to follow in giving the induction. Instead they appear to have developed a common practice which was described in evidence by Mr Patience and illustrated by a letter dated 5 April 1987 from Mr Robertson to his immediate superior, Mr A Bodie, who was the shore-based Safety Superintendent. The letter contained a list of 11 subjects stated to be included in the induction. In brief the list comprised helicopter safety procedures; prohibited areas; protective clothing requirements, cleanliness and hygiene of personnel; no smoking areas/smoking permit areas; emergency procedures and required action of personnel during emergency situations (including alarm systems, lifeboat allocation, helicopter evacuation and emergency telephones); explanation of permit to work system, housekeeping and common sense; reporting of incidents/accidents/potential hazards/near misses; fire-fighting equipment; lifting gear; low specific activity (LSA) (ie radioactive materials); and scaffolding. Mr Patience said in evidence, and the letter also indicated, that what was said at the induction was tailored to some extent to the work which the audience had come to perform. Thus for drillers there would be an indication of the type of hazards associated with their work. Further guidance would be given by their supervisor on the job. Anybody who had not been on the combined course "would obviously be given a little bit of additional detail". Mr Patience also explained that he would ask his audience to confirm that they had been assigned to a lifeboat; and would explain where the lifeboats were located. He would explain that on a platform general alarm personnel were to go to the muster station associated with their lifeboat and report to the coxswain there. In the event of a real or simulated evacuation by helicopter they would proceed in accordance with the coxswain's instructions to a secondary muster area in the accommodation. If they could not get to their lifeboat station they should go to another lifeboat station, which failing to the life rafts. The number and location of the life rafts were described. They were told to familiarise themselves with stairways and passages through the plant. In the event that it was not possible to reach either lifeboats or life rafts they would be instructed to proceed to the accommodation. No guidance was given against the event that evacuation by helicopter was also impossible. Personnel were told about the means of reaching sea level by stairways and knotted ropes. It was generally indicated that it was inadvisable for personnel to jump off the platform. As regards fire-fighting equipment the induction was confined to what was available for the purposes of extinguishing fires. It did not extend to instruction in the method of operation. In practice safety operators would give instructions for specific tasks such as fire-watching duties as required.

13.6 Mr Patience went on to state that following the briefing in the accommodation the personnel were taken to their respective lifeboat stations, where he would make sure that they knew how to strap themselves in. He would enter the lifeboat with them and point out the items of equipment and the lowering and release mechanisms. Those who were new to the offshore environment were shown how to put on a life-jacket. Once that had been done they were generally shown the location of the life rafts on the 68 ft level, at which point the induction came to an end. Personnel were, however, advised to make themselves familiar with direction signs and with alternative routes to lifeboats, life rafts and life-saving appliances. (I should add that Mr Bodie, who had been a safety operator and lead safety operator between 1976 and 1983, stated that it was his recollection that when he gave safety inductions he would state that 140 ft of line required to be pulled out of the life raft capsule.)

13.7 According to Mr Patience the whole induction could last about three quarters of an hour, including about 15 minutes for the visit to the lifeboat and life raft locations. The shortest time for the briefing which he could envisage was about 20 minutes. On the other hand a note of a seminar attended by supervisory staff on 7 May 1987 recorded that Occidental's induction took up to one hour offshore, whereas it took up to 2 hours at Flotta. According to Occidental's records in 1987 455 "newcomers" arrived at Piper; and 320 man-hours were devoted to giving induction.

Evidence given by survivors

13.8 The evidence of a significant number of the survivors, which I have no reason to consider to be unreliable, disclosed a different picture from that portrayed by Mr Patience. 26 of the survivors (all contractors' personnel) were asked whether they had received a safety induction. Six of them said that they had never done so. One thought that he had not: and one could not recall. The remaining 18 said that they had received an induction. But 4 said that it had lasted for 5-10 minutes. These included Mr D M Thompson who had arrived at Piper 2 days before the disaster. When he was asked about his briefing he replied: "He asked if we had been on the Piper before. I said 'No'. He said 'Have you worked offshore before?', and I said 'Yes'. He said 'Well, you will know what the score is then'. That was much about what it was." He was told the number of his lifeboat but he had to look for it himself. Four others also said that they had not been shown their lifeboats. Of the 18 to whom I have referred 9 had visited Piper for the first time prior to 1988. Three had received no repeat of the induction since their initial one. These included Mr W P Barron who had returned to Piper in late 1987. He said: "When I went on this rig I was asked if I had worked on an offshore rig before, and I said 'Yes', that I had been on two, that I had been on Piper in 1982 and also the Claymore in 1985. This was at the safety induction, so he said 'Well, nothing has changed'." This was the sum total of the induction. As I have stated earlier in para 8.27 a number of the survivors who assembled at the north-west corner of the 68 ft level after the initial explosion had never been shown the location of the life rafts nor how to launch and inflate them. Some did not know how long was the painter line which required to be pulled out; others thought that it was considerably shorter than it was.

The monitoring of safety inductions

13.9 The safety personnel on the platform and their superiors onshore were in no doubt as to the importance of the systematic giving of induction training at the earliest opportunity when a "newcomer" arrived at the platform. Mr F McGeogh who had been Safety Training Co-ordinator with Occidental since February 1988 said that he had received favourable comments from supervisors as to the quality of the induction provided by Occidental. Mr Robertson said that checks were made about every 2 months to ensure that induction was being properly carried out. By this he meant making enquiries of the medic who was responsible for passing the information on the telex to safety personnel. He also said that he had checked with safety personnel that they were going to the lifeboats and the life rafts with the "newcomers". However he had not checked on the extent to which the inductions were being completed and he had not asked the "newcomers" what they had received.

Changes in Occidental's approach to inductions prior to the disaster

13.10 Mr McGeogh was given the task of considering whether the provision by Occidental for training and safety awareness should be improved. He took the view that induction "could be made slicker" for the large number of contract personnel who were travelling offshore, as was normal in the industry. In June 1988 he had instituted a system of onshore induction for 5 or more personnel in order to supplement the offshore induction which they would receive when they reached the platform. The onshore induction lasted half a day and ended with the attendance of various members of the senior staff of Occidental. Guidance notes giving a safety training and awareness plan had been produced. At these inductions he explained that the one thing he could not do in the classroom was to orientate contractors' personnel. When they arrived offshore they would still have an induction and be shown to their lifeboats. Thereafter they would be introduced to their supervisor, part of whose function was to help them to be orientated on the platform. Nevertheless he emphasised that they should also take time themselves to walk round the platform and help to familiarise themselves with it. He had planned to go offshore in August 1988 for 2 weeks in order to canvass ideas for the safety training programme.

13.11 Mr McGeogh also said that he believed that the existing offshore induction of about 30 minutes should be extended by the showing of a video for those spending longer time offshore. This should be followed up by a guided tour of the platform in the company of someone who was in the same department as the "newcomer". Finally there should be a feedback session. A record should be kept of the attendances at, and the extent of, the induction given.

Observations on inductions

13.12 Occidental were right to emphasise the importance of induction training at the earliest opportunity when a "newcomer" arrived at the platform. This applied especially in the case of contractors' employees who might be on the platform for a comparatively short period but might need to face an emergency at a moment's notice. Occidental were also right to plan that personnel should receive a repeat of induction training. However, I am not satisfied that the system as operated on Piper came close to achieving the necessary understanding on the part of all personnel as to how to react in the event of an emergency. The lack of an exact format or content for the induction training; the brevity of the time devoted to it; the almost cursory assessment of whether an individual required to attend the training; the uncertainty on the part of safety personnel as to the time interval before a repeat of the induction training was required; the failure to ensure that each person was shown the location of his lifeboat; and the errors in the safety handbook all point to a failure to ensure that all were properly informed on matters critical to their safety in an emergency.

Drills, exercises and training in emergency duties

13.13 Occidental's manual on general safety procedures made provision for the drills, exercises and training for emergencies which were to be followed on its offshore installations. These followed the general statement that:

> "Each person present on an offshore installation shall receive sufficient and appropriate emergency safety training to ensure his own personal safety and to enable him to perform all duties expected of him efficiently." (4.18.1.1).

The responsibility for ensuring compliance with these requirements lay with line management, and in particular the OIM, in accordance with Occidental's policy. Records of what was carried out were kept in the OIM's log and were summarised in Monthly Activities Reports which were sent from the platform safety supervisor to Mr Bodie. It was Mr Bodie's responsibility to assess the adequacy of what had been done. On the other hand it fell to the safety personnel on the platform to attend to the safety content in these activities.

Evacuation drills

13.14 According to the Occidental manual on General Safety Procedures offshore drills were to be held at intervals not exceeding 12 days; drills involving alternative evacuation routes were to be carried out at least once in every 3 tours of duty; and exercises should be as realistic as possible, including full-scale emergency scenarios assessed by qualified personnel external to the installation.

13.15 Mr G Richards, the back-to-back OIM, said that it was the aim on Piper to have evacuation drills once a week, if that was possible, and that these were pre-arranged to take place at 21.00 hours on Saturdays in order to minimise disruption. However, a study of the Monthly Activities Reports for the first half of 1988 showed that 2 lifeboat drills had been held in January, March and June, 3 in February and April and one in May, a total of 13. This pattern was in accordance with the evidence of various survivors as to their recollection over a longer period prior to the disaster. Mr Richards agreed that this was an unsatisfactory situation but attributed the shortfall to cancellations due to bad weather. He said that there was "not much you can do against the weather" and that it was too disturbing on the platform to have evacuation drills at different times. In this he was supported by Mr Bodie who said "My experience of having these drills on the platforms is that it is a very traumatic business for everybody to get up at the accommodation, break their work cycles and have them coming to the lifeboats and carrying out a drill. It is a 24 hour operation. There are some people going to bed, some people getting up, some people have to stay up late to go to these drills."

13.16 Mr Robertson said that at each evacuation drill life-jackets were worn by the participants. The coxwains and some of the complement boarded each lifeboat. The lowering of a lifeboat was done occasionally. The last time was 2-3 months before the disaster. At least 1 in 3 of the drills included a simulated helicopter evacuation in which personnel were summoned from their lifeboat stations to reception. The drills never included taking personnel to the 20 ft level. It was quite properly considered that this would involve too great a danger to them. However, no particular attention was drawn to the means of getting from the accommodation to that level. Of the normal complement about 80 persons did not normally go to muster stations as they had specific duties to perform in designated areas on the platform. However, apart from 20 who were entirely exempt, they were occasionally sent to their muster stations at lifeboats 4 and 5. The evidence as to whether, and how frequently, the drills involved alternative evacuation routes was unclear. Mr Patience could recall only one occasion in which a route was treated as blocked off; whereas Mr Robertson said that perhaps every 2 or 3 muster drills used alternative routes.

13.17 As regards full-scale emergency scenarios, no such exercise had taken place in the 3 years before the disaster, let alone been "assessed by qualified personnel external to the installation". No total shutdown emergency scenario had taken place in the 3 years prior to the disaster. One had been planned for 1986 but was overtaken by an oil spillage. Another had been planned for June 1988 but was delayed until October because production was not being fully shut down. The object of such an exercise was to seek out deficiencies in the procedures and communications and would have taken place unannounced.

Training of personnel with specialist duties

13.18 The Occidental manual on General Safety Procedures states that:-

> "The following personnel may be called upon to perform specialist duties in an emergency:
>
> — helicopter landing officer
> — fire team members
> — fire team leaders
> — helideck fire crews
> — lifeboat coxswains
> — first-aiders
>
> These personnel must have had appropriate instruction/training prior to taking up their specialist duties.
>
> The following drills, involving specially appointed personnel, should be carried out at weekly intervals:
>
> — fire-fighting
> — breathing apparatus
> — emergency equipment handling
> — casualty handling
> — first-aid
> — man overboard."

13.19 It is reasonably clear that drills in the 6 subjects mentioned above were not carried out at weekly intervals or anything approaching that. Thus the Monthly

Activities Reports for the first half of 1988 show only 3 occasions on which there were breathing apparatus drills, although Mr Robertson claimed that they could have been done along with casualty handling as part of the fire-fighting drills undertaken by the emergency response teams. The Monthly Activities Report for April 1988 does not show that drills were carried out in any of the 6 subjects, although Mr Robertson said that it was likely that they were incorporated with the 3 lifeboat drills which had taken place during that month. The Monthly Activities Report for May 1988 shows only that there were 3 man overboard drills and nothing in regard to the other 5 subjects. The Monthly Activities Report for June 1988 shows 3 drills in fire-fighting; one drill in breathing apparatus; and one man overboard drill. Mr Robertson agreed that even if the drills carried out were not adequately recorded in the Monthly Activities Reports the fact remained that drills in these subjects were not being carried out with the regularity specified in the manual, although attempts were being made to improve the situation. According to him they were obtaining better results but not what they had hoped to achieve. The OIMs were attempting to make changes and encourage regular safety training at week-ends. Mr Richards claimed that on most Saturday and Sunday afternoons there was training of fire teams and first-aiders. Mr Bodie said that he had discussed the frequency of training with Mr C Seaton, the deceased OIM, after the manual had been produced at the end of 1987. He said that Mr Seaton had felt that the intended frequence was "a bit ambitious" as did Mr A Wicks, the safety supervisor. Mr Bodie added "What we were doing was saying 'let's try and get to this level of training and see how it works out and then we can take it from there' ". These difficulties did not appear to be known to Mr G E Grogan, Vice-President Engineering, who was responsible for the Loss Prevention Department. He said that on the basis of the reports which were sent from the platform to Mr Bodie (which he did not monitor) he considered that the drills and exercises which the emergency response teams carried out were adequate.

13.20 In 1988 Occidental introduced modular training as additional training for coxswains, members of the emergency response teams and personnel with responsibilities for giving first-aid. According to Mr Bodie the bulk of the first-aid training was completed and the training for coxswains was on-going at the time of the disaster. As regards training in fire-fighting for the emergency response teams Mr Robertson stated that it comprised 5 modules with about 12 parts in each module. At the time of the disaster the first module of which one part was the introduction to fire-fighting had been introduced. There had been 4 or 5 training sessions. Reference to the minutes of the supervisors' safety meeting dated 28 May 1988 shows that these sessions began sometime after the end of April 1988. It was and is obvious that the completion of the modular training for fire-fighting would have taken a considerable time. There appeared to be no plan or target as to the period within which this modular training was to be completed; nor any definite view as to what improvement in progress should be made, however that was to be achieved.

13.21 On 29 May 1988 Mr Richards wrote to Mr Gordon complaining of a shortage of safety personnel offshore following the non-replacement of safety operators who had been promoted to the position of safety supervisors. According to the letter one thing that suffered as a result of this shortage of manpower was "the regular 'emergency' training that is required to ensure the competency of our offshore emergency teams, as they only receive infrequent basic training. A lot of time has been spent in putting together a modular training package for first-aiders, coxwains and emergency fire teams. We are unable to implement this fully due to other work commitment. Other 'safety awareness' training has suffered due to the necessary commitment to the modular training previously mentioned." The letter concluded by proposing the addition of one safety operator per crew, stating "this would enable us to meet all our commitments to Occidental's health and safety policy." Mr Gordon said that Mr Richards' representations were to have been put to the Management Safety Committee in August 1988. In evidence Mr Richards said that the only reason which he had for requiring additional safety personnel was because of the need to implement the additional modular training. At some stage which he was unable to specify the safety personnel had been made up to the original strength by means of a contractor. However the need for additional personnel in order to meet the modular training remained at the time of the disaster. However he was emphatic that the safety of the platform was not impaired at all. Mr Bodie pointed out that on Piper Occidental was trying to get to "a very high level of training for the offshore staff". He had to agree with Mr Richards that at times when the safety department went down to the minimum manning level approved by the company the first thing that would suffer would probably be the safety training. At the time of the disaster he had not collated the figures in order to reach a view as to whether the safety department on Piper required additional staff in order to implement the modular training scheme. Meanwhile he had been pushing his safety supervisors to maintain as much training as they possibly could. Mr Patience agreed that it was very likely that the fact that the modular scheme was not fully implemented was due to other work commitments on the part of the safety personnel. As regards training generally both he and Mr Robertson indicated that one reason why training was not being carried out with the frequency which had been intended was because line management did not make personnel available for the training. Mr Robertson said that he had taken up this point. Mr Bodie said that the OIMs had agreed to do their best to release personnel; and that he had heard from the supervisors of a favourable response to this. Mr Richards said that the production department had been asked to co-operate in making personnel available, but agreed that at times the safety department were being held back by the production department, depending on the workload. On the other hand Mr Gordon was not aware of any failure on the part of the production department to release personnel. He would have expected to hear about it if it had been a problem.

Onshore training

13.22 I have noted above that according to the Occidental manual on General Safety Procedures personnel who may be called upon to perform certain specialist duties "must have had appropriate instruction/training prior to taking up their specialist duties". The manual also provides that "personnel with specialist skills should receive refresher training at intervals determined by the company".

13.23 The members of the Occidental emergency response team in addition to having attended the combined fire-fighting and survival course of the type provided by RGIT had also attended a 4-day fire-fighting course of the type provided by the Offshore Fire Training Centre at Montrose. The leader of that team had also attended a fire leader's course. In addition the safety supervisor attached to that team attended a fire control course which was offered for those responsible for organising overall control of offshore fires. On the other hand Occidental did not require or arrange that the members of the contractors' emergency response teams, apart from their leaders, should attend the 4-day fire-fighting course or an equivalent course. This was unsatisfactory, as Mr Richards and Mr Gordon appeared to accept. Mr J L Gutteridge, the toolpusher, who was the leader of the Bawden emergency response team, said in evidence that he had undertaken the 4-day course at Montrose, which had been paid for by Occidental. Apart from him there was only one other member of the Bawden team who had been on such a course. He said that the lack of basic training in fire-fighting of the persons in his team had been brought up on many occasions at safety meetings but without result. According to Mr Robertson it was an established practice in regard to the Bawden team that when a Bawden employee reached a certain rank he automatically became a member of the team without regard to whether he had had any training in fire-fighting. He agreed that this was unsatisfactory and said that he had mentioned to others that he thought the teams would benefit by additional training. On the other hand Mr McGeogh did not appear to be troubled by the fact that members of the Bawden team would require to have their fire-fighting training wholly on the platform. He said "One of the things I was very much aware of compared to other operations I had seen was that there was a very very high level of activity of training on the platform, not only in response training, fire team training, first-aid and so forth, but in the general occupational health subjects and technical matters. In fact it was different from anything I had seen elsewhere."

13.24 In a memorandum to Mr T Rogers, OPG Superintendent, dated 3 January 1988 Mr T J Scanlon, the Wood Group Offshore Supervisor, reported that the view of Wood Group personnel was that on-platform training in fire-fighting was inadequate and that platform safety and fire team performance would be enhanced if personnel attended an onshore fire-fighting course. The Wood Group had made a similar request when they were first requested to supply a team for fire-fighting. At a supervisors' safety meeting on 20 March 1988 it was recorded that the Occidental management had indicated that they would not fund onshore fire training and that accordingly in-house offshore fire training would continue as planned. This had been decided by Mr J L MacAllan, Production and Pipeline Manager, on the ground that personnel who had been trained might go to other work so that the cost of the training would not be of benefit to Occidental. However at the conclusion of his evidence he said that after further discussion it had been decided that there would be training onshore.

Observations on training

13.25 The evidence to which I have referred above demonstrates that none of the drills required for practising evacuation procedures for the platform personnel or for the training of persons who had specific duties to perform in an emergency were carried out to the frequency predetermined by Occidental management. The responsibility for this failure lay with the platform management and the OIMs in particular. In my view they did not demonstrate the necessary determination to ensure that regularity was achieved or dissatisfaction expressed with the inadequate results. The lack of a determined commitment to emergency training on the platform meant that the platform personnel were not as prepared for the disaster as they should have been. While the platform management did not exhibit the leadership required in this important area of training, the onshore safety staff did not operate an effective monitoring system with regard to emergency training. Where strong critical comment was called for they were ineffective.

Certificates of attendance at onshore courses

13.26 In the course of the Inquiry a number of unsatisfactory aspects of certificates of attendance at courses were the subject of evidence. It has been known for some time that false certificates were being used to mislead employers and operators. Mr J H Cross, Managing Director of RGIT, informed the Inquiry that his organisation had changed their certificates 3 times in order to overcome forgery and had asked companies not to accept photocopies. They now employed a member of staff to answer queries from the companies about the credentials of individuals who had offered certificates. Mr J S Henderson, Commandant of the Offshore Fire Training Centre at Montrose, said that the centre had been asked to assist in the investigation of allegedly forged certificates of attendance at their courses. The problem had been dealt with recently by embossing their certificates, so rendering them incapable of being reproduced by photocopying. In the case of personnel from Piper who were either deceased or missing an investigation by Grampian Police disclosed the existence of 3 apparently false certificates. Two of these purported to be from RGIT in respect of the combined survival and fire-fighting course. The third purported to have been issued by Petans Ltd, Lowestoft, in respect of a survival refresher course. In 2 cases there was no record of attendance of the persons named in the certificate of which a photocopy was held. In the third case the certificate had been issued to a person with the same name as, but a different address and date of birth from, the person in respect of whom it was held. The police enquiries also showed that apart from these 3 cases 18 of those who were deceased or missing after the disaster held no certificate. The general practice appeared to be that employers were prepared to accept photocopies of certificates and made no check on whether the person tendering the certificate had attended the relevant course. However, the experience of the police in making enquiries into the false certificates indicated that it would not take long for employers to obtain the information which would be necessary in order to enable them to treat certificates or their photocopies as valid.

Chapter 14

Occidental's Management of Safety

Introduction

14.1 In the light of the matters discussed earlier, I considered that it was appropriate for me to seek evidence as to management's knowledge of, and attitude to, them. This chapter relates to that examination and the conclusions which I was able to form about the quality of Occidental's management of safety in these respects. After describing Occidental's safety policy and system (paras 14.3-11) and their approach to the risk of, and hazards involved in, a major platform emergency (paras 14.12-24), I will consider the quality of their management of safety in regard to the prevention of incidents (paras 14.25-43); and the mitigation of incidents (paras 14.44-51). I conclude with my general observations (para 14.52).

14.2 The sources of evidence from management to which I will be referring consisted of the following witnesses:-

(i) Mr G Richards, the back-to-back OIM of Piper since 1984, who had been with Occidental since entering their employment in 1975 as an utilities operator and who had served on Piper for all but 11 months of that period.

(ii) Mr J L MacAllan, Production and Pipeline Manager since 1987, who had previously been an OIM on Claymore and Production and Pipeline Superintendent.

(iii) Mr A D McReynolds, Vice-President Operations from 1982 until May 1988, who had previously been Production and Pipeline Manager and Offshore Operations Manager.

(iv) Mr R M Gordon, Loss Prevention Department Manager since 1985, having previously been Head of Safety for Shell Expro.

(v) Mr G E Grogan, Vice-President Engineering since 1987, having become Manager of Engineering in 1983.

In view of the fact that Mr J B Coffee had succeeded Mr McReynolds only shortly before the disaster I did not consider that it would be of assistance to have his evidence also. Fig 14.1 shows the organisational structure of Occidental.

Occidental's policy and system for the management of safety

14.3 Occidental's statement of general policy under Sec 2(3) of the Health and Safety at Work etc Act 1974 (HSWA) stated,*inter alia*,: "The promotion of health and safety is an integral part of the duties of line management and should be afforded the same priority as other key responsibilities." This statement was commonly interpreted on Piper as meaning that the safety of personnel came first at all times, according to Mr Richards. It followed from this statement that the responsibility for safety and ensuring that all safety procedures were adhered to lay with line management. Accordingly responsibility for safety on Piper rested, in terms of the structure of onshore management, with the Production and Pipeline Department which reported to the Vice-President Operations. This included operations, maintenance, offshore projects and quality assurance.

14.4 On the platform safety was one of the responsibilities of the OIM. He kept abreast of what was going on in a number of ways including a daily meeting with the heads of departments on the platform and receiving copies of outgoing reports and incoming job packs for those departments. He had a daily meeting with the safety supervisor in the morning. In order to provide information and obtain advice he took part in a morning conference call with the beach, which was updated by a call to the

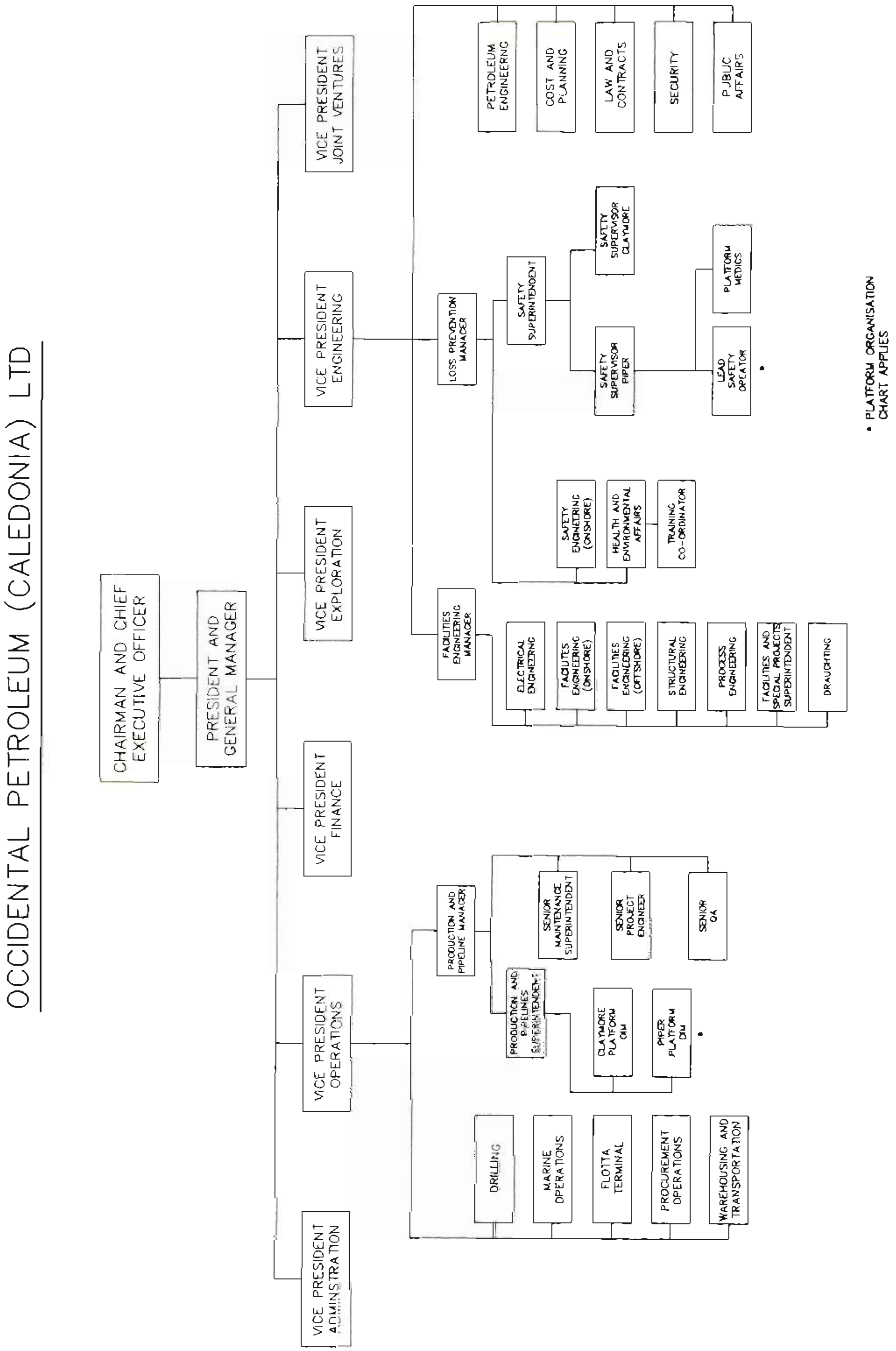


Fig. 14.1 Organisational structure of Occidental Petroleum (Caledonia) Ltd.

Production and Pipeline Superintendent in the afternoon. He usually called the onshore Safety Superintendent during the day. About every 5 weeks each department on the platform had a safety meeting, followed by the supervisors' safety meeting, which was chaired by the OIM. There was an established system for the reporting of accidents and incidents including "near misses" and significant leaks so that management were in a position to observe trends and take action. This system included informing contractors where their employees were involved. Since October 1987 there was also a system by which employees could submit safety-related work requests to management. The OIMs had a monthly meeting onshore with the Production Department and the group leaders of other departments, at which matters of safety were discussed.

14.5 On the shore the Production and Pipeline Department received daily reports from the platform and held regular meetings, some jointly with the Engineering Department. Mr MacAllan said that he was regularly in daily contact with the onshore Safety Superintendent. He also said that he went offshore from time to time to make presentations in which he stressed that "safety was first". The departmental managers, along with the safety training co-ordinator, took part in a monthly Safety Co-ordination Meeting, which was chaired by the Vice-President Engineering, at which the current safety record and possible safety initiatives were discussed. Senior management attended quarterly management safety meetings, which were chaired by the President & General Manager.

14.6 The principal activities of the Loss Prevention Department were:

(i) Providing specialist advice and assistance on occupational health, safety and environmental matters to other departments. Examples given in evidence ranged from their input in regard to engineering work to making available literature on health and safety to the whole workforce.

(ii) Developing and revising company loss prevention policies and procedures in consultation with line departments and monitoring the effectiveness of these policies and procedures. Under this heading the department was responsible for compiling amendments to the manuals and setting out safety and emergency procedures in the light of incidents, information from other operators and notices from the DEn.

(iii) Reviewing the overall effectiveness of the company safety performance. This included routine and *ad hoc* safety inspections.

(iv) Co-ordinating and facilitating in-house and external loss prevention reviews, assessments and audits.

14.7 On the platform, safety personnel were responsible for, *inter alia,* gas testing for "hot work"; daily monitoring of the operation of the PTW system, including inspections of work sites; the regular testing of safety and emergency equipment; the organisation of training for emergencies; and the provision of guidance and advice on health and safety to the workforce. The safety supervisor was on the one hand responsible on a day to day basis to the OIM. On the other hand he had a separate reporting line to the onshore Safety Superintendent. Reporting was carried out on a daily, weekly and monthly basis, covering information as to incidents, the results of testing, survey reports and certificates relating to equipment which had been tested. This reporting line which had been set up in order to secure independence from the Production Department led to the Loss Prevention Department for which the Vice-President Engineering was responsible as well as for the Engineering Department itself. The Loss Prevention Department organised safety training sessions onshore for supervisors, including contractors' personnel, which were conducted by external trainers and included discussions with representatives of management.

14.8 It was stated in evidence that safety was monitored by, *inter alia*, project briefings, the supervisors' meetings, the reviewing of incident reports, the safety co-ordination meetings, daily safety inspections and safety reviews. It was emphasised that employees were encouraged to report incidents and matters of safety concern to Occidental.

14.9 Occidental operated a comprehensive system of audits, which included the following:

(i) Regular "in-depth technical audits" carried out over extended periods on equipment, systems or procedures by line personnel and specialists co-ordinated by a senior engineer from the Loss Prevention Department.

(ii) Corporate audits, carried out by personnel from the American parent organisation. These involved 2-3 days of work offshore.

(iii) Fire and gas audits, carried out by consultants as a condition of insurance on an annual basis.

(iv) Partners' audits every 3 years. These involved 3 days of work offshore.

The audits were followed by exit meetings. Following the issue of a final report there was a system of checking to see whether the findings of the audit had been attended to.

14.10 The system which I have outlined above enabled line management, with the support of the Loss Prevention Department, to carry out its safety responsibility. It provided a system which should have been adequate for the purposes of securing that appropriate safety and emergency equipment and procedures were in place and working as they should. I do not fault Occidental's policy or organisation in relation to matters of safety. However, in previous chapters I have had to consider a number of shortcomings in what existed or took place on Piper. This calls in question the quality of Occidental's management of safety, and in particular whether the systems which they had for implementing the company policy on safety were being operated in an effective manner.

14.11 Before coming to the management evidence in regard to these shortcomings it is necessary for me to examine the evidence as to a number of events within a few years of the disaster which came to the attention of the Inquiry and appear to me to have an important bearing on this chapter.

Evacuation in a major emergency

14.12 On 24 March 1984 there was an equipment failure, explosion and release of gas on Piper, followed by a fire in the GCM. The alarms and deluge functioned on demand. The fire pumps came on line and continued to operate. The supply of fuel to the fire was cut off. The fire was put out by fire-fighters in just over 2 hours. It was essentially always under control. Platform personnel were evacuated by a number of helicopters which were in the area. By this means 179 persons were evacuated within about 50 minutes.

14.13 This incident was the subject of an Occidental board of inquiry and arising out of it a number of changes were made in the evacuation procedures. These included procedures for evacuation by helicopter which clearly was or had become the favoured method of evacuation. Occidental continued to employ a FILO on the platform to monitor in-field and passing helicopter traffic so that in an emergency their services could be called for and co-ordinated. Occidental also set up the EEC team and increased the Emergency Response Teams (see paras 8.6-7). Mr McReynolds pointed out that if the emergency happened at night-time Occidental could have scrambled 3 or 4 large helicopters from the shore. Mr Richards said that in such circumstances the longest time which the platform would require to wait for a helicopter was 2½ hours until the first personnel left the platform. I should say in passing that this seemed to me to be unrealistic as a means of delivering personnel from the hazard posed by an emergency. Long before the end of such a period the emergency would either have been brought under control or gravely imperilled those on the platform. Following the incident there was an improvement in the radio communications from Piper, including the installation of a satellite system. However, as I have noted in para 7.52 it was not fully appreciated that in the event of communications with Piper being knocked out the establishing of communications between the other platforms and the shore would prove difficult.

14.14 In May 1984 Captain P G Clayson, then the onshore Safety Superintendent, sent a memorandum to Mr G F Foldes, who was a member of the Facilities Engineering Department and took part in the board of inquiry into the incident. This memorandum was entitled "How it was vs How it could have been". In it Captain Clayson pointed out that the successful evacuation was made possible by a number of favourable conditions. These included that the helideck was operational throughout and was not affected by explosion, fire or smoke. Unimpaired ground to air communications had been maintained. It was daylight and weather conditions were conducive to helicopter operations. Enough helicopters happened to be in the area, available and capable of responding to the emergency call. The *Tharos* was close by with less than 500 ft between the helidecks. There were no problems in refuelling the helicopters. However, he postulated a situation in which the incident might have taken place at 01.30 hours on a Sunday morning; the wind north-westerly, a sea and swell of 50-70 ft and the temperature below freezing; the standby vessel 4 miles to the south-west; the RIV 8 miles to the west, roughly half way between Piper and Claymore; and the *Tharos* not available. If evacuation by helicopter was impossible (and it did not matter why this was so), it was his opinion that injuries and risk of loss of life would be "reasonably high". As regards the lifeboats there would be little opportunity or point in attempting to launch the 4 which were on the north face. If they did get into the water and unhooked "that would be the end of them as a means of evacuation and a form of life support". He suggested that in wind velocities of force 6 and above lifeboats launched beam-on to the sea would never clear the platform before being smashed against the structure and destroyed. As regards the life rafts he said: "Just how they could be even partially loaded in bad weather boggles the mind. A fit young man would have problems and maybe fail. Many of the unfit, over-weight personnel would have no chance at all." He went on to say: "We would be very lucky indeed to get anyone aboard any of the 7 rafts. I will go further, and say we would be lucky to get anybody on any of the rafts in a 50-70 ft sea condition." Experience with ships had shown that the chances of survival were infinitely greater if personnel could stay with the ship rather than take a chance in a lifeboat. He did not challenge the philosophy of getting as many off as possible if it was safe and practical to do so. "What I am saying is, we should look at being as safe, and as comfortable as possible, in the event that we cannot go *anywhere* immediately." He suggested the following points for consideration: "(i) recognise that evacuation by sea in bad weather is not practical (many people do already but just will not admit it); (ii) shift the bias of training for mustering and drills towards evacuation by air; (iii) consider provision of offshore-based helicopter and secondary helideck provision; and (iv) re-appraise practicality and usefulness of RIV boats in realistic terms." Mr Foldes passed this memorandum to Mr Grogan along with a memorandum of his own dated 17 May 1984 in which he expressed his full agreement with the points raised and recommended that arrangements should be made to have standby helicopters available round the clock for emergency evacuation purposes. These papers came before Mr Grogan in the middle of June at a point when the Occidental board of inquiry had submitted its report. Captain Clayson was not aware of any response to his memorandum but both Mr McReynolds and Mr Grogan considered and discussed it. It may be noted that Mr Richards could not remember having seen it before the disaster; and neither Mr Gordon nor Mr Bodie knew of its existence. However Mr Bodie had discussed what would be the means of evacuation in the event that evacuation by helicopter or lifeboat or both was precluded. He said: "I still seriously thought up until the event that we could hang on to the platform with the systems we had. Given that the helicopter evacuation was unviable and lifeboat evacuation was unviable, then we would fight the fire or the emergency on the platform with the platform capability ... until such time as we could effect a rescue by whatever means."

14.15 Mr McReynolds said that after the incident the philosophy was reviewed in recognition of the fact that evacuation by sea in bad weather may not always be practical and account needed to be taken of the alternative of evacuation by helicopter. However as lifeboats would always be available but helicopters might not be, the bias of training was not shifted from mustering and drills at lifeboats. He felt that Captain Clayson's scenario was "painting the worst case situation". However he was not aware whether Occidental had attempted by means of risk analysis to assess the probability of this situation coming about. His view was that "our approach against these risks or worst case scenarios is to try and make sure that the platform itself is self-sufficient to address the scenarios whereby the people do not have to evacuate the platform." "We relied on the on-board system to safeguard people on the platform; the system was designed to be self-sufficient; it would cater for any type of emergency that we could envisage." Occidental had considered on several occasions how to upgrade the evacuation system. He pointed out that Captain Clayson himself had admitted that it was difficult for him to know what to suggest. Consideration had been given to re-siting the lifeboats but they were felt to be at the safest end of the platform as drilling involved the greatest area of concern. Additionally the probability of having to use the lifeboats was not high as it was expected that it would be possible to contain any fire-related emergency situation on board the platform. Occidental had decided that all coxswains should be Occidental staff and had upgraded their training, but on safety grounds had not increased the frequency of drills in which lifeboats were actually launched. The re-siting of an alternative helideck had been considered but this was not practical as the only alternative would have been at the south end of the platform which would be too close to the flares and the cranes. An in-field helicopter had been rejected as it would have been too small to be effective in evacuating personnel before land-based helicopters arrived. He posed the theoretical situation of an in-field helicopter with a pay load of about 10 persons taking 400-600 minutes to evacuate 200 personnel. This, of course, assumed that such a helicopter was the only one available for use.

14.16 Mr Grogan did not accept that the wind blew more frequently from the north. The pattern of wind direction around Piper was almost evenly distributed. Captain Clayson's scenario was considered to be very unlikely. If the wind was from the north smoke and flames would be blown away from the helideck; the accommodation would provide a safe haven until helicopters arrived; and it would still be possible to launch at least the lifeboats from the east and west faces of the platform. The problem of lifeboat orientation and of getting away from the platform was one faced by the industry. Occidental had joined in the study by a working group of UKOOA of various methods but no good solution had emerged. For a number of reasons Occidental had decided that the lifeboats were best left where they were, which was similar to that found on most platforms in the North Sea. They had also rejected the suggestion of additional lifeboats as there were no good options. Occidental had also rejected an in-field helicopter and the re-siting of the alternative helideck for a number of reasons which he gave. The location of a FILO on Piper put Occidental in a better position than most operators to obtain the assistance of helicopters. His view was that Occidental "had considered all the things we felt necessary to remove the men from the platform. If they could not be evacuated by lifeboats, if they could not be evacuated by helicopter, there is only one thing left for them to do and that is for them to get into the life rafts." He said that Captain Clayson had been asked to examine the life raft situation but he could not recall what was done as a consequence of that examination; and it did not appear that he had followed that matter up with him.

14.17 The Inquiry heard evidence as to the limits within which helicopters can land and take off from a platform. Mr I L Griffiths, who was the pilot of the *Tharos* helicopter, a Sikorski S76, at the time of the disaster said that the limits for that aircraft were a 200 ft cloud base and three quarters of a mile visibility. The turbulence due to wind could also be a limiting factor. Flight Lieutenant S A Hodgson, who was the captain and pilot of a Sea King helicopter from Lossiemouth (R137) said that what was most likely to present a problem would be strong wind and very low cloud or fog. The top limit for the wind would be in the region of probably 75-80 knots. He also agreed that a fire on the platform could also give problems of turbulence.

14.18 The evidence to which I have referred in the last 6 paragraphs serves to demonstrate that there may well be situations in which evacuation by helicopters is not possible, at any rate in time to avert danger from personnel on the platform. Evacuation by lifeboats of the conventional type, and even more so escape by life raft, can be both difficult and dangerous. Neither Captain Clayson nor Occidental, in common with the industry at that time, were able to suggest any significant improvement on the methods of evacuation which already could be used on Piper. In my view the difficulties which faced Occidental were real ones and made it all the more imperative that both incident prevention and the means of fighting any fire should have been of the highest standard.

The risk of a prolonged high pressure gas fire

14.19 Occidental management can have been in no doubt as to the grave consequences for the platform and its personnel in the event of a prolonged high pressure gas fire. In para 12.2 I have referred to Mr Wottge's memorandum dated 18 March 1988 in which he stated that structural integrity could be lost within 10-15 minutes if a fire was fed from a large pressurised hydrocarbon inventory. In their property loss prevention report to Occidental dated 14 October 1986 Elmslie Consultancy Services Inc commented on the pipelines to and from the platform. They said:

> "These pipelines, especially the gas pipelines, would take hours to depressurise because of their capacity. This could result in a high pressure gas fire on the cellar deck that would be virtually impossible to fight and the protection systems would not be effective in providing the cooling needed for the duration of the depressurisation."

In 1987 the Marine Department commissioned from the Loss Prevention Department of Occidental a report in connection with their consideration of the need to continue with the hire of an RIV. Mr I Saldana prepared a preliminary report which was considered at a meeting on 16 June 1987 which was attended by Mr Gordon, Mr McReynolds, Mr Grogan and others. In his report Mr Saldana described various scenarios which could weaken the platform's structural steel support members and the means of fire-fighting in each case. One of these was an oil/gas riser rupture. In the case of a rupture on the pipeline side of the emergency shutdown valve no direct action could be taken on the platform to stem the flow of hydrocarbon. Even when the line was depressurised at the other end the flow could go on for many hours, depending upon line size, line length and system pressure. The most serious situation was a jet flame impinging on a part of the platform support structure. A detailed examination offshore was necessary to identify any such location. However, he went on to say:

> "It is likely that an aerial deflagration from escaping gas or a fire on the sea from the escaping oil represents a more serious hazard to personnel and to platform abandonment plans than to the integrity of the structure itself and this may become the major concern in such an incident."

These passages could be used to describe what happened in the disaster.

14.20 Occidental's approach to the hazard was to rely on a number of safety measures. These were:

(i) The provision of ESVs on the risers, in order to achieve isolation of the fuel source. The Tartan and MCP-01 risers had hydraulically actuated valves with nitrogen back-up. The MOL and the Claymore riser had an electrically operated valve with pneumatic back-up, to which a further nitrogen back-up had been retrofitted in early 1988. According to Mr Grogan subsea isolation valves (SSIVs) had been discussed in the light of a guideline from the Institute of Petroleum which suggested that they should be considered on pipelines of a certain type. However, the Elmslie report said that "the lack of subsea valves on the pipelines is an inherent hazard to the platform that is impractical to resolve at this point of platform life." Mr Richards thought SSIVs were still impractical.

(ii) The provision of a system for rapid blowdown to reduce pressure as quickly as possible. Mr McReynolds said that in 1986 Occidental had carried out a hazard and operability study on the blowdown and flare system. Mr Wottge stated that in December 1987 his department started a safety review of the gas lift system, part of which involved a review of the hydrocarbon inventory in C Module. He had written as he did in his memorandum dated 18 March 1988 because he had been led to believe that in a platform ESD the reciprocating compressors would not automatically depressurise. This was incorrect; and it was found that following an emergency blowdown the remaining process inventory would be only about 5 barrels.

(iii) Taking steps to ensure the integrity of the pipeline on the other side of the ESV from the platform. Mr Richards and Mr McReynolds described work which had been done some years before the disaster to ensure that there were no fittings on that side. On the Claymore line they had removed a pressure indicator. The risers were examined every year but no area of weakness had been identified.

(iv) The provision of a deluge and other means of fire-fighting. The significance of fire-water in the case of a gas fire would lie in its use to cool the surrounding area until the fuel could be cut off. As far as the risers were concerned Mr Grogan said that the deluge covered the pig trap area; and that nearby there were monitors which could be directed at any part of the riser. However there was no other part of the deluge system which was specifically directed to the riser "because if anything fell on the riser it would fall on to the sea, to the surface of the sea".

As regards the possibility of providing fireproofing for the structure of Piper Mr Gordon said that Occidental relied very largely on the expertise of Elmslie. Mr Grogan said that it was considered impracticable because of the complexity of the operation on a platform which was fully laden with equipment; and because the additional weight would not have been supported by the structure.

14.21 As regards Mr Saldana's report Mr Gordon, Mr McReynolds and Mr Grogan all gave evidence that at the meeting it was considered that no further action was required in view of the arrangements which had already been made to prevent a catastrophe. In the light of figures obtained by the engineer from other sources Mr Gordon said that the probability of the event "was so low that it was considered that it would not happen". He added that the scenario of a platform fire burning out of control to the destruction of the metal support work had been considered in a number of studies done by Elmslie and others. "It was not considered that in the lifetime of the platform there would be a situation where all the systems failed and that such a scenario would indeed occur." He also said that Mr Wottge had assured the meeting that all reasonably practicable steps had been taken to upgrade the platform fire-fighting systems, although he accepted that at the time there were continuing problems with the deluge systems in A and C Modules and that the replacement of distribution pipework had not then started. Mr Grogan said that he and Mr Wottge had "many times considered and talked about the situation of a riser rupture because that is one of the things that we should be concerned about". "We always knew that a major riser rupture was an event which needed to be avoided. In that light we had considered that kind of situation would be one which we would not want to encounter". However it did not appear from the evidence of these 3 witnesses that the hazard posed by an aerial deflagration to which Mr Saldana had pointed was specifically considered at the meeting. Mr McReynolds in particular said that the paragraph did not impact on him when he read the report. Both Mr McReynolds and Mr Grogan made comments on Mr Saldana's state of knowledge. Mr McReynolds said that while he was a good young engineer he was not aware of the various studies that had been done previously as he had not worked on Piper. Mr Grogan said he regarded him as not particularly familiar with the offshore scene nor aware of all the actions which had been taken and were being taken with regard to the matters which he had raised in his report.

14.22 Although the Loss Prevention Department provided advice on qualitative and quantitative risk analysis (QRA) for the auditing of the blowdown and relief system Mr Gordon could not recall that this report had considered the impossibility of blowing down the inventory of the pipelines in any reasonable time. The type of scenario that happened in the disaster in which the inventories of pipelines vented on Piper had never been considered by his department. They had not used their expertise to determine the probability of failure in circumstances specific to Piper. It was pointed out by Mr McReynolds that in his report Mr Saldana had shown the frequency for the rupture of an oil/gas riser as 10^{-4}/year. The witness commented: "I think this assessment in Appendix B was recognised to be a general assessment of industry statistics not related to Piper or Claymore. If anything these statistics would probably have given us some comfort, quite frankly, because I think our risers were designed very competently." He confirmed that no member of the management team considering the report had sought to apply the same type of analysis to the particular circumstances of Piper or Claymore. Mr Grogan also questioned the validity of Mr Saldana's frequency, pointing out that it was derived from all offshore incidents including those arising out of collision and corrosion. No consideration was given to fireproofing the risers.

14.23 I have 2 main observations to make about the evidence which I have endeavoured to summarise in the last 2 paragraphs. The first is related to the attitude of the management witnesses to the hazard posed by a prolonged high pressure gas fire. I do not think that Mr Saldana provided them with any insight into the magnitude of the hazard which they would not otherwise have appreciated. If the fuel source were not isolated, the danger to the structure and to personnel would be very great. Further, management had reasonable grounds for confidence in the measures which had been taken to prevent such an eventuality, so far as these measures went. I can also appreciate that Mr Saldana may well have appeared to be over-enthusiastic and over-ambitious in the scope of his report. However, the attitude of the management witnesses to the assessment of risk was, in my view, unsatisfactory. No doubt holes could be picked in the frequency which Mr Saldana had mentioned in his report but the witnesses' reliance on merely a qualitative opinion showed, in my view, a dangerously superficial approach to a major hazard. This was all the more pointed in the case of Piper where, unlike Claymore, there was no fireproofing of structural members; the fireproofing of risers had not been considered; and the deluge protection to the risers was apparently limited to what Mr Grogan described. I must make every effort to avoid being influenced by hindsight, but making all allowances for that I consider that management were remiss in not enquiring further into the risks of a rupture of one of the gas risers and in such an event the risk of structural damage and injury to personnel.

14.24 Quite apart from the considerations which I have discussed in the previous paragraph, the major hazard involved in the risk of a high pressure gas fire, whether prolonged or not, underlined once more the need for the highest standards in incident prevention and the means of fire-fighting.

The prevention of incidents

14.25 The quality of the management of safety in regard to the prevention of incidents depends upon what management achieve in a number of areas, including (i) the reviewing and monitoring of safety procedures; (ii) the investigation of past incidents and equipment failures and applying the lessons of those investigations; and (iii) the examination of the safety implications of changes in equipment and activities. The evidence given in the Inquiry enabled me to consider management performance in regard to these matters. In particular I heard evidence as to their approach to reviewing, monitoring and auditing the PTW system; their response to the Sutherland fatality; their response to the discovery of stud bolt failure on a reciprocating compressor; and their decision to maintain production in the period leading up to the day of the disaster. I will deal with these subjects in turn.

The permit to work system

14.26 In Chapter 11 I examined a number of deficiencies in the PTW system. Mr Richards recognised that as a line manager one of his duties was to maintain adequate procedures for the safe control of work and to monitor their effectiveness. Accordingly he was concerned to see that the PTW system worked properly and that its efficiency was kept under review. He had no formal procedures for reviewing the system. But he said: "When an accident occurred, the permit was part and parcel of the investigation which was checked and reviewed. Occasionally I monitored, by looking at permits and I went around the site. Invariably at the time I visited the site there was no work going on because it was usually in the evening. Line supervision monitored the permits. They were checked and we never found anything seriously wrong with the permits." Minor deficiencies in the operation of the system were brought to his attention from time to time in safety meetings. His approach seemed to be, in his own words, "surely that is all you are concerned with about the permit system ... If the system is working and no problems are identified ... then you should be reasonably happy with it, surely?" He was aware that suspended permits were kept in the Safety Office. This had been the practice for years. Prior to the disaster he had paid no attention to it; but he now realised with hindsight that it was unsatisfactory. He had been surprised at the number of deficiencies in the operation of the permit system which had been revealed in the Inquiry. He had checked this out and found it to be true. He had asked himself how those deficiencies could exist without his knowledge. His conclusion was that a proper audit system should be set up. Mr MacAllan said he knew that the system was monitored on a daily basis by safety personnel. By the lack of feedback he "knew that things were going all right and there was no indication that we had any significant permit to work problems". From his own experience of 10 years offshore on Piper and Claymore he felt he knew how the crew worked and was comfortable with it. He was satisfied that the discipline necessary to operate the pressure system including the permit system existed as there were many experienced personnel on Piper. On his visits to the platform about 6 times a year he made a point of checking permits by looking at job descriptions and safety precautions. The only deficiency he had noticed was that the permit was sometimes not displayed at the job site. In such a case he would tell the man concerned to put it on display. During his time on Piper Performing Authorities did not leave suspended permits on the lead production operator's desk. His own practice had been to interrupt the handover in order to suspend the permit. Mr McReynolds explained that the permit system had been developed originally by the Loss Prevention Department, and thereafter reviewed and, if necessary, revised on a regular basis. The last review in 1985 had been prompted by an audit in 1984 which observed that the procedure was being administered somewhat differently as between Piper and Claymore. He had commissioned Mr J Barnes, an experienced OIM, to review and re-write the procedure so that it would "fulfil its purpose for controlling work and find acceptance from as many people as possible so that it would be administered in the same way". The resulting procedure was very little different from its predecessor but the witness felt that the re-writing had "tightened up the system and we were not seeing permit-related accidents". The witness accepted that it was his responsibility to see that the system was monitored. From the outset safety staff had a specific responsibility to make sure that they were satisfied with the details of the permit including the precautions to be followed and to check whether they were being followed. A similar message was given to both Occidental and contractors' supervisors in safety seminars. On his own visits to a platform he would take notice of the work going on and whether permits were being displayed at the job site. Overall he did not get any feedback from anyone in the Operations Department that the permit system was not being operated as it should have been. In the absence of that he assumed that the system was working properly. The only points of concern about the system which he could recall were the administrative differences between Piper and Claymore and a question relating to the number of hot permits out at any one time. He was not aware of the DEn ever criticising the permit system. "From many general conversations I had a good feeling that people felt well about the permit system being able to control the work and people were reasonably happy with the system."

14.27 Mr Gordon said that monitoring was achieved by the daily checking by safety personnel on the platform. If the system was not being followed on a regular basis he would have expected to hear about it. He "had no feeling that there were deficiencies with the system". He could offer no explanation as to why none of the audits in which his department were involved revealed what had emerged at the Inquiry. A corporate audit in the last quarter of 1987 had looked at hundreds of permits which had been sent in from Piper and had not reported any deficiency to Mr Grogan. This was confirmed by Mr Grogan himself.

14.28 The quality of the laid down permit procedure was the acknowledged responsibility of management, and Mr McReynolds in particular. Although that procedure was revised as recently as 1985 there appears to have been no attempt to assess whether it stood comparison with the systems of other operators or satisfied the guidelines available to the industry as a whole. In view of the wealth of experience available within Occidental it is hard to understand how there were critical and obvious omissions in the PTW system, such as a method of locking off isolation valves to prevent inadvertent de-isolation (to which I have referred in para 11.4). The managers who had responsibility for the correct operation of the PTW system were all aware that the safety personnel on the platform were expected to monitor the daily operation of the system. All of them assumed that because they received no reports of failings the system was working properly. However none of them checked the quality of that monitoring nor did they carry out more than the most cursory examination of permits when they had occasion to visit Piper. The lack of any critical reference to the PTW system in the audits which had been carried out on Piper reinforced the assumption that all was well. However it is difficult to understand how it came about that this auditing did not identify the deficiencies which so quickly became apparent in the course of evidence at the Inquiry. Mr Richards was evidently correct when he said that his conclusion was "that a proper audit system should be set up".

14.29 Earlier in this report I reached the conclusion that a failure in the PTW system had occurred on the evening of the disaster and that if this had not occurred Mr Vernon would not have attempted to re-start condensate injection pump A and thus unwittingly caused a leak of condensate from the site of PSV 504 (see paras 6.188 and 6.191). The evidence which I considered in Chapter 11 showed that this failure was not an isolated mistake but that in a number of respects the PTW system was being operated routinely in a casual and unsafe manner. That evidence along with the evidence to which I have referred earlier in this chapter shows, in my view, the operation of the PTW system was not being adequately monitored or audited. These were failures for which management were responsible. If there had been adequate monitoring and auditing it is likely that these deficiencies in the PTW system would have been corrected.

Occidental's response to the Sutherland fatality

14.30 As I have already stated in para 11.16 the report of the Occidental board of inquiry contains no examination of the adequacy or quality of the handover between the maintenance lead hands. Nor did it examine the implications of the expansion of the scope of the work beyond what had been covered by the PTW. However, the complaint to which they had pleaded guilty specified that there had been a failure of supervision in both these areas. In my view the work of the board of inquiry was superficial in respect that it did not examine either of these areas, at the latest after the stage at which Occidental had tendered their plea of guilty on 17 March 1987. *Prima facie* if there had been an adequate handover or if the work had been limited to the scope and conditions of one or more permits to work the fatality could have been prevented.

14.31 Mr Richards, who disagreed with the suggestion that there had been a failure in handover or that any deficiency in the operation of the permit system had any bearing on the fatality, said that no changes were made either to handover procedure or the permit system. He considered it important that each person coming on shift was properly informed of what was going on. He said that he would expect all handovers to comprise both a written log and a discussion lasting 10-30 minutes. It was his belief that handover procedures were good and he saw no reason to change them. Handovers were not formally monitored. He did not personally check on their quality but would keep his eye on them. No problems with them had been identified. Mr MacAllan's immediate assessment was that the fatality was due to a structure being used for access and as a walkway when it had not been designed for those purposes. From his experience of working on Piper he was familiar with the routine adopted for handover. He had not checked on handovers during his visits to the platform but "essentially there was a good handover period". Mr McReynolds agreed that the failure to take out a new permit for the change in lifting arrangements was a serious infraction. He said that he had given instructions that separate permits were to be taken out for the rigging component in maintenance jobs. As far as he was aware everyone was content with the handover system although there was no formal procedure covering it. The information which was passed on seemed adequate and no problems had been identified. He had no concerns about the handover system, but he was not aware that the DEn had criticised the shift handover in the case of the Sutherland fatality. Mr Grogan agreed that the change in the scope of the work was a contributory factor to the fatality and that this should not have taken place without the supervisor being informed. He treated this as an aberration of a good system, although there was nothing in the report to support that interpretation. Mr Gordon believed that the complaint related to the handover was ill-founded, but the basis for this was Mr Bodie's assurance that the handover had been well done. His department had not considered handover practice despite the findings of the DEn and Occidental's plea of guilty. The report had highlighted that supervisors must approve any change in the scope of the job. However, this had not alerted him to question the scope of what was covered by the permit in that case.

14.32 It is clear that following the Sutherland fatality Occidental personnel took a number of steps in reaction to what had happened. Two of them I have already mentioned in para. 11.16. Further it is clear that as a result of a request by the President of Occidental, Mr J F Snape, at a meeting of the management safety committee on 3 March 1988, Mr J Letham of the Loss Prevention Department prepared a memorandum dated 13 May 1988 which set out the extent to which the fatality had been followed up. However the approach adopted by management to the contents of the report of the board of inquiry was such that the result of the investigation was not passed on to senior onshore personnel, let alone senior personnel on the platform. Mr Gordon told the Inquiry that copies of the report itself were issued only to senior management, the Legal Department and himself. Accordingly Mr Richards, who had been the OIM at the time of the fatality, did not receive a copy of the report. Apart from hearing some of them "on the grapevine" he was not told what were the conclusions of the report. Mr MacAllan did not see a copy of the report but saw a photocopy of part of the recommendations which Mr McReynolds showed to him. This appeared to be in line with the policy described in a memorandum which had been submitted to Mr Grogan dated 29 March 1984 by a member of the Legal Department in connection with the incident which had occurred a few days earlier on Piper. The relevant passage of the memorandum was as follows:

> "I would confirm that there is significant exposure here and that prosecution is possible. I would therefore respectfully suggest that we proceed with care, particularly in our dealings with the Department of Energy. I would also suggest that staff be reminded not to discuss the detail of the incident itself or follow-up investigation."

I may say at this point that safety personnel appear to have been in a similar situation. Mr G G Robertson, who was then the safety supervisor on Piper, did not know what the management team had decided to do about the deficiencies which had been shown up by the fatality. Mr Bodie, the onshore Safety Superintendent, was aware of the practice whereby the discussion of any accident such as the fatality was discouraged. He said that he had to concur with that policy, which was still in force at the time of the disaster. When he was asked whether he had made representations against it he replied: "We certainly had discussions. It really is a problem, having found out what had happened in any particular incident, then to have to disguise your writing and send out memos without any mention of that particular incident but try to get action taken." When asked whether that militated against the proper feedback which ought to have arisen he replied: "No, we managed to get the messages across to the personnel, in a lot of cases verbally, and, as I said, by very cleverly worded memos."

14.33 The evidence given by senior management, on the other hand, rejected any suggestion that discussion was inhibited by company policy. Mr McReynolds was asked:

> "Q. Was there any policy known to you whereby, in the event that an accident happened on an Occidental installation, discussion of the circumstances of the accident and lessons to be learnt, would be discouraged for fear of potential prosecution?
>
> A. Absolutely not. We discussed every accident in detail. We discussed the recommendations. The only thing we did not do was to duplicate that report and give it wide distribution."

Asked whether he wished to modify that answer in the light of the passage in the memorandum to which I have referred above he replied:

> "No, I do not. I would say, without doubt, that every incident of this nature was always fully discussed amongst management and amongst our subordinates. I see what the man said but that was invariably done."

Mr Grogan's version of the policy was as follows: "The directive from the President was one which said we want to pass the information down that is necessary for people to take action on, but we do not want to distribute reports which may have extraneous information which other people did not require to know."

14.34 Earlier in this report I concluded that there had been a failure to communicate information as to the removal of PSV 504 in the handovers to Mr Clark and Mr Richard and that if that information had been given to them Mr Vernon would not have attempted to re-start condensate injection pump A, with the consequences which I have described earlier (see paras 6.189-192). Turning to the evidence which I have summarised above, Occidental management should not, in my view, have acted as they did by dismissing from further consideration the possible shortcomings in the PTW system and the handover practice which the prosecution in the Sutherland fatality had called in question. As regards handovers, there was, as I have pointed out in Chapter 11, some dissatisfaction as to the amount of information which was transmitted. There was no laid down procedure for carrying them out and little, if any, monitoring of them. If the practice had been adequately investigated it appears to me to be likely that failures of the type which occurred on the evening of the disaster would have been detected. As regards the results of investigation into incidents such as the Sutherland fatality, while the attitude of senior management may have been as stated by Mr McReynolds and Mr Grogan, I am far from satisfied that this took effect at lower levels. In the result I consider that whether by direction or by inaction Occidental management failed to use the circumstances of particular incidents to drive home the lessons of the investigation of those incidents to those who were immediately responsible for safety on Piper on a day to day basis.

The response to the discovery of stud bolt failures

14.35 As I stated in para 6.176 it was discovered in February 1988 that 7 of the stud bolts on the yoke/frame extension flange on No 1 cylinder of reciprocating compressor A had failed. These were fatigue failures. All the stud bolts at the flange were replaced; and the bolts on the other cylinders were retorqued to establish that they had not cracked or lost their pre-tension. However when these failures were discovered no check was made on similar bolts on reciprocating compressor B. This was not done until May 1988. Mr MacAllan, who recalled the discovery, agreed that proper practice would have been to check the latter compressor forthwith. The fact that this was not done until May 1988 he put down to an oversight on the part of himself and the maintenance superintendents when they discussed the original problem. Mr McReynolds was aware of the original discovery but was not involved personally and did not ask why failure had occurred. He agreed that good practice would have been to inspect the latter compressor immediately. The fact that this was not done he put down to an oversight on the part of those who were dealing with the problem. Mr Gordon recalled the discovery as it was important enough to be discussed at the monthly safety co-ordination meeting. The problem was handled by the Facilities Engineering Manager and the Production and Pipeline Manager. While he knew that there was a similar compressor he could not recall whether it was discussed at that meeting but imagined that it would have been. He was surprised that several months had passed before it was examined but he was not aware of that at the time.

14.36 The failure to check the latter compressor was an extremely serious error which could have had disastrous consequences. However, in the light of the evidence I treat it as a failure on the part of those who were directly involved rather than indicating a deficiency in Occidental's general approach to such matters.

The decision to maintain production prior to the day of the disaster

14.37 Earlier in this report I described the unusually high level of work which was proceeding on Piper in the period leading up to the time of the disaster. This included major construction work, additional maintenance work, the changeout of the GCM and the associated changeover from phase 2 to phase 1 operation (see paras 3.111-117). The maintenance work included the tailend of the programme of recertification of PSVs which had taken longer than expected (para 6.80). In addition from the morning of 4 July until about 17.00 hours on 6 July it was intended to include the 24 month preventive maintenance of condensate injection pump A (paras 6.62-64).

14.38 As a result of the abnormally high level of work the number of personnel working on Piper was unusually high. A substantial number of contractors' personnel required to be accommodated on the *Tharos*.

14.39 During the period leading up to the day of the disaster there were a number of gas leaks (see para 3.120). The volume of gas being flared was unusually high, being on average 30 MMSCFD, as compared with 1-5 MMSCFD in phase 2 operation, and was subject to considerable surging. The heat generated by flaring was so great that it was necessary to protect equipment and materials. Abnormal icing was also found on the flare line passing through the dive area (para 3.125). The water cut of the processed oil was about 10% on the evening of 6 July, as opposed to a normal figure of about 2%. This was attributed to operational upset in the production separators. Mr Bollands, the Control Room operator, could not recall such a level but considered that action would have been required to reduce it (para 3.131).

14.40 The changeout of the GCM was required in order to replace the dessicant in the molecular sieve dryers. The GCM was installed in December 1980. The first replacement of dessicant was in 1984. Thereafter it required to be at 2-yearly intervals. During the changeout in 1984 the platform was operated in the phase 1 mode for 2 months. In 1986 the platform was totally shut down during the changeout and the carrying out of other maintenance work. In these circumstances since December 1980 the only period in which the platform had previously been operated in the phase 1 mode was for the 2 months in 1984. Phase 1 operations entailed that pipework and pressure vessels were to be subjected to higher pressures and in some instances used for a different purpose from that which they served during phase 2 operation.

14.41 In regard to 1988 it is clear that it was originally contemplated that the platform would be totally shut down in June while the GCM changeout and other work was carried out. However, Mr MacAllan, Occidental's Production and Pipelines Manager, decided that production should continue during this work on the basis of phase 1 operation. In these circumstances production was maintained until the time of the disaster at the level which it had reached in the month before the additional work was started. Mr MacAllan explained that his decision was based on the view that the only part of the work for which a total shutdown was considered necessary was the planned maintenance of electrical switchgear. This particular work had been deferred to 1989. The safety implications of phase 1 operation had been considered with the Facilities Engineering Department, which was mainly concerned with the suppression of hydrates by additional methanol injection. Mr MacAllan said that he had considered that the other work which was to be done at the same time as the changeout would be achieved under control. Mr A Carter who had been responsible for working out the detailed changes required for phase 1 operation in 1984 had carried out the same responsibility in 1988. Mr MacAllan said that while he had taken the decision on the basis that this was within the authority which was delegated to him he had kept Mr Coffee informed of progress.

14.42 Mr MacAllan agreed that there was room for mistakes to occur more readily at the time of the disaster than in normal circumstances. However he was sure that the programme had been adequately planned and that contractors' personnel were familiar with the operation and were adequate from a safety point of view. He was emphatic that the OIMs and superintendents on the platform were familiar with what was going to happen. If they had had any qualms at all they would have said so. They were encouraged to do so by senior personnel. If they had thought that there was too much work to be done without a total shutdown, all that they had to do was simply to say so. "There was no pressure put on them to have too much work. They had the authority to approve and to disapprove work." I noted, however, that Mr Richards, the back-to-back OIM, said that he had not been personally involved in the decision to continue production under phase 1 operation. He was apparently unable himself to explain the reason for the decision. As regards the future, Mr MacAllan said that, although Claymore was very different from Piper, Occidental would be considering a total shutdown during the time that major works were carried out.

14.43 The decision to continue production on Piper and at the prevailing rate while carrying out a substantial and diverse programme of construction and maintenance works is puzzling. If this course was to be followed, it should have required strengthened management and supervision on the platform. In the event 2 senior posts, lead safety operator and deputy maintenance superintendent, were vacant and 3 posts, maintenance superintendent, operations superintendent and deputy operations superintendent, were filled by personnel who had been temporarily upgraded. The abnormal mode of operation and any upset conditions should have put platform management on the alert for any sign of impending problems. In the event on the evening of the disaster any decision as to whether to shut down production was left to the judgement of the lead production operator. He would have learnt how to cope with such a decision by an experienced lead operator working with him initially "to show him the ropes". There were no exercises or scenarios to give practice in dealing with this type of situation. Usually there was no time for him to refer the question of a partial or total shutdown to the OIM. Invariably he would have to make the decision himself and he would inform not the OIM but the operations superintendent first. At least in the unusual conditions in which the platform was being operated prior to the disaster this seems to me to have imposed an excessive burden on the lead production operator and compounded the risk of something going wrong. I find it surprising that management did not consider that it was their responsibility to provide the lead production operator with greater support or guidance for this period during which process upsets were more likely and could call for the shutting down of production.

The mitigation of the effects of incidents

14.44 In realistic terms the fighting of fire on Piper depended essentially on the platform's own capability to do so. As far as external fire-fighting was concerned, the usefulness of an RIV was limited in 2 ways. In the first place, as Occidental management well knew, it would be of little or no effect against a prolonged fire fed from a ruptured gas riser, as was shown at the time of the disaster. In the second place, although Occidental elected to continue using an RIV, despite the comments which Captain Clayson had made, it was retained only as a back-up and might be 4-8 hours away from the platform, according to Mr McReynolds. Accordingly an RIV would not be at Piper unless there was a particular reason for having it there.

14.45 As regards the diesel fire pumps, Mr Richards felt no great concern that they were put on manual mode when the divers were in the water as the electric fire pumps kept the fire main primed and could supply the deluge system. The diesel pumps could be started up in less than 30 seconds. Mr McReynolds believed that the diesel pumps were kept on manual mode only when divers were working in the vicinity of the intakes. This had been the system when he had been the Production and Pipelines Superintendent in the early 1980s. When asked whether he considered that the automatic start facilities on the diesel pumps were a necessary part of platform safety he said "I thought it was a nice enhancement to the platform safety; yes." A switch in the Control Room to start the diesel pumps similar to that on Claymore had not been considered. Mr Gordon's position was that he had not been aware of the practice of putting the diesel pumps into the manual mode when divers were in the water. However he said that he would not have necessarily objected to it.

14.46 The practice which was followed on Piper of keeping the diesel pumps on manual mode whenever divers were in the water was directly due to the decision of the OIM. I have already expressed the view in para 12.11 that this inhibited the operability of the diesel pumps in an unnecessary and dangerous way. It happened despite the audit recommendation to which I have referred in para 12.9 and which was apparently not followed up by management. The absence of a switch in the Control Room by means of which they could be returned immediately to automatic mode was an obvious deficiency which ought to have been picked up during one of the many safety audits which were carried out on Piper and for which management were directly responsible.

14.47 As regards the deluge system I return to the discussion at the point where I left it in para 12.23. Evidence was given in regard to it by Mr McReynolds, Mr Grogan and Mr Gordon.

14.48 Mr McReynolds expressed the view that while the deluge system was a very important feature it was not a critical one in the sense of "the one and only thing we hang our hat on". There was more than one system which was used for fire-fighting. There were fire monitors and hose reel stations. He was familiar with the past problems of the deluge system but he said that he was satisfied that between 1986 and 1988 the deluge system would operate efficiently in the event of an emergency. There was ample water capacity as there was quite a bit of redundancy built into the system due to the uprating of the fire pumps in 1983. The problems were properly monitored. He understood that on routine testing 4-6 nozzles per part of a module were found to be blocked. He had not perceived any change by the time when he left in May 1988.

This would not prejudice the density of the spray. He also pointed out that the nozzles that tended to block were those on the outer extremities of the laterals of the pipework whereas most of the equipment was located in the centre of the modules. He said that he would have been informed if anything was found to have changed as a result of routine testing. He had told his staff in 1986 that if anything changed he would take another look at what required to be done. As he had heard nothing after 1986 he assumed that conditions had not changed. He also relied on the insurance auditors but he could not recall any comments on the deluge system in their reports. (It may be noted that whereas the audit reports in 1984 and 1985 refer to the problem of blockage, the reports in 1986 and 1987 make no reference to that problem or to the testing of the deluge system.) He was aware of the delay in the replacement of pipework in A and C Modules. He said that that was requested by the insurance auditors "who wanted to re-look at the system before we replaced it and make sure there was not something we were missing".

14.49 Mr Grogan said that he had been assured by production, safety and engineering staff that the deluge system would operate efficiently in an emergency. He was satisfied from reports of routine testing and insurance audits that the problems were not critical, although he could not recall reading that in any audit report. He said that the issue was frequently discussed by senior management but could not recall whether it had been on the agenda at the quarterly management safety meetings. (It was not recorded in the minutes of those meetings between June 1986 and May 1988.) He had no part in the decision to delay replacement of pipework in A and C Modules but he agreed with it as there were no particular problems in A Module and the problems in C Module were being controlled by regular maintenance. His information was that throughout 1987 there was a low percentage of blockage at the end of pipe runs in A Module and 10-20% blocking in the same areas in C Module. He was unaware of what was found on routine testing of C Module in February 1988. The final decision was to put not fireproofing but cooling water on the structural members. The deluge covered the pig trap area. In the area below that there were fire monitors which could be directed at any point on the riser. Apart from the pig trap area there was no deluge specifically directed to the riser "because if anything fell on the riser, it would fall on to the sea, to the surface of the sea". He felt sure that he would have discussed with Mr Wottge the problem created by the shortage of contract draftsmen, but he could not recall doing so or taking any specific action to expedite the work. At no stage did he ask for a check as to whether the system could still meet the requirements of the Fire Fighting Equipment Regulations but he assumed that it did. He visited Piper twice a year but had not asked to witness a test on the deluge system to see for himself the problems which were being experienced.

14.50 Mr Gordon who had supported the plan to phase the replacement and to start with B Module which had the highest hydrocarbon inventory, had agreed with the delay in the replacement of A and C Modules. This was on the advice of Elmslie that Occidental should look at the water protection of the structure. Mr Gordon agreed that the deluge system was very important for the safety of the platform. He said: "Our department made checks on the system at regular intervals, and we were keeping a constant watch on the position." He himself did not receive specific reports but relied on Mr Bodie to keep him informed. The position of his department was that the deluge system was operating satisfactorily although not to capacity. He was assured by the Facilities Engineering Department that the water capacity was still sufficient to address any fire situation within the modules. The system would perform if required and was acceptable in the short term, despite the statement by that department on 6 June 1986 that there was "a serious question on how many deluge nozzles could block during an emergency situation. This problem has been getting worse over the last few years ...". Mr Gordon did not call for any testing of the deluge system other than was carried out under safety personnel on the platform. He relied on the insurance audit as an independent check. That system had not been commented on in the audit reports for 1986 and 1987. Therefore he inferred that the situation was satisfactory to the auditors.

14.51 In contrast with onshore plants where a local fire service and expert fire crews can be called up within minutes an offshore platform such as Piper requires to be self-sufficient in fighting a fire. On Piper the main systems of active fire-fighting were the deluge system and the fire monitors. It was essential that these systems along with the facility to blow down the hydrocarbon inventory were maintained in first class working condition. It was reasonable for Occidental to attempt to cure the difficulties which had come to light by fitting larger nozzles and carrying out regular cleaning, before embarking on a complete replacement of the distribution system in non-corrosive material. As I said in para 12.22 it was not unreasonable for them to proceed by taking the replacement of pipework in one module at a time and to do the work in such a way as to avoid putting the whole of the system in one module out of operation at any given time. However, having regard to the very great, if not critical, importance of the deluge system it was in my view unacceptable that the process of rectification should be still only one third complete 4 years after the problem had been clearly identified. Even if it was reasonable for the initial replacement in B Module to take as long as 2 years Occidental should have been able to draw on their experience by following on rapidly with replacement in the other modules. They could and should have eliminated delay caused by the lack of enough contract draftsmen. The prolonged process appears to me to have stemmed from the failure of senior management to manage the rectification with the urgency that such a vital safety system warranted. No senior manager appeared to me to "own" the problem and pursue it to an early and satisfactory conclusion. None of the management who gave evidence took the step of witnessing deluge tests for himself. They too readily accepted the advice of more junior staff that the system would still be effective in handling an emergency; whereas in reality by at least February 1988 it was clear that it would not.

General observations

14.52 The evidence which I have considered in this chapter should be considered along with my observations in Chapters 11-13. It appears to me that there were significant flaws in the quality of Occidental's management of safety which affected the circumstances of the events of the disaster. Senior management were too easily satisfied that the PTW system was being operated correctly, relying on the absence of any feedback of problems as indicating that all was well. They failed to provide the training required to ensure that an effective PTW system was operated in practice. In the face of a known problem with the deluge system they did not become personally involved in probing the extent of the problem and what should be done to resolve it as soon as possible. They adopted a superficial response when issues of safety were raised by others, as for example at the time of Mr Saldana's report and the Sutherland prosecution. They failed to ensure that emergency training was being provided as they intended. Platform personnel and management were not prepared for a major emergency as they should have been.

Chapter 15

Piper Alpha and the Department of Energy

Introduction

15.1 In this chapter I will examine the involvement of the Department of Energy (DEn) with safety on Piper from June 1987 until the disaster; and consider how it was that this did not reveal deficiencies which I have set out in preceding chapters.

15.2 The statutory background to the roles of the DEn and other bodies is set out in the following chapter. For the present it is sufficient to state that a large number of specific duties are placed upon operators and OIMs by the Mineral Workings (Offshore Installations) Act 1971 (MWA) and numerous regulations made under that Act. In addition the Health and Safety at Work etc Act 1974 (HSWA) imposes wide-ranging general duties on employers to ensure, so far as is reasonably practicable, the health and safety of their employees and those who may be affected by the conduct of their undertakings. The Government has no direct legal responsibility for safety. On the other hand it is responsible for developing, administering and enforcing the statutory framework. It also seeks in various ways to assist those who are directly responsible for safety to meet their responsibilities and seeks to promote progressive improvement in safety standards. Much of this work is carried out by the Safety Directorate which forms part of the Petroleum Engineering Division (PED) of the DEn. Under an agency agreement with the Health and Safety Commission (HSC) the Secretary of State for Energy undertook responsibility for the enforcement of the HSWA and the regulations made under that Act. The enforcement of the legislation is sought to be achieved mainly through inspections and investigations carried out by inspectors from PED. However the adequacy of fire-fighting equipment, life-saving appliances and navigational aids is sought to be achieved by means of biannual examinations by surveyors of the Department of Transport (DoT) on behalf of the Secretary of State for Energy. In addition, offshore installations require to be certified as fit for various purposes affecting safety. In that connection during their working life they are subject to periodic survey by a certifying authority, such as Lloyd's Register of Shipping.

Inspections and investigations by the Department of Energy

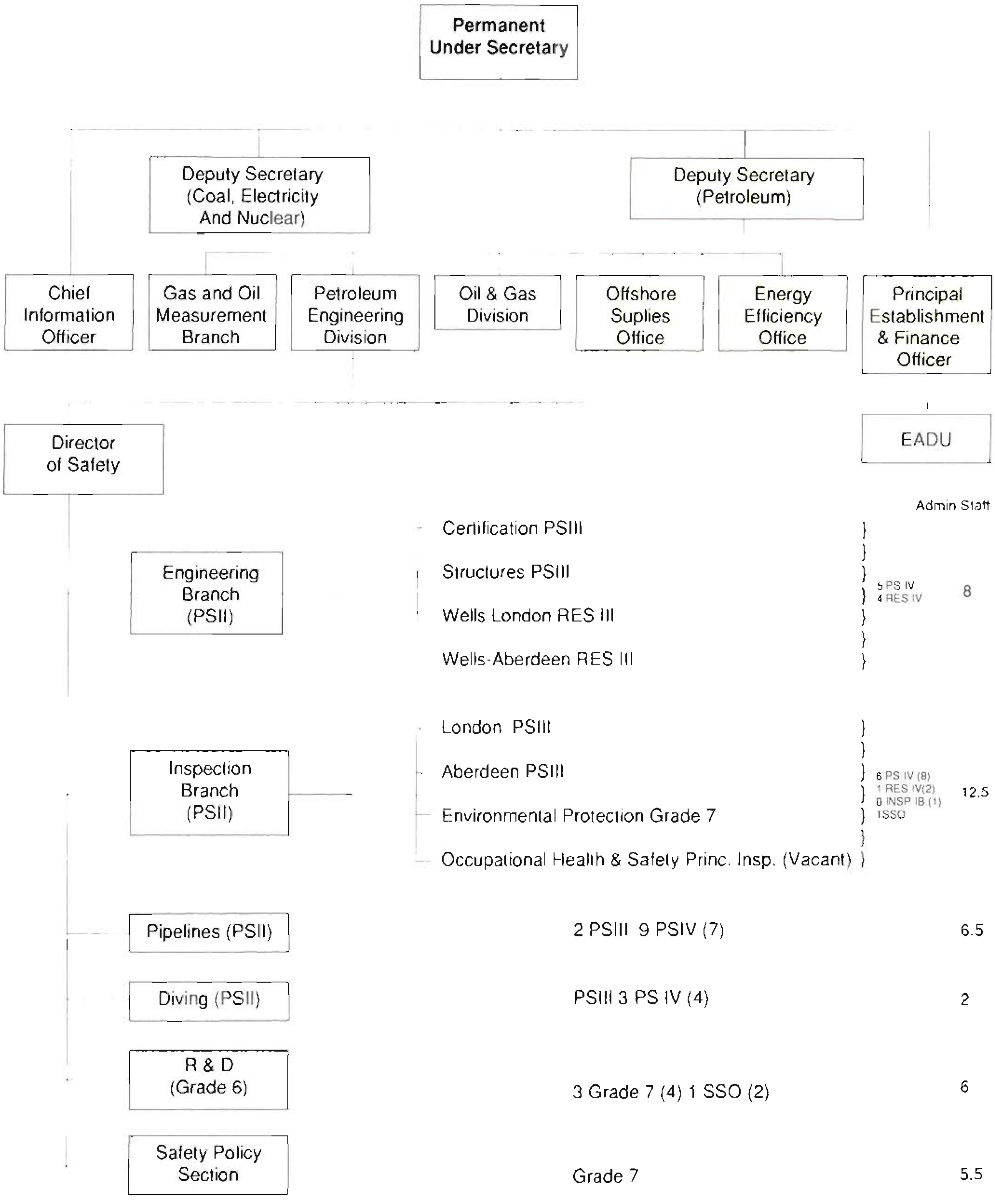
15.3 The Inquiry heard the evidence of Mr J R Petrie, who has been the Director of Safety since 1987; Mr R J Priddle, Deputy Secretary of the DEn since September 1989; and Mr R D Jenkins, one of the Senior Inspectors of PED who carried out inspections of Piper in June 1987 and June 1988, along with the investigation of the Sutherland fatality to which I have already referred in para 11.15 *et seq*. This evidence enabled me to consider the inspections and the investigation against the background of the system of which they formed part, and examine the extent to which that system was effective to secure its stated objectives. Fig 15.1 shows the organisational structure of the DEn and of the Safety Directorate.

Inspections

15.4 According to Mr Petrie in giving evidence from a prepared statement the primary objectives of inspections carried out by the DEn are to:

> "(a) monitor compliance with the legislation; (b) secure compliance where necessary; and (c) promote safety, health and welfare, in particular by disseminating relevant information to industry and keeping abreast of developments."

The type of inspection practised by the DEn plainly calls for the exercise of judgement on the part of the inspector. As is put in a document describing the offshore regime and produced by the DEn at the Inquiry,



Key:

PS - Petroleum Specialist
RES - Reservoir Evaluation Specialist
INSP - Factories Inspector
SSO - Senior Scientific Officer

Fig. 15.1 Organisational structure of the Department of Energy and of the Safety Directorate. Figures show staff in post on 11/8/89, excluding consultants. Staff complement, where different, is shown in brackets.

> "The purpose of inspection is not exclusively to seek out cases of non-compliance with the regulations, but more to assess the adequacy of the safety of the installation as a whole. This is an essentially selective procedure. Neither in this, or in any other area of industrial safety, would it be possible or right to provide total supervision of the operator's activity, which he carries out in pursuance of his own primary responsibility for safety. The purpose of inspection, supported as necessary by enforcement, is to provide stimulus and support to that eventual activity and to ensure that standards are maintained."

15.5 At the time of the disaster there were 59 fixed installations and 42 active mobile installations in the northern waters of the North Sea within the UKCS. At July 1989 there were 139 fixed installations and 76 active mobile installations in the whole of the UKCS. An annual programme of inspection is drawn up and agreed with the HSC. The frequency with which an installation is inspected is determined by the use of a rating system, which was revised in early 1988. According to this system, which is operated with the use of a computer program, points are added in proportion to the lapse of time since the last inspection; and a rating is given by an inspector at the time of an inspection, based on the type of operation, the effectiveness of management to maintain acceptable standards, the complement on board and a general view of all aspects of safety, health and welfare including training, maintenance and emergency procedures and equipment. The higher the total of the marks, the sooner the installation will be visited again. The number of visits to an installation varies from 3 or 4 per year during the construction phase to less than one every 2 years for unmanned installations. The average period between inspections is in the region of 12-18 months. The rating system reflects the fact that greater emphasis is placed on installations which are perceived to be "at greater risk". The Principal Inspector assigns the inspectors who are to inspect particular installations. Inspectors of different disciplines are frequently assigned to successive inspections of an installation. Mr Priddle pointed out that although there were advantages in an inspector becoming familiar with a platform it was undesirable for too close a relationship to develop between him and an OIM. According to Mr Jenkins the target set for inspectors is a total of 35 offshore visits per year, inclusive of both inspections and investigations.

15.6 Mr Petrie described the inspection as:

> "essentially a sampling exercise. The inspector samples and audits the state of equipment and working and manangement procedures. He talks to personnel and seeks to obtain an over-all picture of how well the installation is being operated, maintained and managed. An inspector must exercise his professional judgement in determining the scope and depth of the inspection and is selected, trained and supervised by line management to this end. He is not given a fixed list of procedures, equipment and items which he must tick off in the form of a check list. This could create considerable difficulties given the variety of operations, working procedures and installations involved. In addition it would lead to operators anticipating those areas which an inspector always checked."

He distinguished inspections from surveys - such as carried out by certifying authorities. "They are required to report positively in that they must indicate what they have actually checked; on our inspections we report what actually catches our eye at the time of the inspection." It was for the inspector to decide what were the areas in which his time could be most fruitfully spent. In focusing his attention on the areas which were most in need he could give a better quality of inspection.

15.7 Inspections are planned in advance. This preparation takes on average about one day's work. Its scope depends on the size, type and activities of the installation, and the results of previous inspections and investigations. Apart from looking at the relevant documents the inspector may seek information from colleagues who are skilled in other disciplines. The inspector should amend his plan in the light of any problems encountered on the platform which require special attention. Mr Petrie also said that special visits may be made concentrating on one aspect or checking on some particular deficiency. The reports of investigations were previously held in London and sent to Aberdeen only on request. They are now held in Aberdeen. Mr Jenkins said that he had not been given any written guidance in how to go about preparing for an inspection but in the 3 or 4 months after he had joined the PED in March 1987 he had picked up the method from other inspectors in the first inspections which he had attended. He selected the areas in which he would carry out his sampling process on the basis of a reading of the inspection reports for the previous 2 or 3 years.

15.8 During an inspection an inspector often will check fire-fighting equipment and life-saving appliances. He may require all or part of a drill to be carried out. His main concern would be the effectiveness of the maintenance and the emergency procedures. If he found defects in any equipment which was relevant to the work of the surveyors he would discuss this matter with the Principal Inspector, who might raise the matter locally or take it up on a inter-departmental basis.

15.9 Transport to installations is by means of helicopter on charter to the licensee or operator. The Inquiry heard evidence as to the practicability of inspectors making surprise visits; and as to the possible advantages and disadvantages of such a practice. Mr Petrie pointed out that in view of the need for advance booking of passengers into a flight it was not possible to keep a visit secret. Generally 3 days' notice was required. If a helicopter were to be chartered or obtained at very short notice the filing of flight plans and normal communications would mean that there could be no question of a surprise visit. In any event clearance to land would be required from that installation. This might not be possible for a variety of reasons such as the use of explosives in drilling activities at the time of arrival. The opportunity to make a surprise visit had occasionally arisen and been taken. More recently an arrangement had been made whereby helicopter operators were authorised to make seats available on particular flights even if it meant that someone else required to miss the flight. It was recognised that this might cause problems of accommodation on the installation. It had been used occasionally, allowing the inspector to arrive with only a few hours' notice. On the other hand both Mr Petrie and Mr Jenkins pointed out that there were certain advantages in advance notice of an inspector's visit. A higher profile for the visit was created. There was no excuse for any failures in the operation or house-keeping of the installation. Personnel knew when they would be able to approach an inspector with any points which they wished to raise. Mr Jenkins also made the point that advance notice "usually means that the installation is cleaned up and an inspector can concentrate on more fundamental and important matters".

15.10 In the northern waters inspections typically take 2 days, including the time for travelling to and from the installation. According to the evidence, inspections might cover any aspect of an installation, its systems and practices. The inspector might decide to concentrate on a particular topic and extend the visit. If he saw anything requiring immediate correction he would direct the necessary action. If the problem was in an area of expertise where his own knowledge was not sufficient he would discuss it with colleagues and might pass it on to another inspector of the appropriate discipline if this was agreed by the Principal Inspector. During the inspection the inspector would ensure that he was available to discuss any points which personnel wished to raise with him. Mr Petrie said that the value of feed-back from personnel was that "the inspector will gain direct from the workforce their concerns, their worries and how they do their job, which are valuable matters to him in deciding on the thrust of his inspection and matters that he may wish to take up with the manager or onshore management". Notices were posted on installations giving contact numbers of the DEn. Anyone might complain by letter, telephone or by personal appearance. He said that a worker would often wish to maintain anonymity. This created difficulties from time to time. It could be difficult to carry out investigations offshore in such a manner as to hide the identity of the complainer. Prior to the disaster there were not many complaints. "There have been quite a lot since." Mr Jenkins pointed out that there was a further point of contact with the workforce, namely by meeting elected safety representatives. Many companies had had a voluntary system of elected safety representatives and committees. However on Piper the safety representatives who met on the safety committee were supervisors from various departments and not independently elected individuals. Accordingly a formal meeting was not held with them.

15.11 After the inspection the inspector would discuss any matters of concern with the OIM and give him a note of them. These points were later included in a letter to the company. If a satisfactory reply was received the inspector might take the matter no further. If he remained dissatisfied he would discuss the matter with the Principal Inspector and perhaps carry out a check visit. The actions open to him were:- (i) to indicate the improvements to be made; (ii) to enforce these by use of improvement or prohibition notices under the HSWA; or (iii) to recommend prosecution. The inspector also had powers under the Inspectors and Casualties Regulations to require operators and OIMs to "do or refrain from doing any act as appears necessary" to avert any casualty, immediate or otherwise, or to minimise the consequences of a casualty. The use of such powers could result in the temporary shutdown of an installation. Under Reg 7 of the Operational Safety, Health and Welfare Regulations the inspector could require the operator to amend written instructions so as to make adequate provision for the safe use of equipment and safety in the carrying out of operations on an installation. In exceptional cases Mr Petrie might intervene by writing to the senior management of the operator. He said that this had been found to produce prompt corrective action. Although in principle the licence could be revoked, this has not so far been considered necessary.

15.12 Following his inspection an inspector would prepare a report of the inspection. This is submitted to the Principal Inspector and then passed on to the higher levels within the Safety Directorate. According to Mr Petrie the report is intended to indicate to PED management and the next visiting inspector what has been attended to and any matters of concern. It should contain a reasonably comprehensive description of what the inspector has done. According to Mr Jenkins a report is normally expected to be 2-3 pages long. This was set by the Principal Inspector as the ideal target. He did not set out to note everything that went through his mind on an inspection. He put in the items which he considered to be most relevant on the visit.

15.13 The operator is not sent a copy of the rating form or of the inspector's report.

Investigations

15.14 The investigation of accidents and dangerous occurrences is clearly recognised as an important aspect of the work of the Safety Directorate since it can point to lessons which can be learnt. Under the Inspectors and Casualties Regulations operators are required "in the most expeditious manner practicable" to report to the DEn any "casualty", which means for practical purposes any fatal or dangerous accident. According to the informal guidance given by the DEn, the reporting requirement covers (i) fatalities and cases of serious bodily injury; (ii) accidents involving the integrity of the structure; and (iii) accidents which could have directly caused serious bodily injury and which fall under one of the following 6 heads:- (a) a blowout from a well or emission of noxious vapours e.g. hydrogen sulphide; (b) bursting of high pressure hoses, pipes, pressure vessels or boilers; (c) structural failure of any plant, machinery, equipment or material; (d) explosion or fire; (e) collapse or failure of a crane or part of a crane or crane rope or chain or other equipment used in the lifting of loads; and (f) any other form of accident that could have had similar serious results. In the passing it may be noted that a leak of hydrocarbon is not specifically mentioned. Accordingly it would only come within the reporting requirement if it fell under one of the above heads. According to Mr Jenkins a leak would qualify for reporting if there was sufficient gas to cause a significant explosion if it was ignited.

15.15 An immediate offshore investigation is carried out in every case in which the accident has proved or is likely to prove fatal. Apart from these cases it is for the duty inspector, or for the Principal Inspector on the next working day to determine whether such an investigation should take place. The decision as to whether there should be an offshore investigation depends largely on the view taken of the severity of the result of the accident and the information that may be learnt from it. Mr Petrie agreed that learning came from a study of the causes of accidents as opposed to their results but said that the results usually gave some indication of the original causation. Further, part of the reporting procedure was that the person reporting stated what was understood to have gone wrong. Investigations were initiated either immediately or at any rate within a few days of the receipt of the report. All the reports were read. In some instances the investigation was onshore only. Mr Jenkins explained that the Principal Inspector decided whether there was to be an onshore investigation or none at all. Pending the visit of an inspector operators were required to "freeze" the area of the casualty for 3 days.

15.16 As regards the number of reports which were investigated, Mr Petrie said that all fatalities and accidents involving extensive injuries, if there were any major lessons to be learnt, were investigated. So also were the larger explosions and any "near misses", having regard to their potential severity. Overall, 40% of the total of fatal and serious accidents reported to the Department were investigated, either by an offshore or an onshore investigation. Mr Petrie regarded this level of investigation as acceptable, and indeed quite high. Limitations on manpower prevented the Department from investigating all accidents. Further, he did not know of any industry in which this was practised. It would be practicable for the Department to call on the Health and Safety Executive (HSE) for additional manpower, but the HSE have their own staffing problems and any inspector who was seconded from the HSE would require to work under a DEn inspector who alone had the statutory powers through which the legislation could be enforced. However, he had arranged for assistance, from the Technology Division and Research Laboratory of the HSE. Help could also be obtained through contracts with consultants such as The Robert Gordon Institute of Technology.

15.17 In connection with casualties inspectors have open to them the various courses of action which I have set out above in connection with inspections.

The inspection of Piper in June 1987

15.18 Mr Jenkins carried out an inspection on Piper on 3-4 June 1987. This was his first visit to Piper and the first inspection which he had carried out on his own since becoming an inspector in the Safety Directorate in March 1987. He said that he found the platform was well run. He was quite impressed by the quality and confidence of the personnel. The methods of working were not necessarily committed to writing. Although they were often based on custom and habit they appeared to be satisfactory. Housekeeping appeared to be good; the log books, maintenance records, lists of personnel on board, and records of musters and drill frequencies were in order. He was aware that the platform equipment was getting old and that the Occidental personnel had served there for a long time. In his report he stated "There are indications that the staff are looking over their shoulders and cannot see any fresh developments from Occidental in the North Sea. This is an operator where morale and job interest could drop as the years progress." In his report he also noted that a number of areas on the platform had been refurbished and commented that it would be necessary for this effort to continue. He noted that the Control Room was an alarm and indicating station in which a small number of automatic controls could be performed by conventional pneumatic controllers; and that the remaining actions required to be carried out by operators at the plant itself. He said that he favoured the use of small intermediate control rooms in the various areas of the plant.

15.19 Following his inspection Mr Jenkins discussed a number of comparatively trivial points with the OIM which he put in writing on 12 June 1987. On 10 July Occidental replied stating how the various points had been attended to. This response was regarded as satisfactory. As nothing dangerous or life-threatening was found during his inspection no immediate follow-up was necessary.

The investigation of the Sutherland Fatality

15.20 The death of Mr F Sutherland on 7 September 1987 was investigated by Mr Jenkins who visited Piper on the following day and submitted his report on 29 September 1987. He found that the handover between the day-shift and night-shift was unco-ordinated. The supervisors handed over in one location. The tradesmen did so simultaneously in another place. The night-shift supervisor did not subsequently visit the site or discuss the job with the men before the accident. The procedure for handling the canopy was not clear. The day-shift supervisor had delayed deciding how he would handle the canopy until after the cover was removed. The night-shift supervisor did not grasp this problem and the job continued without adequate supervision. The personnel on the night-shift changed the procedure without informing the supervisors. It was Mr Jenkins' view that the fatality was due to poor handover procedure and inadequate supervision. The original task had been to inspect the pump bearing and repair it if possible. A permit to work had been issued for this work. The job then developed into replacing the bearing. A new permit to work was not taken out to cover the enlarged scope of the work. "It was a case where people were too lazy to take the permit out". He agreed that if the work had been confined to what was covered by the permit Mr Sutherland would not have died. However, he said that in his investigation he had concentrated on areas other than the permit.

15.21 As I have stated earlier in para 11.16 Occidental were prosecuted for a breach of Secs 3(1) and 33(1)(a) of the HSWA. In the complaint to which they pleaded guilty on 17 March 1988 it was charged:

> "And you did fail to supervise said job in the following respects, viz (1) there was inadequate communication of information from the preceding day-shift to the night-shift during which said accident occurred; (2) no new permit was taken out to cover the installation of said lifting gear and other necessary work; (3) the said deceased had been allowed to select his own method of performing the job without discussion with the supervisor; (4) suitable access to the working area had not been provided nor had safety equipment such as harness and lines; and (5) said canopy was not bolted down and was being used as a working platform."

The inspection of Piper in June 1988

15.22 Following Occidental's plea of guilty on 17 March 1988 Mr Jenkins was asked by Mr D Bainbridge, the Principal Inspector in Aberdeen, to examine changes in Occidental's work procedures and at their offices and then carry out a "check visit" to Piper in April or May 1988. On 25 March he attended a meeting at Occidental's office in Aberdeen and was given a description of job task analysis which Occidental proposed to introduce. As they were in the throes of introducing this he did not go into the new work procedures in detail. He considered that new procedures would develop from job task analysis but that it would take a long time to set up the latter. At the meeting there was also discussion of Occidental's award of a 3 year contract to the Wood Group for the provision of all-trade services. This was intended to minimise the disruption caused by the changing of short-term contractors and improve supervision of tradesmen.

15.23 In the event Mr Jenkins' third visit to Piper was delayed until 26 June 1988. This visit was intended to combine the "check visit" with a routine inspection of the platform. The length of this visit is of some significance. Mr Jenkins arrived at Piper in the middle of the morning and worked there until 22.00 hours. The normal routine would have been to continue the inspection on the following day until it was time to depart for the shore. However, on this occasion he was due to be transferred by shuttle helicopter to the *Tharos*. He rose early and carried out an inspection on the *Tharos* in regard to its accommodation role until lunch time. After that he met the OIM and caught the crew-change helicopter back to the shore. In the result he was able to devote only about 10 hours to the inspection of Piper. During that time he took "a comprehensive walk" round all the production and drilling areas and the 68 ft level. His walk took most of the afternoon. The areas which he concentrated upon were those in which there was construction work in progress.

15.24 In his report on this inspection dated 4 July 1988 Mr Jenkins stated "With respect to the Sutherland fatality, the following improvements in working practices were noted: (a) handovers between shifts have been tidied up; (b) Occidental are looking at the more formal methods of undertaking jobs through the job task analysis scheme ...". As regards the "tidying up", Mr Jenkins said that he was informed during his inspection that Occidental had arranged that "supervisors did handover to the incoming supervisor at the workshops where they sat in on the tradesmens' handover. This ensured continuity between handovers. In other words, all relevant personnel were at the same location for the handover." He had discussed the method of handover with Mr A G Clark, maintenance lead hand, who indicated that Occidental had taken it in hand and that they then had a satisfactory method of handing over, so that there was no need for him to make a recommendation. Mr Clark had described the method of handover and he was satisfied with it. However, Mr Jenkins did not witness an actual handover as he did not have time to do so. Nor did he check what Mr Clark had said to him. He said in evidence that if he had known that Mr Clark was not satisfied that the handover procedure was watertight he would have been dissatisfied. As regards job task analysis Mr Jenkins was aware that this involved the preparation of written procedures, including details of the methods to be followed, the type of persons to be employed, the tools and materials required and the safety isolation steps. It was usual to employ consultants to set this up initially. "I wondered how busy personnel were doing their usual work before touching any job task analysis, and I questioned if they had the manpower or the impetus to carry it through. For the system to work it does require that the management onshore are fully behind it, and that they in turn enforce on the lower-level management the requirement to see that it is put into effect."

15.25 As regards the permit to work system, Mr Jenkins examined about half of the 20-30 permits in the Control Room. In the case of 6 of them he checked to see whether the precautions at the work site matched those stated in the permit and were suitable for the job. He asked to see permits which were being used by contractors and endeavoured to find out whether they understood what was on the permit. During these checks nothing abnormal was found. He had also asked personnel in the Control Room if permits were being filled in properly. Since the permit to work was not regarded as a key factor in the Sutherland fatality he did not concentrate on the permit to work system. No attempt was made to assess the overall quality of the permit to work system in the light of that fatality.

15.26 Mr Jenkins concluded his report by stating: "There appears to be a new air of confidence in Occidental with appraisal drilling and well testing both on fixed platforms and from a number of semi-submersibles round about. Lessons appear to have been learnt from the Sutherland fatal accident. A routine inspection in one year's time is appropriate." He provided a short list of points for the OIM. There were no points of major concern. Following the visit he had a meeting on 4 July with Mr R M Gordon, Occidental's Loss Prevention Manager, at which there was some discussion of the fatality and the progress made since then in the quality of supervision and procedures. However, the main subject of that meeting was a routine inspection of Claymore where for commercial reasons a production separator had been welded in a hazardous area without a complete platform shutdown.

Comments on the inspections

15.27 The findings made by Mr Jenkins in his inspection in June 1988 bear a striking contrast to what was revealed by the evidence in the Inquiry. A number of examples may be taken.

15.28 As regards the permit to work system Mr Jenkins said in evidence that the practice of having work permits relating to the same plant in both the Control Room and the Safety Office was not conducive to the correct functioning of the permit to work system. This imposed an even greater need for cross-referencing. Permits should not be separated on the basis that the jobs to which they related were on different levels. If there were many suspended permits this suggested that forward planning might not have been good. He wondered how contractors' employees would necessarily know about the practice of placing suspended permits in the Safety Office, for which no provision was made in the General Safety Procedures Manual. He also commented on the time which would elapse if the checking of work sites was left until after work was suspended or cancelled. Had these points come to his attention he would have brought them to the notice of the OIM. He said that he had not known that suspended permits were kept in the Safety Office. He also expressed concern about the implication in the evidence that gas testing was carried out on Piper on a fairly regular basis. This suggested that there were a large number of hot work permits issued. On many installations, he said, it would not be the norm for hot work permits to be granted unless it was impracticable to do otherwise. Many installations endeavour to save hot work for shutdown for safety reasons. In this connection he referred back to the welding on the production separator discussed at the meeting on 4 July with Mr Gordon. In that case it appeared to him that Occidental had considered production more important than safety. In addition the practice they carried out on that occasion led to a loss of production which would have been little different from that which would have been suffered if they had completely shut down before carrying out the necessary repair. Mr Jenkins said that he had accepted the form of the permit to work as reasonable for the nature of the installation. As far as he was concerned it conformed in spirit with Reg 3 of the Operational Safety, Health and Welfare Regulations.

15.29 Mr Jenkins' attention was drawn to the "Guide to the Principles and Operation of Permit-to-work Procedures as Applied in the UK Oil Industry" which was prepared by the OIAC. This contains amongst other things a checklist, consisting of a series of questions, to enable permit to work procedures to be assessed in order to determine whether they cover all the essential points. Mr Jenkins knew of this document but was not familiar with the checklist. The inspectors had not been provided with any checklist on which to base an assessment of a permit to work system. He said that to carry out a detailed, comprehensive check on the permit to work system on Piper would require a study over a period of days, ideally by persons with specialised knowledge. He had never prepared, reviewed or brought into operation a permit to work procedure. He did not look at Occidental's Operating Procedures Manual in connection with the permit to work procedure on Piper because he did not have time to perform a full audit which, as he said, would take 2 or 3 days.

> "It would involve reviewing the procedures, which is such an exercise that it would probably be done onshore; it would involve seeing the planning exercise that went on in a specific number of jobs; it would involve watching the permits being taken out for these jobs; it would involve watching the jobs being undertaken; it would involve observing the precautions that were being taken to initiate these jobs; it would involve observing the permits being suspended at the end of the day and seeing them being taken out again the following day and eventually being cancelled at the end of the job. Typically, even a short-term job can take 2 or 3 days, and I do not have that sort of time during my inspections."

He agreed, however, that with the knowledge he now had of what did take place on the platform, so far as the permit to work procedure was concerned, such an exercise would have been very revealing.

15.30 In regard to handovers at the end of shifts Mr Jenkins agreed, as I have stated above, that had he been told the full story he would have been dissatisfied and would have brought matters to the attention of the OIM.

15.31 As regards the fire-fighting system, Mr Jenkins was totally unaware of the practice of switching the diesel fire pumps to manual mode during the shifts in which there was diving. He did not inspect the deluge system. He might have asked whether the platform were having any problems with the system but could not recall doing so. He could not remember whether there was anything wrong. However, he was sure that during both inspections he examined the certificate issued by the DoT surveyors. If there had been something wrong with the deluge system he would have expected the certificate to tell him so.

15.32 As regards lifeboat drills Mr Jenkins said that he frequently but not invariably checked the records of these drills. Even if he did so he did not necessarily put it in his report. Apart from the target length for the report, he put in the items which he considered to be most relevant on the visit. As regards drills "it depends on whether they catch the eye during the visit or not".

15.33 Mr Petrie was asked to comment on the fact that Mr Jenkins' reports made no mention of (i) weaknesses in the permit to work system; (ii) maintenance problems with the deluge system; (iii) holding of diesel fire pumps on manual mode; (iv) the frequency of drills; and (v) difficulties in release of personnel for training and drills. He could not explain why neither inspection had disclosed any of those deficiencies. He said "I think within the context of carrying out an inspection and the very wide-ranging Inquiry that is going on here there is a total difference in approach. All I can say is that if the inspector had come across anything in those items I would have expected him to comment upon it." However he maintained the view that the sampling system worked. He had not, as a result of the disaster, looked personally at the quality of the work which the DEn had done in regard to Piper.

The quality of the Department of Energy's inspections and investigations

15.34 In the light of the evidence which is reflected in the preceding paragraphs of this chapter I turn next to consider a number of factors which were the subject of evidence and which may have a bearing on the quality of the DEn's inspections and investigations and their failure to detect a number of significant weaknesses and deficiencies on Piper which had serious safety implications.

The qualifications and training of inspectors

15.35 The basic qualification for an inspector is that he should be a chartered or graduate engineer with at least 5 years' background experience. The range of acceptable backgrounds includes structural, mechanical, electrical and process engineering, naval architecture and drilling. The DEn have been unable to recruit process or chemical engineers. However, according to Mr Petrie, "I have people who are aware of process control and can look at the process system from the point of view of safety." One of the inspectors is a former OIM. All inspectors became "Senior Inspectors" upon recruitment. A new recruit during his first months would attend internal seminars or he would probably go to the OPITB course for OIMs. An attempt would be made to get him on to the first available legal course provided by the HSE as part of the 22 week course for its intake. His attendance at other modules in that course would be a question of management control and assessment of the needs of the individual recruit. However, Mr Petrie stressed the difference in background and experience between recruits to the DEn and recruits to the HSE. Efforts are made to ensure that DEn inspectors do not concentrate attention on the disciplines with which they were already familiar. During the course of their work they gain additional skills. They do not carry out inspections on their own until they have been working for 3-6 months. Their appointment is subject to confirmation at the end of 2 years. When Mr Jenkins joined the Inspectorate as a Senior Inspector in March 1987 he had no past experience in process or chemical engineering. He is an electrical engineer. Prior to the disaster he had attended the course for OIMs and courses on law enforcement and drilling. It had been his intention to attend a course on production in the autumn of 1988 but the disaster intervened. As I have stated above, his visit to Piper in June 1987 was his first unaccompanied inspection as well as his first visit to Piper.

15.36 Mr Petrie agreed that his inspectors had no expertise in the scrutiny of hazard and operability studies, whereas this expertise existed within the HSE. He explained that one of his Principal Inspectors was consulting with the HSE and others in connection with the Department's proposals for safety assessment. However he saw no need to seek advice from the HSE in regard to their approach to general inspection work. One inspector remained on secondment from the HSE to the Safety Directorate. His function was to keep in touch with current practice in the HSE and also to provide additional expertise in occupational health and safety. There were difficulties in employing HSE factory inspectors for general inspection work offshore because of their different qualifications and experience. Mr Petrie said that he regarded his inspectors as being more like Mines and Quarries inspectors, who form a separate group within the HSE, requiring special qualifications and experience of the industry with which they are involved. Mr Priddle gave a number of examples of external training which DEn inspectors had undertaken during 1989. These included risk assessment, drilling and workover, noise mitigation and the problems associated with high pressure wells. There was, however, no internal training course which was aimed at how to carry out an inspection and make the judgements which it required. Training was predominantly "on the job". He shared a concern with Mr Petrie about the need to develop more effective training of inspectors.

The guidance given to inspectors

15.37 The Inquiry was provided with a copy of instructions to inspectors for inspections and investigations and for the application of the DEn's enforcement policy, which have been in preparation since July 1987 and were issued as a working document on 31 July 1989. According to the evidence of Mr Petrie these:

> "set out the organisational framework within which the inspectors operate and the procedures they should adopt in the exercise of their professional judgement. They do not seek to define the technical and safety management system standards inspectors should secure. Inspectors will in the first instance rely on the standards prescribed by regulations. Where standards are not set out in regulations they will be guided by authoritative codes and standards such as the guidance notes published by the Department. These and safety notices which bring recent developments to the attention of the industry and inspectors alike, provide a bench-mark of reasonable practicability."

These instructions were reviewed in the light of 3 months' operational experience. No changes of substance were made save that inspectors were instructed to meet the safety representatives both at the beginning and end of their inspection. These instructions were prepared following the report on the Inquiry into the fire at the Bradford Football Ground. The instructions cover, *inter alia*, the following subjects:- (i) preparation for the visit; (ii) the sampling of working systems, maintenance procedures and documentation; and (iii) the appropriate follow-up actions. They are not intended to operate as a detailed checklist. It is clear from the evidence that these instructions to a large extent set out existing practice so that it may be followed in a consistent fashion. Thus as far as Mr Jenkins was concerned the document did not make any substantial changes to what was already done.

15.38 In regard to inspections para 1.6 states:

> "... Inspection involves assessing the extent to which operators and others meet their legal obligations for the overall safety of the installation and the personnel on board. Inspection therefore includes the installation and its equipment and working practices, procedures and arrangement on the installation at all levels."

Para 1.8 states:

> "... It is impracticable for inspectors to attempt a detailed inspection of every part of an installation and its equipment as well as current activities and procedures. The approach must therefore be to sample and audit various aspects with the

> objective of gaining an overall impression of how well the installation is being operated, maintained and managed."

When he was referred to these passages Mr Jenkins said: "What I said to the Inquiry is that we do sample and we do audit working practices and working procedures, but we have never conducted full audits in any area, so we have no experience of having conducted full audits which we could then correlate back to improving the sampling technique." However, he claimed that he had the expertise to carry out an audit of the permit to work procedure, based on an understanding of how installations are managed, what is required of permit to work systems and an understanding of the regulations. Such an audit would be impossible within the time currently available.

15.39 Para 2.2 of the instructions states:

> "An inspection should monitor, *inter alia*, the duty of the operator, the owner and employees to provide a safe place of work and safe working practices (i.e. the overall management, operation and control). The inspector must not be seen to usurp the responsibility of these persons or the OIM for safety."

When he was referred to this passage Mr Jenkins stated: "My assessment of the management does include the overall management of the company." He explained that he normally had a meeting onshore with management where he found that personnel on the installation were not receiving support from that direction. He said: "I believe that the purpose of the inspections is to target on the offshore installation. It is not to target on the onshore office, and the only time when the onshore office comes into the picture is when they are found not to be supporting the offshore installation or carrying out changes which are required as a result of the findings of the inspection." If the instructions meant that the overall management required to be monitored "someone will have to instruct me how we would go about doing that". He later said: "What I was saying is that the way I am encouraged to go about my work is that I require to find the problems offshore, which then takes me onshore. An inspector is not encouraged to go to the door of somebody like Occidental, knock on the door, walk in and perform an audit of the management of that company." However he said that he did not believe that he had any difficulty in coming to a view about the general management performance when he was on the platform and then knowing what action to take. In his evidence Mr Petrie said that it was essential that the quality of the management of safety was assessed and found to be adequate. One way in which this was done was through inspections. The inspections fulfilled an auditing function. Any failure on the part of management which was apparent should be pursued by inspectors back through the management chain as occasion arose. He also pointed out that, while it was not done as a matter of routine, it was not unusual for an inspector to require the operator to produce the safety policy statement (under Sec 2(3) of the HSWA) and other safety documents for his consideration, including if necessary at the inspector's office onshore.

15.40 Para 11.3 of the instructions states:

> "As a minimum the inspection report should describe the extent of the inspection. It should record the nature of the inspections undertaken e.g. observation of working practices, tests of equipment, discussions, examinations of records, witness of musters and drills etc. The report should record those areas found to be satisfactory as well as the unsatisfactory ones ..."

Mr Jenkins' comment on this passage was: "I believe that whoever wrote this will have to provide me with more information on what they are looking for ... I believe that a report of that nature would take a considerable number of pages ... It will increase the time that is required to conduct an inspection ... It may be that someone will have to allocate more time to me to conduct an inspection."

15.41 It appeared from the evidence of Mr Jenkins that he had not been given specific guidance on a number of aspects of inspection including: (i) the use of the checklist on the permit to work system to which I have referred above; (ii) the completion of the form for rating installations for future inspection; and (iii) the monitoring of the overall management as expressed in the instructions to which I have referred above. Mr Petrie had never spoken to him about how he was getting on with his work.

The monitoring of the work of inspectors

15.42 Mr Petrie said that the monitoring of the quality of inspections was in the first instance a matter for the Principal Inspector. He would discuss such matters with the Principal Inspectors from time to time. On occasions he saw reports of inspectors and discussed the overall philosophy and results with the Principal Inspector who was the head of the branch. Additionally he would visit the office in Aberdeen and talk to the Principal Inspector. Each year there was an annual performance review in which the performance of individual inspectors was set against the objectives which had been set for them. This involved overall assessment covering about 15 areas. The quality of inspections was not one of these areas but the reporting officer would inevitably cover that in his overall assessment of the inspector's performance during the year. The Principal Inspector, who was the reporting officer, would in the ordinary course of his work see every report which the inspector produced. Part of his job was to go offshore with an inspector probably about once a year in order to measure his performance in the actual undertaking of the inspection.

The manning of the Inspectorate

15.43 In 1980 the Burgoyne Committee, to which further reference will be made in Chapter 16, recommended that the DEn should continue its policy to employ an Inspectorate consisting of well-qualified and industrially experienced individuals, capable of a broad but authoritative approach to the monitoring and enforcement functions (6.7). The Committee pointed out that the current Inspectorate was to a certain extent under-staffed. This together with extensions of role suggested in the Committee's report entailed the need for further recruitment (4.14).

15.44 In the event there has been a persistent shortfall in the required complement of inspectors for the purposes of carrying out inspections of the type described earlier in this chapter. At the time of the disaster the Aberdeen office, which was concerned with the northern waters (extending northwards from the Solway Firth on the west and the 56° parallel on the east) comprised 1 Principal Inspector and 3 inspectors, as against a complement (fixed by a management board of the DEn) of 1 Principal Inspector and 5 inspectors. This shortfall had existed for about 2 years. At the same time the London office which was concerned with southern waters comprised 1 Principal Inspector and 2 inspectors, as against a complement of 1 Principal Inspector and 5 inspectors. Accordingly at that time there was a shortfall of inspectors of 50%. By August 1989 there had been a net increase of 1 inspector in Aberdeen and 1 inspector in London, leaving a shortfall of 1 in Aberdeen and 2 in London.

15.45 The recruitment of personnel in the Safety Directorate is carried out by the Civil Service Commission through the Establishment and Finance Division of the DEn. Mr Petrie said that there had been considerable publicity and advertising in an attempt to make up the shortfall. The Department was able to recruit on a continuous basis. However, despite these efforts it had not been possible to make up the shortfall. The HSC had also been aware that as a result of the shortfall there had been a reduction in the frequency of inspections. They had expressed concern and there had been correspondence between them and the Minister. The Minister had replied that all efforts were being made. Mr Petrie also said that he had had discussions with the HSE with a view to additional assistance. One inspector had been seconded to the DEn on a permanent basis as a result of one of the recommendations of the Burgoyne Committee in order to provide assistance with occupational health and safety, such as in regard to working practices and procedures and the use of equipment. However, posts such as that held by Mr Jenkins, were not so interchangeable. The holders of these posts were classified as petroleum specialists, having regard to the experience and expertise for which the Department were looking. He said that it would be appropriate to consider the needs of PED as similar in this respect to those of the Mines Inspectorate which formed a separate group within the HSE. Mr Priddle said that when he took up office in September 1989 he saw it of immediate importance that the resources of PED matched its requirements. It was clearly not satisfactory that the inspectorate was at half strength at the time of the disaster. He found that the Department had reviewed the salary scales (see para 15.46 below) and had tried to make recruitment more attractive. He had encouraged the launching of a further recruitment exercise which was to be announced in early 1990. He had spoken to the Minister about this matter. Priority was being given to the inspection team. He believed that this initiative would be successful. If it was not he would devise new initiatives in recruitment. He also pointed out: "There are attractions about work in the Department. There are responsibilities there which cannot be matched outside. There is a breadth of experience here which has a real value and there is a public service element which has a real value, so we have a number of positive things going for us when we seek to project our recruitment efforts." Mr Petrie and Mr Priddle said that consideration had been given to creating a lower grade of inspectors, similar to general inspectors of the HSE, but regarded this as very much a longer term exercise.

15.46 As regards the possible reasons for the Department's past lack of success in achieving its complement, Mr Petrie said that he was satisfied that the right persons existed and in the right numbers for these jobs. However, it had been found that applicants had little experience which was relevant to the job which would be expected of them even with the amount of training and instruction which they would receive. Some clearly misunderstood what the job entailed. There was no easy answer to the question of how to attract the right people. He agreed that the level of remuneration inevitably played some part. However, similar salaries were offered in industry. He agreed that industry provided opportunities for higher salaries and promotion, along with other attractions such as foreign travel. Within the PED the prospects of career development were limited for inspectors because of the departmental grading which they were in and because of the comparatively small size of the PED. They would not be expected, nor perhaps have the ability, to move into the administrative stream. The loss of inspectors to industry was not an annual event but it was not infrequent. Mr Priddle pointed out that over 1988 and 1989 PED had been able to recruit 5 inspectors with the loss of 1 otherwise than by retirement. Since about 1980 petroleum specialists have been treated as a specialist grade within the DEn. Accordingly the negotiations for the fixing of salary levels have been outside the normal salary negotiations for general grades in the Civil Service. Their salary level was very close to that of factory inspectors. An increase in the salary scale was made early in 1989. This provided a higher percentage increase for the recruitment grade i.e. Senior Inspectors, than for the higher grades. This involved an increase in the maximum for the recruitment grade from £27,005 to £30,332 *per annum*. According to Mr Priddle the objective of such salary levels was to be competitive with those on offer in the private sector. The salary scale was not brought into effect until late in 1989 and the recruitment exercise in early 1990 was to be based on those figures. As at January 1990 a post as inspector had been offered to one applicant, whose response was at that time unknown. By way of comparison it may be noted that as part of the same alteration in salary levels the maximum payable to a reservoir evaluation specialist at the inspectorate level was increased from a little under £30,000 to a little over £35,000. Mr Petrie said that this was an entirely different grading from that of the petroleum specialists for which candidates came from different sources.

15.47 As I stated above the shortfall in manpower for inspections was met by a change in the frequency of inspection. However, as regards Piper Mr Petrie adopted the position that even if there had been more senior inspectors in the Aberdeen office there would not have been any greater frequency of inspection than there was in 1987 and 1988. Speaking more generally Mr Petrie said that if there were the full complement of senior inspectors they would largely be devoted to the same type of work. He said that in the meantime "the quality will not be sacrificed. The frequency is not a real measure in so far as the inspections are targeted at the areas most in need. We do not say that every installation must be inspected in x months or years. The criterion is the rating system which attempts to put on to the installation an overall assessment of safety or risk in a positive manner based on an inspector's rating system, time lapsed and any other factors. The number of inspections that are carried out are, I believe, still sufficient for the purpose of the inspection programme, and that is to monitor the industry and their compliance with the requirements." He agreed that "inevitably with additional resources there is a potential to cover more things, and more installations". He disagreed with the suggestion that the shortfall affected the extent of what was inspected. He said: "Not the extent because an inspector during every inspection should look at all parts of the installation to some extent ... When I said look at all parts of the installation, it was within the context that an inspection is a sampling technique." However he appeared to agree that with increased manpower the depth of his inspection would inevitably be able to be increased. From his viewpoint Mr Jenkins said in evidence that if the positions in the Aberdeen office were filled "there would be less pressure to make the same number of inspections and there would be more time to meet people from the industry onshore." He thought that inspections would take approximately the same time but that certain installations might be inspected more frequently.

Observations on the inspection system

15.48 Even after making allowances for the fact that the inspection in June 1988 proceeded on the basis of sampling it is clear to me that it was superficial to the point of being of little use as a test of safety on the platform. It did not reveal any one of a number of clear-cut and readily ascertainable deficiencies. The visit failed to follow up the investigation into the Sutherland fatality in an effective way, in that Mr Jenkins failed to grasp the importance of the weakness in the permit to work system and misunderstood the position in regard to the procedure for handovers.

15.49 It would be easy to place responsibility for these criticisms on Mr Jenkins but I do not consider that this would be fair, having regard to his relative inexperience and the limited guidance which he was given. Further this would not address the shortcomings in the inspection system itself. In my view the inspectors were and are inadequately trained, guided and led. Persistent under-manning has affected not only the frequency but also the depth of their inspections. These shortcomings affected the quality of the inspections on Piper, and in particular the inspection in June 1988. Apart from any other consideration, the length of the visit at that time was manifestly inadequate having regard to the size of the installation, the activities then taking place and the recent fatality.

15.50 However, the evidence which I heard caused me to question the inspection system in a more fundamental sense. Even if the shortcomings which I have mentioned above were made good would inspections be able by their nature to achieve the objective of assessing the adequacy of the installation as a whole? In giving evidence from a prepared statement Mr Petrie said, *inter alia*,:

> "As responsibility for safety remains with the operator, the installation manager and other personnel, inspections do not diminish that responsibility. An inspection involves assessing the extent to which operators and others may meet their legal obligations for the overall safety of the installation and the personnel on board."

However he accepted the latter sentence "must be read within the overall sampling techniques of an inspection." When asked to re-state what he had said in a way that was consistent with what in fact was done he said: "I think I would re-state it along the lines of an inspection involves sampling the work and activities on the installation to an extent to have a reasonable view as to how operators and others may meet their legal obligations." However the limitations of sampling, especially on the basis of "what catches the eye" within a relatively short visit to an installation runs a plain risk of missing what lies deeper than a surface inspection and of failing to reach a true assessment of the installation as a whole. Further, while it is true that if an inspector finds something that is amiss he may be able to prevent it leading to an accident, the inspection is not targeted at preventing the occurrence of what was amiss. For this one would have to turn to the management of safety by the operator. It is clear from the evidence that the DEn inspectors do not become involved to any extent with the onshore management of safety except in an incidental way. These considerations led me to doubt whether the type of inspection practised by the DEn was an effective means of assessing or monitoring the management of safety by operators. This brings me to matters which were the subject of evidence in Part 2 of the Inquiry, which I will discuss below in Chapter 21.

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Presented to Parliament
by the Secretary of State for Energy
by Command of Her Majesty
November 1990

LONDON: HMSO

Cm 1310

£38.00 net
(Two volumes not sold separately)

VOLUME TWO

Page

SECTION FOUR: THE FUTURE

LIST OF PLATES

APPENDICES

Appendix J:
Large figures

Printed in the United Kingdom for Her Majesty's Stationery Office
Dd 0503434/11/90, C75

SECTION FOUR: THE FUTURE

Chapter 16

Offshore and Onshore Safety Regimes

Introduction

16.1 In this chapter I will give by way of background to the following chapters a brief outline of the existing UK offshore safety regime and, since comparison with them has been of assistance to me, the UK onshore safety regime and the Norwegian offshore safety regime. A complete account is not practicable. I will concentrate on aspects which were of most relevance to the issues discussed in Part 2 of the Inquiry. I heard the evidence of Mr J R Petrie, Director of Safety, PED, and Mr R J Priddle, Deputy Secretary at the Department of Energy since September 1989; Mr J Rimington, Director General of the HSE and Mr D J Hodgkins, Director of the Safety and General Policy Division, HSE; and Mr M Ognedal, Director of the Safety and Working Environment Division, NPD since 1980; in addition to the evidence in Part 1 of Mr F H Atkinson, Manager of the Offshore Division, Lloyd's Register of Shipping. This chapter ends with some remarks on future trends in offshore operations in the North Sea, in the light of evidence given by Dr B G S Taylor, Director of Technical Affairs, UKOOA.

The UK offshore safety regime

16.2 Exploration and production licences are subject to model clauses prescribed by regulations under the Petroleum (Production) Act 1934 (PPA) as applied to the areas of the continental shelf which are subject to UK jurisdiction. The clauses which are concerned with safety require licensees to (i) obtain the consent of the Minister to the drilling or abandonment of a well; (ii) execute all operations in accordance with good oilfield practice; and (iii) comply with instructions given by the Minister for the health, safety and welfare of persons employed in or about the area to which the licence relates. However, in the light of the MWA, which was specifically designed to cater for offshore safety, the main significance of the clauses is in regard to the minimising of the risk of a well "blowout". The regulations also require the identification and approval of the "operator" which for practical purposes is to discharge the responsibilities of the licensees.

The Mineral Workings (Offshore Installations) Act 1971 (MWA)

16.3 The MWA was enacted as a consequence of the investigation of the collapse of the exploration rig "Sea Gem" in 1965 and the recognition that arrangements based on the PPA were not appropriate for the purposes of securing offshore safety. The MWA, as amended, *inter alia*:

(i) required the registration of offshore installations (Sec 2).

(ii) empowered the Secretary of State to make regulations "requiring offshore installations or parts of offshore installations to be certified by such persons and in such manner as may be provided by the regulations to be, in respect of such matters affecting safety as may be so provided, fit for the purpose or purposes specified by the regulations ..." (Sec 3(1)).

(iii) empowered him to make regulations "for the safety, health and welfare of persons on offshore installations ... and generally, and whether or not by way of supplementing the preceding sections of this Act, for the safety of such installations and the prevention of accidents on or near them"; and to appoint as inspectors to discharge the functions conferred by the regulations, and generally to assist him in the execution of the Act, "such number of persons appearing to him to be qualified for the purpose as he may from time to time consider necessary or expedient ...". (Sec 6).

(iv) required the appointment of an OIM who was given a general responsibility for safety, health and welfare and for maintaining discipline and order (Secs 4 and 5).

16.4 Under the MWA an "offshore installation" includes any floating structure or device maintained on station by whatever means; and any pipeline works or apparatus deemed to form part of it, such as those covered by the Included Apparatus or Works Order; but did not otherwise include any part of a pipeline (Sec 1(5)). The MWA also made provision for a power on the part of the Secretary of State to give directions for the exemption of installations from the operation of regulations made under it (Sec 7).

16.5 Prior to the disaster a number of sets of regulations on specific subjects had been made. The most relevant for present purposes were the Inspectors and Casualties Regulations in 1973; the Construction and Survey Regulations in 1974; the Operational Safety, Health and Welfare Regulations and the Emergency Procedures Regulations in 1976; the Life-saving Appliances Regulations in 1977; the Fire Fighting Equipment Regulations in 1978; and the Well Control Regulations in 1980.

The Petroleum and Submarine Pipe-lines Act 1975 (PSPA)

16.6 A separate regulatory system was set up for offshore pipelines by the PSPA in 1975, under which the construction and use of such pipelines required authorisation by the Secretary of State. This involved considerations of planning and safety. He was also empowered to make regulations for the safe construction and operation of pipelines and the safety, health and welfare of pipeline workers; and the appointment of inspectors to enforce the regulations. Prior to the disaster regulations had been made under the PSPA on a number of subjects including diving operations and inspectors.

The Health and Safety at Work etc Act 1974 (HSWA)

16.7 In the meantime the HSWA was passed in 1974. This Act arose out of the report of the Robens Committee in 1972 (Cmnd 5034). That committee identified a number of major defects in the then existing statutory system for the advancement of safety and health. According to them the first and perhaps most fundamental was that there was too much law. This had had the unfortunate effect of conditioning people to think of safety and health at work as in the first and most important instance a matter of detailed rules imposed by external agencies.

> "The matter goes deeper. We suggested at the outset that apathy is the greatest single contributing factor to accidents at work. This attitude will not be cured so long as people are encouraged to think that safety and health at work can be ensured by an ever-expanding body of legal regulations enforced by an ever-increasing army of inspectors. The primary responsibility for doing something about the present levels of occupational accidents and disease lies with those who create the risks and those who work with them. The point is quite crucial. Our present system encourages rather too much reliance on state regulation, and rather too little on personal responsibility and voluntary, self-generating effort. This imbalance must be redressed. A start should be made by reducing the sheer weight of the legislation. There is a role in this field for regulatory law and a role for Government action. But these roles should be predominantly concerned not with detailed prescriptions for innumerable day-to-day circumstances but with influencing attitudes and with creating a framework for better safety and health organisation and action by industry itself." (para 28).

The second main defect was that too much of the existing law was intrinsically unsatisfactory. The committee referred to problems created by unintelligibility and obsolescence. Further, the great bulk of the existing provisions were concerned with physical circumstances.

> "But it has long been widely accepted that equally important factors in safety and health at work are the attitudes, capacities and performance of people and the efficiency of the organisational systems within which they work. This is not yet adequately reflected in the legislation. As a result, much of the legislation appears irrelevant to the real, underlying problems." (para 30).

A third major problem area identified by the committee was the fragmentation of administrative jurisdictions and the absence of a clear and comprehensive system of official provision for safety and health at work. As regards the objectives of future policy the committee observed:

> "The most fundamental conclusion to which our investigations have led us is this. There are severe practical limits on the extent to which progressively better standards of safety and health at work can be brought about through negative regulation by external agencies. We need a more effectively self-regulating system. This calls for the acceptance and exercise of appropriate responsibilities at all levels within industry and commerce. It calls for better systems of safety organisation, for more management initiatives, and for more involvement of work people themselves. The objectives of future policy must therefore include not only increasing the effectiveness of the state's contribution to safety and health at work but also, and more importantly, creating conditions for more effective self-regulation." (para 41).

16.8 The HSWA made provision with a view to the progressive replacement of specific Acts and instruments relating to health and safety by a system of regulations and approved codes of practice. It imposed on an employer a duty "to ensure, so far as is reasonably practicable, the health, safety and welfare at work of all his employees" and "to conduct his undertaking in such a way as to ensure, so far as is reasonably practicable, that persons not in his employment who may be affected thereby are not thereby exposed to risks to their health or safety" (Secs 2 and 3). It established the Health and Safety Commission (HSC) as the body responsible for effecting the general purposes of the Act; and it established the Health and Safety Executive (HSE) as the body generally responsible for the enforcement of health and safety legislation and for exercising on behalf of the HSC such of its functions as the HSC directed it to exercise. For the purposes of enforcement provision was made for the appointment of inspectors, whose powers included the service of improvement and prohibition notices. The province of the work of the HSE excluded certain areas of industrial and technological hazard such as consumer and food safety and transport other than that of hazardous goods.

16.9 So far as health and safety offshore were concerned there were two differences. First, the HSWA did not apply outside Great Britain until an Order in Council so provided. Second, the HSWA did not treat the MWA or regulations made under it as part of the legislation which was subject to progressive replacement, despite the fact that the Robens Committee thought that they should be brought within the unified system "perhaps as a second stage after the main arrangements have been tackled - unless very sound reasons can be adduced for leaving them outside". (Para 109). It appears that this exclusion may have been influenced by a comparison between ships and installations, and in particular mobile installations, in respect of the hazards to which they were subject.

16.10 On 30 July 1976 the Prime Minister made a statement that the Government had decided that the HSWA should be extended to cover workers engaged in the offshore oil and gas industry, including divers, so that one agency, the HSC, would be responsible for ensuring that common standards of occupational safety were applied both on and offshore. However, in view of the knowledge and experience developed by the DEn (which had come into separate existence in 1974) on the technical aspects of structural safety and "blowout" risks, the Secretary of State for Energy would retain his existing responsibilities for safeguarding offshore workers against such dangers. The responsibility for inspecting offshore installations would remain with the PED, which would act as the agent of the HSC as regards occupational safety.

16.11 The HSWA (except Part III) was extended to the UK territorial waters and the UKCS by an Order in Council in 1977 (in 1989 superseded by a similar Order). However the regulations made under the HSWA were not to apply there except in so far as the regulations expressly so provided (Sec 15(9) of the HSWA). Prior to the disaster 7 sets of regulations dealing with particular types of hazard were given this extended effect. The only set of regulations which has so far been made under the HSWA which applies only to offshore operations is the Offshore Installations and Pipeline Works (First Aid) Regulations 1989.

16.12 Following the Prime Minister's statement the HSC in pursuance of its powers under Sec 13(1)(a) of the HSWA entered into an agency agreement with the Secretary of State for Energy dated 1 November 1978.

The report of the Burgoyne Committee

16.13 In view of the increasing level of offshore activity the Secretary of State for Energy in 1978 appointed a committee under Dr J H Burgoyne "To consider so far as they are concerned with safety, the nature, coverage and effectiveness of the Department of Energy's regulations governing the exploration, development and production of oil and gas offshore and their administration and enforcement. To consider and assess the role of the certifying authorities. To present its report, conclusions and any recommendations as soon as possible." In practice the Committee found it necessary to consider the work of other bodies under other legislation, and in particular the HSWA. In their report, which was submitted in 1980 (Cmnd 7866), the Committee made the following recommendations under the heading of "Administration and Enforcement":

> "6.5 The Government shall discharge its responsibility for offshore safety via a single Government agency whose task is to set standards and ensure their achievement (4.10).
>
> 6.6 We consider that the Department of Energy is capable of discharging this responsibility effectively, provided it is suitably strengthened and seeks advice from other bodies on matters of common concern. The strengthening is to provide the ability to monitor and where necessary set safety standards in relation to the selection, training and qualification of offshore personnel (5.130), and to acquire additional expertise in matters of occupational safety generally (4.24). The principal sources of advice to which we refer are the Department of Trade on marine safety, the Civil Aviation Authority on aviation safety and the HSE on occupational safety (4.11).
>
> 6.7 We recommend that the Department of Energy should continue its policy to employ an inspectorate consisting of well-qualified and industrially-experienced individuals, capable of a broad but authoritative approach to their monitoring and enforcement functions (4.39). We further recommend that inspectors should be given the resources to conduct independent technical investigations into failures and accidents (Appendix 15)."

These recommendations will be considered further in Chapters 21 and 22. A note of dissent was attached to the report by 2 members of the Committee who argued that as a matter of principle the responsibility for occupational health and safety in any industry should not be held by the department with policy responsibility for that industry; and that if there was to be a single agency for offshore safety it should be part of the HSE.

16.14 The Government's reply to these recommendations, in a statement deposited in the libraries of both Houses of Parliament on 3 November 1980 was as follows:

> "Accepted in principle.
>
> The Prime Minister has decided that the Secretary of State for Energy should take over the present responsibility of the Secretary of State for Employment for occupational health and safety offshore under the provisions of the Health and Safety at Work etc Act 1974. This means that the Secretary of State for Energy will in future carry sole Ministerial responsibility for all aspects of offshore safety, save for the responsibility for the safety of ships and seafarers engaged in offshore work, which will remain, as the report recommended, with the Secretary of State for Trade. In discharging this responsibility, the Secretary of State for Energy will be advised on policy matters (including the need for any new legislation) by the Health and Safety Commission (HSC), who will in turn look to the Petroleum Engineering Division (PED) of the Department of Energy for advice. HSC's role will be extended to include advice on structural safety and safeguards against fires, blowouts and other operating emergencies offshore, (on which advice has previously been given to Ministers direct by PED).
>
> In the case of diving safety, PED and the Health and Safety Executive (HSE) have worked closely together in the production of Unified Diving Regulations which will soon be issued. Advice to the HSC on diving matters will continue to be given jointly by PED and HSE.
>
> PED will continue to enforce the requirements of the Mineral Workings (Offshore Installations) Act 1971 and the Petroleum and Submarine Pipe-lines Act 1975, and to act as the agents of the HSE in enforcing offshore the requirements of the Health and Safety at Work etc Act 1974. Responsibility for enforcing the HSW Act in connection with pipeline works will be transferred from HM Factory Inspectorate to PED.
>
> PED will be strengthened by the transfer of Inspectors from HSE both for policy and enforcement work on occupational health and safety offshore.
>
> The Government believes that these arrangements will enable the development of offshore safety policy and the enforcement of safety standards to be developed in the most efficient and effective way."

16.15 Following this reply a new agency agreement was made with effect from 1 June 1981. This was implemented by arrangements outlined in correspondence between the HSE and the PED, in particular in a letter dated 23 March 1982. In addition to providing for the continued enforcement of the HSWA and its regulations on behalf of the HSE it outlined arrangements for (i) advice from the PED to the HSC and the HSE on diving operations and the safety of workers on installations; (ii) the development of health and safety regulations for submission to the HSE and the HSC; (iii) the appointment and training of inspectors; and (iv) the presentation of annual programmes of, and reports upon, work undertaken under the agency agreement. The agency agreement provided a channel for the exchange of information and advice between the HSE and the PED, principally at the instance of the latter. The HSE provided training courses, workshops and the secondment of personnel.

The organisation and functions of the Safety Directorate of the PED

16.16 Mr Priddle stated that in the light of the legislative framework the DEn saw its role as "developing appropriate standards and controls within that framework; monitoring and enforcement of compliance with the legal requirements; promoting the interests of safety generally through the development and dissemination of information and advice". Much of this work is carried out by the Safety Directorate of the PED which was not formed until 1987, under Mr Petrie as its first Director of Safety. Prior to that time various safety functions were performed in 5 out of the 6 branches into which the PED was then divided.

16.17 The work of the Safety Directorate (see Fig 15.1) is performed by the following branches:

(i) the Installations and Well Engineering Branch. This specialist branch is concerned with (a) consents for exploration and appraisal wells offshore; all onshore wells; and offshore development wells; and (b) the safety of offshore structures and their equipment through the development of guidance for certifying authorities and the DoT, and monitoring the work of those bodies. It also handles the registration of installations, the issue of well control certificates and considers regulations and guidance for abandonment operations.

(ii) the Inspections and Operations Branch. This specialist branch is concerned with the health, safety and welfare of offshore workers and the protection of the marine environment. The work of inspectors from the Aberdeen and London offices has already been mentioned in Chapter 15. Further sections deal with general issues of occupational health and safety, the prevention of pollution, security of installations and contingency planning. This branch also maintains liaison with the Marine Directorate of the DoT in regard to life-saving appliances and other maritime matters such as standby vessels.

(iii) the Pipelines Branch. This specialist branch is responsible for authorising the construction of, and enforcing safety regulations in respect of, pipelines under the PSPA. It also fulfils a similar function in respect of onshore pipelines on behalf of the HSE under a separate agency agreement. Enforcement involves monitoring the implementation of quality assurance programmes and undertaking a technical evaluation of a sample of key areas.

(iv) the Diving Branch. This support branch seeks to promote the health, safety and welfare of divers in relation to installations and pipelines.

(v) the Research and Development Branch. This support branch commissions and manages all research for other branches. The current research programme involves an expenditure by the Department of Energy of about £6m per annum.

(vi) the Safety Policy Branch. This branch provides assistance to the Director in developing safety policy and strategy; carrying out an on-going review of legislation; preparing the annual plan and report for submission to the HSE; and administering requests for exemption from regulations under the MWA.

16.18 From the above it can be seen that the Safety Directorate performs a number of functions in addition to that of monitoring and enforcing compliance by operators with the relevant legislation. It audits and provides guidance to the certifying authorities and the DoT. It grants consents in respect of wells and authorises the construction and use of pipelines. It should also be added that it is consulted about, and can express reservation on safety grounds in regard to, stages in the licensing system, namely (i) the issue of licences; (ii) the approval of operators; and (iii) the approval of development plans at the "Annex B" stage.

16.19 The Safety Directorate employs about 45 specialist staff. If those employed by the certifying authorities and the DoT are included the total would be about 300. As part of a "devolved system" the Director of Safety is responsible for all policy issues within his field of activity. The other part of the PED is the Exploration Appraisal and Development Unit (EADU) which maintains control over exploitation of resources in the UKCS. The PED is one of 8 divisions reporting to the Deputy Secretary. Central management issues are decided by a management board on which he sits along with the Principal Establishment and Finance Officer under the chairmanship of the Permanent Under-Secretary. This board covers the allocation of funds to the various divisions. Mr Priddle said that by virtue of his wider responsibilities and his contacts with persons at a more senior level in the outside world he would bring a wider experience to bear on the development of policy and would intervene as and when he felt it necessary, for example in his discussions with Mr Petrie as to the current functioning of the Safety Directorate. Mr Petrie himself was in a position of being able to discuss any matter of concern directly with Ministers should he think this necessary. Mr Priddle also said that he regularly discussed matters of policy with the head of the PED.

Links between the PED and the HSC and the HSE

16.20 As stated above the PED is responsible to the HSC for the enforcement of the HSWA and its regulations offshore and for providing advice for offshore safety in general. The HSE is not responsible for health and safety policy offshore, but the HSC is. Each year the PED is expected to submit to the HSC for their approval a programme of work for the next financial year and an outline forward programme for the next 5 financial years. It is also expected to submit each year to the HSC a report outlining their activities in the past year and following the outline previously approved by the HSC. Neither the HSC nor the HSE carry out a detailed audit of the work of the PED. In accordance with Government accounting conventions the PED remains responsible for the efficiency and economy with which it implements its responsibilities, such as under the agency agreement.

16.21 The PED also acts as one of the advisers and assessors to the OIAC, which is composed of representatives of the TUC and the CBI and provides advice to the HSC in relation to the whole oil and gas industry both onshore and offshore. This committee is chaired by the HSE. Both the HSE and the Marine Directorate of the DoT may also send assessors and advisers. This committee is on occasion used as an alternative source of guidance to the Safety Directorate. The Director of Safety is able to participate in the discussions of the management board of the HSE. He presents the proposals of the Safety Directorate to the HSE before they are submitted to the HSC and participates in consideration of any other proposals which may have relevance to the offshore petroleum industry. Apart from these official points of contact DEn inspectors are members of the HSE's technical working groups and industry liaison committees. Further, staff of the Safety Directorate participate in workshops presented by specialist groups within the HSE.

16.22 The HSE has always been ready to assist the PED in any material respect. It has provided training and technological support. It has also seconded inspectors from time to time.

The development of regulations and guidance

16.23 Before a regulation is made under the MWA or the PSPA the Secretary of State for Energy is under a statutory duty to consult with organisations in the United Kingdom appearing to him to be representative of those persons who will be affected by it. In practice he also takes the advice of the HSC. Where the HSE proposes a set of regulations under the HSWA the PED is asked to advise the HSC whether they should be applied offshore. The PED has also provided advice to the HSC as to the use which should be made of the various Acts to which reference has been made earlier in this chapter. I will discuss this subject in more detail in Chapters 21 and 22.

16.24 In recognition of the need for more specific guidance as to the implementation of regulations the PED have produced guidance notes on broad areas such as design and construction (relevant to the Construction and Survey Regulations); on life-saving appliance and fire-fighting equipment (relevant to the regulations bearing these titles); and in regard to training. These notes are subject to formal consultation when issued or amended. Guidance is also provided on more specific matters in the form of diving safety memoranda, continental shelf operations notices, safety letters, safety notices and safety alerts. As regards guidance notes and safety notices Mr Petrie stated that the DEn expected operators to take account of their substance "much as we would expect them to take account of other similarly authoritative codes and standards issued by standards-making bodies such as the British Standards Institution and the professional bodies. In our experience they do take account of them."

Certifying authorities

16.25 For the purposes of Sec 3 of the MWA the Construction and Survey Regulations require that both fixed and mobile installations should be the subject of a certificate of fitness issued by a certifying authority which is valid for a maximum of 5 years. Although the Secretary of State for Energy may act as a certifying authority in practice this role is undertaken by one or other of 6 bodies which were appointed by him for the purpose and which work under contract with the operators who bear the entire cost of their services. This is one of a number of respects in which the regime was originally modelled on that developed for ships. The bodies are essentially ship classification societies. It is clear that there were seen to be practical advantages in drawing upon their expertise with particular reference to the structural and marine aspects of installations. The role of certifying authorities in the regime was clearly endorsed by the Burgoyne Committee (paras 6.8-12 of their report).

16.26 The work of a certifying authority may be put briefly under the following broad heads: (i) the assessment of design and method of construction; (ii) the assessment of the operations manual; (iii) the inspection of the installation and its equipment in fulfilment of the requirements for major surveys over a 5 year period and for annual surveys. Events such as damage and structural deterioration; and alterations, repairs and replacements require to be reported to the certifying authority with a view to its determining whether or not an additional survey is required. It also reviews the operator's programme of planned maintenance under the Operational Safety, Health and Welfare Regulations. The basic requirement which requires to be fulfilled by the above work is that the design and construction should comply and continue to comply with the Second Schedule to the Construction and Survey Regulations; and that the operations manual should contain information, guidance and instructions which are adequate and appropriate in relation to the installation. The Second Schedule covers environmental considerations, foundations, primary structure, secondary structure and fittings, materials, construction and equipment. In the light of its findings a certifying authority may attach a limitation or qualification to a certificate of fitness.

16.27 Much of the Second Schedule is concerned with structural requirements directed to enabling the installation to withstand the environmental and other forces imposed upon it. However, it also contains some requirements which are of significance for the prevention and mitigation of incidents on installations. These include those relating to: (i) equipment; (ii) material; (iii) living accommodation; decks, stairways, etc; and escape routes; (iv) ventilation heating and cooling; lighting; and emergency power supply. The work of a certifying authority is limited by the scope of the Construction and Survey Regulations. Within that scope it appears to be concerned with the conceptual and detailed design of the structure and the operation of the platform as a marine installation. As regards process plant, the design concept would be taken into account in deciding whether a particular item of equipment was "suitable for its intended purpose". According to Mr Petrie the certifying authority would consider the operating parameters of a proposed system and assess whether it could safely operate within them and what controls were provided to limit them. However, the certifying authority is not, in general, required to undertake a conceptual analysis. In particular it is not required to review plant design in relation to major hazards. It should be added that a body which was a certifying authority could undertake a conceptual design analysis on a consultancy basis so long as it was not in conflict with its role as certifying authority in the particular case.

16.28 As I have mentioned above the PED provides guidance notes in supplement to the requirements of the Construction and Survey Regulations. These are based on recognised standards and procedures which have been established by internationally recognised organisations. The fourth edition of these guidance notes was prepared during the currency of the Inquiry. It states *inter alia* that:

> "The certifying authority has discretion to accept methods, techniques, standards and codes of practice other than those in Guidance subject to being satisfied that

> the installation substantially complies with the requirements specified in Schedule 2 to the regulations and that no diminution in safety or integrity will result. The DEn should be informed of any proposal of unusual or controversial character."

This statement is broadly in line with the text of previous editions. Although a large measure of discretion is entrusted to the certifying authorities only the DEn can revoke a certificate of fitness or can take action to prevent an installation being operated in the absence of a valid certificate of fitness. The DEn does not itself undertake assessment, survey or certification. Its auditing of the work of certifying authorities (as from 1987) is intended to confirm that its requirements are being complied with. Audits are carried out both on a random basis and on the basis of a specific project which is of interest to the Department.

16.29 Lloyd's Register of Shipping acts as the certifying authority in respect of over 80% of the fixed installations in the UKCS. At its London headquarters it approves plans and appraises designs: outport offices such as in Aberdeen, carry out the work of surveying, subject to procedures, instructions and specialist support provided from headquarters.

The Department of Transport (DoT)

16.30 So far as installations are concerned the Marine Directorate of the DoT (formerly of the Department of Trade) carry on work on behalf of the DEn in relation to fire-fighting equipment and life-saving appliances. Fire-fighting equipment for new installations is examined by the DoT in order to see that it is in accordance with the plans, the Fire Fighting Equipment Regulations and the relative guidance notes. It is stated in the guidance notes that the DoT has discretion to accept methods and techniques equivalent to those outlined in the guidance notes subject to being satisfied that no diminution of safety will be involved: but that the DEn will be informed if the proposal is of an unusual or controversial character. Fire-fighting equipment is subject to examination by the DoT every 2 years in order to see that it is properly maintained and in good working order. Life-saving appliances for new installations are examined by the DoT in order to see that they are in accordance with the Life-saving Appliances Regulations and the relative guidance notes. Their approval of the appliances is required. The appliances are subject to examination by the DoT every 2 years in order to see that they are properly maintained and in good working order. These arrangements provide another instance where the expertise of those familiar with the regime which applies to ships has been used as part of the regime for installations. The work of the DoT on behalf of the DEn is subject to audit. The DoT are also concerned with navigational aids; and with whether standby vessels provided under the Emergency Procedure Regulations meet the code for assessment of their suitability in accordance with a voluntary agreement with UKOOA.

The Civil Aviation Authority

16.31 The other body which has a specific responsibility in regard to installations is the CAA which is responsible for safety in commercial helicopter operations.

The UK onshore safety regime

16.32 The origins of the HSC and the HSE have been briefly referred to in paragraph 16.8 above. Their general aims can be clearly understood by reference to the following passages in the HSC's published plan of work for 1989-90 and beyond:

> "We and the executive are regulatory bodies, concerned with protecting people from harm. This is true in the formal sense of our having a statutory duty to submit proposals for regulation and the executive having a similar duty to make arrangements to enforce them. It is equally or more true in the profounder sense of our being the prime movers in a vast activity, undertaken day by day within industry, to prevent accidents and ill-health and to protect workers and the public, essentially from the

release of the energies that work involves. The first of the statutory duties specified to us in the HSWA is to 'assist and encourage' those engaged in this task." (Para 26).

"Our basic aims continue to be to:

(a) stimulate and guide the efforts of industry to achieve higher standards of health and safety at a cost that is realistic; and

(b) protect both people at work and the public who may be affected by risks arising from work activities, and keep them properly informed about the risks and the protective measures adopted." (Para 65).

The Health and Safety Commission

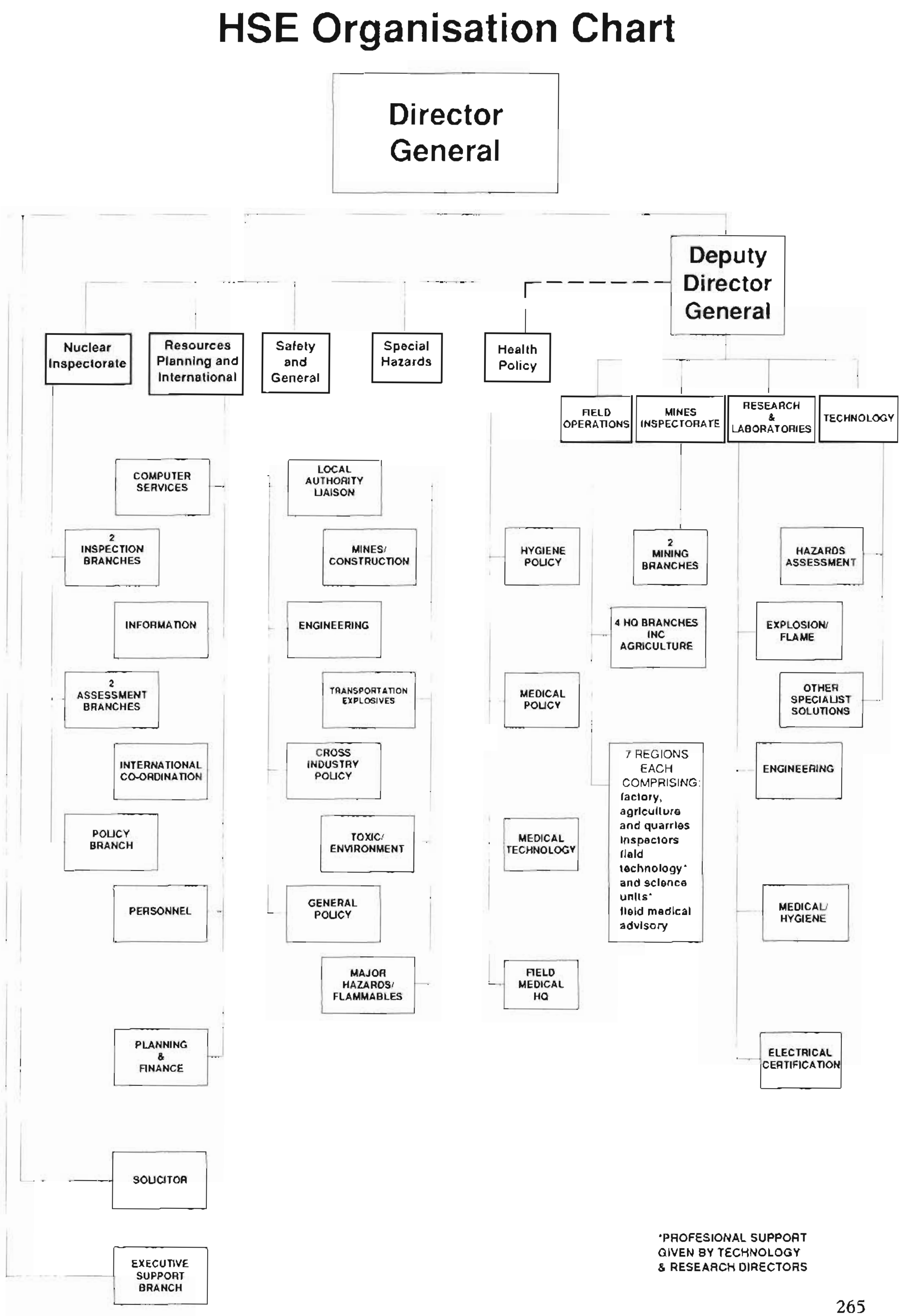
16.33 The HSC is composed of 8 members nominated by the CBI, the TUC and local authority associations, and a chairman appointed by the Secretary of State for Employment. It proceeds essentially on the basis of consensus; and, according to Mr Rimington, takes every possible step to ensure that those affected by its activities are in at least broad agreement. It makes substantial use of advisory committees, either in regard to particular types of hazard or (as in the case of the OIAC) in regard to whole industries. In these committees much of the work of determining safety standards is carried out.

The Health and Safety Executive

16.34 The HSE is a corporate body of 3 persons appointed by the HSC, namely the Director General, the Deputy Director General and the Director of the Safety Policy Division. It has about 3,600 employees, mainly inspectors and technical, scientific and medical experts. Its management board includes the Chief Inspectors of the various inspectorates which are concerned with the enforcement of industrial safety and health. The HSE is the licensing authority for nuclear installations. Following recent changes the Nuclear Inspectorate and 4 divisions which are concerned with policy and planning report to the Director General. The Mines Inspectorate, Field Operations (which includes the Factory, Agricultural and Quarries Inspectorates and the field consultancy groups which provide technical and scientific support to the inspectorates) and the divisions concerned with technology, research and laboratories report to the Deputy Director General (see Fig 16.1).

16.35 Para 164 of the plan already referred to describes the expertise of the HSE as made up of 3 main kinds, namely (i) policy branches which advise the HSC on matters such as possible changes in legislation or standards; (ii) inspectorates which secure compliance with legal requirements and accepted standards through inspection, advice, investigation of incidents and, where necessary, enforcement; and (iii) the technical, scientific and medical group which are principally responsible for promoting and supplying excellence in the scientific and technical advice available to the HSC and others concerned with safety. The plan also states:

> "Our function is to oversee almost all aspects of industrial safety and health in the UK, whether they affect people at work or the public. We lay down the standards for the safe conduct of virtually all industrial processes and the safe use and transportation of dangerous materials and pathogenic organisms, frequently following international negotiation. In no other country is this very large task so largely concentrated in a single body; in most it is distributed over many central and regional bodies. This concentration in the hands of the Executive of a wide range of professional and scientific expertise produces advantages beyond mere economies of scale. Our responsibility in relation to a wide field of risks enables fruitful exchanges of experience and ideas. It qualifies us to speak with authority on general questions concerning the nature and tolerability of risks, necessary and at the same time acceptable controls, and effective approaches to enforcement; and gives us advantages internationally. But we can only carry out our work through new



*PROFESIONAL SUPPORT GIVEN BY TECHNOLOGY & RESEARCH DIRECTORS

Fig. 16.1 Simplified organisational structure of the Health and Safety Executive.

measures, getting people together to decide on best practice, and by stimulating and encouraging those within industry who carry the legal responsibility for health and safety in individual enterprises." (Paras 66-67).

Apart from its own resources the HSC through its research committee commissions a large amount of extramural research. This includes work undertaken by and in conjunction with the nuclear industry.

The HSC's approach to regulations

16.36 The progressive replacement of the existing onshore legislation relating to health and safety has necessarily required a long period for its implementation. The plan already referred to states that by then HSC had brought about the repeal of 143 sets of regulations and introduced 35 "new packages on modern principles". It also stated that the law on a high proportion of hazards, including that on hazardous and dangerous substances and their transportation, had been comprehensively reformed, and major packages on mining, electricity and pressure systems were progressing well (para 32). The new style of regulations specify principles rather than solutions and are thus intended to encourage innovation on the one hand but be effective against lack of precaution on the other. Mr Rimington explained that one implication of the revised approach was that regulations should so far as possible apply across the board ie to every industry where the hazard in question applies. However, it has sometimes been found necessary where hazards assume a special form in a particular environment for there to be special regimes. In such cases the principles of the more general regulations are applied with particular additions as appropriate. He explained that regulations under the HSWA were necessary only where in some particular respect the general requirements of the act needed to be spelt out in a form which was in some sense mandatory, such as the expression of a legal duty, a principle of action or a strict requirement of some detailed kind. The new style of regulations were backed up by approved codes of practice which created a presumption that the law had been breached unless it could be shown that some equally satisfactory approach had been adopted; or by guidance; or by both. The fact that codes of practice and guidance were neither mandatory nor required complex parliamentary procedures for their amendment made them an ideal vehicle for incorporating the results of changing technology.

Compliance with legislation

16.37 Mr Rimington described the primary object of inspection as being "to stimulate the operator to carry out his duty to maintain safety, against the background that the inspector can and will apply coercion through the courts where this is necessary or salutary". The intention was always to ensure that a high standard of compliance with reasonable standards had been attained. He also said: "An inspector's immediate purpose in visiting is to satisfy her or himself that systems exist that are likely to lead to the identification and prevention by management of significant faults, and that the attitude of management is conducive to this." It was also very important that inspection should be targeted on aspects that were critical to safety "so that time is not wasted and discoveries, if made, are likely to open up further vistas for enquiry". In this context he drew attention to the fact that the HSE's inspectorates were of two kinds, namely those which concentrated on particular industries where the inspections covered plant which was likely to be relatively familiar to the inspectors who would generally be recruited from highly qualified people with experience of the industry itself; and those inspectorates (particularly factories and agriculture) which cover much larger territories. The latter were recruited at graduate level. They often though not necessarily possessed technical degrees or qualifications. All received very substantial initial training. Many inspectors spent a large part of their working lives dealing with particular industries.

16.38 Inspectors in the HSE are able to call upon a wide range of resouces within the HSE's Technology Division, the Employment Medical Advisory Service and the specialist sections of the Nuclear and Mines Inspectorates; and the forensic and general scientific capabilities of the Research and Laboratory Services Division. The specialist inspectors and scientists when called upon in this way did not lead an inspection or investigation but were called in as experts to investigate particular aspects and also as necessary to give expert evidence in court. The specialist inspectors in the Technology Divison and the Nuclear and Mines Inspectorates generally have substantial industrial experience. They and the HSE's scientific staff are in contact with the latest advances in thinking and good practice. Specialist inspectors are also engaged in the assessment of Safety Cases under the Control of Industrial Major Accident Hazards (CIMAH) Regulations, whether in the nuclear or non-nuclear areas; and expertise is maintained in the techniques involved in the assessment of risk.

16.39 Particular mention should be made of the HSE's Accident Prevention Advisory Unit (APAU). This unit has been maintained since 1977 in order to exercise influence on the management of safety and the design of safe systems. Its main task has been to carry out safety audits in co-operation with large companies and undertakings in order to investigate the standards of management control and advise how a structured safety system at corporate and subsidiary levels can contribute to high standards of health and safety. In 1984 the HSE had put forward a scheme for "safety assurance", linking safety and quality assurance. Under this scheme the HSE would have audited the employers' safety systems. However, this was on the basis that the employers would be exempt from basic inspection. The proposal was dropped after it did not prove widely attractive to employers and was strongly opposed by trade unions. Mr Rimington said that the APAU had gradually gained for itself a considerable reputation and its experience had enabled it to begin to formulate a body of knowledge and principles on safety management. Monitoring of companies which had accepted the advice of the APAU had shown conclusively that lasting results had been obtained not simply on the basis of the advice given but through stimulating the attention of management to a subject which had been frequently neglected or regarded as technical or obscure. The HSC's plan of work for 1989-90 and beyond which has been referred to earlier in this chapter records at para 98 that the unit evaluates safety monitoring packages and advises the HSE's inspectors and the public about their use. Field inspectors would take suitable opportunities to inform companies about them. The unit also intended to evaluate the potential link between various quality concepts such as that in BS 5750 - the UK national standard for quality systems - and standards of safety. They were also collaborating with companies and other parts of the HSE in an attempt to define the costs of occupational accidents and ill-health and quantify the economic benefits derived from high standards of occupational health and safety.

The Norwegian offshore safety regime

16.40 The exploitation of petroleum resources in the NCS is controlled by the issuing of licences and the granting of consents which enable licensees to progress through various stages leading to production. Since 1979 the Norwegian Petroleum Directorate (NPD) (which was established in 1973) has been responsible to the Ministry of Local Government and Labour in matters relating to the working environment, safety and emergency preparedness; and to the Ministry of Petroleum and Industry for the administration of petroleum resources in an efficient manner. On this basis the NPD's objectives are "actively to contribute to a sound administration of the Norwegian petroleum resources through a balanced evaluation of the natural, safety-related, technological and economic aspects of the activity within an overall social framework." The control of Statoil which engages in the business of petroleum production and is wholly owned by the Norwegian state is exercised directly by the Ministry of Petroleum and Industry. In its supervisory capacity the NPD has the task of seeing that both safety legislation and the terms of licences, consents and approvals are complied with. Under authority delegated by the Ministry of Local Government and Labour the NPD has the power to issue regulations and conduct overall safety evaluations. In exercising its supervisory authority the NPD obtains assistance from other public bodies, institutions and companies with special expertise. The NPD also acts as adviser to the 2 Ministries, and is responsible for providing guidance to all participants in the petroleum industry.

The organisation of the NPD

16.41 The highest administrative authority of the NPD is the board of directors which consists of the chairman and 7 members. The day to day business of the NPD is in the hands of the Director General. Apart from the administration and legal branches and the information office, the NPD is divided into 2 divisions, namely the Resource Management Division and the Safety and Working Environment Division, the work of which respectively relates to the 2 responsibilities of the NPD referred to in para 16.40.

16.42 The main objective of the Safety and Working Environment Division is to establish, maintain and further develop a fully satisfactory level of safety and working environment within the petroleum industry. It consists of the following branches:

(i) the Supervisory Activities Branch. Its main task is to manage supervisory activities in the Norwegian part of the continental shelf (NCS). Six Heads of Supervisory Activities are responsible for the supervision of specific operators. In the NCS there are about 40-50 installations, operated by 12-15 companies, including many which operate internationally. About 15,000 persons work offshore, of whom about 5000 are there at any given time.

(ii) the Technical and Working Environment Branch. This provides a pool of expertise in safety and the working environment. It is responsible for providing personnel on a priority basis for various tasks such as the development of regulations.

(iii) the Strategy Branch. Its principal responsibilities are that of offering advice and guidance, undertaking development of regulations and co-ordinating and managing certain tasks. In addition it is responsible for the execution of a number of administrative functions for the division as a whole.

About 90 professional staff are employed in the Safety and Working Environment Division. Mr Ognedal stated that installations in the NCS could be visited 3-5 times a year; and that about 80 of his staff would be expected to be a couple of times offshore each year. This could range between a simple verification taking a few hours and a week's investigation.

16.43 The purpose of the Resource Management Division is to survey petroleum resources and evaluate alternative ways of extracting and utilising these resources in the best way, with a view to advising the Ministry of Petroleum and Energy how to control exploitation for the greatest benefit of society.

The NPD's approach to legislation

16.44 Since 1985 the NPD has been responsible for the review and reformulation of regulations which prior to that time had been issued by 9 independent Government agencies which had separate responsibilities in different areas of the petroleum industry. Since the beginning of 1987 the NPD has been examining all existing regulations with a view to reformulating them and reducing their number by about 50%. Mr Ogendal said that about 15% of the total resources of his division were involved in this work. The new style of regulations were concerned with objectives to be achieved and so were "goal-setting". In connection with the development of new regulations the NPD had created a forum of some 35 persons drawn from the NPD, the industry, the Government and trade unions. A reference group had the oversight of the development of the regulations. In addition experts had been chosen for their particular expertise in relation to the individual regulations to be drafted. Mr Ognedal said that this forum enabled the NPD to exchange ideas with the industry from a very early stage. The NPD also intended to provide supplementary documentation in the form of guidance notes. The available codes and standards would play an important part in the future Norwegian legislation.

Internal control and supervisory activities

16.45 A fundamental principle of the Norwegian safety regime is that since the operator controls his business he therefore should control the safety aspect of his operations. This principle began to be developed in 1975 and is currently formulated in Internal Control regulations stipulated by Royal Decree of 28 June 1985 in pursuance of a number of Acts of the Norwegian Parliament concerned with safety in petroleum activities, worker protection and the working environment and protection against pollution in petroleum activities. In accordance with the regulations the licensee through internal control is to ensure that the activity is in accordance with the provisions stipulated in and in accordance with those Acts (Reg 3). "Internal control" is defined as: "All systematic actions which the Licensee shall initiate to ensure that the activity is planned, organised, executed and maintained according to requirements stipulated in or in accordance with acts or regulations." (Reg 2). The regulations set out a large number of matters which the licensee's internal control is to ensure, such as "that safety evaluations are undertaken both prior to start of exploration drilling, prior to the final selection of project plan and its subsequent phases, including the operating phase"; "that the licensee's and contractors' employees are given necessary training"; and "that the contractors' Quality Assurance system is evaluated and assessed, and is subject to system audit". According to the regulations responsibility for the monitoring and enforcement of the control system is to be assigned to a separate unit within the licensee's organisation. This unit is to have sufficient organisational freedom to monitor and enforce all subordinate control systems and to perform system audits on these. This organisational unit is normally to be placed outside the operative responsibility. The licensee is to arrange the organisation in such a way that the unit normally reports to a higher organisational level than those units which it is to monitor. A "system audit" means a "planned and systematic examination of systems to ensure that these have been established, followed and maintained as specified". The internal control system is to be kept up to date in a systematic and controlled manner; and the up-dated information is to be communicated to the NPD and within the licensee's organisation, workforce and contractors.

16.46 In order to ensure compliance with the requirement for internal control the licensee has accordingly to establish and describe the system which is used to control its own activity. This description is the main tool which the NPD use in carrying out its supervisory activities which are separate from and additional to the internal control exercised by the licensee. The object of NPD's supervisory activities is to make a systematic assessment of the internal control system of the company in order to check that its activity is correctly reflected in the documentation and is performed within the requirements of the law. The NPD performs this assessment in 2 ways - by audit of the operator's systems and by verification of the output of those systems. The NPD endeavour to schedule an audit of each licensee at least once every 3 years; normally it is more frequent than that. The NPD select a section of the licensee's operation and audit this section from the most senior person down the management structure. In advance of the audit the company is advised in general terms of NPD's plan for the following year; and will be required to provide the NPD with specified information and documentation including the company's own plan for auditing. Having considered this documentation the NPD plan one or more audits and the timescale for them. An audit team, usually consisting of 4 or 5 persons under a team leader plan a questionnaire for use in interviewing company personnel. Following the interviews, which are informal in character, the team then may carry out a verification on the installation in order to ascertain whether a particular procedure has been set up, is documented and is understood and operated by the appropriate personnel. Equipment may also be checked. The NPD may involve consultants in carrying out specific checks, for example in the areas of welding, corrosion and diving. Sometimes the NPD use management consultants in the planning of the audit. The company which is being audited is invited to have a representative present as an observer throughout the audit. The elected safety delegate from the workforce also normally takes part, especially offshore. When the audit has been concluded the NPD make a presentation of the result to the company following the presentation by the company's observer of his findings. Thereafter the NPD prepare a report and send it to the company for their reaction. The final report will be sent to the company with a covering letter detailing the points which have been identified in the audit and require action by the company. The letter will also ask the company to submit to the NPD a plan for corrective action by a given date. Both the final letter and all attachments to it are available both to the press and to the public. Within the NPD the responsibility for following up its findings rests with the appropriate Head of Supervisory Activity. The Heads are in daily contact with the companies for which they are responsible. The Ministry of Local Government and Labour will not normally become involved but may do so if something very serious is thrown up by the audit. The Ministry do not receive a copy of the NPD reports as a matter of routine but are aware of the companies which the NPD are auditing as this information is contained in the NPD Supervisory Activities Plan for each year about which the Ministry is informed. The supervisory activity of the NPD is paid for by the company which is being audited. A major audit will take on average 3 weeks from the start of detail planning to the writing of the report. In the planning of an audit a decision requires to be taken at an early stage as to whether any contractors should be included in the activities. This will depend on the extent of auditing by the operator. It may be necessary to involve contractors either in the NPD audit or at the stage of verification. Mr Ognedal stressed that it was necessary for the objectives and scope of the particular audit to be described clearly. The methods of obtaining verification by reviewing documents and carrying out inspections require to be thoroughly discussed and decided with the objectives of the particular audit in mind. A knowledge of the available documentation was essential. It was also important for the necessary expertise for the particular audit to be discussed and decided on in advance. He saw this system, which was based on open communication between the company and the NPD, as presenting a new challenge for both.

16.47 This regime has never used a separate body to carry out the assessment of design or surveys with a view to certification of installations. Mr Ognedal mentioned 2 reasons: the insistence on a one point responsibility and the aim of having short lines of communication between those who supervised and those who drew up the regulations. It was and is a matter for individual companies to decide whether they wished to use the expertise of such bodies in their internal control activities. Further the NPD does not certify or approve company systems or procedures. The point at which they exercise control is when application is made by a company for the required consent on the part of the NPD to a stage in their activities. At that stage the NPD can refuse consent if they are not satisfied with the particular application. They can also take into account any matters which are outstanding, such as the failure of a company to present its evacuation plan to the NPD. The NPD can refuse consent until the plan is forthcoming.

16.48 The NPD is provided with powers to enforce the legislation. These range from the imposition of day fines to the shutting down of a company's activities. An NPD inspector has the power to shut down an activity on the spot. He would immediately inform the NPD at Stavanger where a decision would be taken on the information available as to whether the shutdown should be continued or not. Mr Ognedal stated that if it came to his attention over a period of time that a company was not performing adequately he could summon the company's "top man" to see him at very short notice. He had found this to be very effective in producing results. Where a serious problem had been identified in relation to a company the NPD could recommend to the Minister that the company be required to see the Ministry or the Minister himself; or that the company was not fit to continue operations.

16.49 Mr Ognedal estimated that almost half of the work of his division was devoted to supervisory activities covering present and new projects and the evaluation of new applicants for licences. About 10% of its time was concerned with giving information and advice. So far as could be done his division produced a plan of activities for the forthcoming year. In 1990 it was intended to obtain further insight as to the competence required of personnel in the NPD, its consultants and other agencies with which the NPD worked. This was intended to provide specific guidance as to future training and assist in recruiting philosophy. The priorities for 1990 were to ensure better compliance with the Act relating to the working environment; to ensure activity in the very early stages of any project; and to follow up a re-evaluation of the older installations.

16.50 Personnel employed by the NPD are recruited both from the offshore industry and from the shipping and engineering industries. Training needs are defined by the manager and the employee and a plan is created. Training comprises on-the-job training together with courses on the legal framework and the philosophy of internal control. A new recruit could also be taken into an audit team as part of his training. Personnel are also seconded to the companies for a period of time. Most recruits have university training and more than 60% are graduate engineers. The NPD also recruit university graduates with degrees in other subjects such as management and social sciences. Mr Ognedal would not expect a new recruit to perform an audit or carry out verification activities on his own for at least 2 years after he joined the NPD. However, he stressed that it was the procedure of the NPD for at least 2 persons to go offshore for a supervisory activity. When a new recruit began work a member of staff would be appointed to have special responsibility for him and his training on behalf of the manager. Although personnel could be lost to industry the turnover was only about 7%, so the numbers were "normally pretty close to maximum".

Future trends in offshore developments

16.51 In approaching the subjects discussed in later chapters, and in particular Chapters 19 and 20 it is right that I should bear in mind what the Inquiry heard as to the future trends in offshore developments since these may give some indication of how frequently a certain type of feature which is of interest is likely to be installed. One example is the inter-connection of installations by pipeline. A study of future trends may also assist me in determining whether and how far it is advisable or practicable to make a recommendation. On this point the diversity of future types of development may be of some significance.

Trends in the size of fields

16.52 Although the number of oilfields under development increased between 1980 and 1988 their average size decreased over that period. To illustrate that, Dr Taylor pointed out that the 15 oilfields in production at the end of 1980 had an average size of 855 million barrels; whereas the average size of the 26 oilfields brought into production since then was 173 million barrels. A survey carried out by UKOOA in mid-1988 had shown that there were then 44 oilfields in production or under development which had an average size of 323 million barrels; whereas there were 92 oilfields which had been discovered but were not yet developed having an average size of 52 million barrels. Accordingly the undeveloped oil discoveries averaged only one sixth of the size of the fields already in production or under development. Oil production from existing fields which was currently a little above 2 million barrels per day was in decline and was projected to halve by the mid-1990s. As at mid-1988 there were 25 gas-fields in production or under development and 35 discovered but undeveloped. Gas production which was currently about 4500 million cubic feet per day was projected to halve by the end of the century. This decline in oil and gas production would be slowed down by production from new fields some of which had already been found and others yet to be discovered.

Factors affecting the pace of development

16.53 Dr Taylor said that since 1984 a number of changes had occurred which had significantly influenced the outlook for the upstream petroleum industry. For example oil and gas prices had fallen substantially; the cost of new developments had been significantly reduced, in particular as the result of the use of heavy lift barges; and changes in depreciation allowances for corporation tax had reduced the profitability which was achievable on new investments. He said that in assessing potential future production, whether generated from existing but as yet undeveloped discoveries, or from discoveries yet to be made, the rate of appraisal and development of the inventory of discoveries depended upon a price and fiscal environment which supported commercial development, the availability of cost-effective technology and the provision of adequate resources to support the activity.

The types of development

16.54 The earliest installations in the North Sea were in the southern area (all for gas) where the water depth was relatively shallow. Later developments were in the central and northern areas in deeper water where a number of major oil discoveries were made in the 1970s. Larger and more substantial installations were required for the deeper water areas. In these areas drilling, processing, utilities and accommodation were integrated into a single platform.

16.55 There are considerable differences in the environment in different parts of the North Sea. Dr Taylor illustrated this by reference to the range of depth of water, wind speeds and wave heights. Because of these differences and other factors such as the geology and geography of the reservoirs there were many different types of offshore installation. In the southern area there were over 100 small fixed platforms mostly fairly close together. In one part of this area, covering about 40 miles from north to south and 50 miles from east to west there have been more than 30 gas discoveries. These included the very large Leman field which has 18 platforms spread over 15 x 5 miles. Some of the platforms consist of several structures linked together. This linking is also found in the group of "V" fields. One example was the North Valiant gas gathering installation which consisted of 4 structures linked together to make one installation. He compared these examples with the Brent area in the northern North Sea where there were 18 large and heavy platforms to cope with the deeper water and hostile environment. These structures were set out in an area which spanned 60 miles from north to south and 30 miles from east to west. The group included a number of different designs of concrete and steel platforms. Fairly close to these were the Statfjord group of 4 platforms on the median line between the UKCS and the NCS. Elsewhere in the northern area installations were more scattered. This had implications for the design with regard to the means of transporting products, the type of accommodation for personnel and the organisation of systems for evacuation of hydrocarbons.

16.56 The fields in production at the end of 1988 showed a diversity of methods of development. 31 used fixed platforms. 8 used floating production systems. 7 used subsea completions. One used the tension leg system.

16.57 Looking to the future developments for the production of oil, Dr Taylor said that fewer and fewer large fields requiring fixed structures would be discovered. The successful recovery of oil from many of the small discoveries would depend on the introduction of improved oil recovery and production systems. Heavy fixed steel and concrete platforms would increasingly be replaced by re-usable floating production systems and subsea developments. The latter were especially attractive where developments were favourably located near existing facilities into which they could be linked. Floating structures were applicable over the whole range. As regards the production of gas condensate, this would mostly be done by means of fixed platforms with some smaller developments done by subsea installations. For gas discoveries, the larger fields would normally be developed using central fixed installations tied to not normally-manned wellhead towers. Smaller gas fields would use similar unmanned towers which would be tied to existing production platforms.

16.58 Dr Taylor described a method of predictive analysis which had been carried out by UKOOA in order to examine the distribution of size and development of fields within the next 25 years. By the use of this analysis it had been estimated that out of the 101 existing and future undeveloped oil discoveries, 51 would use subsea methods, 25 would use floating production systems and 25 would use fixed platforms. About 30% of the reserves accounted for in this way would be accumulations of less than 50 million barrels. Development of the very small fields would depend heavily on the complexity of the geological structures, oil prices, the fiscal position and the available technology. Access to existing installations and pipelines would be required. Technological advances in the last 5 years had made it probable that these small discoveries would be developed by subsea completions tied into parent installations. On the basis of past experience and the current uncertain outlook facing the offshore industry the study carried out by UKOOA had adopted an average development rate of 3 oil-fields per year over the next 25 years. As regards gas-fields size was no longer considered to be of great significance in determining the order in which fields came forward for development. This had been due to the extent of the existing infrastructure of pipelines, terminals and gathering platforms which was now in place, especially in the southern North Sea. Further many oil companies had a diversity of holdings which provided them with an incentive to develop smaller fields. Against that background Dr Taylor said that it was possible to postulate a future development scenario which included 3 new oilfield developments per year (which could extend to 4 if subsea completions were involved); 6 new platforms per year for new gasfield developments; and 1 new gas condensate field development every 3 years until the end of the century and 1 per year thereafter. Dr Taylor said that it could be concluded from the overall result of the study that in the northern and central North Sea the potential existed over the next 25 years for the development of around 100-150 oilfields and 20-30 gas condensate fields requiring in total around 45-55 fixed platforms, 20-30 floating production systems and 40-60 subsea installations.

16.59 Dr Taylor referred to the installation for the Tern field as being representative of the type of manned fixed installation likely to be built in the future. The field was among the group containing between 180 and 320 million barrels of oil. The platform would be typical of the future fixed platforms required to develop the larger of the remaining small fields in the northern North Sea. Platforms of this type would be dealing with much the same operations as the larger platforms but on a reduced scale. Where satellite systems were involved oil and gas would emerge from these in single pipelines delivering to the main platform for separation. The gas would probably be used as a fuel. He illustrated the use of floating production systems by reference to the Ivanhoe/Rob Roy development. This installation was semi-submersible, kept on station by dynamic positioning. Oil and gas was collected from subsea connections through a system of flow lines and flexible risers. The development was the first to combine oil and gas production in a floating system. It would be able to pump water into the reservoir and maintain reservoir pressure. The gas produced would be taken by way of the Tartan field into the Frigg system. The oil would be transported to Claymore and then to Flotta. If necessary it could be discharged into an oil tanker near the development. Another floating system under construction was designed for extracting oil from very small reservoirs. This was described as a single well oil production system (SWOPS). It consisted of a ship-like facility which could be used as a subsea production system on an existing exploration or appraisal well and possibly to develop some of the very small discoveries I have mentioned above. The oil could be processed on board. The advantage of that system was that it could be moved elsewhere when the reservoir had been exhausted.

16.60 It appears that satellite subsea developments and small unmanned installations will increase as a proportion of future developments in the UKCS. However, the large number of existing fixed platforms and the substantial, if decreasing, proportion of new manned installations will continue to demand a high degree of attention to personal safety. At the same time technological change and the increasing proportion of unmanned installations will call for a flexible approach to regulation.

Chapter 17

Safety Assessment

17.1 I now turn to outline the specific elements in the regime which I envisage, starting in this chapter with safety assessment. I will first describe the nature and value of safety assessment (paras 17.3-7), the models for its regulatory use furnished by the Safety Case in the Control of Industrial Major Accident Hazards (CIMAH) Regulations 1984 (paras 17.8-16) and by the arrangements in the Norwegian Continental Shelf (NCS) (paras 17.17-21), and the practice and intentions of the DEn (paras 17.22-28). Next I will state my views on, and proposals for, the role of safety assessment in the regime (paras 17.29-47). I will then consider the role of quantification and quantitative risk assessment (paras 17.48-61). I will conclude by considering the implications of my proposals for regulations, for the regime and for the regulatory body (paras 17.62-71).

17.2 The Piper disaster involved the realisation of potential major hazards. There was a leak and an explosion inside a module followed by the rupture of gas risers. Although Occidental could not but be aware of the existence of such hazards, it did not possess any system which ensured that such remote, but potentially disastrous, events were subjected to systematic scrutiny. There was for major projects no comprehensive system of safety assessment and management did not appear to appreciate fully the contribution which it could make. By contrast, the evidence showed that some companies, both those operating in the UKCS and in the NCS, require the formal use of safety assessment for major projects, and did so prior to Piper. The companies which gave evidence on this were clear that these activities were beneficial in the identification and control of hazards.

Formal safety assessment

17.3 Formal safety assessment (FSA) involves the identification and assessment of hazards over the whole life cycle of a project from the initial feasibility study through the concept design study and the detail design to construction and commissioning, then to operation, and finally to decommissioning and abandonment. The techniques used include hazard and operability (HAZOP) studies; quantitative risk assessment (QRA); fault tree analysis; human factors analyses; and safety audits. The need for FSA arises because the combinations of potential hardware and human failures are so numerous that a major accident hardly ever repeats itself. A strategy for risk management must therefore address the entire spectrum of possibilities.

17.4 In accordance with the usage of the main witnesses in this passage of evidence, I shall use the term "formal safety assessment", or FSA, to mean the process of assessment and "an FSA" to mean the output from this process and in particular an assessment essentially equivalent to a Safety Case. It is with this latter that I shall be primarily concerned in the first part of this chapter.

Current use of FSA offshore

17.5 Some companies operating in the North Sea already produce FSAs for major projects. Dr M S Hogh, Manager of Projects and External Affairs, Group Safety Centre, BP International, described the formal system used within BP. There is a formal Project Review Procedure conducted at 6 distinct stages in the course of a project, starting with definition and feasibility and going through to operation, in which independent audit teams seek to identify any outstanding safety issues. There is a formal requirement to carry out HAZOP studies at the detail design stage and the results are scrutinised by the audit team. FSAs were also described by Mr R E McKee, Chairman and Managing Director of Conoco (UK) Ltd, who stated that since Piper a separate group had been created to deal with this.

17.6 The value of an FSA to the company was illustrated by the Engineering Safety Plan for the Southern Basin Gas Development, or V Fields project, described by Mr M Ferrow, Manager, Safety and Quality Assurance, Conoco (UK) Ltd. The development involved a number of gas fields some 50 miles east of the Lincolnshire coast. The exercise was modelled on the Norwegian concept safety evaluation (CSE), a form of FSA carried out at the conceptual stage. The objectives were to demonstrate the safety and reliability of the design; to detail the operational requirements and limitations; and to provide the basis for continuing safety assurance after handover. One outcome of the work was a systematic, documented review of all significant accident scenarios and the associated precautions. Another was a lead in to the operating group of all the issues which the design group felt were important for safety. Some 500 operating practices were derived from the work. The documentation comprised in its detailed form some 11 volumes. The value of the plan was demonstrated, when, following Piper, the company reviewed its safety precautions. The availability of the plan documentation made this a relatively straightforward exercise.

17.7 As his own title indicated, Mr Ferrow regarded safety and quality assurance (QA) as linked. He described FSA as a subset of quality assurance. The in-house quality assurance system was used to ensure that findings of the V Fields study just described were properly closed out.

The CIMAH model

17.8 I now turn to consider the role of an FSA in the regulatory regime. The Inquiry heard of 2 existing models for this, the onshore Safety Case and the arrangements in the NCS. The Safety Case was described by Dr A D Sefton, a factory inspector based at Sheffield and leader of the HSE's Hazardous Installations and Transport of Dangerous Substances National Interest Group.

17.9 Onshore major hazard installations are subject to the CIMAH Regulations. Reg 7 requires that the operator should provide the HSE with a written report on the safety of the installation. The report is commonly called the Safety Case. These regulations had their origins in the Flixborough disaster in 1974 and the work of the Advisory Committee on Major Hazards (ACMH) and in the Seveso disaster. They effect, and are confined to, the implementation of the EC Directive on Major Accident Hazards, the so-called "Seveso" Directive. They require demonstration of safe operation (Reg 4), notification of major accidents (Reg 5), a written report (the Safety Case) (Reg 7), updating of the report (Reg 8), an obligation to supply the HSE with further information (Reg 9), preparation of an on-site emergency plan (Reg 10) and provision of information to the public (Reg 12). There are also requirements on the local authority to prepare an off-site emergency plan (Reg 11).

17.10 The contents of the written report are specified in Schedule 6 of the regulations. The 4 main headings relate to information on every dangerous substance involved in the activity; on the installation itself; on the management system; and on the potential major accidents. The information required on the management system includes the staffing arrangements; the arrangements made to ensure that the means provided for safe operation are properly designed, constructed, tested, operated, inspected and maintained; and the arrangements for training. That required on the potential major accidents includes the potential sources of a major accident and the conditions or events which could be significant in bringing one about; the features of the plant which are significant as regards potential for a major accident or its prevention or control; the measures taken to prevent, control or minimise the consequences of a major accident; and the emergency procedures.

17.11 In the first instance the Safety Case is a means by which an operator demonstrates to itself the safety of its activities. The value of such a demonstration was illustrated in the evidence of Mr Ferrow concerning an FSA which I have already mentioned.

17.12 The Safety Case also serves as the basis for the regulation of major hazard activities, as described by Dr Sefton. Existing major hazard installations were already subject to the Health and Safety at Work etc Act (HSWA) and even before the CIMAH Regulations had been the subject of attention by the local inspector. A CIMAH site is normally visited annually. On receipt of a Safety Case the HSE first checks to ensure that all the information required is provided and to identify any matter of immediate concern. The report is then assessed by a multi-disciplinary team including specialists from HSE's Technology Division, the local area inspectors and as necessary local specialists in the Field Consultant Groups. Any matters of concern are then taken up by letter or by visit. Following this initial response, the report constitutes an important input into the inspection strategy and provides a basis for selecting areas which should receive priority attention. Examples cited by Dr Sefton were the use and maintenance of an item of hardware such as pressure relief devices or a procedural matter such as operating instructions. In the course of in-depth inspection of these items inspectors would always test management and organisation of the installation by reference to any failings detected. Many operators have reported that they found the exercise of producing a Safety Case valuable. Often it would be the first time that a report had been made of the major hazard aspects of the installation. Many stated that the exercise had led them to make changes in their approach and improvements to systems and procedures. Dr Sefton was at pains to point out that the Safety Case was not a licensing or approval system, which might be thought to transfer some of the responsibility to the licensing authority. He was not even sure that the HSE "accepted" the report. What it did was to satisfy itself that the information provided complied with that required and then use that information in its inspection; if there were any serious concerns arising out of the report, it would take them up.

17.13 With regard to the level of expertise required within the company to prepare the Safety Case, the guidance notes state:

> "A partial answer is to suggest that if a manufacturer was unable to meet most if not all of the aims of the Safety Case set out in para 106 by using his own staff, doubts would arise about his competence to manage a major hazard activity ..." (para 114).

In practice Safety Cases submitted are for the most part prepared by the operator's personnel, although some use is made of consultants for specialist work such as consequence modelling, particularly by smaller companies. In assessing the Safety Case, the HSE is able to bring to bear the full range of expertise required. It possesses this expertise in-house. However, it does make use of consultants to assist with peak workloads.

17.14 The Safety Case is concerned with management and software as well as with hardware, as indicated by the information on management and management systems required in para 4 of the Schedule. Amplifying these requirements Dr Sefton stated:

> "Information should be given which details operation and revision of safety policies; the setting or adoption of design and construction standards; quality assurance arrangements, operating procedures, training, management supervision, monitoring, staff welfare and management structure. All these separate elements are necessary to describe fully a system of management control and the report should give some indication of activity within every element. Control in the above spheres of activity requires:
>
> > (a) identification of work required to achieve the desired objectives; (b) the establishment of standards for described activities; (c) performance measurement to assess the degree of compliance with standards; (d) evaluation of performance

> over time which is communicated to accountable persons; and (e) the means to correct deficiencies in performance standards."

17.15 Dr Sefton was questioned on the way in which HSE goes about assessment of management and management systems. He replied that it was not possible to separate hardware and software concerns in the manner implied in the questioning. Scrutiny of preventive mechanisms might reveal weaknesses in management controls. Any perceived deficiencies in this area would be taken up by the local inspector. He stated:

> "It is one of the skills of inspectors, to be able to interrogate the operations of companies to look not only at the hardware that is easy to see and easy to look at, but to get under the skin of a company, to ensure that they are setting the appropriate standards, that they do know what are the potential problems that they have, and that they are monitoring and assessing what they are and what they are doing. Much of the training of inspectors is associated with that. You cannot have one without the other. You cannot simply look at the hardware; you have to look closely at the management control of that hardware and of the hazards associated with it."

Asked whether an inspector would take the matter as high up the management tree as necessary, Dr Sefton replied:

> "I think if we were convinced that there were failures of management we would go very quickly to the very highest level of management. I do not think inspectors would delay going to see and deal with the highest level of management. Once they had evidence of management failings it is no good talking to a foreman or works manager if the failing is a failing of the direction of the company. The great skill of inspectors, I suggest, is identifying quickly the failings that are leading to inadequacies on the ground and identifying where in the overall management structure the weakness is and homing in on it as quickly and effectively as possible."

If the local inspector required assistance on matters of management, he could call for specialist advice from the APAU.

17.16 The HSE witnesses clearly thought that the CIMAH Regulations had been a success. Mr Rimington called the regulations "a major step forward", but also said that when they were first brought in, he could not have said with confidence that they would produce the results which they had in fact produced. Dr Sefton too thought the regulations had largely achieved their aims. He believed this success owned much to the high level of technical expertise which the HSE had deployed and which the industry respected. It had shown an understanding of the issues of managing industry. Another HSE witness, Dr A F Ellis, Deputy Chief Inspector of the Technology Division, which includes the Major Hazards Assessment Unit (MHAU), was asked whether he thought the Safety Case was working out well, and in particular the role of quantification; he believed it was.

The Norwegian model

17.17 The Norwegian offshore regime, described by Mr Ognedal, has developed in the same general direction. The requirement for some form of risk evaluation is a long-standing one. The Regulations Concerning Safety Related to Production and Installation in 1976 contained a requirement that if the living quarters were to be located on a platform where drilling, production or processing of petroleum was taking place, a risk evaluation should be carried out. It was Mr Ognedal's recollection that at this date such an evaluation would have been mainly qualitative. In 1976 the NPD rejected a design for the Statfjord B platform as a copy of Statfjord A and required the living quarters to be put on a separate platform. In 1977 Mobil put forward a new concept of a platform integrated but with separation of the accommodation by a 6 hour rated firewall, which was accepted. The Statfjord B exercise influenced the legislation which followed.

17.18 The move to a more quantitative approach came with the Guidelines for Safety Evaluation of Platform Conceptual Design published in 1981. These centred around the provision of a shelter area, required the conduct of a concept safety evaluation (CSE), and specified numerical acceptance standards. A design accidental event was defined as one which did not violate any of the following 3 criteria:

> "(a) at least one escape way from central positions which may be subjected to an accident, shall normally be intact for at least one hour during a design accidental event
>
> (b) shelter areas shall be intact during a calculated accidental event until safe evacuation is possible
>
> (c) depending on the platform type, function and location, when exposed to the design accidental event, the main support structure must maintain its load carrying capacity for a specified time." (clause 5.2).

The following categories of event were required to be evaluated, where relevant: blowout; fire; explosion and similar incidents; falling objects; ship and helicopter collisions; earthquakes; other possible relevant types of accident; extreme weather conditions; and relevant combinations of these accidents. It was required that based on these design accidental events a set of design accidental effects should be specified, expressed in terms of heat flux and duration; impact pressure, impulse or energy; and acceleration. Explicit numerical acceptance criteria were stated:

> "In practical terms, it may be considered necessary to exclude the most improbable accidental events from the analysis. However, the total probability of occurrence of each type of excluded situation (see 4.1.3) should not by best available estimate, exceed 10^{-4} per year for any of the main functions specified in 5.2, 5.5 and 5.6."
>
> "This number is meant to indicate the magnitude to aim for, as detailed calculations of probabilities in many cases will be impossible due to lack of relevant data." (clause 4.2.2).

In effect, therefore, since there were some 9 categories, the requirement was that the frequency of the totality of events more serious than design accidental events, which are termed residual accidental events, should not exceed 9×10^{-4} per year, or in round figures 10^{-3} per year. These numerical criteria have been applied with flexibility.

17.19 The role of this FSA in the regime, as described by Mr Ognedal, is that the Guidelines are superior to the other, more prescriptive regulations. He confirmed that this meant that if a regulation laid down a particular requirement but risk analysis indicated that it was not necessary, an exemption from the regulation could be granted. Conversely, the analysis might show that the minimum requirement in the regulation was not sufficient.

17.20 The 1981 Guidelines were still in force but were to be replaced in 1990 by the Regulation on Risk Analysis, currently in draft. These new regulations require that safety analyses should be carried out through all phases from concept to operation, but the choice of the methods would be left to the operator. The new regulations would no longer contain a stated numerical acceptance criterion. Instead, the operator would be required to establish its criteria before the start of the conceptual design. Mr Ognedal stated that one of the reasons for the change was to "avoid further number game discussions". He affirmed that in making this change the NPD was not abandoning its original approach but building on it. The acceptance criteria required would not be less stringent. The whole philosophy underlying the legislation is one of progressive improvement.

17.21 The system operated by Statoil was described by Mr O J Tveit, a senior engineer with the company. In addition to carrying out a CSE at the conceptual stage, a total risk analysis (TRA) is performed at the detail design stage; this latter is an assessment developed by Statoil itself.

DEn practice and intentions

17.22 Prior to Piper there was no requirement in the British offshore regime for an FSA dealing with the whole range of major hazards. When I look at what the DEn had done, including the regulations and the associated guidance, to which certifying authorities work, and at the evidence given by Mr Petrie, there seems to me to be an imbalance between the attention given to the threats to the platform from environmental conditions and ship collision and those from the hydrocarbons. The approach which Mr Petrie described did not impress me as an effective one for the identification and control of the major hazards from the hydrocarbons at high pressure. He agreed that a large proportion of the inspection effort was in fact concerned with high pressure plant and that familiarity with pressure systems was a prime skill required in an inspector, yet his inspectorate was not strong in this area.

17.23 That this failure affected large parts of the UKCS was illustrated by the evidence of Mr A J Adams, a Principal Pipeline Inspector in the Safety Directorate of the PED, that prior to Piper there were some 70 risers, out of about 400 covered by the new ESV regulations, which did not have a true ESV and which required changes to the valve itself or to its actuator, control logic, etc, to make it such.

17.24 The DEn presented a discussion document on Formal Safety Assessments of Offshore Installations, which was spoken to by its author, Mr E J Gorse, a Principal Inspector and head of the section dealing with the auditing of the work of the certifying authorities. The document was in 2 parts, the first dealing with the principles of FSA and the second with factors to be taken into account, and was meant to cover both hardware and management aspects. The first part listed installations to be covered, hazards to be considered, techniques which might be used and project stages at which assessments should be carried out. It stated that there should be written procedures for undertaking FSA and that the outcome of the FSA should be documented and subject to independent regulatory review. The second part gave more detail of some of the techniques, including HAZOP and QRA. In effect, therefore, the document created a requirement for something analogous to the onshore Safety Case. However, the document was perceived to be weak on management and human factors aspects and Mr Gorse was questioned at length on this.

17.25 With regard to the regulatory review of such an FSA, it was the intention that the hardware, or technological, aspects, should be integrated into the certificate of fitness regime and that this aspect of the safety assessment should be taken into account when the certificate was issued. The assessment of the hardware aspects of the FSA would be done by the certifying authority. The importance of covering management as well as hardware was recognised, but the Department was still working on how this aspect should be assessed; it was "early days". An engineer was being seconded from the APAU on a permanent basis to assist. There was as yet no concluded view except that the assessment of written procedures and human aspects would be subject to some form of independent assessment. Questions were also asked on the expertise available within the DEn on FSA, QRA and management assessment. Mr Gorse stated that the Department did not possess the expertise to cover the whole range of FSA and that it had no expert on QRA or on management aspects.

17.26 The introduction to the discussion document described it as a major step forward, but despite the similarity between the FSA described and the onshore Safety Case, the document made no reference, even in the bibliography, to the CIMAH Regulations. Mr Gorse said that there were so many references which might have been quoted and it was necessary to be selective. This is in line with Mr Petrie's attitude to the CIMAH Regulations which I consider in Chapter 22.

17.27 It was made plain by Mr Petrie that in the regime which he envisaged an FSA would complement rather than replace regulations. As far as concerns the kind of regulation, he was in principle in favour of regulations of the goal-setting type.

However, although the Department had reviewed the body of regulations, it had not started on the task of formulating goal-setting regulations. No existing regulations had as yet been amended to goal-setting form. Whilst manpower constraints were a factor in this, another factor was the question of the balance between goal-setting and prescription. His position was that he was reluctant to lose the ability to make prescriptive regulations, though they would not be used unless there was a clear need for them. In any case he thought the difference was not clear-cut. It appeared that the Department continued to be attached to prescription of hardware. This was illustrated by the discussion document on Fire and Explosion Protection, considered in Chapter 19. This document was intended to fit in with a regime which was moving towards use of FSA. It still contained numerous prescriptive requirements for hardware, albeit some were expressed as default requirements. A similar approach underlay Mr Petrie's comments on guidance notes. He saw these as setting a minimum standard. It was put to him that there seemed to be an iron law that material intended as guidance came to be interpreted as mandatory. He agreed there was frequently a misconception about the status of guidance, but believed the present situation struck the right balance.

17.28 Mr Gorse confirmed that the FSA envisaged in the discussion document would apply to mobile as well as fixed installations, in fact to all installations, including floating production vessels and multi-purpose vessels.

Parties' submissions on an FSA

17.29 UKOOA submitted that the operator should be required to carry out an FSA, equivalent to a CIMAH Safety Case, in a planned manner at specific stages of the project such that the findings could be incorporated into the design or any proposed change in operating activity. The operator should define the design accidental events and the acceptance criteria. Quantitative methods should be used where appropriate. This FSA should be done by company personnel with the outside consultants confined to specialised work such as consequence analysis or QRA. Specifically, it was submitted that the following features should be dealt with in this manner:

> Management systems; need for a safe haven and its location, protection and facilities; location of accommodation and its protection against smoke; location and protection from smoke of control room, radio room, and emergency command post; number, location and protection of risers; subsea isolation valves; fire and gas detection systems; protection against fire and explosion; escape routes and embarkation points; evacuation and escape system.

17.30 Further, UKOOA proposed that the regime should move to one based entirely on the single regulation for an FSA and that other regulations would then be unnecessary. However, if this was not acceptable, the regime should at least cease to be based on prescriptive regulations and should move to one based on goal-setting regulations with compliance demonstrated by FSA.

17.31 The submissions of the Trade Union Group, the Piper Disaster Group and the Contractors' Interest all supported the concept of an FSA or Safety Case applicable to both new and existing installations, though they differed in the extent to which mandatory QRA should be required.

17.32 The Trade Union Group submitted that the Safety Case should be brought in forthwith by implementing the CIMAH Regulations offshore. This proposal was spoken to by Dr V C Marshall, a consultant, and its implications were examined with Dr Sefton.

An offshore Safety Case

17.33 I am convinced by the evidence that an FSA is an essential element in a modern safety regime for major hazard installations and that it has a crucial role to play in assuring safety offshore. Not only was there a consensus on this but also a large measure of agreement on how the matter might be taken forward. This consensus was confirmed by the parties' submissions. I consider that this FSA should take the form of a Safety Case.

17.34 The regime should have as its central feature demonstration of safe operation by the operator. To this end there should be a requirement for a Safety Case, based broadly on the CIMAH model for onshore installations. The CIMAH and Norwegian models show that this is both practical and desirable, the DEn was moving in this direction and it was in essence what UKOOA proposed.

Nature and purpose of Safety Case

17.35 Primarily the Safety Case is a matter of ensuring that every company produces an FSA to assure itself that its operations are safe and gains the benefits of the FSA already described. Only secondarily is it a matter of demonstrating this to the regulatory body. That said, such a demonstration both meets a legitimate expectation of the workforce and the public and provides a sound basis for regulatory control.

17.36 Both the evidence which I have already described and that which I will describe later make it clear that safety is crucially dependent on management and management systems. The Safety Case should show among other things that the company has a suitable safety management system. I defer further consideration of this aspect to Chapter 21.

17.37 The offshore Safety Case, like that onshore, should be a demonstration that the hazards of the installation have been identified and assessed, and are under control and that the exposure of personnel to these hazards has been minimised. I envisage that the general approach of the offshore Safety Case will be similar in many respects to that onshore. However, there will also be significant differences. In the offshore case the demonstration that the hazards are under control should include as a central feature a demonstration that the threat from these hazards to the arrangements for refuge for, and evacuation and escape of, personnel in the event of an emergency, is under control. The Norwegian regime follows this approach. I consider these matters further in Chapters 19 and 20.

17.38 An installation needs to be self-sufficient in providing protection for personnel. The Safety Case should demonstrate that it possesses a temporary safe refuge (TSR) and escape routes which will endure for a sufficient time to allow safe and full evacuation. I consider these matters further in Chapter 19. It is difficult to see how such a demonstration could be done other than by QRA and accordingly it is proposed that QRA be required. This requirement therefore goes beyond what is required onshore. It is clearly practical, since it is included in many onshore Safety Cases and is the basis of the Norwegian CSE. It is considered justified for offshore installations because large numbers of people not only work but live on them; the risks on the installations are relatively high; it is expected that the proportion of cases where the benefit of the QRA is marginal will be outweighed by those where it is substantial; the installations are much less heterogeneous than those onshore; they are substantial installations which justify the resources required to perform the QRA; and, not least, because in one tragic instance the hazards have been realised. It is proposed that the requirement should be for the estimation of the frequency with which there occur accidental events exceeding the design accidental events. In general, therefore, this is a requirement for explicit estimation of both frequency and consequences. However, it may be possible for certain hazards, perhaps even an appreciable proportion, to meet the requirement by a calculation of consequences only which makes it unnecessary to calculate the frequency. I consider QRA further in paras 17.48 *et seq.*

17.39 I have considered but rejected the proposal that a version of the CIMAH Regulations should be applied offshore with only those changes clearly essential for such application. It will be apparent that the offshore Safety Case which I envisage is sufficiently different from that onshore that this would not be the right way to proceed.

17.40 The Safety Case should normally be prepared primarily by company personnel. I accept the argument that a company which is competent to operate an offshore installation should be competent to produce the Safety Case. Moreover, involvement of the company's own personnel is the best way to obtain the full benefits within the company and for the purpose of dialogue with the regulators. Similarly, it is desirable that the operator should deal itself with the QRA aspects of the Safety Case rather than contract them out. Familiarity with the system is essential for good QRA and companies often prefer to employ engineers familiar with the system and train them in QRA techniques rather than to call in risk analysts and acquaint them with the system. Moreover, use of company personnel allows expertise to be built up in-house. On the other hand consultants have a role in bringing an independent perspective and assisting with novel and specialist techniques.

17.41 The Safety Case should apply to both fixed and mobile installations. The question of the application of an FSA to mobiles was explored and no impediment was identified. It was the intention of the DEn to make the FSA which they proposed applicable to mobile as well as fixed installations.

Safety case for new installations

17.42 Onshore there is a requirement for a Safety Case both for new and existing installations. I believe that the same should apply offshore. There is little dispute about the benefits to be gained from a Safety Case for a new installation. For such an installation there is clearly great value in some form of CSE. The initial form of the Safety Case should have this character. As the design develops so should the Safety Case, taking on more the aspect of a TRA. It is intended that in the final form in which it is submitted the Safety Case should be based on detail design information. I note that the CIMAH Regulations require the onshore case for a new installation to be submitted not less than 3 months before the commencement of the activity (Reg 7(1)), which indicates that the case will contain detail design information.

17.43 It will be for the regulatory body to specify the precise stage in the project for submission of the Safety Case. It is clearly desirable that some preliminary assessment of matters related to the Safety Case be submitted early in the project, preferably on application for Annex B consent. The regulatory body should consult with the industry on this.

Safety Case for existing installations

17.44 I consider that a Safety Case should also be required for existing installations. This is the requirement onshore. The risks offshore are clearly no less. It is not acceptable that installations should be operated without a thorough assessment of what those risks are. While certain options are foreclosed once an installation is built, there will generally be a variety of measures, both hardware and software, which can be taken to improve safety if the risks justify them. Since in this case the full detail design information is available, the Safety Case will have the character of a TRA.

17.45 Safety Cases for existing installations should be brought in as rapidly as practicable, on a schedule to be determined by the regulatory body.

The continuing Safety Case

17.46 The Safety Case should be seen not as a one-off exercise but as part of a continuing dialogue between the operator and the regulatory body. I have already described the increasingly central role assumed by the Safety Case in the onshore regime for major hazards and envisage a similar role for the offshore Safety Case. It follows that the Safety Case needs to be kept up-to-date. It should be updated at regular intervals or if there is any material change affecting it. The most fundamental change will be a change of operator; an updating of the Safety Case is essential in this case. An updating should also be triggered if there is a major emergency on the installation, with or without precautionary evacuation; if there are major modifications; or if there is some major technological innovation or the discovery or improved understanding of a major hazard which might justify it.

17.47 Given that the Safety Case should be updated if there is a major modification to the installation, there will be a need for the regulatory body to define what constitutes a major modification for this purpose.

Quantitative risk assessment

Role and status of QRA

17.48 Accounts of QRA were given to the Inquiry by Dr Cox and Dr Hogh. I deal here with just one or two points in order to make clear the role which I envisage for it as an aspect of an FSA.

17.49 I endorse the emphasis placed by both witnesses on the fact that QRA is only one input to the decision-making process, though an important one. Its strength is that it provides a structured, objective and quantitative approach. It gives a better understanding of the hazards and of the measures needed to control them. The operator is required by the HSWA to take all reasonably practicable measures to ensure safety. QRA is a prime means for the operator to demonstrate firstly to itself and secondly to the regulator that it has done this and thus provides a good basis for the dialogue between operator and regulator. It should not be used, however, in isolation or as an automatic mechanism for decision-making. The point is made in one of the documents on QRA published by the HSE, "Quantified Risk Assessment: Its Input to Decision-making", quoted by Dr Cox:

> "QRA is an element that cannot be ignored in decision-making about risk since it is the only discipline capable, however imperfectly, of enabling a number to be applied and comparisons of a sort to be made, other than of a purely qualitative kind. This said, the numerical element must be viewed with great caution and treated as only one parameter in an essentially judgmental exercise." (para 10).

17.50 I am aware that QRA has been a matter of some controversy. There was general agreement that it is a complex subject. However, as Dr Hogh said, complexity is not synonymous with difficulty. Whatever may have been true some 10 years ago, both Dr Cox and Dr Hogh considered that there was now no serious problem in obtaining the data required to estimate frequency or models to estimate consequences; the area of human factors was acknowledged to be one where improved techniques were desirable. Dr Hogh in fact described QRA as a normal tool of project management. In giving this evidence both witnesses were referring to the application of QRA offshore as well as onshore. I am satisfied that there is no impediment to the use of QRA offshore. I agree, however, that it is desirable to be quite open about the uncertainties inherent in QRA and to take these into account in its conduct and evaluation, using the methods of sensitivity analysis described by the witnesses.

Regulatory uses of QRA

17.51 HSE's view of the role of QRA in the regulatory regime was put by Dr Ellis and Dr R P Pape, Head of the Major Hazards Assessment Unit. For nuclear installations QRA is a normal part of the Safety Case. It does not have this status for process plants.

17.52 HSE accepts that there is some controversy about the use of QRA and has recently published 3 documents to make its views known and to stimulate discussion. Dr Ellis quoted from the same publication as Dr Cox:

> "It is therefore important to be able to predict what could happen and as far as possible how likely or unlikely it is - as well as recording what has actually happened, and then to see how best to control, and if possible reduce, the risks that are identified. For this QRA is an indispensable element, but one to be used with caution and not applied mechanistically to demonstrate compliance with legislative requirements." (para 15).

17.53 HSE's own interest in QRA arises because it is an organisation which regards it as important to found any legal or political judgement as firmly as possible on a rigorous scrutiny of the facts, using the available techniques. It is conscious that it is dealing with technologically based industries or scientifically numerate organisations which expect a structured and logical approach. Equally, it is conscious that not all health and safety problems can be reduced to mathematical terms. Nevertheless, it believes that quantification, or in some cases just the attempt to quantify, imposes a discipline beneficial to safety. Dr Ellis drew a distinction between quantification and full QRA. He agreed there was enthusiasm in the HSE for the former, while for the latter there was "cautious enthusiasm". In some cases the full process of QRA is not necessary. The quantification of the potential consequences of an accident may be sufficient. HSE's views were much stronger on quantification of consequences than on full QRA. He quoted as an example of HSE's attitude to quantification the following extract from the guidance notes to the CIMAH Regulations:

> "Whilst it may be possible for manufacturers to write a safety case in qualitative terms, HSE may well find it easier to accept conclusions which are supported by quantified arguments. A quantitative assessment is also a convenient way of limiting the scope of a safety case by demonstrating either that an adverse event has a very remote probability of occurring or that a particular consequence is relatively minor." (para 112).

Dr Ellis stated that while QRA might not be specifically required by regulations under the HSWA, the general requirements of that Act could imply a need for QRA where it is likely to be worthwhile. He agreed that in order to decide whether an installation was acceptably safe, it is reasonable to want to know the level of risk which it poses. Asked whether the HSE had the powers to require a QRA from an operator, Dr Ellis said the question was difficult to answer; it had never tried to enforce such a requirement.

17.54 The selective use of QRA by regulatory bodies was supported by Dr Hogh as providing a framework for dialogue. However, the industry had been resistant to the blanket application of QRA to existing onshore major hazard installations as a requirement of the CIMAH Safety Case. It was an essentially futile exercise unless carried out for a defined purpose.

Acceptance standards for QRA

17.55 The practice of QRA requires acceptance standards. There is more than one form of acceptance standard. Examples are accommodation endurance times, equipment availability targets and risk criteria. As far as risk criteria are concerned, I would expect the general approach to be that described in the HSE discussion document on the tolerability of risk and shown in Fig 17.1, which was introduced by Dr Hogh and endorsed by the other witnesses. The upper line is that above which risk is intolerable and action must be taken, the lower region is that in which risk is negligible and no action is required, while in the intermediate region the requirement is to reduce the risk "as low as reasonably practicable" (ALARP). This latter implies a cost-benefit analysis. In formulating risk criteria, due regard should be had to risk aversion, the aversion which society has to major accidents. Risk aversion should receive recognition not only in setting the upper bound of what is acceptable, but in the cost-benefit analysis.

17.56 It is normal practice that acceptance standards for QRA are set by the operator. This accords with the fact that QRA is generally an activity undertaken voluntarily

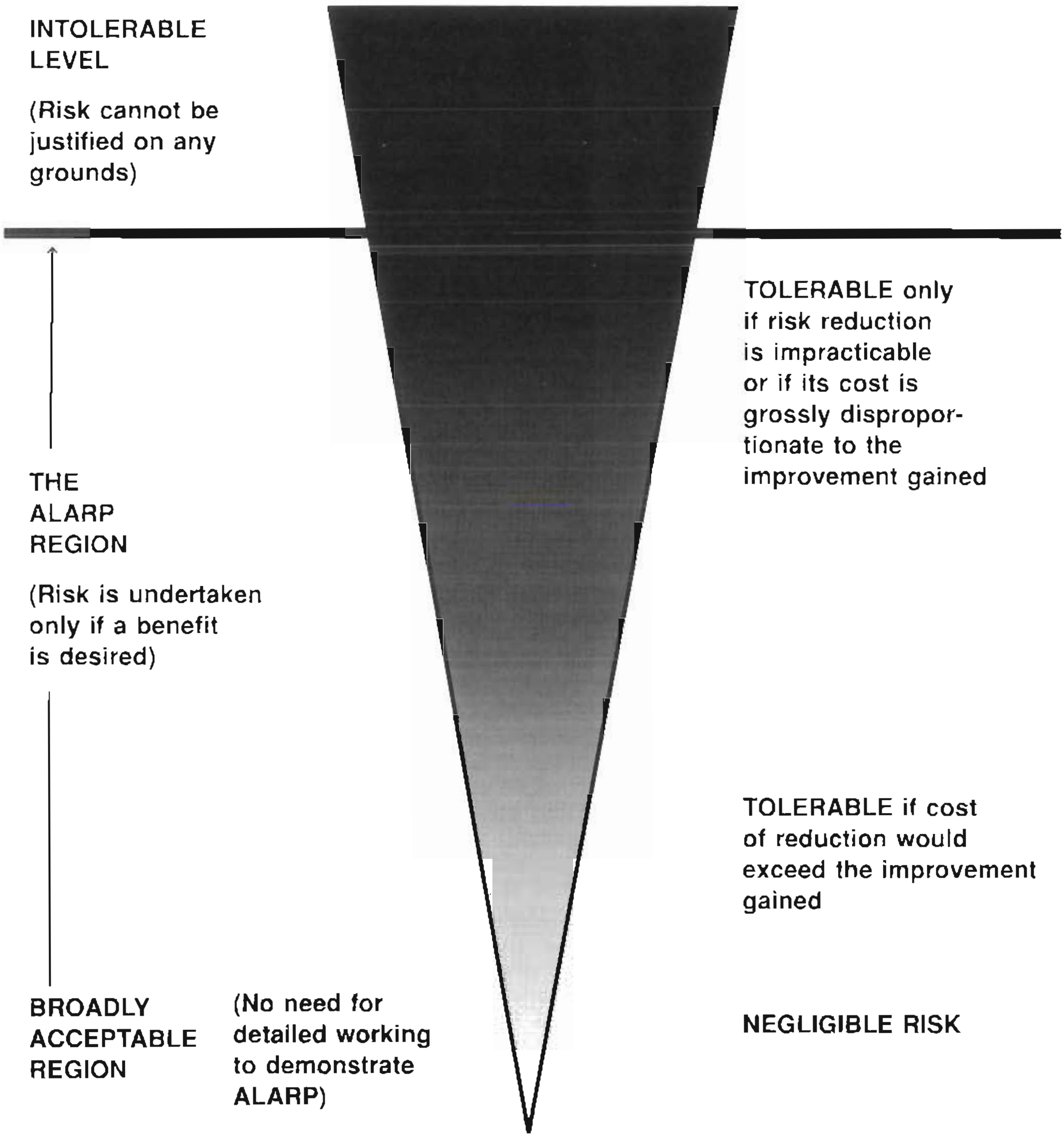


Fig. 17.1 Levels of risk and the ALARP principle.

to demonstrate compliance. The HSE has published documents on risks and risk criteria but as guidance. I consider that this is the approach which should also be adopted offshore.

17.57 I propose, however, one exception to this general principle. The Safety Case involves a demonstration that the frequency of events which threaten the endurance of the accommodation, or TSR, will not exceed a certain value. In order to provide at least one fixed point in the regime, both the minimum endurance and the frequency with which there is a failure of such endurance should be specified by the regulatory body, at least in the first instance. This proposal is described further in Chapter 19.

17.58 I fully endorse the view expressed that acceptance standards, including risk criteria, should be interpreted with flexibility by the regulatory body.

17.59 This is not to say, however, that the acceptance standards should not be tough; they should be. In the regime proposed these standards will be one of the main pressures for improvement. Unless they are set sufficiently high, they will not be effective. It is my intention that the regulatory body should require acceptance standards which will result in real improvements in safety. In particular, there needs to be a reduction of the risks from major accidents. The Inquiry did not go into risk comparisons, but it is clear that the historical risk to the workforce in the UKCS is now dominated by a single accident, the Piper disaster. A similar situation pertains in the NCS following the Alexander Kielland disaster in which 123 died.

17.60 Whilst in general QRA requires some standard of comparison, it does not always involve absolute risk criteria. The point was made that there is a distinction between inherent features such as layout and add-on features such as a protective system. It was not possible not to have a layout, the question is to choose between different layouts, and QRA may be used to assist the choice by comparing safety aspects, without necessarily using absolute risk criteria. On the other hand a protective system is in a sense an optional extra and in this case the use of QRA to aid this decision implies the use of some absolute criterion.

Application of QRA to existing installations

17.61 As I have already stated, I propose both that the Safety Case should involve QRA and that there should be a Safety Case for existing as well as for new installations. It therefore follows that I am proposing QRA for existing installations. I have already mentioned Dr Hogh's comment that the industry had been resistant to the blanket application of QRA to existing onshore major hazard installations as a requirement of the CIMAH Safety Case. I am satisfied that the QRA in the Safety Case which I propose has a well-defined purpose. In brief, it is to assess the risks, to identify and assess potential safety improvements, and to ensure that the TSR meets the standard set.

Safety assessment and regulations

17.62 I now turn to consider some other aspects of FSA in the regime. So far I have deliberately confined myself to the question of an FSA, or Safety Case. I now consider FSA in its more general sense, and in particular as an activity which may be undertaken to demonstrate compliance with legislation.

17.63 The regime should not rely solely on the Safety Case. I reject the argument of UKOOA that the only regulation should be one requiring an FSA as going much too far. In general, any large system or problem is usually best handled by breaking it down into more manageable parts, in some form of hierarchy. I propose that the regulation requiring the Safety Case should be complemented by other regulations dealing with specific features. This is in accordance with the approach taken onshore, where the regulations continue to exist alongside the Safety Case, and this not just for historical reasons but as a matter of policy. With regard to the type of regulation, the Safety Case would sit well with regulations which set goals rather than prescribe solutions. These regulations would complement the Safety Case by setting intermediate goals and would give the regime a solidity which it might otherwise lack.

17.64 Construction of the installation, fire and explosion protection, and evacuation, escape and rescue are all areas where I consider it appropriate to retain regulations, though in goal-setting form. One method of demonstrating compliance would then be by FSA.

17.65 Since it may appear that these are all areas which might be covered by the Safety Case, it may be helpful to give an example of a specific requirement of a goal-setting regulation. It is proposed that the regulation dealing with fire and explosion protection should contain a requirement for a reliability assessment of the fire pumps. The precise means by which fire pump availability is to be achieved would be left to the operator, but it should be able to demonstrate independently of the Safety Case that, at least for all eventualities other than disablement by the accident itself, availability targets have been specified and will be met. While arguably this, like almost everything else, could be left to the Safety Case, it is inconceivable that there should not be such an assessment, and it is therefore entirely appropriate to cover it by means of a regulation. What the Safety Case contributes is a set of major hazard accident scenarios against which the design of the system can be further assessed.

17.66 It is envisaged that the operator will demonstrate compliance with a goal-setting regulation by a variety of means. It may do so by reference to guidance, or to in-house standards, or to FSA or to some combination of these.

17.67 The transition to the new regime cannot take place overnight. I propose that there should be a regulation requiring a Safety Case and that this should be complemented by a limited number of further, defined regulations, but beyond this it must be for the regulatory body to develop the regime in accordance with the principles outlined. As regards existing regulations and guidance during the transition, I do not envisage any wholesale revocation of regulations or withdrawal of guidance, but suggest that the regulatory body advise the industry of those regulations to which it is prepared to grant exemption in the light of a demonstration of a satisfactory alternative in the Safety Case.

Safety assessment in the regime

17.68 The operation of the regime would then involve FSA

(i) in compliance with the regulation for a Safety Case;

(ii) in compliance with any other regulation requiring a safety assessment;

(iii) as a means of demonstrating compliance with a goal-setting regulation; and

(iv) as a means of demonstrating compliance with the HSWA.

In the first two cases the safety assessment would be mandatory, in the last two it would be voluntary.

17.69 In some cases a goal-setting regulation will contain a requirement that the design should be subject to an analysis to demonstrate that it is satisfactory. I describe below my proposals that there should be analyses of fire risk and of evacuation, escape and rescue and I have already proposed that there should be a Safety Case. I envisage that the Safety Case should test the design in respect of major hazard accident scenarios and that the analysis should test it at least in respect of all matters short of those scenarios. I have given above (para 17.65) the example of fire pump availability as part of a fire risk analysis. Similarly, an analysis of evacuation, escape and rescue would test among other things the arrangements for man overboard (MOB) incidents.

Safety assessment and the regulatory body

17.70 My proposal to assign to FSA in general and to the Safety Case in particular a central role in the regime has obvious implications for the regulatory body. Although this was considered in the Inquiry largely in relation to the ability of that body to evaluate an FSA, the question is much wider than that. Onshore the Safety Case has come to form the basis for the HSE's inspection activity on major hazard installations. Similarly, offshore the regime which I envisage is one in which the emphasis moves to audit of the operator's systems and in which the Safety Case provides a starting point for such audit. The regulatory body must be one which is not only able to evaluate the Safety Case itself but is at ease with this whole approach.

17.71 However, considering the narrower issue of the ability of the regulatory body to evaluate the operator's Safety Case, it is clear to me that this must be done by a single regulatory body. A strong plea for a single point of contact was made by Mr Ferrow, who argued that the FSA is an integrated whole, comprising hardware and software aspects which interact, and it would not be satisfactory to split the evaluation between different bodies. The weight of the evidence pointed to the need for a single body competent in FSA, confident in its own ability and capable of being flexible, and credible with the industry. The nature of the decisions involved in responding to FSA is such that they cannot readily be delegated and the attempt to do so is liable to result in divided responsibility, excessive caution and undue delays, whereas what is wanted is an authoritative and prompt response. Separation of hardware and software is artificial. It follows that I reject the approach which the DEn was intending to adopt.

Chapter 18

The Prevention of Incidents Causing Fires and Explosions

Introduction

18.1 In order to meet its duty to provide, as far as reasonably practicable, a safe system and place of work an operator has to seek to prevent incidents which can lead to fires and explosions, to mitigate the consequences of incidents which do take place, and to provide a safe method of evacuation and escape and rescue. In this chapter I will examine the first of these, the prevention of incidents.

18.2 The nature of the process fluids in any hydrocarbon plant is such that they will burn readily and, when combined with air, can lead to a mixture which will explode if ignited. Consequently the first objective of any safety policy and programme is to prevent incidents which may cause a loss of containment of hydrocarbons. This is particularly important in the offshore industry as mitigation of the effects of fire and explosions and evacuation or escape of personnel are inhibited by the remoteness and isolation of oil platforms. I will consider the specific lessons which can be drawn from the disaster on Piper in relation to preventing such incidents, with particular reference to the PTW system, the control of the process, the introduction of modifications to a platform process, and the investigation of accidents.

18.3 However important those lessons might be no one incident, even one as disastrous as that on Piper, can point up more than a few important improvements in offshore safety. Equally in practice exactly the same accident hardly ever repeats itself, so management needs to address the spectrum of possibilities and not just seek to prevent recurrences. Accordingly I have in the later part of this chapter examined how offshore operators approach the issue of managing in order to prevent incidents which can lead to emergency situations.

Permit to work systems

18.4 I have set out in earlier chapters that the PTW procedure on Piper failed as a component of a safe system of work. It suffered from deficiencies in regard to the actions taken to suspend a permit, the absence of a procedure for locking off isolation valves, the lack of cross-referencing, the lack of a procedure for handover of permits at shift change, inadequate training of contractors' staff and an ineffective auditing system. Evidence on those aspects of PTW systems was presented by Mr S R Kyle, Environment and Safety Co-ordinator for the Brae Operations of Marathon Oil UK and chairman of UKOOA's working group on permits to work, supported by examples from the procedures of particular operators. Mr G H Davies of the HSE set out the practices in onshore industry, and Mr T J Scanlon, who had been employed by Wood Group Engineering, a major contracting company, gave evidence on behalf of the Contractors' Interests.

Suspending a permit

18.5 The bulk of maintenance work offshore is carried out on day-shifts only, normally extending from 06.00 hours to 18.00 hours. Inevitably there are many tasks that cannot be completed in one day. Additionally there are occasions where work will be interrupted for longer periods, mainly when the platform has to await the supply of spare parts from the shore. It is essential that any PTW system incorporates a procedure to ensure that in such circumstances the equipment being worked on is retained in a safe condition and no attempt is made to use it in operations.

18.6 Mr Kyle explained that the key procedural steps to achieve this are

— at the end of the shift when the work is to be suspended, the Performing Authority should, after inspecting the site, sign the permit to the effect that the work is suspended and return it to the Designated Authority;

— the Designated Authority, or one of his delegated operators, should inspect the site to check that conditions are such that the work may be safely suspended and should then sign the permit accordingly;

— the permit, together with other suspended permits, should be located in a prominent position in the control room or permit office clearly labelled as "suspended";

— to ensure that equipment on which work is suspended is not used the PTW system must be supported by a secure method of isolation (see para 18.10);

— prior to re-issuing the permit the Designated Authority must ensure that the site is inspected again to make certain all required isolations are still in place.

18.7 Mr Davies explained that suspension of PTWs is not a practice widely recognised in the onshore oil and chemical industries and the common practice is for the permit to be properly cancelled and re-issued when work is to resume. Whichever approach is adopted the principle that should apply is that, when work ceases for a temporary period, the equipment must be left in a safe state. While it is not being worked on all the specified precautions, such as isolations, must remain in place and when work is to re-start those precautions must be checked. The importance of this principle was emphasised by a recent survey in the onshore chemical industry which found that in 25% of the PTW systems examined there were inadequate handback procedures.

18.8 I am satisfied that the procedural steps outlined by Mr Kyle are consistent with the principle set out by Mr Davies of the HSE. They are simple to operate in practice and straightforward to incorporate in any PTW system. They should be used in all offshore PTW systems.

Locking off isolation valves

18.9 It was Mr Kyle's evidence that it is essential that a PTW system is supported by a secure method of isolation and that necessary security should incorporate the locking off of isolation valves such that they cannot be accidentally or inadvertently opened. One such method used by Marathon Oil UK and demonstrated to the Inquiry involves a system of locks and key safes, whereby all the keys held by both Designated Authority and Performing Authority have to be returned to the key safe box before the box can be opened and de-isolation effected. Several offshore operators have similar effective methods of securing isolation. Mr Davies was aware that locking off systems are frequently employed in the onshore industry.

18.10 I consider that a physical locking off system should be an integral part of any PTW procedure because of the security it provides against inadvertent or unauthorised de-isolation. Certainly, if such a system had been employed on the Piper platform, it would have prevented the operating staff from opening the isolation valves which admitted condensate to the A condensate pump, which led to the leak of hydrocarbons.

Cross-referencing of permits

18.11 Both Mr Kyle and Mr Davies were agreed that where jobs involving separate teams of people interact, particularly in relation to the isolation of equipment, the permits for those jobs must be cross-referenced one to the other to ensure that no interaction takes place which might threaten the safety of the personnel or the platform. The responsibility for recognising the potential for interaction rests with the Designated Authority who must be supported by a good communication system on a daily basis to ensure that planned critical activities are made known to all affected personnel.

18.12 Where it is necessary for more than one task to be carried out on one piece of equipment or system utilising the same isolations a means of ensuring the integrity of the isolations until all jobs are complete must be established. In addition to cross-referencing the permit forms, a physical means of achieving this should be employed. Various methods are known and available to the industry, such as multiple locks or keys and key safes used in conjunction with the physical locking off methods I have recommended in para 18.10. At the completion of any one task the locking mechanism specific to its permit is removed but de-isolation cannot be effected until all such mechanisms for every permit have been removed.

Handover of permits

18.13 Mr Kyle considered that company procedures should ensure that adequate arrangements are in place for handover between Designated Authorities at shift change, that those should include specifically effective means of communicating the status of all active and suspended permits, and that sufficient time is available to achieve an effective handover. The means of communicating the status of permits may be by permit log books, permit files, or display boards. It would be expected that both Designated Authorities, outgoing and incoming, should review each permit together. Mr Davies' advice was that the handover arrangements should include also that the incoming lead operator sign for the continuation of any permit and no handover should rely on memory alone or be solely verbal.

Training in the PTW procedures

18.14 It was Mr Kyle's experience that PTW systems are only as good as the care and competence of the people who operate them. It is therefore essential that all persons who are required to operate the procedures and the tradesmen who work under permits are adequately trained. Specifically, detailed and formalised training in the PTW system for the platform on which they are to work should be given to both Designated Authorities and Performing Authorities, and they should be formally assessed prior to their appointment. Records of all PTW training should be maintained. Designated Authorities require in-depth training covering all aspects of the PTW system and procedures. Such training would take 2-3 days full time, concluding with a formal written examination. However, examination alone will not guarantee competence and it is important that individuals have demonstrated adequate experience, local knowledge and their ability to discharge their responsibilities competently prior to appointment by the OIM. It was expected that formal training of a similar nature for a Performing Authority would take one day full time. In this case also the appointment should be confirmed by the OIM.

18.15 Mr Davies' view was that formal training in the operation of the PTW system was a necessity and the system was unlikely to succeed in providing a safe system of work if it relied entirely on on-the-job training by another, however experienced, operator and if there was no formal assessment of how the training had been absorbed.

18.16 Mr Davies explained that onshore particular attention has to be paid to the training of contractors' personnel who may not be familiar with the plant's hazards, with the work procedures or to any extent with the detailed equipment. That training should be provided by the occupier of the installation - the operator in offshore terms - and the training for contractors should be specific to the installation on which they will work. This view was strongly supported by Mr Scanlon who argued that permits and all they entail should be explained by the operators as "contractors are not the best people to do that". Mr Kyle's own company, Marathon Oil, require the same training and assessment of contractors' personnel who are going to act as Performing Authorities as it does of its own employees and that each Performing Authority undergo refresher training every 2 years. Marathon do not envisage contracting companies giving any training to their employees in the Marathon PTW system. Surprisingly Mr Kyle's evidence was that this subject, the training of contractors' personnel, had not been discussed in the UKOOA working group on PTW systems.

18.17 There is no dispute that adequate training is a vital part of any PTW system if that system is to be effective. The training of personnel who are to act as Designated Authorities and Performing Authorities needs to be particularly thorough. Irrespective of whether those personnel are the operator's own employees or are from a contractor, I am convinced that that training should be and can only be provided by the installation operator, as it has to be specific to the operator's PTW procedure. There is also merit in the OIM formally appointing Designated and Performing Authorities, after assessing their general knowledge of the installation and its work practices.

Auditing the PTW procedure

18.18 Mr Kyle stated that a PTW system should include auditing of procedures in practice and the frequency of audits would be determined by the operating management on the basis of the size of the installation, the number of permits normally in use at any one time, and the extent of discrepancies from the laid down system found on previous audits. For large installations there should be

— daily monitoring by safety officers, departmental heads and the OIM on a spot check basis for permit form accuracy, that safety equipment specified was in place, and that all specified precautions were being taken;

— more in-depth auditing undertaken on a routine weekly basis using prepared check lists, covering for example isolation and shift changeover arrangements and the training undertaken. These audits should be carried out by the platform's chief safety officer or a nominated departmental head. The completed check list should be signed by the auditor and retained;

— auditing by persons not employed on the installation on an annual basis as a minimum. These audits would use the check list in the OIAC guide to PTW procedures which addresses the overall design of a permit to work procedure. Reports on these audits should be reviewed by a nominated manager.

If persistent faults were discovered the frequency of audits would be increased until the situation was satisfactory again.

18.19 Mr Davies' view was that arrangements to monitor that the permit procedures were being followed and for review of the procedures were a necessary part of a complete PTW system. Over time there is an increasing probability that the procedure in practice will have departed from that originally laid down. Monitoring is required to pick up these changes in a timely way. It is then necessary for management to decide whether the system should be modified in the light of the perceived departures or whether additional training is required to ensure operation as originally intended. Monitoring is also required to ensure that individuals participating in the permit system comply with the duties placed upon them by the laid down procedure. Auditing by persons not directly responsible for operation of the plant and procedure is required. This should be on an annual basis looking not only at the operation at the time of the audit but also performance over the previous year. In the onshore survey of PTW systems referred to previously the most commonly encountered defect reported was the lack of a monitoring system. On monitoring frequency Mr Davies would not expect to see daily monitoring. This would suggest that the PTW procedure was not working correctly. Instead there should be a weekly check by the immediate supervisors and perhaps monthly by managers.

Standardisation of PTW systems

18.20 Both the Trade Union Group and the Contractors' Interests submitted that there was considerable merit in seeking to standardise the PTW system throughout the UKCS. The offshore workforce was composed in the majority of contracting personnel, varying from 60% to 80% of personnel on a platform. While some of the contract workforce was seconded to a particular installation on a long-term basis, there would be a considerable number, especially at times of major maintenance or modification, who were unfamiliar with the platform's procedures. In such circumstances standardisation of PTW systems would avoid confusion and thereby promote safety. Standardisation for example would enable training to be given as a matter of routine to all persons who required it. The training would be given on a regular pro forma basis onshore in a standard training centre, such as RGIT. There would be no need to rely on busy platform supervisors giving on-platform briefings.

18.21 Mr Kyle explained that UKOOA had carried out a survey of PTW systems among its members to determine to what extent standardisation of procedures could be achieved. From that review it was concluded that much common procedure already existed in the various operators' PTW systems but that detailed standardisation of permit forms and procedures would not be practicable or beneficial. Detailed procedures depended on offshore management structures. Installations having different populations and different types of operation might well have different management organisations. Procedures must be sufficiently flexible and be capable of regular review and improvement to suit local situations. Additionally, significant changes in forms or procedures might require a major re-training programme for all operators; this could give rise to a lengthy period of confusion during which unsafe conditions could arise. All operators had procedures which complied with the requirements of the Operational Safety, Health and Welfare Regulations which detailed requirements for PTW systems. Further, operators' permit systems generally reflected the guidance given in the OIAC guide. The overriding requirement was that operators provide a safe place and a safe system of work, not that they had identical permits and procedures. Given that there was compliance with the regulations and guidance, it followed that the main framework upon which safe PTW systems are based was the same for all operators.

18.22 In spite of that argument Mr Kyle explained that the UKOOA working group on permits to work believe that it would be beneficial if certain key elements were common to all operators. Those areas where further harmonisation is both desirable and practical are:

— the colours of permit forms;

— validation and life of permits, such that permits should be revalidated every 12 hours or at the completion of a shift;

— isolation arrangements. These must be effective and provide secure isolation, be fully documented and referenced in all relevant work permits, including provision for labelling of isolation valves, switches and equipment and, where practicable, utilise a locking arrangement which physically prevents accidental or unauthorised operation. All operators should prepare formalised procedures in advance for isolation of plant and equipment. This would not preclude the necessity for thorough checks when plant is isolated;

— a minimum number of specified signatures to a permit;

— copies of the permit retained at the work site, in the control room and by the Designated Authority if he was located remote from the control room;

— check lists which should be used on permits or separate sheets for assessing hazards and the precautions required;

— formal detailed handover procedures.

Mr Kyle believed that the combination of existing regulations, the planned tightening of and additions on isolation and training to the OIAC guidelines, and the UKOOA working group recommendations on common procedures set out above would provide the right balance to ensure operators could meet all the desired objectives. This would leave sufficient flexibility to enable operators to develop procedures to suit their specific site situations.

18.23 For the HSE, Mr Davies' view was that the PTW system was part of a safe system of work which was very dependent on the culture of the operating organisation.

It had to take that overall culture into account in its design for that particular location. The PTW system was likely to fall into disrepute more easily if it was at odds with the overall systems of the installation. While most steps in a PTW system were common and there could be a standardisation of principles, there would need to be flexibility to allow individual variations. For example, the needs of large companies and small companies might differ. Any system must take account of the underlying philosophy of the company, how it controlled all its systems of work, whether they were maintenance procedures or operational procedures. While there were advantages in standardisation there were also advantages in having the system as job specific as possible.

18.24 The Trade Union Group and the Contractors' Interests as advocates for standardisation considered that the UKOOA objection on the grounds of differing management structures might be overcome by seeking a common organisational theme. The problem of large scale re-training was there in any case as PTW systems were being continuously modified to effect improvements. The UKOOA proposals on common procedures implicitly accepted that a substantial degree of standardisation was possible.

Intentions of the Department of Energy

18.25 The requirement for operators of offshore installations to have in place a PTW system is covered in the Operational Safety, Health and Welfare Regulations. In the light of its own investigation into the Piper disaster the DEn issued Safety Notice 16/88 in November 1988 asking operators to review the scope, operation and control of PTW procedures. This was followed in July 1989 by the DEn setting out for comment its intention to strengthen the statutory requirements for work permit procedures. Its proposals are for an extension of those areas of work on an offshore installation which must be covered by a work permit system and the clarification of administrative procedures which should apply. The latter have much in common with some of the detailed principles set out by Mr Kyle as to be included in the UKOOA guide.

Conclusions on PTW systems

18.26 It is clear to me that much needed to be done to improve the general standard of PTW procedures in the UKCS, demonstrated by the number of changes that have already been introduced by various operators, as the evidence to the Inquiry showed. Many operators formed specific teams to ensure that the lessons of the Piper disaster were analysed in relation to their own activities. That was a praiseworthy response by the industry. The deficiencies revealed in the Occidental PTW system were not new problems, either offshore or onshore, and the better PTW systems have avoided them by straightforward procedural steps.

18.27 I am not persuaded that the introduction of a standardised PTW system offshore is either necessary or desirable. The concept originates in seeking a solution to the problem of contractors' supervisors having to act as Performing Authorities. I am satisfied this problem can be safely overcome by full and adequate training but it is clear that the responsibility for and the cost of that training should rest with the operator of the installation and cannot and should not be undertaken by the management of the contracting company. While it is preferable that an operator's own employees act as Performing Authorities it is inherent in the nature of the way maintenance work is executed offshore that there will be the need for contractors' staff to act in that capacity.

18.28 Standardisation is not desirable because the PTW system must marry with the individual operator's safety philosophy, organisation and methods of doing work. Additionally the need to change PTW procedures in the light of audit findings would be inhibited and the implementation of improvements made cumbersome if the whole industry were subject to each detailed change. Although standardisation in detail is undesirable there is no doubt that there must be common principles underlying any PTW system. Accordingly I welcome the UKOOA proposals on guidelines applicable throughout the offshore industry and I look to that organisation to accept the responsibility for ensuring that those common principles are implemented by each and every operator.

18.29 Such an approach would be consistent with seeking to have goal-setting rather than prescriptive regulations. However two improvements to PTW practices are of such overriding importance they should be incorporated in the current review of the Operational Safety, Health and Welfare Regulations planned by the DEn. They are:

— all permit to work systems should incorporate a mechanical isolation procedure which involves, wherever practicable, the physical locking off and tagging of isolation valves to prevent their accidental or unauthorised opening;

— operators should be responsible for and undertake the training of all staff, the operators' own or those of contractors, in the detailed PTW procedures where those staff are required to act as Designated or Performing Authorities. The training should be recorded and staff should carry documentary proof of having undergone such training.

Control of the process

Piper Alpha

18.30 It was evident in examining the circumstances of the disaster that the Piper control system had some limitations when it came to handling a developing emergency situation. In reacting to the events in the condensate system nothing could be done from the Control Room. The lead process operator, Mr Vernon, had to leave the Control Room to take command at the site of the condensate pumps. In consequence the supervisor with the responsibility and authority to decide whether the developing situation warranted partial or complete shutdown of the platform was absent from the control centre. He was not aware of the gas alarms and other signals that preceded the explosion. The Control Room was more a monitoring and message station than a place from which the process could be controlled. While instrumentation in the Control Room showed the status of equipment and alarms, the actual panels from which equipment operation could be adjusted were located within individual plant modules. These panels gave more detailed information on the condition of the plant; and the equipment controls could be operated from them.

Modern control systems

18.31 Mr M Ashworth, a Senior Control Engineer of BP International, explained that the type of control system on Piper was out-dated. It was expensive to provide in terms of space, weight and cost. Equally it was expensive to operate and maintain, being manpower-intensive and based on older technologies. There had been a progressive development of control room facilities over the past 15 years, the overriding influence being the technological advancement in computers and data communication. The modern concept was to provide a single central control room. The instrumentation was designed to control the platform process within a defined safe operating range. By means of alarms operators were warned when this range was likely to be exceeded; and such warning was given in time to allow the operator to initiate corrective action. The Control Room gave a detailed display of all equipment and process conditions and contained the necessary means of control for both normal and emergency operation. This allowed the installation to be operated safely with greater efficiency at reduced cost. The control room should be manned at all times by an experienced and trained control room operator.

Emergency shutdown systems

18.32 Mr Ashworth also pointed out that, in a modern control system, the first objective of a properly designed ESD system was to prevent an uncontrolled or hazardous situation occurring, in addition to its wider known use in reducing the consequences of a hazardous event when activated manually by an operator observing an emergency situation. By continually monitoring the process equipment with a range of protective instrumentation and taking automatic action to shut down when a predetermined value is reached, the ESD system became the principal mechanism for setting the installation to a known and safe state by stopping the process and isolating electrical equipment. The ESD system was therefore one component in a network of equipment and procedures which were designed to prevent process incidents developing in such a way as to lead to a release of hydrocarbons, and to maintain safe operation in both normal and emergency situations. The philosophy was to control the process within normal bounds and to detect and restrain abnormal events before they could escalate into an emergency.

Regulation of control systems

18.33 Apart from the requirement to have an ESD system there is no regulation specifying the type of process control system that should be installed on an installation. Mr M Ognedal, Director of the Safety and Working Environment Division of NPD, gave evidence that in Norway also there was no regulation as to the control of the process. The operating company was responsible for control of the plant. It was in its own interests to avoid unnecessary use of the ESD system and the stopping of production.

Training of control room operators

18.34 Mr Heiberg-Andersen, the OIM of Statoil's Gullfaks C platform, explained that it was necessary to give control room operators thorough training before they took up their positions on a platform. He described the onshore training of process operators using a process simulator which was a full scale replica of the platform control room together with an operating computer. The Gullfaks Control Room operators receive training on such a simulator before being appointed to the platform. That training included specific training in responding to an emergency.

Conclusions on process control

18.35 I am satisfied that there is no need to specify by regulation the type of control system that should be used on North Sea platforms, as it is in an operator's own interests on safety and cost grounds to adopt the available modern technology. What is clear from the evidence presented is that the control room should be manned at all times and be in the charge of a person trained and qualified to undertake the work of a control room operator. The training of control room operators must include instruction, in a properly developed onshore course, in the handling of emergencies, and that should involve practice in simulated emergencies.

18.36 It is evident that there are a number of platforms in the UKCS which have control systems which are of the same age as that on Piper and therefore are less able to deal with an emergency than a modern control system. This is a matter which could not be tackled effectively within the Inquiry although it was clear that complete replacement of those systems is not practicable. As a minimum I recommend that alterations should be made such that key process variables, as established by the FSA, are capable of being monitored and controlled from the Control Room.

The installation of modifications

18.37 I have pointed out in Chapter 6 that the institution of the temporary process system to inject methanol into the Piper process to prevent hydrate choking left much to be desired. The deficiencies in that task could have led to a potentially serious process upset and the release of hydrocarbons.

18.38 The requirement for the safe management of the installation of modifications is well known throughout the oil industry, in part as a result of the investigation into the major onshore disaster at Flixborough in 1974, which was traced to the inadequate management of a modification to the process and equipment. However, the circumstances surrounding the methanol injection system on Piper demonstrate that offshore operating companies would do well to monitor continuously their systems for the design and installation of modifications.

Incident reporting

Fatal accident on Piper

18.39 In Chapter 14 I commented adversely on Occidental's investigation of the fatal accident to Mr Sutherland and on the dissemination of lessons from that accident. The investigation lacked thoroughness in that it did not seek out the root causes of the accident or try to determine whether the particular failures associated with the incident were endemic in the way operations were carried out on Piper. The lessons from the investigation were not properly communicated throughout the organisation.

Offshore industry practice

18.40 The Inquiry heard evidence on the practice as to the investigation of incidents.

18.41 In Conoco (UK) Ltd it is part of the safety policy that all accidents or near misses are automatically investigated. A "near miss" is defined as a near accident that could have involved serious injury or had the potential for serious damage to property or the environment. The chief executive has a system to ensure that he is informed immediately of every significant incident and virtually all accidents no matter how minor. He is kept fully briefed on the progress and results of any investigation. Any personal injury greater than "first aid" severity is discussed in fortnightly meetings of the company directors. I have to point out that the frequency of accidents in Conoco is so low that the commitment of time by the directors to the discussion of injuries is not burdensome. It is also company policy to disseminate incident reports up and down throughout the organisation.

18.42 It is also the policy of the Amoco (UK) Exploration Company that all accidents and dangerous occurrences are the subject of an investigation and report describing the incident, the cause and the proposed corrective action. That action is checked out by both line management and safety specialists to ensure it is adequate. Significant dangerous occurrences or accidents involving injury to either company or contractors' employees are investigated by a committee of non-involved staff, normally comprising a safety specialist, an operating supervisor and an engineer. Written procedures exist for the investigating team to follow and their report is distributed throughout the company and specifically to the chief executive officer. Once agreed, corrective actions are followed through until all are complete.

Conclusions on incident investigation and reporting

18.43 I am convinced that learning from accidents and incidents is an important way of improving safety performance. That view is commonly held throughout the UK offshore industry. In relation to preventing incidents which cause hydrocarbon leaks that could lead to fires and explosions I consider it would be useful if there was a systematic means by which what could be learnt from such accidents and near misses was shared by all operators. The regulatory body should be responsible for maintaining a database with regard to hydrocarbon leaks, spills and ignitions in the industry and for the benefit of the industry. The regulatory body should

- — discuss and agree with the industry the method of collection and use of the data;
- — regularly assess the data to determine the existence of any trends and report them to the industry;

— provide operating companies with a means of obtaining access to the data, particularly for the purpose of carrying out quantified risk assessment.

Managing to prevent incidents

Introduction

18.44 While I am convinced that the lessons from the investigation of the Piper disaster which I have set out above will lead to improvements in safety offshore I recognise that those improvements are inevitably limited in their scope by the circumstances of the disaster. The prevention of incidents in the industry at large is dependent on the approach and quality of the management of safety by each and every offshore operator. Accordingly I sought evidence in the Inquiry as to good industry practice in the management of safety. Mr R E McKee, Chairman and Managing Director of Conoco (UK) Ltd and Mr R A Sheppard, Vice-President of Production and a Director of Amoco (UK) Exploration Company Ltd gave evidence. As would be expected the approach of the 2 companies was different in detail and it would not serve any useful purpose to list those differences in this report. However there were many basic and common principles.

Commitment by top management

18.45 Companies with a good safety record are dedicated to the proposition that safety starts with the unfailing commitment of the most senior management, and that of the chief executive officer in particular. They are personally responsible for setting the safety standards for the whole company and for setting the safety philosophy and communicating it to all the workforce. The latter may be expressed in such simple and easily understood concepts as "nothing is so important that it cannot be done safely" or "if we cannot do it safely we won't do it" but underlying those is the belief that safety is a basic element in conducting business and cannot be considered a discrete and separate activity. Safe, prudent working practices and procedures are good business practices.

Creating the safety culture

18.46 It is essential to create a corporate atmosphere or culture in which safety is understood to be, and is accepted as, the number one priority. Management have to communicate the safety philosophy at all times and at all levels within the organisation but most particularly by their everyday decisions and actions in tackling the many issues that arise in operating in the North Sea. Those provide the opportunity for subordinates to see real, practical substance put to the safety philosophy and for exploring the soundness of the safety policy against the realities of operating.

Organising for safety

18.47 To ensure that the safety philosophy becomes a tangible safety programme there must be defined organisational responsibilities for safety; and each part of the organisation has to be set and held accountable for safety objectives. It is essential that from the conceptual design stage of any installation the first objective is to design a safe plant. Thereafter safety has to be a prime objective of on-going operations. Typically the bulk of the responsibility for safety rests with line managers and supervisors, normally backed up by a safety or loss prevention department, which supports and advises line management. Safety objectives have to be built into both short and long term plans, and achievements against those defined objectives have to be part of personnel performance assessment.

Involvement of the workforce

18.48 It is essential that the whole workforce is committed to and involved in safe operations. The first-line supervisors are a key link in achieving that as each is personally responsible for ensuring that all employees, whether the company's own or contractors, are trained to and do work safely and that they not only know how to perform their jobs safely but are convinced that they have a responsibility to do so. Possibly the most visible instrument for the involvement of the workforce in safety is a safety committee system. In Conoco the system involves every member of the platform crew attending a safety committee once per tour of duty, while the Amoco system is based on safety representatives. Both draw no distinction between their own employees and those of contractors. Both companies consider the safety committee system an integral part of managing safety, providing an opportunity for new ideas and new solutions to safety problems to be brought up and a means of passing verbatim and uncensored safety comments up the management line. It also helps reinforce the principle that each employee is responsible for his own safety and that of his fellow workers.

Safety auditing

18.49 Monitoring and auditing the safety process is a critical activity to ensure that any safety programme is being followed. These may be conducted by first line supervisors, managers, safety department staff or personnel from outside the organisation. The requirement for auditing is normally written into company procedures and will encompass the design as well as the operational practices on installations. Audit reports are assessed by management and all recommendations pursued to a conclusion. The chief executive officer will be involved in the processing of the outcome of major audits.

Observations on quality of safety management

18.50 I am convinced from the evidence from both Conoco and Amoco, and indeed from the examination of the background to the Piper disaster, that the quality of safety management by operators is fundamental to offshore safety. No amount of detailed regulations for safety improvements could make up for deficiencies in the way that safety is managed by operators. It therefore is imperative that the quality of safety management should be a component in the regulatory regime. I will return to that issue in Chapter 21, but before doing so I will consider in Chapters 19 and 20 the achievement of the objectives of mitigating the effects of incidents and the securing of safe evacuation or escape and rescue in an emergency situation.

Chapter 19

The Mitigation of Incidents

19.1 The measures which I addressed in the preceding chapter were those required to prevent accidents. In this chapter I turn to measures to mitigate the effects of any accident which may occur. These measures fall under 6 broad headings. Three of these are concerned with minimising the escalation of any leak: (i) the minimisation of hydrocarbon inventory on the platform and in risers and pipelines and isolation of pipelines (paras 19.4-37); (ii) fire and gas detection and emergency shutdown systems (paras 19.38-43); and (iii) fire and explosion protection (paras 19.44-103). The next 2 topics are concerned primarily with the protection of personnel: (iv) temporary safe refuge, or safe haven, escape routes and embarkation points (paras 19.104-175); (v) emergency centres and systems (paras 19.176-194); and the final topic is (vi) pipeline emergency procedures (paras 19.195-197). I conclude with my observations on the mitigation of incidents (paras 19.198-199).

19.2 In the aftermath of Piper there were many calls for there to be requirements for particular hardware solutions and these were echoed in some of the submissions. Examples are subsea isolation valves, blast walls, separate accommodation platforms and enclosed escape routes. I have heard a wide range of evidence on these matters. I will give my views in this chapter on the extent to which it is appropriate for me to make specific recommendations and, where I do not, I will explain how I believe the matter should be handled.

19.3 As I have indicated in Chapter 17, I am in favour of goal-setting regulations and a Safety Case. Some topics, such as fire and explosion protection, may be dealt with both by regulations and by the Safety Case. Broadly speaking, the regulations set goals for the basic design and operation of the system. The Safety Case demonstrates the adequacy of the system in relation to major hazard accidents.

Hydrocarbon inventory, risers and pipelines

19.4 The Piper disaster highlights the importance of the hydrocarbon inventory both on the platform itself and in the pipelines. The scale of the fires was due to the failure first of the Tartan gas riser and later of the other gas risers. In the words of one of the survivors, Mr J M MacDonald: "The Piper did not burn us; it was the other rigs which burnt us." As far as concerns the inventory on the platform, the gas and condensate in the plant appear to have been vented and blown down within a few minutes, but there were significant quantities of oil in B Module, the major sources being the separators and the MOL, which fed the pool fire responsible for the further escalation.

19.5 In this section I will review the evidence on the ways in which hydrocarbon inventory on the platform may be minimised and will consider the prospects for reducing the number of pipelines and risers connected to it and, failing that, for minimising the risk from them, in particular the various types of valve available for shutting off the flow in an emergency.

Minimisation of installation inventory

19.6 Increasingly minimisation of hydrocarbon inventory is being made a design objective for onshore plants. It was a major theme of the Advisory Committee on Major Hazards (ACMH). Such inventory reduction is a specific example of the more general principle of inherently safer design, that is to say, designing hazards out. It is necessarily more difficult in any plant handling fuels. Nevertheless, the principle is valid offshore also and should be applied.

19.7 A well designed venting and blowdown system is able to dispose of most of the inventory of hydrocarbon gas and condensate on the platform to flare within a few minutes. The guidance notes to the Construction and Survey Regulations deal with blowdown and venting of the hydrocarbon inventory. There appears to be no other explicit requirement for, or guidance on, the minimisation of the hydrocarbon inventory on the platform.

19.8 The other main sources of hydrocarbons are the liquid inventories, particularly the oil in the separators and the diesel fuel. The contribution of the oil in the separators to the fires on Piper has already been described; that of the diesel fuel is not known, but may well have been significant. Mr A B Fleishman, Senior Safety Engineer with BP International, in his risk assessment of the Gyda platform found that the diesel fuel gave rise to an appreciable risk. Measures taken to minimise inventory in the design of the Shell Kittiwake platform were described by Mr P A C Doble, Deputy Project Manager. He devoted a section of his account of the design to this topic and described the efforts made to minimise inventory in the separators.

Minimisation of number of risers

19.9 In accordance with the principle of inherently safer design, the first possibility which should be considered in addressing the hazard from the risers is to remove them altogether.

19.10 Some means of exporting the products, oil and/or gas, is unavoidable on a production platform. Such a platform will normally have an oil and/or gas export riser. In many cases platforms have additional risers. Historically, there are a number of reasons for this, including the ease of tying in a new connection on a platform compared with doing so beneath the sea; and the need of some platforms such as Claymore to import gas. Developments in the UKCS, spoken to by Dr Taylor, to which I referred in Chapter 16, mean that there will be an increasing trend to tie in satellite developments to existing platforms by pipeline so that the number of risers will tend to increase. Many of these pipelines will be flow lines, containing 2-phase gas-oil mixtures.

19.11 Evidence on the potential for reducing the risk from risers by keeping their number to a minimum was given by Mr R Willatt, Senior Pipeline Engineer in the Engineering Pipelines Group of BP. The burden of his evidence was that the scope for reducing the proportion of pipelines which were brought on to platforms was limited. Typically additional pipelines were brought to a platform from satellite developments and from remote platforms. The need to tie in a pipeline to other pipelines was one reason. There were available methods of undersea tie-in such as the use of Y and T pieces, but these might involve problems of line diameter, pressure letdown and pigging. Another reason was that for satellite developments the considerable advances made in subsea separation and instrumentation had not yet obviated the need for fluid processing and metering on a parent platform.

19.12 A separate riser platform allowed pipelines to be brought to a main platform which might have limited space or inadequate strength for additional risers. Normally the riser platform would be bridge-linked to the main platform and the pipelines would pass across a pipe bridge. The main platform would be less vulnerable to riser failure and the risers would be less at risk from process incidents. A separate riser platform was, however, a very costly solution. Mr Willatt was unaware of any platform which has the sole function of supporting risers.

Minimisation of risk from risers

19.13 Given that a pipeline is to come to a platform, measures need to be taken to minimise the risk from the riser. Measures available include the design of the riser, location of the riser, fire protection of the riser, and the fitting of valves which will shut off flow. These may include a topsides emergency shutdown valve (ESV) and subsea valves, whether a non-return valve (NRV) or a subsea isolation valve (SSIV).

19.14 Mr Willatt described some of the features to be considered in location of risers, in order both to reduce the frequency, and to limit the consequences of, failure. The riser might be at risk from fire and explosion from process or wellhead areas or other risers, from dropped objects, or from attendant vessels. It might constitute a hazard to the safe haven and the control room and to the process and drilling areas. He advocated that the length of the riser pipe between sea level and the pig trap be kept to a minimum and long horizontal runs avoided.

Fire protection of risers

19.15 Fire protection of a riser may be active fire protection using a water deluge or passive fire protection using a fire resistant coating. Passive fire protection using a fire resistant coating appears attractive because it is less liable to be disabled by the incident itself. Unfortunately, it has the disadvantage that corrosion of the riser pipe may occur under, and be aggravated by, the coating. Mr Ognedal described one of the first major accidents in the North Sea which occurred on 1 November 1975 when a 10 inch riser burst on Ekofisk A, a severe fire followed and 3 men died due to maloperation of a rescue capsule. The failure was caused by corrosion of a section of riser which had been repaired but had not been properly recoated and which was located more or less at sea level. Passive fire protection of risers was explored with several witnesses. The risk from corrosion will depend partly on the type of corrosion which occurs. Some types reduce the thickness of the metal, others weaken the metal which remains; the latter would be particularly insidious. It was Mr Willatt's expectation that the corrosion would tend to be general pitting corrosion, but that the extent of corrosion which might occur between normal inspection intervals could be significant. On the fireproofing of risers Dr R B Gilbert, Chief Engineer on the Nelson Project Team with Shell, was asked whether the state of knowledge was such that it was not known whether the application of fireproofing might make the situation worse or not, and agreed this was a fair statement of the position. Mr A J Adams, Principal Pipeline Inspector with the Safety Directorate, described a joint programme of research commissioned by UKOOA and the DEn at the British Gas Spadeadam site on the ability of coatings used for fireproofing to withstand the erosive effect of jet flames.

19.16 With regard to practice in respect of the fireproofing of risers, Mr Adams stated that it was not common practice. Mr E F Brandie, Safety and Compliance Manager of Chevron (UK) Ltd, knew of no riser with fireproofing in the UKCS. Mr Ognedal stated that since the Ekofisk A accident it has been normal practice in the NCS to consider fireproofing of risers, but he was unable to give even an approximate figure for the proportion which are fireproofed. Mr T Nordgard of Statoil stated that the risers on Gullfaks A are not fireproofed.

Observations on minimisation of inventory and on risers

19.17 The minimisation of the hydrocarbon inventory both on the installation and in the risers and pipelines connected to it should be a design objective and should be a feature of the Safety Case. As regards the former, the Safety Case should address the minimisation of hydrocarbon inventory not only in the main process plant but also in fuel storages such as those for diesel and aviation fuel.

19.18 Emergency disposal of gas and condensate is effected during ESD through the venting and blowdown system. No evidence was heard of any serious deficiency on Piper in the venting and blowdown system, either during the disaster or otherwise. However, it is right to emphasise that this system is a vital part of the arrangements for preventing the fuel inventory from feeding a fire.

19.19 A major role was played in the Piper disaster by a large pool fire. The risk of such a pool fire would be greatly reduced if some method could be found of disposing of the large oil inventories such as those in the separators. This is doubtless not straightforward, but studies should be undertaken to determine whether a practical method can be found.

19.20 Control of the hazards from hydrocarbon risers should be a feature of the Safety Case, but should also be addressed in those regulations dealing with aspects which bear on the problem, including those dealing with the emergency shutdown system and with fire and explosion protection. Possible risks from later, additional risers should also be considered in the Safety Case.

19.21 Studies should be done in support of the aim of minimising pipeline connections to platforms. The development of subsea technology for fluid treatment and metering should be progressed so that there is less need to bring pipelines to platforms.

19.22 The regulatory body should press hard for the resolution of the question of passive fire protection of risers. Passive fire protection of risers is attractive in that it appears less likely to be disabled by the incident itself. There is the risk, however, that corrosion of the riser may occur beneath the coating and actually cause riser failure. There is also some question whether the coatings available will withstand jet flames. Work needs to be done on both these aspects. The aim should be to bring the technology rapidly to the point where either such protection is a reasonably practicable option in a much larger proportion of cases or it is shown that it does not have a significant contribution.

19.23 Active fire protection of risers should not be neglected, but due allowance should be made in any assessment for the possibility that such protection will be disabled by the incident.

Emergency isolation of risers

19.24 Prior to the Piper disaster the isolation requirements for pipelines were those given in the Submarine Pipelines Safety Regulations. Reg 6 requires the provision of effective means of shutting down a controlled pipeline at each of its initial termination points. The inadequacy of these arrangements was revealed when, following Piper, the DEn wrote to operators requesting them to examine their arrangements for pipeline isolation. Analysis of the responses indicated that there were appreciable differences in respect of such valves and 2 principal defects. Some risers had valves which were not true ESVs and needed changes to their actuators, control logic, etc. Although some valves were located near sea level, others were much higher up. Mr Adams agreed that prior to the disaster neither the industry nor the DEn had appreciated the importance of locating these valves low down on the platform. I note that Piper was provided with ESVs on the 3 gas risers, but that one of these, the Claymore line ESV, had only recently been uprated and that the valves were not near sea level but high up on the platform.

19.25 The regulations now made by the DEn, the Emergency Pipe-line Valves Regulations 1989, require that a full ESV be fitted on a riser and that, in effect, this valve be located as near to sea level as practicable. The regulations apply to some 400 existing pipelines. They have resulted in modifications to some 200 pipelines. Of these modifications some 130 involve relocation of the ESVs, some 40 upgrading of the valves to make them fully functional as ESVs and some 30 installation of new valves where the existing valves were not suitable for such upgrading.

Subsea valves

19.26 Another method of isolating a pipeline is the use of a subsea valve. Such a valve needs to be located some distance from the platform, so that it is less at risk from objects dropped from vessels or dragging anchors and so that it is far enough away to ensure that a gas cloud from a rupture on its far side is not ignited from the platform. There is necessarily therefore an appreciable inventory in the pipeline between the valve and the platform. It was emphasised by Dr Gilbert that if riser rupture occurs, a subsea valve cannot prevent a release; it can only mitigate it.

19.27 There is a distinction to be made in subsea valves between NRVs and SSIVs. An NRV may be installed on an export pipeline, but, by its nature, not on an import line. An NRV has the advantage that it responds very rapidly, but it has a number of disadvantages. It may prevent a flow in an export pipeline being reversed for operational reasons such as routine depressurisation, it makes it more difficult to pig the line, it is liable to be damaged by pigging and it will not prevent a small leak.

Subsea isolation valves

19.28 Two studies conducted to assist in deciding whether to install subsea isolation valves (SSIVs) were presented to the Inquiry, one by Dr Gilbert and one by Mr M P Broadribb, Central Safety Engineering Superintendent with BP Exploration. Although the approaches taken in these 2 studies appeared quite different, the BP work comprising a full QRA and the Shell work concentrating on consequence modelling, Mr Gilbert did not admit any fundamental difference. In his case there were no areas of doubt which might make a full QRA necessary. The company had sufficient information from the consequence modelling to make its decision.

19.29 The Shell study highlighted the importance of the criteria used for the integrity of the accommodation and its supporting structure with a jet flame playing on it. For quarters with an A60 wall it was estimated that the air temperature would reach the breathing tolerance limit in about 25-30 minutes, but that fumes generated from the insulation would render the air unbreathable within about 16-17 minutes. The endurance of the quarters was thus taken as 17 minutes. It was estimated that an unprotected supporting structure would fail to support the quarters after about 8 minutes, and this period was thus taken for the endurance of such a structure. The endurance of a fireproofed structural support was estimated as about 60 minutes.

19.30 Another significant point in the Shell study was the effect of the duration as well as the length of the flame. A full bore rupture was not necessarily the worst case. Partial rupture which resulted in a longer duration flame was in some cases a greater threat. In modelling the flames use was made of research into large natural gas jet fires carried out in 1988 by Shell and British Gas at Shell's Thornton Research Centre.

19.31 The Shell study, which covered some 48 gas risers, resulted in the decision to install SSIVs on the 8 risers rupture of which could cause failure of the quarters; and to take other measures in the case of 11 other risers. In 3 cases these measures were to provide shielding for the quarters and in the other cases to review the fireproofing of the structure. The BP study had led to recommendations of about 8 SSIVs on some 5 separate installations.

Subsea valve reliability

19.32 The reliability of all 3 types of valve - ESVs, NRVs and SSIVs - was explored in some detail. For all 3 types the reliability of prime interest here is the probability of giving tight shutoff on demand. The other aspect of reliability is the probability of avoiding spurious action. For ESVs Mr Broadribb quoted a 0.97 reliability for tight shutoff based on a published collection of offshore reliability data. For subsea valves Dr Gilbert stated that the reliability has in the past proved less than satisfactory. He doubted if data on the probability of successful operation on demand of any large population of such valves were available. From the cases he quoted I understood that he was referring mainly to NRVs. As for SSIVs, Mr Broadribb described them as not yet a mature technology. The valves are not commercially available in the full range of sizes and classes. The number of SSIVs installed is not large and the database from which to determine their reliability is therefore small. He considered SSIVs as nowhere near as reliable as the equivalent topsides valves. The value which he used for the reliability of SSIVs was 0.95, which he said was a figure which the industry expects to be able to achieve in the relatively near future.

Subsea isolation valve practicalities

19.33 Dr Gilbert was questioned on the details of the SSIVs which Shell are installing. The installations will consist of a pair of valves at each location. The larger 30 inch valves are among the largest produced; the valves are "specials"; and the number of suppliers is limited. The time for delivery was estimated as perhaps 15 months and that for completion some 6 months thereafter, but installation would be possible only during the summer. He was not able to give the cost of an SSIV or its installation, but agreed that putting in the SSIVs described was one of the largest single safety bills currently faced by his company and that an estimate for the cost of the best part of £50m seemed reasonable. It was also indicated in the submission by Occidental that the company believes that the technology of SSIVs has progressed to the stage where these valves have a significant contribution to make to safety, though they are not necessary on every pipeline. Such valves have been installed on the hydrocarbon pipelines on the Claymore platform and it is the intention to install them on new platforms. As far as concerns Norwegian practice, it was Mr Ognedal's evidence that there are NRVs installed in, for example, the Statfjord field, but that to date there were no SSIVs. Research by Shell on the reliability of subsea valves was described by Dr Gilbert. A programme to improve valve reliability was started in the early 1980s and is still continuing. The work is concerned particularly with problems of corrosion and maintainability on the seabed.

Observations on emergency isolation and subsea valves

19.34 Hydrocarbon risers, except those which present no threat, should be fitted with a full ESV located as near to the sea level as practicable, taking into account the need to avoid corrosion and to maintain the valve. The DEn has already acted to ensure this through the Emergency Pipe-line Valves Regulations. This action is endorsed.

19.35 The requirement to have an ESV and to locate it near sea level is a specific prescriptive requirement relating to hardware. In general I take the view that prescriptive requirements on hardware are undesirable, but there are exceptions. There are cases where a measure addresses a significant hazard where there is an overwhelmingly clear balance of advantage in its favour; where it is clearly reasonably practicable; and where this situation is likely to pertain for an appreciable period, so that it is inconceivable that it should not be taken. I regard this as such a case. My support for the DEn regulation in this case, therefore, is based on the view that it is appropriate, and not simply on an unwillingness to disturb a set of regulations before they have had a fair trial.

19.36 It was submitted that the Inquiry should also recommend that there should be a requirement for SSIVs. The Trade Union Group and the Piper Disaster Group wished to see essentially default requirements for SSIVs. However, I accept the evidence that there is a wide variety of situations involving risers and that the variation of risk is correspondingly great. This being the case, SSIVs can make a major contribution to safety by reducing the risk from risers, but they are a reasonably practicable solution only in a proportion of cases. The proper approach, therefore, is to determine the need for SSIVs on the basis of the Safety Case.

19.37 Nevertheless, it is my view that the evidence also shows that if progress were made in the technology of SSIVs, there would be a larger proportion of cases where it would be reasonably practicable to use them. It is praiseworthy that some companies have gone ahead and installed SSIVs despite the undoubted difficulties. There remains, however, a chicken and egg situation: installation of SSIVs is held up by lack of information on performance but the latter will be slow in coming unless more valves are installed. There needs, therefore, to be pressure towards the development of more reliable and less costly subsea isolation valves. The aim should be to bring the technology rapidly to a point where such a valve is a reasonably practicable option in a much larger proportion of cases. Since it is the field performance of these devices which matters and since a reasonably large sample is likely to be required, the regulatory body may need to develop unconventional methods of progressing this work. Configurations where there are 2 SSIVs in parallel will permit more frequent test closures. Work should also be done to advance the technology of NRVs.

Fire and gas detection and emergency shutdown systems

19.38 Turning to fire and gas detection and emergency shutdown systems, there are 3 main points which I take from the evidence on these systems on Piper. Firstly, the explosion occurred before signals from the gas detection system had led to either a manual or automatic ESD. Secondly, the ESD of the gas pipelines was not part of the platform ESD, and ESD had to be effected manually for each pipeline separately from the Control Room. Thirdly, some of the ESVs appear not to have closed fully.

19.39 I did not seek evidence in Part 2 on fire and gas (F&G) detection systems, but it is convenient to mention here a particular point made by Mr E F Brandie, Safety and Compliance Manager of Chevron (UK) Ltd and Chairman of the UKOOA Fire Protection Working Group. It concerns infra-red (IR) fire detectors. In the guidance notes to the Fire Fighting Equipment Regulations the fire detection devices referred to are limited to ultra-violet (UV) detectors, but these have proved historically to be prone to spurious trips from welding or from flare radiation with the result that systems are sometimes keyed out. He went so far as to agree that for some applications such systems were not fit for purpose. IR detectors which at one time were prone to spurious trips are now much more reliable in this regard and should be allowed as an alternative to UV devices. He did not, however, recommend a blanket change.

19.40 I have already referred in Chapter 18 to the account given by Mr Ashworth of control and ESD systems.

Observations on fire and gas detection systems

19.41 In the light of the evidence in Part 1 I am not convinced that gas detection systems are making their full contribution to protecting against leaks which may cause serious explosions. In particular, if a leak occurs which warrants an ESD, it is very desirable that this ESD be effected before ignition of the leak occurs, since there is a risk that an explosion will interfere with the smooth execution of the ESD. In the case of Piper the leak ignited quite quickly and it is perhaps debatable whether a gas detection system which gave higher quality information would have made much difference. In other cases it might.

Observations on emergency shutdown systems

19.42 In general, ESD is well covered in the guidance notes to the Construction and Survey Regulations, but I am concerned by the 2 points which I mentioned above. One is the activation of the ESD for the pipelines. There were reasons for the system on Piper in which ESD had to be effected separately for each gas pipeline, since ESD of a pipeline would force an ESD on the connected platform and such forced ESD is generally undesirable. However, the arrangements for the ESD of pipelines are a matter of some importance if the full value of ESVs and SSIVs is to be realised. They should be one of the features considered in the Safety Case.

19.43 The second point concerns the failure of ESVs to close under severe accident conditions, which include fire, explosion and strong vibration. Platform vibration, or shock, caused by the explosion was discussed by Dr Cubbage and was one of the few explanations advanced for the apparent incomplete closure of ESVs on Piper. Work needs to be done to determine the vulnerability of ESVs to severe accident conditions and to enhance their ability to survive such conditions.

Fire and explosion protection

19.44 I turn now to protection against fire and explosion. The initial explosion on Piper knocked out the Control Room and disabled power supplies, communications and the fire-water deluge system, and caused severe vibration which may have affected the ESD system. It generated missiles and led within seconds to further releases and fires, in particular a major fire which gave a massive smoke plume enveloping large parts of the installation and leading within about 20 minutes to the rupture of the Tartan riser. From the start the fire and smoke threatened the accommodation and hindered escape, both from the accommodation and outside, and access to and use of the lifeboats.

19.45 I will give in this section my review of the evidence on protection against both fire and explosion, starting with the latter, but will defer my observations till the end, since I have come to the conclusion that what is needed is an integrated approach.

Explosions in partially confined modules

19.46 The explosion on Piper occurred in a partially confined module and it was on this type of explosion that attention was concentrated. An account of partially confined explosions, or vented explosions, was given by Dr G A Chamberlain, Technical Leader of the Explosion Protection Review Task Force of Shell Expro. His account made clear that such an explosion is a complex process. The over-pressure developed in the explosion derives in the first instance from the volume production of hot gas but there is also a contribution from the effect of flame speed. The pressure is reduced by release of gas through vent apertures and increased by obstructions which cause the flame to accelerate. There is also the possibility of an external explosion, unambiguously confirmed only in 1987, which in turn reacts back on the pressure in the module. The severity of a vented explosion depends on a large number of factors, including the fuel, fuel-air ratio, initial temperature, initial turbulence, location and strength of the ignition source, enclosure size, vent area and obstructed regions.

19.47 There is no fully satisfactory fundamental method of predicting the over-pressure of an explosion within a vented enclosure. There exist empirical equations, but they are generally of limited use; they have usually been derived for empty vessels and tend not to take into account complicating factors such as internal obstacles or external explosions. More useful are computer models and scale model experiments. Computer models include the FLACS code of CMI and the CLICHE code of British Gas, to which I have already referred in Chapter 5. Dr Chamberlain also described another kind of computer model exemplified by the Shell VENTEX code. The model is semi-empirical and is based on extensive experimental work at Thornton Research Centre. The purpose of the code is to provide the engineer with a knowledge of the principal features of a vented explosion and an indication of the extent of the hazard, prior to the use of more fundamental models. These theoretical models may be complemented by scale model experiments.

19.48 Turning to practical applications, Dr Chamberlain described the features which affect the severity of a vented explosion and which the designer should take into account. The explosion severity is minimised if the volume of the enclosure and the extent of the obstacles in it are minimised and the vent area is maximised. Long narrow modules should be avoided. The distance between obstacles should be increased and the blockage ratio decreased. He presented a number of examples illustrating layout features which enhance or reduce the severity of a vented explosion. The principal measures favoured by Dr Chamberlain to mitigate an explosion in a partially vented module were good ventilation and good venting. Essentially the approach advocated was to keep down the over-pressure of the explosion.

19.49 Dr M W Vasey, Manager of Safety Modelling and Offshore Safety at British Gas Midlands Research Station, described work being done by British Gas to investigate the efficacy of water deluge for the suppression of explosions in modules. The concept behind the work was that if water deluge could be activated to drench a flammable gas cloud before it ignited, the strength of the explosion might be greatly diminished. This concept is being tested in experimental work at Spadeadam by British Gas. The work has shown that water deluge can effect an appreciable reduction in explosion over-pressure. There is, however, a significant problem in activation of the deluge, which, to be effective, needs to be operating before ignition occurs. Dr Vasey envisaged that it might be activated by the gas detection system, but acknowledged a difficulty in effecting such activation and suggested as an alternative the possibility of water curtains spaced at about 5m intervals and running continuously. He agreed this would affect the natural ventilation.

Explosion mitigation by venting and other methods

19.50 Dr Chamberlain went on to describe the design options for mitigation of explosions by way of venting and other methods. He prefaced his remarks by emphasising the importance of preventing explosions by eliminating leaks and ignition sources and by dispersing leaks by ventilation. The measures which have been used to mitigate any explosion which does occur are to provide vents to reduce the over-pressure and blast walls to contain it.

19.51 Vent area may be provided in a module by leaving open the ends, by the use of open grating for floors and ceilings, by putting hatches in ceilings and by removing walls or weakening them so they fail at low pressures. There has been some move towards the use at open ends of lightweight weather barriers which both promote natural ventilation and provide a vent area. Where an open grating floor might create problems with spillages, use has been made of lightweight blowout panels sufficient to channel away any spillage but weak enough to come off in the event of an explosion.

19.52 For a new platform, measures which can be taken to mitigate an explosion include the layout of the modules and of the equipment within them. Venting is less effective in long, narrow modules, particularly if the ignition source is far from the open end; short, wide modules are preferable in this regard. The vessels, equipment and pipework may be arranged so as to reduce their effect as obstructions in enhancing an explosion. For an existing platform, where the layout is fixed and the equipment not readily rearranged, venting may be improved by modification of walls, floors and ceilings, as described above. Dr Chamberlain gave examples of retrofitting involving the installation of grated floors and ceilings and of removal or weakening of walls. This general approach was supported by Dr Vasey, who stated that it was his belief that if walls between modules were removed and solid floors replaced by grating, this would greatly improve the effectiveness not only of venting of explosions but of dispersion of leaks. However, he drew attention to the fact that in some cases this may be contrary to regulatory requirements. The allusion was evidently to Reg 11 of the Fire Fighting Equipment Regulations and the associated guidance on reference areas.

19.53 The practical application of methods of mitigation of explosions, and particularly venting, in the design of the Kittiwake platform was described by Mr Doble. Studies were done involving extensive wind tunnel tests to ensure good ventilation to disperse leaks. The segregation of vulnerable features from high risk areas by platform layout provided the first defence against explosion. Explosion modelling was used to assess the risk from these areas. Venting was utilised extensively to minimise explosion over-pressures. The outer sides of the process and wellhead modules were provided with walls of just sufficient area to provide protection from the weather and with gaps top and bottom and weak enough to act as vent panels in the event of a strong explosion. In some areas, particularly the wellheads, use was made of grated decks. Walls in the process area at one end of the platform constituted vent panels. Mr Doble was examined on possible difficulties due to spillages in using grated floors. He agreed there was some problem, particularly with mud spillages in the wellhead area, but did not regard it as a major one, in either the wellhead or the process areas.

Explosion containment by blast walls

19.54 The design of blast walls to contain an explosion was described by Mr A W Van Beek, Head of Offshore Structures Engineering of Shell Expro. He stressed that the designer should seek first to reduce the explosion over-pressure by venting and other measures. For a new platform there was a range of layout and venting options, while for an existing one the venting method which was often practical was the use of open grating.

19.55 As far as concerns existing platforms, Mr Van Beek confirmed that some platforms had only firewalls and not blast walls. He was asked whether such firewalls could be strengthened to protect against blast, but was reluctant to commit himself. He agreed that the measures to strengthen a wall which he described might well mean tearing the whole wall apart. He was asked whether he was aware of any blast wall fitted since the Piper disaster, but did not know of any. Installation of blast walls presented problems of space and weight, which were especially severe for retrofitting of existing platforms. Access might be a further difficulty. With regard to the strength of blast walls on existing platforms he was reluctant to generalise, but stated that from analyses done the strength of a typical blast wall (not a firewall) on an existing platform was of the order of 0.4-0.5 bar. In new designs a typical range of strengths was 0.2-1 bar.

19.56 Comments on blast walls were also made by Mr Brandie. He pointed out that the fire resistance of a wall bore no relation to its blast resistance; a wall with a 1-hour rating might withstand explosion over-pressures better than one with 4 hours resistance. He was asked about combined fire and blast walls; he believed walls approved against both fire and blast existed. He did not know of any installed. He regarded firewalls and blast walls as "different animals".

19.57 Although in the Kittiwake design the prime emphasis is on venting, use is also made of blast walls. Two main blast walls are installed to contain the effects of an explosion, one between the process area and the wellheads; and one between the wellheads and the utilities. Earlier blast walls had been designed to withstand by elastic deformation an over-pressure of 0.3 bar. The blast walls on Kittiwake have been designed using explosion modelling and using an alternative failure criterion based on plastic deformation. Mr Doble stated that it was practice in such modelling to use a worst case ignition source location and he believed the scenario considered had been a module filled with a stoichiometric mixture. For the blowout preventer (BOP) area the original predicted over-pressure was 0.8 bar. In this case there was scope to provide 25% additional vent area by utilising the area under the drilling derrick; and the predicted over-pressure was reduced to 0.6 bar. The blast wall was designed to withstand 0.6 bar. For the separator area the predicted over-pressure was 0.9 bar and no method of improving the venting had been found. It was necessary to design a correspondingly stronger blast wall.

19.58 The use of a blast wall involves the danger that if an over-pressure occurs which the wall is not strong enough to withstand, the wall will disintegrate and give rise to missiles. The higher the pressure at which the disintegration occurs, the greater the energy imparted to the missiles.

Fire prevention and protection

19.59 Fire prevention and protection was spoken to by Mr Brandie in a paper devoted to this and also in his paper on safe haven. He began by listing some of the basic concepts of prevention, mitigation and protection, described active and passive fire protection and went on to develop the argument that currently design against fire was hampered by the regulatory requirements and that the regime should move to one based on fire risk analysis.

Fire risk analysis

19.60 In Mr Brandie's view the principal threat to the platform was major fires. Essentially means existed to cope with lesser fires, but major fires were becoming of growing concern to fire engineers. Increasingly the fire hazard was the subject of a fire risk analysis. This involved in the first place the identification of fire scenarios. The scenarios might be studied using the methods of risk analysis such as fault trees. The risk might then be eliminated. Alternatively, preventive or protective measures might be taken.

Pool fires, jet fires and smoke

19.61 The 2 principal types of fire against which fire protection is required are pool fires and jet fires. In Mr Brandie's view jet fires constituted the greater threat. He felt fairly confident of being able to control any but the largest pool fire; he was less confident about a jet fire. As videos shown to the Inquiry illustrated, a large jet flame may traverse a module. The heat flux from a jet fire tends to be much greater than that from a pool fire. According to Dr Gilbert, the levels of thermal radiation from a non-impinging flame, from an enveloping pool fire and from a riser jet fire were some 100, 250 and 300 kW/m^2, respectively.

19.62 However, as the disaster showed, a large pool fire is also a significant hazard. One measure which can be taken to minimise this is reduction of inventory. Another is sloping the floor under vessels and pipework containing significant inventory so that any liquid oil spill is drained away, and generally taking steps to minimise the areas of potential pool fires. As far as control of a pool fire is concerned, the method used is to smother it with foam inducted through the regular water deluge system.

19.63 As far as Mr Brandie was aware, the minimisation of smoke from platform fires had not been *per se* the subject of much investigation, but measures which minimise or control a pool fire, particularly foam blanketing, would reduce smoke.

Active and passive fire protection

19.64 Ideally fire protection should be a suitable combination of active and passive measures, but in Mr Brandie's experience the adoption of the best technical solution has been hampered by the split of the regulatory requirements for passive and active fire protection between 2 different sets of regulations administered for the DEn by different authorities. Passive fire protection was dealt with in the Construction and Survey Regulations and active fire protection in the Fire Fighting Equipment Regulations. For these the industry had to deal with the certifying authorities and the DoT, respectively. The existing guidance on passive fire protection did not actually prevent the operator from implementing active fire protection in addition but by failing to allow credit for the active fire protection it tended to frustrate the best technical solution. Similarly, guidance on active fire protection tended not to allow credit for passive measures. Moreover, Mr Brandie believed that the volume of detailed guidance, running to some 80 pages, on active fire protection had led to an over-emphasis on this to the detriment of other measures. In his view there were other aspects of fire protection which in some cases were more important, including layout and passive fire protection, but there was much less guidance on these. He stated that in 1986 the UKOOA Fire Protection Work Group had made a strong plea to the DEn for the relevant sections of the 2 guidance notes to these 2 sets of regulations to be amalgamated. However, he saw the draft fourth edition of the Construction and Survey guidance notes as perpetuating the split.

19.65 Although he described it as a "black art" and a developing one, Mr Brandie considered that passive fire protection had an important role to play. It had the great advantage that it gave immediate protection without the need for specific initiation and was less dependent on systems which might be disabled by an explosion such as power supplies. Moreover, it had relatively low maintenance requirements. As against this it provided protection for a limited duration compared with active systems. It might degrade due to weathering and marine environment effects. Its resistance to impact and explosion and to water jets was uncertain. It might conceal or even aggravate corrosion of the surfaces to which it was applied. Overall, however, his company considered passive fire protection sufficiently valuable to have spent some £2m in the last 2 years on refurbishing and upgrading passive fire protection on 3 of its platforms.

Water deluge systems by reference areas

19.66 The Fire Fighting Equipment Regulations require in Reg 11 that an installation should have a water deluge system or monitors, or both. The guidance notes introduce the concept of a "reference area" for application of the water bounded by vertical class A divisions or the edges of the installation; and give a minimum water rate of 12.2 litres/m^2 min. This reference area concept is unique to the UK offshore oil industry. It is not recognised for onshore plants in the UK nor does it occur in the codes of the National Fire Protection Association. The guidance notes state that "the intention is to assess proposals for water protection on an installation by installation basis"; and again that "A water deluge system designed and installed in accord with a suitable standard or code which meets the specification of the general reference area, might be accepted." Despite this Mr Brandie estimated that more than 90% of deluge systems installed offshore followed the guidelines in the guidance notes. He pointed out that active fire protection was typically designed by contractors who found it easiest to adhere to the guidance. The approach had become stereotyped.

19.67 One adverse effect had been on ventilation. Reference areas were basically defined as the complete floor areas of hydrocarbon processing modules and were enclosed by A or H rated firewalls and the edges of the installation. In order to limit the size of reference areas, and hence the water to be delivered, additional firewalls had often been used, so that modules became compartmentalised. This reduced natural ventilation and led to the need for mechanical ventilation and might increase the risk of explosion.

19.68 Another effect had been the installation of massive water deluge and pump systems. The deluge systems used involved a vast number of individual nozzles and associated small bore pipework. The delivery of a uniform water rate of 12.2 litres/m^2 min over the whole reference area led to very high water requirements; and the need to provide additional water to counter the 'shadow' area underneath equipment could almost double the requirements.

19.69 Even so, the systems might be of limited effectiveness against major fires. For protection of individual items of equipment, the water directed straight at the floor was "wasted", though it was a high proportion of the total. On the other hand only very limited pool fires would be extinguished by an application of 12.2 litres/m^2 min and this would require the use of foam induction.

19.70 These deluge systems with their small bore pipework were prone to uneven distribution of the water. Discharge nozzles close to the deluge control valve might be at a pressure up to 3 bar higher than remote nozzles. The systems tended to suffer from severe blockage problems. Nozzles and small pipework were prone to plug. This had led to the use of wet tests to check the state of the system, which tended to compound the problem. Often the systems were too large to be drained, flushed with fresh water or blown dry. Plugging even occurred in the headers. Older systems using galvanised steel were particularly prone to blockage, but despite the use of corrosion resistant materials the problem persisted.

19.71 As far as concerns explosion, the water deluge pipework added significantly to the "clutter" effect and might enhance the over-pressure from an explosion. The systems themselves with their small bore pipework were vulnerable to explosion.

Fire protection systems by scenario-based design

19.72 The alternative approach advocated by Mr Brandie was the use of fire risk analysis and what he called "scenario-based design". This was already practised by companies to varying degrees, but he sought a regulatory regime which would positively encourage it. The scenario-based design approach involved carrying out a fire risk analysis to identify and assess the fire scenarios. Measures to control the risk derived from these scenarios might or might not involve active fire protection. The latter was only one weapon in the fire engineer's armoury. In a given case some combination of measures might be more appropriate which might involve in addition or instead measures such as layout or blowdown or passive fire protection. As far as concerned active fire protection, the method involved protection of specific items such as vessels and equipment rather than blanket protection of areas. On the basis of the fire risk analysis the objectives of the fire protection were then defined; these might be to control or to extinguish the fire or to provide fire exposure cooling. A deluge system was then designed to fulfil these functions.

19.73 The system of nozzles and pipework suitable to a deluge directed to specific items was quite different from that required for area coverage. The nozzles required were fewer but larger and they could be selected to ensure better penetration of even jet flames by the water droplets. Larger bore pipes could be used, with consequent benefits in facilitating fresh water flushing, reducing blockage and imbalance problems, minimising the "clutter" effect and rendering the system less vulnerable to explosion. Mr Brandie expected that with this method the total water requirement would be somewhat less, although averaged out over the total area it would comfortably exceed the standard 12.2 litres/m^2 min. This appeared to mean that the standard rate would be exceeded with all deluges operating, but that in practice even the worst design scenario would not require this.

19.74 Mr Brandie saw a number of advantages in his proposed approach. Major fire hazards were specifically addressed and protection afforded commensurate with the risk. Vulnerable items might be protected with larger quantities of water. Water was conserved and directed to points where it would be most effective. He was questioned on possible disadvantages. He believed that the principal perceived disadvantage was that it would require greater expertise in both the operator and the regulatory body. The current approach made design of active fire protection systems fairly straightforward. He was also asked about possible disadvantages of foregoing a uniform deluge. He believed that the omission of the odd scenario in the hazard identification would not be too serious; the system should cope and there was manual fire-fighting back-up. He considered that the system would be more effective against major fires, both jet and pool fires. Items at risk would be protected with larger quantities of water. The system should also be more effective against minor fires, which would tend to be on items protected by the deluge. In any case minor fires were usually controllable without the deluge. Asked whether he saw any role for the reference area concept, he replied that some situations might well be adequately protected by that approach, but he was opposed to bringing in the scenario-based approach simply as an addition to the existing reference area system.

Fire pump systems

19.75 Existing offshore fire-water systems based on the reference area concept had a very large capacity and required very large fire pumps. The pump capacity was governed by Regs 9 and 11 of the Fire Fighting Equipment Regulations which were commonly understood to mean that each fire pump unit should have the capacity to supply the water requirement for the largest single reference area, which was invariably the wellhead area. Fire-water requirements could exceed 3000 m^3/h. The pump capacity required could be very large. Four or even 5 pump units might have to be installed.

19.76 The requirement for assured power supply to the fire pumps had led to the installation of diesel-driven pumps. It had been the invariable practice, therefore, to install large diesel fire pumps. Historically such pumps had required a high degree of maintenance and had had a poor availability on demand, which in turn had necessitated additional pumps to meet the regulatory requirement. Many of these pumps were now ageing, which compounded the problem. The enclosures needed to house such diesel fire pumps were also large. Mr Brandie quoted an enclosure size of 10m x 8m. It was therefore no easy task to locate such enclosures to achieve segregation.

19.77 A move away from reference areas would alleviate this situation, by reducing the fire-water supply capacity needed and permitting the use of smaller, electrically driven pumps. This would ease problems of location, segregation and protection. Provided the electrical supply was assured, such pumps were highly reliable. There remained, however, the problem of disablement of the electrical supplies by severe accident conditions.

19.78 Mr Brandie was asked about the requirements for fire pump availability given in a DEn letter of 31 May 1989. He agreed that this created an apparent requirement for 100% pump unit availability and that such a requirement was based on a different philosophy from that usually applied in the design of protective systems, such as instrumented protective, or trip, systems, where some unavailability, albeit usually a very small one, is accepted.

Hydrocarbon fire test

19.79 I have already discussed the role of acceptance standards. One of the principal such standards required in fire protection work is a hydrocarbon fire test. However, Mr Brandie stated that there was still no internationally recognised hydrocarbon fire test standard, that this was a problem and that he believed it had been so for some 15 years. The conventional fire test involves putting the assembly in a furnace, heating it up according to a standard time-temperature curve, and determining the times of failure of the assembly and of any insulation. There are 2 principal types of fire test, those for cellulosic, basically wood, fires and those for hydrocarbon fires. These lead to A and H ratings, respectively. Failure in the test is defined in terms of integrity and load bearing capacity and of insulation performance of the assembly.

19.80 Fig 19.1 is that shown by Mr Brandie to illustrate a number of well known time-temperature curves. The BS 476 curve is for cellulosic fires and leads to an A rating; its use for hydrocarbon fires leads to a design with a lower safety margin unless suitable allowance is made. Another somewhat similar curve is the American Society for Testing and Materials (ASTM) E119 curve. The SOLAS curve, referenced in the MODU code, is equivalent to this ASTM curve. The curve shown as "oil company" is commonly referred to as the Mobil curve; and purports to be more representative of hydrocarbon fires. The NPD curve is the Norwegian hydrocarbon fire test curve. The curve marked in the figure with an asterisk is an interim hydrocarbon fire curve proposed by the DEn. The Mobil, NPD and DEn curves lead to hydrocarbon fire test, or H, ratings. The Mobil and NPD curves are both well recognised.

19.81 According to Mr Brandie, the time-temperature curve method is regarded as far from satisfactory. He considered there was a consensus that ideally the test should be based on heat flux. This was confirmed by Mr A R McIntosh, Principal Inspector, who stated that the DEn had commissioned the Fire Research Station to develop a heat flux test. However, there proved to be severe practical difficulties and the work was aborted in 1983. Work on such a test had come to a stop. UKOOA submitted that the appropriate Government department should be required to assist industry in developing a hydrocarbon fire test.

19.82 Mr Brandie was at pains to emphasise that the standard fire test was no guarantee of the behaviour of a structure in a real fire. In his words: "I think one of the major misconceptions in fire protection is the belief that an assembly rating indicates the time the assembly will survive in an actual fire."

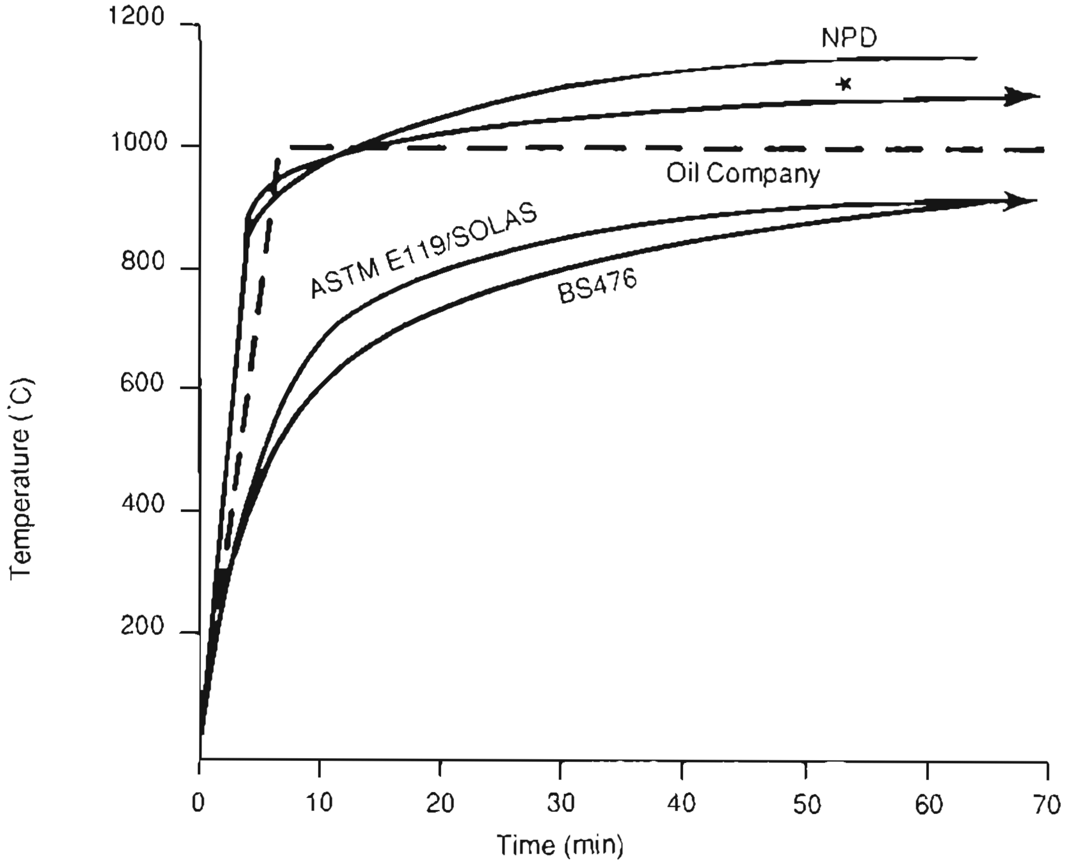


Fig. 19.1 Some principal fire test time-temperature curves. The curve marked with an asterisk is the Department of Energy's interim hydrocarbon fire test curve.

Fire protection in the regulatory regime

19.83 Witnesses led by UKOOA argued that fire protection should become an aspect of the FSA; and the submission of UKOOA was to this effect. UKOOA also submitted that the concept of reference areas and the specification of water rates for the deluge system should be removed from the guidance.

19.84 The evidence of the DEn witnesses was that the Department was to some degree moving in the direction of FSA. The most up-to-date statement of the Department's position was the discussion document on Fire and Explosion Protection, spoken to by Mr McIntosh. The document proposes (Sec 2(a)) that an operator should carry out an FSA of the fire and explosion hazards of the installation and should be able to demonstrate that passive and active fire and explosion protection facilities are sufficient. It also, however, sets out certain specific requirements for all installations (Sec 2(b)). The means of complying with these latter are given in the guidance notes in the form of default criteria, which may need adjustment in the light of the FSA. The document illustrates some of these default criteria. For example, it states that guidance would recommend the use of H120 external boundaries for the accommodation and control stations unless it can be demonstrated that some other standard is sufficient. As another example, it states that guidance would recommend that escape routes between the accommodation and lifeboat embarkation stations close to it should be enclosed and rated to H120 standard unless other standards are demonstrated as satisfactory.

19.85 Questioned on this document, Mr Brandie supported the use of FSA as proposed in Sec 2(a). As far as concerns fire and explosion, he envisaged that there would be a fire risk analysis as part of the FSA. He was opposed, however, to the proposal in Sec 2(b) for specific requirements with default criteria. He interpreted the reference to default criteria as meaning that there would be specific absolute requirements from which the operator would need to apply for an exemption. He thought that the use of FSA and specific requirements was somewhat contradictory. He cited as an illustration of the problem scenario-based design proposals for the Ninian platforms. These proposals were based on fire risk analysis and would supersede the existing system based on reference areas. The company had felt it necessary to put its proposals to representatives of the DEn and the DoT at a single meeting so as to ensure that they were acceptable to both; it still had to "cross the barrier of what the certifying authority might think".

19.86 Mr Brandie considered that the DEn's proposals gave little encouragement to scenario-based design, though it was not actually prohibited. The UKOOA Fire Protection Work Group had held meetings with the DEn over a number of years at which it had pressed for the scenario-based design option, but the DEn had seemed half-hearted. He believed that one reason might be lack of the necessary expertise. Likewise, the perpetuation of the split between active and passive fire protection shown by the draft fourth edition of the Construction and Survey guidance notes suggested that acceptance of a unified approach was still some way off.

Observations on fire and explosion protection

19.87 It is clear to me that prevention of and protection against fire and explosion requires an integrated approach. Design in this area involves balancing a number of factors and making compromises. For example, it is desirable to have good ventilation to disperse any leak which occurs and desirable to prevent fire in one area spreading to another, but the use of additional firewalls for the latter purpose may frustrate the former. There needs, therefore, to be a regulatory framework which facilitates such an integrated approach.

19.88 To this end I have considered 2 options. One is to subsume fire and protection in the Safety Case. The other is to treat it separately by means of its own set of regulations. I have decided to adopt the second option. The fire and explosion hazard will necessarily be a major feature of the Safety Case. However, there are certain features within the Safety Case which have a distinct identity and which will exist on virtually all installations. One of these is fire and explosion protection. It seems sensible to provide for such features by means of goal-setting regulations and thus strengthen the framework of the Safety Case. Furthermore, whereas the emphasis in the Safety Case is on major hazards, these regulations will deal in the usual way with all degrees of hazard.

19.89 The essential requirements for fire and explosion protection should be stated in regulations and should be supported by guidance. Compliance should be demonstrated by reference to a combination of company compliance standards, guidance notes and safety assessment.

19.90 There should be a requirement in the regulations for a fire risk analysis covering both major and lesser hazards. This analysis should involve the identification of the locations where fires may occur; the scenarios of fire and of their escalation; the mitigatory measures available; and the assessment of the hazards and mitigatory measures. The acceptance standards for the design should be developed by the operator.

19.91 The regulations should be framed in such a way as to allow fire protection to be treated as an integrated whole. This means that it should be acceptable for the design options to include the use of active or passive fire protection measures or a combination of the two, and that the design should be assessed on the totality of the measures taken. Here I have in mind the whole range of measures available, including minimisation of hydrocarbon inventory; drainage of spills of flammable liquids; installation layout to segregate vulnerable targets from high risk areas; ventilation to disperse leaks; elimination of ignition sources; systems to give early detection of gas and fire; localisation of fire by fire resistant walls, floors and ceilings; passive measures of fire protection; and active measures to control fire and to cool exposed structures and equipment.

19.92 Likewise, the regulations should be framed in such a way as to allow explosion protection to be treated as an integrated whole, enabling the designer to utilise the whole range of available measures, including installation layout; reduction of overpressures by equipment layout, venting, and other measures; localisation of explosion effects by blast resistant walls, floors and ceilings; and minimisation of missiles.

19.93 Further, the regulations should be such as to allow protection against explosion to be integrated with protection against fire, so that the designer is free to adopt a design which achieves the best overall compromise between various aspects of fire and explosion protection.

19.94 To be explicit, in order to make best use of advances in knowledge, I believe that the operator should have the freedom to consider designs quite different from those which have pertained historically; specifically, designs involving features such as larger vent areas and more open layouts; more frequent use of combined passive and active fire protection; and water deluge systems which emphasise cooling of equipment. It is not, however, for me to say how this freedom should be used in detail.

19.95 As a general principle, the regulations should be sparing in their use of specific requirements, although, as I have already indicated, I do consider that there are cases where it is inconceivable that there should not be a specific requirement.

19.96 Likewise, as a general principle, the regulations and guidance should be so framed and interpreted as to avoid the creation of default requirements from which variation can be obtained only by means of a lengthy exemption process. For example, requirements for the use of firewalls or blast walls in particular applications and specification of the standards of fire resistance such as A60 or H120 or of blast resistance such as the 0.3 bar criterion, should be used sparingly if at all.

19.97 A fire-water deluge system should be provided to control fires of hydrocarbons which have been released; to cool vessels and equipment containing further fuel which may feed the fire; and to cool fire barriers. The standards for the system should be set by the operator and should cover the function, configuration, capacity and availability of the system and its protection against fire and explosion.

19.98 The regime governing the fire-water deluge system should move towards scenario-based design with no requirement for any particular water deluge rate(s). The scenarios considered in the design of such deluge systems should be comprehensive; they should cover both pool and jet fires; and both small fires which tend to occur more frequently and large fires which occur rarely but which constitute a major threat. I recognise, however, that the current regime and most existing systems are based on the reference area concept and propose that this approach should be retained in guidance as an option, at least in the medium term.

19.99 Similar principles should apply to the fire-water pump system. Current regulations and guidance are onerous, being framed so that they apparently purport to assure zero unavailability. It is indisputable that the availability of these pumps should be very high, but the proper approach is for the operator to set the acceptance standards, in this case the capacity and the availability, and to demonstrate these by FSA.

19.100 The regulations and guidance should promote an approach to the design of fire protection systems which ensures that as far as is reasonably practicable the systems are able to survive severe accident conditions, including fire, explosion and strong vibration. The fire protection systems referred to here include the fire-water deluge system, the fire pump system, and the fire pump startup and changeover controls. The ability of these systems to survive severe accident conditions should also be a feature of the Safety Case.

19.101 The behaviour of a fire barrier under actual accident conditions is inevitably subject to uncertainty, but this is increased by the lack of an internationally recognised hydrocarbon fire test. It is clearly desirable that any test used be realistic. It is equally desirable that problems of devising a test should not prevent or delay the installation of fire barriers which, though perhaps not ideal, nevertheless constitute important safety features. The essential problem is not that of a test *per se* but of the information which the test provides to the designer about the probable behaviour of the fire barrier in real hydrocarbon fire conditions and of the degree of uncertainty the designer can live with, bearing in mind that there is inevitably uncertainty in the fire exposure scenarios. The DEn has already issued an interim test standard. This standard is based on a time-temperature test, the profile of which is broadly intermediate between the widely used Mobil and NPD curves. In the short term the regulatory body should use this standard. It should work with the industry to obtain agreement on how this and other tests should be interpreted for design purposes. If in the view of the regulatory body there exists a need for an improved test, possibly a heat flux test, it should work with the industry to develop one.

19.102 The DEn discussion document on Fire and Explosion Protection is not compatible with the approach just outlined and should be withdrawn.

19.103 The fire risk analysis is one of the measures which the regulatory body should ask operators to undertake forthwith.

Safe haven (or temporary safe refuge), accommodation, escape routes and embarkation points

19.104 I now come to the protection of personnel in the immediate aftermath of a major accident. As the fires on Piper escalated, there was no place which provided protection from the flames and the smoke where they could shelter and try to control the emergency and organise evacuation or escape. Such protection as was provided by the ERQ proved inadequate. Personnel working outside were unable to reach the ERQ or the lifeboats.

19.105 This evidence pointed to the need for there to be on an installation a temporary refuge which provides shelter against fires which may be massive and prolonged and against the associated smoke. There need also to be routes which remain passable long enough for personnel to reach the refuge and to move from the refuge to the embarkation points.

Parties' submissions on safe haven

19.106 The concept of a safe haven was a principal feature in the submissions of the parties. UKOOA proposed that the need for, location and protection of, and facilities in, a safe haven should be a feature of the FSA. A safe haven was part of the submissions of the Trade Union Group, the Piper Disaster Group and the Contractors' Interest, all of whom also made specific proposals for its protection.

Safe haven and temporary safe refuge

19.107 The general assumption was that the safe haven would be the accommodation upgraded as necessary to provide a defined degree of protection. Mr Ognedal stated that the safe haven is part of the total concept of evacuation. It provides a place where persons can remain while either the situation is brought under control or a safe evacuation is organised.

19.108 However, several parties expressed reservations on the use of the term, mainly because it might suggest that there is an area on the installation which can be maintained in a liveable condition for an indefinite period and in all circumstances. UKOOA therefore proposed instead the term "temporary safe refuge" (TSR). I will therefore adopt this latter term. Moreover, for the avoidance of confusion, I will use this term in describing evidence even where the witness referred originally to safe haven.

TSR in the regulatory regime

19.109 There should be a TSR on all manned installations. As I stated in Chapter 17, a central feature of the Safety Case should be a demonstration of the integrity of the TSR in relation to the major hazards of the installation. Thus the TSR imparts structure to the Safety Case. In this section I give further consideration to the TSR and to the associated escape routes, embarkation points and lifeboats, to the construction of the accommodation and to the role of the Safety Case and of regulations in relation to these.

Function of and facilities in TSR

19.110 Mr M J Booth, Head of Operations Safety in the Safety and Environmental Affairs Department at Shell Expro, described the TSR as a place where personnel can muster without being exposed to undue risk. It was a place in which personnel should not simply huddle but should act to assess and control the emergency and prepare evacuation. This is essentially how I see the function of the TSR.

19.111 The concept of a TSR has implications for mustering. The 2 main witnesses who spoke to this topic, Mr Brandie and Mr Booth, said that it was the policy of their companies to muster in the accommodation, but acknowledged that practice differs, another policy being to muster at lifeboat stations. I make no proposals on mustering as such, but clearly any policy on mustering should be compatible with the TSR concept.

19.112 Assessment and control of the emergency from the TSR requires the availability within it of the necessary facilities. I consider this aspect in para 19.176 *et seq*.

Endurance of the TSR

19.113 There was general agreement that the basic approach to the design of the TSR should be to specify an endurance time for occupancy and then to identify the hazards to which it may be exposed; to define agreed scenarios which it is to be designed to withstand; and to perform a risk assessment to confirm the design.

19.114 Two general types of consideration were put forward as governing the choice of endurance time, namely the exhaustion of the threat and the time to arrange evacuation. For example, Mr Brandie referred to the need to allow the platform inventory to exhaust itself; Mr Booth to the need to allow any event on the platform to subside. The risk assessments showed that the safety measures taken obviated the need for a longer period. The riser hazard, for example, was handled by limitation of the risk rather than extension of the endurance time.

19.115 The other consideration determining the endurance is the time to effect evacuation. Here the lead times for helicopter evacuation will tend to give long endurance time requirements. Mr Booth disagreed with the suggestion that the endurance should be such as to allow for evacuation by helicopter.

19.116 Mr Booth stated that the endurance time used by his company was 60 minutes. It was the period necessary rather than the limit of what was technically achievable. Mr Brandie also made reference to an endurance time of 60 minutes, but was reluctant to give a firm figure.

19.117 As far as concerns the practicality of particular endurances, Mr Booth said that risk assessments had been carried out on all his company's platforms. The 60 minutes period was seen as the practical figure to aim for. He supported the use of H120 firewalls where the risk assessment showed that this was necessary, but he considered that even with H120 firewalls it was difficult to assure occupancy for more than 60 minutes and that it was realistic to adopt this figure. He regarded this as consistent with the Norwegian approach, described below.

19.118 It is clear that there are a number of factors which may limit quite severely the period for which the TSR is occupiable. Factors mentioned by Mr Booth included heat, smoke, combustion products, toxic fumes and disintegration. Similar factors underlie the endurance criteria used by Dr Gilbert in his study of SSIVs, which I have already described.

19.119 The endurance set for the TSR in the Norwegian system, which is 2 hours, was spoken to by Mr Ognedal and Mr Nordgard. This comprises one hour for collecting personnel into the TSR and one hour for effecting evacuation. While this time may be to a degree arbitrary, it has some basis in evacuation trials carried out on platforms. The time for blowdown of the hydrocarbon inventory on the platform is also a factor. Mr Nordgard stated that this 2 hour period was given in regulations and in guidance. However, while the Guidelines for Safety Evaluation of Platform Conceptual Design set a time of one hour for the availability of at least one escape route against a design accidental event, there was no corresponding specified period for the shelter area, or TSR. Asked directly where the 2 hour period was actually stated, Mr Ognedal said that it was referred to in terms of the H120 firewall in the Regulation for Production and Auxiliary Systems 1976. Para 6.5.2 of these regulations stated that as a minimum the outer surfaces of the living quarters which might be subjected to a hydrocarbon fire should be protected to H120 standard. He indicated that the NPD had made no decision on whether to make any change to the endurance required. With regard to the endurance achievable, Mr Nordgard was of the view that it was not much more difficult to design for an endurance of 2 hours than for one of one hour and that there was no great benefit in specifying the shorter period. In this context he stated that the design accidental events did not include riser failure; such failures were dealt with by reducing the frequency.

19.120 The DEn discussion document on Fire and Explosion Protection states that the TSR should remain viable for at least 2 hours unless demonstrated otherwise by FSA. Mr McIntosh agreed that this figure was somewhat arbitrary. He said it was related to the proposal that the accommodation should be protected by H120 firewalls unless the FSA showed otherwise.

Protection of accommodation against external fire

19.121 Two principal threats to the TSR are external fire and smoke. The construction of the accommodation is one of the items covered in the Construction and Survey

Regulations. The associated guidance notes give guidance on its protection. The third edition states that the bulkheads separating the accommodation from the wellhead and process areas should be to A60 standard or to a standard providing equivalent protection. The draft fourth edition states that the control stations and the accommodation, as a TSR, should have fire durability commensurate with the possible exposure and reiterates the requirement that boundaries between the accommodation and the wellheads and process areas should be to A60 standard. It adds, however, that where the risk of a hydrocarbon fire exists, it should be assumed in the absence of other information that all external boundaries require H120 protection, unless some other level of protection is shown to be appropriate by reason of the likely extent, duration and severity of the fire exposure.

19.122 It was Mr Brandie's evidence that the general practice in the British sector was to put an A60 division on the side of the accommodation facing the hydrocarbon risk and in a number of cases to continue around the sides and inside, if there was a possibility of exposure. On some platforms this passive protection was complemented by water drench systems. The accommodation protection taken by Dr Gilbert as typical for his company's platforms was A60.

19.123 The Norwegian requirements for fire protection were described by Mr Nordgard and Mr Ognedal. They referred to the Regulation for Production and Auxiliary Systems, which required that outer surfaces of the accommodation which might be exposed to a hydrocarbon fire should be protected to H120 standard and those which might be exposed to fire from other areas should be protected to A60 standard. The fire exposure, and hence the protection required, was obtained from the QRA.

19.124 I have already mentioned, in the context of the hydrocarbon fire test, the point made by Mr Brandie that a particular nominal rating of a firewall was no guarantee that the wall would exhibit that degree of endurance in a real fire. An essentially similar point was made by Mr McIntosh when he said that there was nothing sacrosanct about H120 protection; it was to some extent arbitrary. It was not certain that such protection would necessarily last 2 hours. It represented an improvement on A60 protection rather than an absolute level of protection. Likewise, Mr Booth said he would support the use of H120 protection where FSA showed it to be necessary, but as a means of achieving an endurance time of 60 minutes.

19.125 This evidence indicates to me that the proper approach is to define the endurance required and hence the necessary degree of protection rather than to specify the means in terms of firewalls of a particular rating and that the way to do this is through the Safety Case.

Protection of accommodation against smoke

19.126 The endurance of the TSR will be determined in large part by the breathability of the air within it. This topic was addressed by Mr G A Dalzell, a Fire and Safety Engineer with BP International. The principal factors which might render air in the accommodation unbreathable were heat, smoke and toxic fumes. Heat transfer through the external walls would heat the air and heating of the walls may produce toxic vapours, but he estimated that both effects would be delayed for one to 2 hours, depending on the firewall rating and the fire exposure. Carbon dioxide build-up should not be significant within the 2 hours. Nor should oxygen depletion by the occupants. The main problem addressed by Mr Dalzell was therefore smoke.

19.127 Mr Dalzell reviewed the main potential sources of fuel for smoke-generating fires, outlined some of the scenarios for such fires, and described the use of wind tunnel testing to investigate smoke movement for design purposes. The first lines of defence in reducing the risk of smoke ingress into the accommodation were the prevention of and reduction of scale of fires; orientation of the installation so that the prevailing wind blew the smoke away from the accommodation; layout which segregated the accommodation from areas where smoke generation might occur; and positioning of the accommodation at a low level so that at least its lower part was below the main sources of smoke.

19.128 Weak points on the accommodation through which smoke might enter included penetrations through the external walls, doors, windows, and ventilation air intakes and exhausts. Mr Dalzell distinguished 4 classes of door: main entrance doors; emergency entrance doors; emergency exit doors, or escape doors, otherwise known as crash doors; and evacuation doors. The main and emergency entrance doors needed to be on the front of the module, facing the rest of the platform, and hence were more vulnerable. The evacuation doors should be at the back close to the lifeboats. The escape doors, intended for escape from an internal fire rather than evacuation, were commonly put at the end of corridors; they tend to be fairly numerous. Essentially his proposals for doors were that escape doors should be kept shut and main entrance and evacuation doors provided with air locks. He recognised that escape doors might be used and left open, thus letting smoke in. He believed that mustering at low level and muster discipline should minimise the problem, but agreed that self-closing doors were both desirable and practical and saw some merit in break-glass panic bolts. He considered that escape doors did not need protection by air locks. He did advocate air locks for the main entrance doors, where they had traditionally been fitted, and for evacuation doors. Air locks served to conserve air and maintain positive pressurisation. They could be defeated, however, if a continuous stream of people passed through, so keeping the doors open, and needed therefore to be large enough, say 3-4m, to hold 6-10 people. Few accommodation modules were fitted with windows, though more recent designs might have them on the rear wall. There was a problem in obtaining windows rated for hydrocarbon fires. Mr Dalzell said that windows rated A60 were available and he believed some had been tested to H60 rating. He suggested there might be small strategic observation windows near doors and agreed the problem of fire rating might be overcome by fitting such windows with small covers.

19.129 Smoke could be prevented from entering if there was a positive pressure in the accommodation. This pressure was maintained by the ventilation system, of which there were basically 2 main types. Both consisted of inlet fans, ducting and exhaust fans. A forced ventilation system was the basic type. It might give a high degree of protection against smoke ingress if optimised for this, but it was not designed to maintain positive pressure and some rooms might be at negative pressure. The system was balanced for one set of wind conditions and it could compensate for other conditions. It was also liable to deterioration and needed careful maintenance to achieve optimum performance in excluding smoke. More modern platforms might be fitted with a positive pressure ventilation system, essentially a refinement of forced ventilation, which was more flexible and gave closer control of pressure, typically maintaining 6-12 mm water gauge. Ventilation systems were not classed as emergency systems and generally were not powered from the emergency power supply (EPS). However, on some platforms, for reasons of commissioning or maintenance, the system could take power from the EPS. Some platforms had one inlet and one exhaust fan on the EPS. In general Mr Dalzell was opposed to running the ventilation from the EPS, being reluctant to risk jeopardising the other emergency functions. If the ventilation inlet fans were lost, positive pressure would be maintained only for a few minutes. It would not be maintained if a door was left open, though for a period the air flow would be outwards, reducing smoke ingress. The period during which smoke was excluded could be maximised by the use of air locks on doors and of dampers on the ventilation ducts.

19.130 The ventilation air intakes were a weak point through which noxious gases might be drawn into the accommodation. Prevention involved shutting off the ventilation and closing dampers in the intakes. The extent of provision for automatic shutdown of the ventilation system on detection of fire, gas or smoke was unclear from Mr Dalzell's evidence, but he described in some detail the arrangements for closure of the inlet dampers. For these only remote manual closure and automatic closure on heat detection were universally provided, but it was common in addition to have automatic closure on detection of flammable gas. There might also be automatic closure on detection of a particular toxic gas such as hydrogen sulphide. The arrangements for exclusion of gas and of smoke were similar and in many cases the former already exist, so that it was not difficult to add the latter. Some platforms had smoke detectors on the air inlets prior to Piper; most which did not, had since fitted them. Mr Dalzell considered that reliance on manual closure of the ventilation intake dampers was not appropriate; closure should be automatic. Apart from closure on heat, gas and smoke he favoured closure on loss of power but not on loss of positive pressure, since the latter could be caused by an open door. The vulnerability of the ventilation air intakes to smoke ingress could be reduced by positioning them low down, below the level of most smoke plumes. However, the location must take account of exhaust fumes from platform sources and from vessels. Mr Dalzell conceded that it might be possible to provide emergency intakes, but foresaw a possible problem with changeover.

19.131 Mr Dalzell recommended that all installations should have a smoke ingress assessment of the accommodation module; automatic shutdown of ventilation and closure of intake dampers on smoke detection; and air locks on main entrance and evacuation doors. Relocation of air intakes and doors to minimise their vulnerability to smoke should be considered and also provision of observation windows. Forced ventilation systems of older platforms should be reassessed to improve maintenance of positive pressure and new installations should have positive pressure ventilation systems. For new designs smoke movement should be assessed by wind tunnel testing and smoke ingress should be a factor considered in positioning of the accommodation.

TSR as a citadel within accommodation

19.132 For longer term refuge Mr Brandie envisaged the use within the primary protected areas of a secondary protected area, a "box within a box", and instanced the application of this on the Ninian installations. This is effectively a citadel, although he did not use that word.

Upgrading of accommodation to TSR on existing platforms

19.133 The practicability of upgrading the accommodation to a TSR on existing platforms is clearly of prime importance. Mr Brandie described some of the measures which may be taken on an existing installation. These included uprating A60 firewalls to H rating; use of combined passive and active fire protection; installation of radiation screens; removal or reduction of close proximity hazards; enhancement of structural protection; and major incident prevention. He also drew attention to some of the problems in uprating existing A60 protection to H rating which may make such uprating impractical. He agreed that the problems were common to both A and H class protection.

Additional refuges

19.134 It was recognised that at least on some existing large platforms there might be a need for temporary safe refuges additional to the main TSR for personnel who would need to muster elsewhere. Mr Booth instanced the drill crew, who have to make the wells safe. This was a point which Shell were still considering.

Bridge-linked accommodation platforms and flotels

19.135 One of the principal measures canvassed after Piper has been the provision of accommodation separate from the main production platform, typically in the form of a separate, bridge-linked quarters platform or flotel.

19.136 A generalised study of the comparative risks of different platform configurations, originally commissioned in August 1988 by the DEn from Technica and the

Offshore Certification Bureau, was described by Mr J R Spouge of Technica. The cases considered were: case A: Base case design: a base case platform, representative of design practice in the UK Central and Northern North Sea before systematic consideration was given to the safety implications of topsides layout; case B: Modern design: a modern equivalent of the base case, characteristic of recent design practice in which the topsides layout is heavily influenced by safety considerations; case C: Bridge-linked flotel: the base case with accommodation on an adjacent flotel linked by a bridge; case D: Helicopter-linked flotel: the base case platform with accommodation on a nearby flotel linked by helicopter; case E: Smaller capacity platform: a smaller, 4-legged platform, representative of a modern trend towards lift-installed jackets with cantilevered, integrated decks; case F: Bridge-linked quarters platform: the base case platform with accommodation on a separate quarters jacket platform linked by a bridge. These configurations are illustrated in Fig 19.2. Cases A-E were specified by the DEn and case F for the Inquiry. Initially the aim was to determine the frequency of impairment of structure, accommodation and escape routes by residual accidental events along the lines of a Norwegian CSE, but this was later extended to determining the average annual fatalities from high fatality accidents (10 or more deaths) throughout the drilling and production phases.

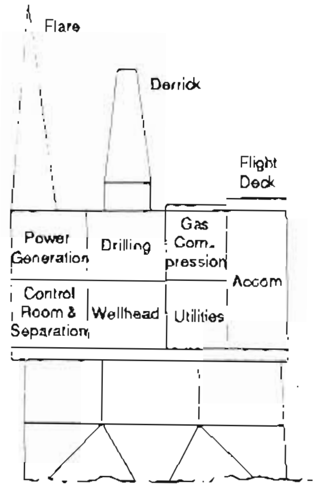
19.137 The average annual fatalities in high fatality accidents for the 6 cases are shown in Table 19.1. The study showed that the average annual fatality risk for the modern design, case B, and for the bridge-linked platform, case F, was about a third of that for the older platform, case A, and that for the bridge-linked flotel about a half, while that for the helicopter linked flotel, case D, was about half as much again, due largely to the contribution of helicopter accidents. The smaller capacity platform, case E, had a risk about one ninth, but also a production rate one quarter, of the base case. A sensitivity analysis had been performed but it remained true that the risks of case B were 50-75% lower than those of case A and that the risks of cases B and F were within 20% of each other.

19.138 The reduction in risk as between cases A and B was due mainly to the stronger jacket on the latter; other significant features were topsides layout, firewalls and riser protection. The reduction as between case A and case F, on the other hand, was due largely to reduction of exposure of personnel. In case F the office staff, who numbered 35, were located on the quarters platform so that the proportion of personnel remaining on the main platform was reduced to 25% of the base case. This effect of the location of office staff was a significant result of the study. The benefit was not available in case C, because the flotel had to stand off in rough weather and so office staff had to be accommodated on the main platform.

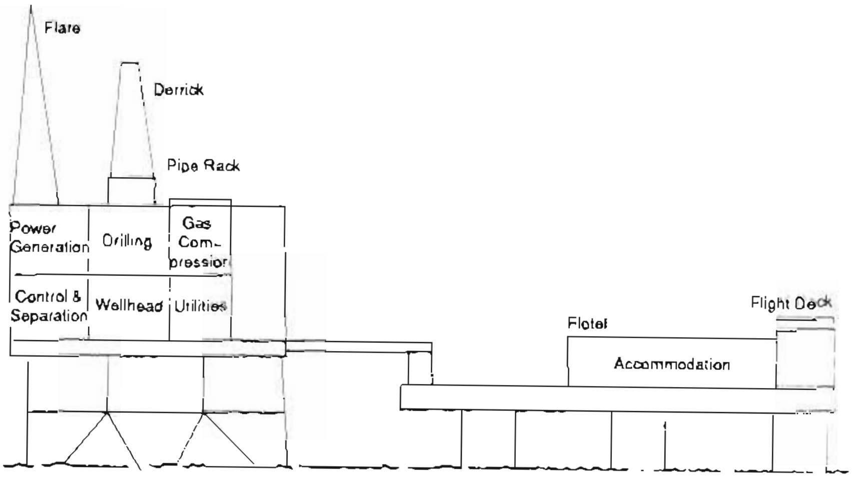
19.139 Of the measures considered in the study for reducing the risk of an existing installation, Mr Spouge stated that the provision of a bridge-linked quarters platform was the most effective. The study did not, however, address other measures such as relocation of ESVs nearer to sea level or the installation of SSIVs. On the practicality of a bridge-linked quarters platform, he stated that such arrangements existed in the southern sector of the UKCS and in the Norwegian sector of the North Sea. In the northern sector of the UKCS he was unaware of any dedicated quarters platform, though he did know of one 2-platform concept where one platform housed the quarters and some other facilities.

19.140 Mr Spouge was careful to point out the limitations of the study, which was a generalised ranking exercise, and agreed that for a particular site it would be necessary to do a specific study. He stated that the same methodology was in fact being used by operators to assess options, especially in respect of accommodation, ESVs and SSIVs.

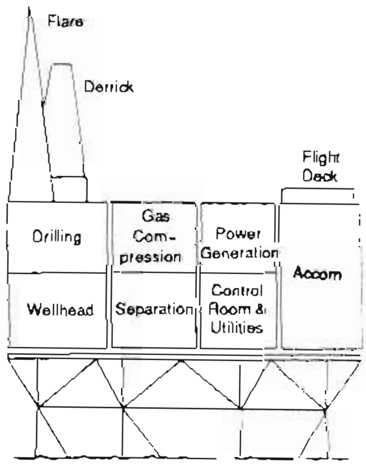
19.141 Risk assessments described by Mr Tveit implied a reduction in risk as between an older and a newer platform of about 4, but he was unable to say how typical these figures were.



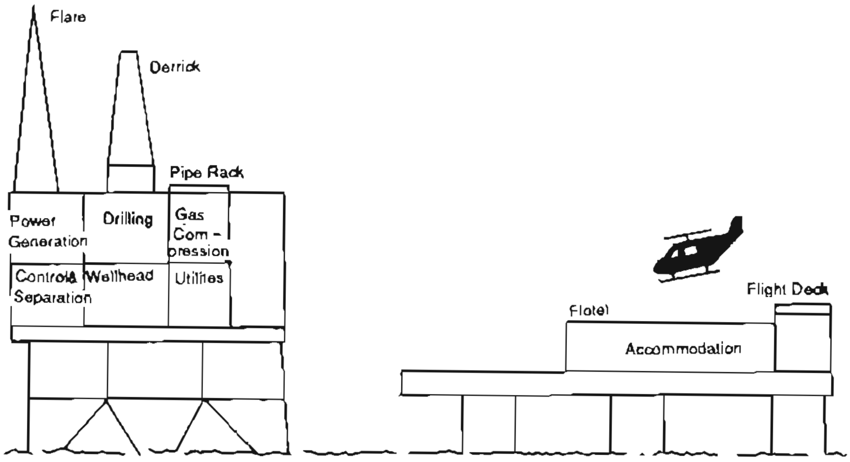
CASE A : BASE CASE



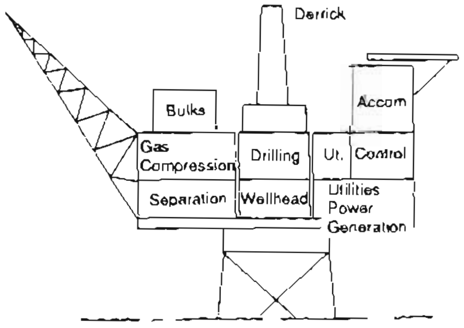
CASE C : PLATFORM AND BRIDGE LINKED FLOTEL



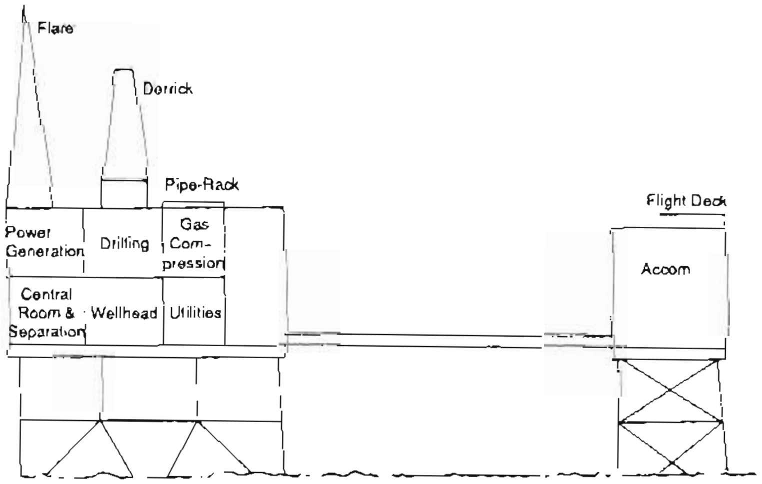
CASE B : MODERN DESIGN



CASE D : HELICOPTER LINKED FLOTEL



CASE E : SMALLER CAPACITY PLATFORM



CASE F : BRIDGE LINKED QUARTERS PLATFORM

Fig. 19.2 Installation configurations studied in the generalised quantitative risk assessment conducted by Technica Ltd: (a) base case; (b) modern design; (c) bridge-linked flotel; (d) helicopter-linked flotel; (e) smaller capacity platform design; and (f) bridge-linked quarters platform.

19.142 The only example of a decision to install a bridge-linked quarters platform about which I heard evidence was Mr Ferrow's evidence that Conoco had decided to locate the accommodation for their Southern Basin Gas Development, or V Field, on a separate platform. The decision, in early 1984, was made at a very early conceptual stage, and before the major hazard review.

19.143 The Trade Union Group and the Piper Disaster Group submitted in effect that there should be a default requirement for quarters separated from the main production platform, the former advocating a separate bridge-linked accommodation platform and the latter separate accommodation, either fixed or floating. UKOOA disagreed and submitted instead that the location of the accommodation should be a matter to be considered in the FSA.

Escape routes to TSR

19.144 A necessary complement to a TSR is escape routes to and from it. On Piper within minutes of the initial explosion virtually all the escape routes provided to the accommodation became impassable and the area on the north face of the ERQ was engulfed in fire and smoke. Evidence on escape routes was given by Mr Booth, who said that since Piper perceptions had changed, the magnitude of the hazard was better appreciated and companies had been conducting reviews of escape routes on their platforms.

19.145 The thrust of Mr Booth's evidence was that escape routes should generally be the normal routes which were used in moving around the platform and which thus had the advantage of familiarity. Passability should be ensured by layout rather than by protection. On existing platforms careful consideration had gone into the design of routes, but this had related primarily to location, path and number of routes and detailed design features rather than to protection against fire, smoke and falling debris. He listed certain principles of escape route design. Escape routes should be as direct as possible. They should lead from internal areas to an external escape route. Primary escape routes should be located wherever practicable external to the modules. He was in favour of permanent walkways around the perimeter of the platform at all levels. Escape routes should not be routed through areas of increased hazard nor past explosion vents or relief walls. Given that the escape routes were afforded protection by their position, there was generally only limited need for other types of protection.

19.146 Conditions for the passability of escape routes are given in Annex 9 of the Petrie Final Report, a report by Technica, quoted by Mr Booth. The report also refers to the criterion that escape routes should remain passable for 30 minutes. He considered this figure reasonable.

Escape routes from TSR to embarkation points

19.147 As far as concerns the escape routes to the embarkation points Mr Booth envisaged that the embarkation points might be in a Protected Area, a term used in Shell to denote an area in the lee of the accommodation and sheltered from the fire hazard. Thus if the wellhead and process areas were on the south end and the accommodation on the north end of the platform, the Protected Area would be at the north face of the accommodation, on the outside. He envisaged that there would be sufficient lifeboats at this point to take everyone in the accommodation. In answer to the point that the area on the north face of Piper did not in fact provide protection for evacuation by lifeboats but was engulfed by smoke within minutes, he replied that a great deal could be done to reduce the risk and that too much should not be taken from this one case.

19.148 He advocated that the escape routes from the TSR to the embarkation points should be short so that movement through them was swift. He envisaged that such escape routes would often run through the Protected Area. They could if necessary be provided with protection such as radiation screens, structures to prevent falling debris and even firewalls, but he stressed that it was important that the OIM should not lose contact with people going to the lifeboats. This would be the probable result of making the escape route an H120 rated tunnel. He agreed that the escape routes from the TSR should survive so that they were usable by personnel at the end of the endurance period of the TSR.

Protection of escape routes and embarkation points

19.149 The essential requirement for an escape route was that it should be passable. It was preferable to achieve this by layout. Otherwise, it might be necessary to protect either the escape route itself or the people passing along it, or both. The protection required was principally protection against heat and smoke. Given the choice, Mr Booth expressed a strong preference for protection of the escape routes rather than reliance on personal protective equipment.

19.150 The main protection which he described was the use of anti-radiation mesh, usually known as radiation screens. Standard double-sided heat shields would provide protection against fire; they might be complemented by a water spray. Water sprays might also be provided on the escape routes themselves; he referred to the relief provided to people on Piper by the water spray from the *Tharos*. He was strongly opposed to the proposal in the DEn discussion document on Fire and Explosion Protection that escape routes might be protected by an enclosure, or tunnel. He said it "confirmed his worst fears". He considered in effect that such tunnels would actually cause safety problems. There would be problems of access to the tunnel, of its ventilation and lighting, of possible loss of integrity, of ingress of smoke, and of disorientation and possibly panic among people using it. He referred to the 1987 fire at Kings Cross Underground Station as an illustration of some of the problems.

19.151 Escape routes needed to be provided with lighting which would function in an emergency. Mr Booth suggested the use of high intensity emergency lighting with battery back-up. He also referred to the use of photoluminescent signs as suggested by survivors of Piper. He agreed that lighting along the floor of the walkways, as in aircraft, would be helpful and that this might best be provided by photoluminescent strips.

19.152 Mr Booth made no proposals for the protection of escape routes from smoke and, while in general preferring to protect the escape route, he agreed that consideration should be given to smoke-hoods and also to lightweight BA sets to allow people to use the escape routes in the face of smoke. He was less disposed to rely for protection against heat on the use of fire-suits, which were cumbersome.

19.153 The protection which he described for the embarkation points was broadly similar to that which he proposed for the escape routes. He was opposed to enclosed embarkation points and concerned that protection should be provided only where it was shown to be necessary. He envisaged that embarkation points would be open to the sea but with radiation screens inboard where appropriate.

Protection of lifeboats

19.154 The lifeboats needed to survive until it was safe for personnel to leave the TSR and go to them to evacuate the platform. The endurance required of the lifeboats was therefore related to that specified for the TSR. Mr Booth thought that it might be necessary to relocate or protect the lifeboats but believed this would not be necessary in most cases. He saw some merit in the suggestion that the lifeboats might be located within the TSR, though there were potential problems such as doors jamming. He did not think such an arrangement favoured free-fall lifeboats particularly.

Escape routes and embarkation points on existing platforms

19.155 Mr Booth outlined a number of measures which could be taken to uprate the escape routes on existing platforms, prefacing his proposals by stressing that account should be taken of the original design philosophy. Steps which he mentioned included measures to reduce the risk from risers, relocation of lifeboats, provision of additional escape doors in the TSR, and protection of routes. He also suggested the provision of smoke-hoods and BA sets.

Observations on TSR, accommodation, escape routes and embarkation points

19.156 The Piper disaster demonstrates that there is a clear need on a platform for a TSR. The industry has recognised this. Companies are already acting to ensure that the main accommodation is protected to a standard such that it constitutes a TSR. There are a number of reasons why the accommodation is the logical choice. Usually it is located furthest from the more hazardous activities, is often the only suitable space in which to assemble large numbers of personnel and at any given time contains a considerable proportion of those personnel. The TSR is therefore taken here to mean the main accommodation.

19.157 I have already proposed in Chapter 17 that the TSR should be a central feature of the Safety Case. The operator should specify the function, the endurance and other acceptance standards for the TSR and should demonstrate by QRA that it has provided one which meets those standards.

19.158 The acceptance standards for the TSR will be of 3 types. The first is the risk criteria, including one for the frequency of loss of integrity of the TSR. The risk criteria should follow the ALARP principle. The second type is the endurance times. The third type is the standards defining loss of integrity. Formulation of these will involve defining the function which the TSR is to perform, the conditions which constitute integrity, the endurance time for which these conditions are to be maintained and the events which may cause these conditions to be violated. The endurance specified for the TSR will determine which hazardous events are residual accidental events which the TSR is not designed to survive. All types of acceptance standard should be specified by the operator.

19.159 However, initially at least, the regulatory body should set minimum standards for the main risk criterion, the frequency of loss of integrity of the TSR. Further, initially at least, the regulatory body should set a minimum endurance time for the TSR. I have weighed carefully the arguments for and against this. The argument against is basically the general one that this is a matter which is best handled as part of the operator's own FSA. The argument for is that the choice of the risk criterion and the endurance necessarily involves a degree of judgement and is to some extent arbitrary; that any gain in flexibility is outweighed by the introduction of a point of probably rather sterile contention; that there is no detriment to safety; and that it puts the Safety Case on a firmer basis.

19.160 The hazards to which the TSR may be subjected should be identified. The hazardous events should be classified as design accidental events and residual accidental events. The TSR should be designed to survive design accidental events. It need not be designed to withstand residual accidental events, though if put to the test it may well survive some of them. The relation between the risk criterion and the endurance time should be seen in this light. For many scenarios the operator will find it more effective to meet the standard by reducing the risks, especially those of fire and explosion, rather than by providing the TSR with extreme levels of protection. This is so particularly in relation to risks from risers.

19.161 It may not be necessary that the whole accommodation module be nominated as the TSR. It should be an option that the TSR should be a limited, protected area, or citadel, within the module. However, since this is uncharted territory, the approach should be a cautious one. In any event, a design based on such a TSR should meet the full requirements for the TSR and escape routes.

19.162 It may be that in some cases the Safety Case will show that the requirements for the TSR can be met only by the use of accommodation separate from the main production facilities such as on a bridge-linked platform. As I have already indicated, it is my view that decisions of this sort be made in the light of the Safety Case.

19.163 The conditions for the integrity of the accommodation are crucial to the risk assessment for the TSR but it is clear that the criteria currently available are rather crude. There is a need for models of the development of the air conditions in an accommodation module and for criteria against which the results from such models can be assessed. The models should address high temperature due to heat transfer through the walls, smoke due to smoke ingress, and toxic fumes from heated fire insulation and any other likely sources. The endurance time used by Dr Gilbert for living quarters exposed to fire, based on build-up of toxic fumes, was relatively short, only 17 minutes. On the other hand Mr Dalzell did not envisage toxic fumes being a problem for 1-2 hours. Unless these matters are sorted out, they are likely to create difficulties in assessing the integrity of the TSR and hence in the development of the Safety Case.

19.164 Staying with the Safety Case, the TSR should be complemented by escape routes to and from it and by embarkation points and lifeboats. These should be treated along with the TSR as central features of the Safety Case. For each location on the platform at least one escape route to the TSR should be passable for a defined endurance time against design accidental events. Likewise, the escape routes from the TSR to the embarkation points, the embarkation points themselves and the lifeboats should each have a defined endurance against design accident events. These endurances should be defined by the operator.

19.165 For existing installations any requirement for upgrading of the accommodation, or TSR, escape routes, embarkation points and lifeboat protection should be decided on the basis of the Safety Case.

19.166 As the TSR, the accommodation will be dealt with in the Safety Case, but it is also a proper subject for regulations on construction. These regulations should set goals for the design of the accommodation and may also contain specific requirements.

19.167 Before considering the protection of the accommodation, I wish first to comment on the loss of integrity of the main accommodation module on Piper, the ERQ, which I described in Chapter 8, and in particular on the special features of this case. The ERQ was protected on the face nearest the fires, the southern face, by other structures. This must have reduced the extent of generation of toxic gases from the module walls which in other circumstances might be much more serious. On the other hand the ERQ was actually breached by the fire. Flames entered in at least 3 places; at the doorway from the LQW, the southern external door to the helideck and in the north-west corner cabins, notably cabin C1.

19.168 As far as concerns the entry of smoke, the evidence is that the ventilation air intakes were not a major route for smoke, but this appears to have been due largely to the fact that loss of power stopped the ventilation fans. There were no smoke detectors to shut the dampers on the air intakes. But for the fortunate chance of this stoppage large volumes of smoke would probably have been sucked in until the dampers closed on high temperature. There was, however, gross ingress of smoke and hot gases through the doorway from the LQW. The southern external door was a second major route for smoke; it was not possible to say which was the more significant. Smoke also entered through broken windows in the cabins on the north-west corner. It may also have entered through other doors and windows.

19.169 Open fire doors allowed smoke to spread within the ERQ. The door between the reception area on D Deck and the stairwell, which was hooked open, attracted most attention, but smoke also spread through open doors along the north corridor of C Deck and into cabins C1 and C11. On the other hand where fire doors were closed, they were effective. This was the case with the door between the passage from reception and the dining area, the other doors off the stairwell and the doors to other cabins on C Deck north corridor. The reception area on D Deck was both a general thoroughfare and an emergency control centre. It was no doubt for this reason that the door to the stairwell was hooked open. Another major route for spread of smoke within the ERQ was through the ceiling voids. This spread was prevented, however, where walls extended through the ceiling or where there were cavity barriers.

19.170 Regulations on construction should include among the goals for the design of the accommodation protection against external fire, exclusion of smoke, prevention of smoke movement and maintenance of breathable air. They should allow an integrated approach to the achievement of these goals which covers the external firewalls, the internal construction, the doors and the ventilation system.

19.171 The need for an integrated approach is illustrated by the ventilation system. It is clearly essential that smoke should not be sucked into the accommodation through the ventilation intakes. On the other hand, positive pressure maintained by the ventilation system allows the use of air locks to prevent smoke entering through main entrance and evacuation doors. The power supply for the ventilation system introduces another factor, since it is essential that emergency power to other functions in the accommodation should not be jeopardised. In short, the ventilation system needs to be thought through to minimise the chance either of its being ineffective or defeated or of its actually making things worse.

19.172 There is, however, one specific measure which I am satisfied I should support. The air intakes of the ventilation system should be provided with hydrocarbon gas and smoke detectors and on alarm the ventilation and dampers should shut down. I note that the draft fourth edition of the guidance notes to the Construction and Survey Regulations contains provisions on this matter.

19.173 In due course assessment of smoke ingress into the accommodation will be part of the Safety Case. Meanwhile, such an assessment is one of the measures which the regulatory body should ask operators to undertake forthwith.

19.174 Escape routes also are a proper topic for treatment in the regulations on construction, which should set the goal that the escape routes should be passable. The regulations should allow an approach integrated as between the twin threats of fire and smoke, as between the different options for protecting the escape route itself, and as between protection of the route and use of personnel protective equipment. Embarkation points should be treated in a similar way.

19.175 There is one set of specific requirements which it is appropriate for the regulations on construction to include. This is that escape routes be provided with adequate and reliable emergency lighting and with photoluminescent direction signs which are not dependent on survival of power supplies.

Emergency centres and emergency systems

Emergency centres

19.176 The next topic which I wish to consider in this chapter is emergency centres and emergency systems. As the emergency on Piper developed there were no facilities in the ERQ to assess or exercise control over it or to communicate with the outside world. The Control Room was knocked out and was in any case outside the ERQ as was the Radio Room, which was abandoned at an early stage. There was no means of obtaining information from, or of determining the status or action of, any of the emergency systems such as the F&G detection, ESD or deluge systems. In an attempt to discover what was happening people opened doors, which led to further ingress of smoke into the accommodation.

19.177 The need for facilities within the TSR which would allow the occupants to assess the situation outside and to exert some control over it was one of the points made by Mr Brandie. He instanced the need for communications and controls, including fire-fighting facilities. He envisaged that the TSR would contain emergency power generation and fire pumps. Controls were most readily available if the control room was located within the TSR. This was his preferred solution for new platforms, though he recognised that on some existing platforms the control room was outside. Mr Booth stated that in his company the control room was always in the TSR and that this was the practice on modern platforms. Both witnesses also envisaged the TSR as containing the radio room. The general trend described by these and other witnesses was towards locating the radio room in the accommodation and to locating the control room either in it or readily accessible from it.

Observations on emergency centres

19.178 I believe there is a clear need for there to be available within the TSR certain minimum facilities for controlling an emergency. There should be means of internal and external communication, of obtaining information on what is going on outside, and of exercising at least some degree of control over it. In general terms, what I have in mind here is information on key process, pipeline and fire system variables and on the operation of the ESD system together with certain key controls on these systems.

19.179 Most of these minimum facilities already exist in the control room and the radio room. It is logical therefore to locate the control room and the radio room in the TSR. This ensures that the facilities are accessible and protected.

19.180 Where on an existing installation the control room, the radio room, or both, are outside the TSR, the minimum facilities need to be made available in the TSR. This requires that there should be created within the TSR an emergency control centre, an emergency radio room, or both, as the case may be, which contain the necessary minimum facilities. The fuller facilities in a control room or radio room outside the TSR may still be valuable and any such rooms should be protected and should have secure means of communication of information with their opposite numbers in the TSR.

19.181 It is not intended that either of these rooms should act as the emergency command centre, which should also be within the TSR but in a separate room.

19.182 I make no proposals on the precise nature of the minimum facilities which should be made available within the TSR. A radio room and a control room which is designed to allow control as well as monitoring are likely to contain most, though perhaps not all, of the facilities required. The provision of these minimum facilities within the TSR should be part of the Safety Case and their selection should be specified by the operator.

Emergency systems

19.183 Turning to the emergency systems, whilst there is some uncertainty as to the precise extent and cause of damage to individual emergency systems on Piper, the general picture is clear. Both the main and emergency power supplies were knocked out, and possibly some of the UPS. Battery power supplies dedicated to individual equipment mainly performed well. The main means of communication to the generality of people on the platform, the GA/PA system, may have been disabled, though this is uncertain. In any event it was not used and the other means of internal communication such as telephones and hand-held radios were no substitute. One of the main means of external communication, the tropospheric link, lost its power supplies, but in this case the existence of alternative links allowed communications to be maintained as long as the radio room functioned.

19.184 Evidence on electrical power supply systems was given by Mr J Day, Head of Electrical Engineering of Shell Expro, with special reference to maintenance of the integrity of emergency power supplies. He took the view that in an accident it was not unlikely that the main generators might be lost and that effort should be concentrated on ensuring that the emergency supplies remained available. The general approach was to classify equipment and services by priority and to match the integrity of the emergency supplies to those priorities. He described modern developments in high integrity generation, implemented on Kittiwake, including fire pumps driven solely by electricity and without diesel back-up, and in recombination cells for battery power supplies.

19.185 Mr Day was asked about protection of electrical power supplies against the effects of an explosion and particularly against severe platform vibration, or shock. He said he did not know of any case where his company was designing to protect against an explosion. He was unaware of any case where shock, whether from explosion, vessel bumps or dropped objects, had caused loss of electrical systems, other than what may have happened on Piper. Mr Nordgard confirmed that vulnerability of the electrical supplies to platform vibration was not something to which particular attention was paid.

19.186 Mr Day referred to the statutory requirement to provide emergency power to a minimum of 24 hours. He was asked whether any relaxation of the time period would open up the possibility of alternative means which would give a more reliable emergency supply, but he did not believe it would.

19.187 A number of witnesses in Part 1 suggested that it would be helpful if there was a greater degree of uniformity in the alarm systems for emergencies. This would be of particular assistance to contractors' personnel, moving as they do from installation to installation. The status light systems used on some platforms were also advocated.

Observations on emergency systems

19.188 It is clear that great efforts are made to maintain power supplies in accident conditions, but it is also clear that if the accident is a severe one, even the emergency supplies may be vulnerable to effects caused by the accident. This vulnerability is shared by the emergency systems generally and I have already referred to the vulnerability of ESVs and of fire protection systems. I am concerned that all emergency systems should possess in a high degree the ability to survive severe accident conditions. The emergency systems which I have in mind include the emergency power supplies and systems, the ESD system and the communications systems and the severe accident conditions to which I refer are primarily fire, explosion and strong vibration.

19.189 The regulations and guidance should promote an approach to the design of emergency systems which ensures that as far as is reasonably practicable the systems are able to survive severe accident conditions. The ability of these systems to survive severe accident conditions should also be a feature of the Safety Case.

19.190 Work needs to be done to determine the vulnerability of emergency systems to severe accident conditions and to enhance their ability to survive such conditions.

19.191 In due course assessment of the ability of the emergency systems to survive severe accident conditions will be part of the Safety Case. Meanwhile, such an assessment is one of the measures which the regulatory body should ask operators to undertake forthwith.

19.192 I believe there is merit in the status light systems which are installed on some platforms and would wish to see them promoted.

19.193 I note that status light systems have the characteristic that they are, or can be designed to be, fail safe. That is to say, they can still convey their essential message even on loss of power. This is a feature which can be crucial in accident conditions and which would seem to have application to other aspects of platform communications. The regulations should promote this general concept.

19.194 I accept that a greater degree of uniformity in the status light systems and the alarm systems for emergencies on installations would be helpful. I can see no argument for not trying to achieve standardisation.

Pipeline emergency procedures

19.195 The disaster on Piper revealed deficiencies in command in emergencies. It also revealed deficiences in the emergency procedures for the other platforms connected to it by pipeline. I will consider in Chapter 20 all matters related to command and procedures for emergencies on the platform affected by an accident and confine myself here to the pipeline emergency procedures. It was clear from Part 1 of the Inquiry that the emergency response of platforms connected by pipeline to a platform affected by an accident is a problem area. No further evidence on this topic was led in Part 2.

Observations on pipeline emergency procedures

19.196 The quality of pipeline emergency procedures needs to be improved. There should be more co-operation between operators in a field in the formulation of arrangements and the writing of manuals. There should also be more involvement in these activities by the personnel most directly affected, those on the installations, to ensure that the information contained is correct and that the procedures proposed are the most practical and effective. The procedures should be reviewed regularly and the manuals updated in a co-ordinated manner.

19.197 The pipeline emergency procedures for the installation should define the conditions which constitute reason to believe that there has been an incident on another installation connected to the first by hydrocarbon pipeline and the conditions for shutdown of the first installation. The overriding aim should be to ensure that the situation on the affected installation is not exacerbated. In general, shutdown should be the default action and should be effected at once unless it can be positively and reliably confirmed that the incident on the other installation is minor. The shutdown procedures should be reviewed regularly and the manuals updated.

Observations on mitigation of incidents

19.198 I said at the beginning of this chapter that I was conscious of the calls which have been made for there to be requirements for various types of hardware. I have in fact made very few such proposals. In a limited number of cases I have taken the view that it is inconceivable that a particular measure should not be adopted. The requirements in the recent regulations on ESVs are a case where I do consider that this is so. In general, however, I have found that the matter is one which should be decided on the basis of the resolution of the often conflicting factors which design typically involves and of what is reasonably practicable. For each particular issue I have explained this as I went along. Here I wish to make a further point. The decisions on the various hardware proposals cannot be viewed in isolation. This is another argument for dealing with these matters in the Safety Case.

19.199 Finally, it is convenient to deal here with a general point concerning acceptance standards, particularly those for protective systems such as the fire-water deluge system and for emergency systems such as the emergency power supplies. I am proposing reliance on goal-setting regulations and on the Safety Case and eschewing prescription of hardware. Such an approach therefore depends heavily on the acceptance standards for achievement of the goals. In general I propose that these should be set by the operator. I envisage that it is around these standards that much of the dialogue between the operator and the regulatory body will centre.

Table 19.1 - Study of installation configurations: average annual fatalities in high fatality accidents

Event	Fatalities per 1000 installation years Case					
	A	B	C	D	E	F
Blowouts	7.9	7.5	6.7	4.9	1.3	4.8
Riser failures	30.2	6.7	14.4	13.2	2.3	8.8
Process leaks	40.4	22.0	15.8	18.7	9.2	10.3
Collisions	4.6	5.0	11.3	55.3	1.9	5.8
Structural events	82.7	9.5	40.0	50.6	3.5	23.0
Non-process fires	0	0	0	0	0	0
Helicopter accidents	0	0	0	101.2	0	0
Total	165.8	50.7	88.2	243.9	18.2	52.7

Notes:

(a) Case E has a production rate one quarter that of the other cases. The complements are 200 persons on cases A and B, and extra 20 marine crew on the flotels in cases C and D, and an extra 5 maintenance crew on the quarters platform in case F; case E has a complement of 60 persons.

(b) Case D includes fatalities from in-field helicopter accidents, regardless of the number of fatalities. Fatalities during crew changes are not included for any of the cases, since they would be the same for all.

Chapter 20

Evacuation, Escape and Rescue

Introduction

20.1 In Chapters 8 and 9 I described how the personnel on board Piper responded to the emergency on the night of the disaster, escaped from the platform and were rescued from the sea. In this chapter I comment on the requirements and regulations for safe evacuation, escape and rescue and review the arrangements and facilities used for them in North Sea conditions. Finally, I discuss the requirements for effective command and control in offshore emergencies.

Evacuation, escape and rescue: definition

20.2 To avoid confusion or doubt, the scope of the terms of evacuation, escape and rescue, as used throughout this chapter, are defined below:

> *Evacuation* refers to the planned method of leaving the installation without directly entering the sea. Successful evacuation results in those on board the installation being transferred to an onshore location or to a safe offshore location or vessel.
>
> *Escape* refers to the process of leaving an offshore installation in the event of part or all of the evacuation system failing, whereby personnel on board make their way into the sea by various means or by jumping.
>
> *Rescue* refers to the process by which escapees and man overboard (MOB) casualties are retrieved to a safe place where medical assistance is available.

History of evacuation, escape and rescue

20.3 Dr J Side of the Institute of Offshore Engineering, Heriot-Watt University, described 4 major offshore incidents, all occurring outside the UKCS, that have themselves been the subject of Government inquiries. All the incidents occurred to mobile offshore structures. In March 1980 the semi-submersible accommodation vessel, the Alexander Kielland, sank in the Ekofisk field off Norway due to a structural failure. The considerable heel of the structure when it capsized made the launching of survival craft extremely difficult but attempts were made to launch 5 of the 7 craft on board. 3 were crushed against the side of the rig and destroyed. One which had not been launched but had been entered, came to the surface inverted after the rig had capsized and was eventually righted. The fifth craft, with 26 men on board, released its hooks with considerable difficulty. Of the 212 men on board, 123 lost their lives. In February 1982 the semi-submersible drilling rig, the Ocean Ranger, capsized and sank in a very bad winter storm off Newfoundland. Warnings that the weather would deteriorate had been broadcast 24 hours before the disaster occurred and drilling operations on the rig had been discontinued some 12 hours before the incident. However a mayday requesting helicopter evacuation was not sent until 2 hours before the rig capsized. At least one survival craft was launched but although the standby vessel made contact with it no one could be saved. The entire crew of 84 persons was lost. In October 1983 the drillship Glomar Java Sea capsized and sank in the South China Sea during a severe typhoon, with the loss of its entire crew of 81 persons. The investigation found that the failure to evacuate at least non-essential personnel from the drillship, after it had been given nearly 3 days' warning of the typhoon, was a contributory factor leading to the loss of life. Examination of the wreckage suggested that attempts had been made to launch one lifeboat; another had torn free as the vessel sank. Neither lifeboat was ever recovered. At least 36 of the 81 crew were trapped in the drillship as it sank. In October 1985, in the Gulf of Mexico, the jack-up drilling rig Penrod 61 collapsed during a hurricane. Soil failures beneath one of its 3 legs apparently caused the failure. The standby vessel, a normal crew boat, which was unable to operate safely in very severe weather, had to leave the area to seek refuge from the worsening weather about 9 hours before the rig collapsed. The crew of 41 escaped to the sea in 2 survival capsules and an inflatable raft; one man jumped into the sea with a life-jacket. Only one life was lost when one of the survival capsules subsequently capsized. In all the last 3 incidents weather conditions at the time of the accident had deteriorated to the point when helicopter evacuation was impossible.

20.4 Dr Side also described 18 precautionary evacuations in the UKCS between 1975 and 1987, following incidents that could have led to a major emergency on an offshore installation. Common to all of these was the immediate requirement for an urgent, unscheduled demanning of personnel. Except for 3 transfers by personnel basket to a vessel, and one in which the means of evacuation remains unknown, the rest were by helicopter. Survival craft were not used. In August 1988 the first full emergency evacuation using survival craft occurred when the crew of the semi-submersible drilling rig Ocean Odyssey had to abandon the rig after a blowout and fire. One man died but the actual evacuation, in good weather, went smoothly. Previously in the NCS there were 2 recorded cases of survival craft being used, apart from that of the Alexander Kielland described in para 20.3. In November 1975 an explosion on the Ekofisk A platform led to an evacuation. The platform shut down automatically and the situation was brought under control but due to the failure of its launching mechanism a survival craft was dropped from the deck level and 3 men were killed. In March 1977 another Ekofisk platform was evacuated by 112 men using 3 survival craft following a blowout. The evacuation was orderly and disciplined; and the weather and sea state were remarkably good at the time.

20.5 In none of the 18 precautionary evacuations in the UKCS did the initial incident develop into a major emergency but the disasters which resulted from delayed reactions to weather warnings demonstrate how severe the resulting penalty can be. They provide the lesson that where there is doubt as to the implications of an incident it is better to achieve certain safety by a precautionary shutdown and evacuation than to risk lives by postponing the decision. A precautionary evacuation will normally be by helicopter which is the preferred and widely available method for such circumstances. As I show later in para 20.14, if a major incident has already developed such a method is unlikely to be available; and evacuation will depend on the uncertainties inherent in the use of survival craft. The decision to evacuate an installation as a precautionary measure is dependent on the perception of the OIM. I will discuss command and control in emergencies later in this chapter (see paras 20.56 *et seq*).

General approach

Requirements and regulations for evacuation, escape and rescue

20.6 The objective of ensuring safe evacuation, escape and rescue on offshore installations was summarised for the Inquiry by Mr Petrie, Director of the Safety Directorate of the DEn, in saying that "Offshore installations should be designed, equipped and organised so as to provide means of safe evacuation of all personnel on the installation in the widest practicable range of circumstances" and that "the means of evacuation should be available for immediate use." The requirements for safe evacuation, escape and rescue are covered by Reg 10 of the Emergency Procedures Regulations and the code of practice for the assessment of the suitability of standby vessels attending offshore installations; and by the Life-Saving Appliances Regulations. As a result of lessons learnt from the Piper disaster the DEn has proposed amendments to the last-mentioned regulations in a statement of intent issued in August 1989.

20.7 Mr Petrie explained that where a bridge link to an adjacent installation was available, this was the preferred means of evacuation. Leaving aside a bridge link, helicopters represented the safest means of evacuation provided that there was sufficient time and no conditions adverse to evacuation by this means existed, such as fire, smoke and emission of combustible gas. The circumstances required for helicopter evacuation might not prevail when an emergency had developed; and installations must be provided with another primary evacuation system, wholly controlled from within the installation, not dependent on any external intervention, and capable of securing safe and full evacuation of all personnel in as wide a range of emergencies as practicable. This evacuation system was based on totally enclosed motor propelled survival craft (TEMPSC). He said that if for any reason these primary systems were partially or wholly unavailable there should also be provided means of descent to the sea and the means of rescuing people from the sea, which should be effective in the widest possible range of weather conditions. Appropriate personal survival equipment should be provided for all the personnel on board. I will deal with all these requirements individually later in this chapter.

Evacuation, escape and rescue and the Safety Case

20.8 In discussing the mitigation of incidents in Chapter 19 I expressed the view that the integrity of the temporary safe refuge (TSR) should be a central feature of the Safety Case (see para 19.109). It is plainly appropriate that the process of formal safety assessment should cover all aspects of the protection of personnel in the event of an emergency and therefore should cover the process of evacuation, escape and rescue. This should accordingly form part of the Safety Case. I would note that Mr Ognedal, Head of the Safety Division of NPD, emphasised that under the Norwegian regulatory regime the operator is required to have a thought-through evacuation and escape philosophy which formed part of the framework of the whole system for the safety of personnel on board.

Evacuation, escape and rescue and the regulations

20.9 Evidence on the regulatory requirements for safe and full evacuation, escape and rescue was heard from UKOOA, the DEn, the NPD and Statoil. UKOOA urged that due to the diversity of installations offshore, the present prescriptive regulations should be replaced by goal-setting regulations which would allow operators more flexibility and would not stifle innovation. Mr Ognedal stated that future Norwegian regulations on evacuation, escape and rescue would be mainly goal-oriented; the emphasis would be on the licensee identifying the best evacuation systems for the installation in question, through purposeful and systematic analysis. Prescriptive regulations would, however, be retained in a few selected areas. The DEn accepted, in general, the replacing of specific requirements by general principles but would also wish to retain specific requirements in defining acceptable standards in certain well-defined cases. I fully support the acceptance of goal-setting regulations in this area. In particular I see an immediate need for regulations under which operators are required to submit to the regulatory body an analysis of the facilities and other arrangements which would be available for evacuation, escape and rescue in the event of an emergency. The analysis would cover the formal command structure, helicopters, TEMPSC, life rafts and other means of escape to the sea, standby and other vessels, fast rescue craft and personal survival and escape equipment. This analysis would also form a part of the Safety Case in its demonstration that adequate provision had been made for ensuring safe and full evacuation, escape and rescue. Operators which have not already done so should be asked to undertake such an analysis without waiting for legislation. While I fully support the acceptance of goal-setting regulations I also take the view that there are certain basic points on which certain minimum standards should be laid down by legislation. Examples of these are given later in this chapter.

Evacuation by helicopter

20.10 Helicopters are the normal means of transport for personnel to and from offshore installations. Everyone working offshore accepts the use and discipline of helicopter travel and would automatically look to helicopters as the prime means of evacuating them from an installation. There are no specific regulatory provisions compelling the use of helicopters although there are provisions in the Construction and Survey Regulations for ancillary matters such as landing arrangements and fire-fighting facilities, and the accessibility of the helicopter deck from the accommodation.

Helicopter availability

20.11 Evidence on the performance and availability of helicopters on the North Sea was given by Captain Ginn, Head of Air Transport for British Gas. Availability is high offshore. Commercial traffic in normal day-time working hours between 07.00 and 18.00 hours on week-days would enable between 100-300 helicopter seats to be located in any one of the 4 sector areas in the northern and central North Sea and thus available to an emergency in less than 30 minutes. All helicopter operators require their crews to make "operations normal" calls into base every 20 minutes or so; and one helicopter company maintains a "flight following" system whereby the identification, position and full status of each machine in the air is entered routinely into a computer at base. If an offshore emergency were to occur, the identity and location of the nearest helicopter and time required to reach the emergency site can be obtained immediately. The shore-based national air traffic service radios do not reach the more distant areas of the North Sea; in the East Shetland basin the Viking Approach system on Cormorant Alpha supplements the shore-based service. Some companies use, or are planning to use, flight information liaison officers (FILOs) on their installations, with whom the pilots of helicopters make contact so that the installation has a constantly up-dated record of helicopter availability in its area. At the time of the disaster Piper was the only installation in the North Sea utilising FILOs. It appears to me that a North Sea-wide flight following system based onshore and operated as a service to all offshore installations would be more efficient than the duplication inherent in individual installation systems but I appreciate that operators may feel more secure with their own systems.

20.12 In addition to land-based helicopters, offshore helicopters are based for logistical purposes on 5 UK and 2 Norwegian North Sea installations. These offshore-based helicopters are smaller (4-13 seat capacity), are crewed on a 24 hour basis, and except for 2 in the UK sector, are equipped for search and rescue. The cost of basing helicopters offshore is very high, amounting to over £2m per year per helicopter for the charter of the helicopter and the provision of crew accommodation offshore. This does not include the capital costs of modifying the facilities where there may be severe structural constraints, particularly on existing installations. Search and rescue helicopters are also available from a number of onshore military establishments as well as from 2 civil helicopter bases maintained by the DoT, at Sumburgh and Stornoway. The declared response times (call-out to take-off), often bettered in practice, are 15 minutes by day and 45 minutes at night. Commercial helicopters are also available after normal working hours from the Aberdeen, Sumburgh and Unst bases and would be despatched to an emergency within 10-30 minutes of call out. In an emergency it is most likely that the evacuation of an installation by helicopter would be initiated by offshore-based logistics helicopters and/or en route commercial helicopters, depending on the time of day. This would generally be in less than an hour. Out of normal working hours (Mondays to Fridays, 07.00-18.00 hours) the first helicopters to arrive would normally be the offshore-based helicopters, in less than one hour, followed by the onshore-based machines. The most rapid evacuation method would be to shuttle personnel on board to nearby installations; or it may be possible to fly them directly to shore. Shortage of helicopters is unlikely to be a problem; access to the helideck becomes the limiting factor when the number of helicopters in a shuttle reaches say 4 or 5. The cycle of a helicopter approaching, landing, and boarding up to 19 evacuees (in the case of the Super Puma) and then taking off is unlikely to average less than 5 minutes.

20.13 The evacuation of 6 typical installation types by helicopter was assessed by UKOOA who found that the maximum time to evacuate (by shuttling to nearby installations or to shore) would be in the order of 2 hours and 45 minutes from call-out for the worst case (an isolated drilling unit at night). Two actual precautionary evacuations, both in late 1989 (North West Hutton and Penrod 92), confirmed that the findings of the study were realistic. Both were in daytime: one was totally evacuated 70 minutes after call-out (110 men), the other in 40 minutes (70 men). The first helicopters arrived in 23 and 5 minutes respectively.

Helicopter evacuation limitations

20.14 Evacuation by helicopter may be limited by adverse weather conditions such as very high winds, low fog or icing, although according to statistics these limiting conditions seldom apply. Helicopters are allowed by their operators to land and take off in winds of up to 60 knots (Beaufort Force 10) although they must keep their rotors moving. In the case of emergency evacuation, however, pilots would be expected to find a clear way to the installation and be forced to abandon their attempts only when the limits on the air-worthiness of the aircraft were reached. Statoil estimates that in the Norwegian sector the availability of helicopters is 98.7% when the platform is evacuated as a safety precaution (see para 20.5). Major incidents, however, normally result in large amounts of fire, smoke, and/or flammable or combustible gas being generated. This would prevent a helicopter approaching or landing on the installation. There may also have been a major structural failure which would prevent a landing. Safety studies done on integrated production platforms in the Norwegian sector show that when such emergencies have developed evacuation by helicopter would be impossible in about 95% of such cases. If these conditions prevail, an alternative primary evacuation system using TEMPSC will be necessary. In an extreme case, resort to direct entry into the sea will be the only remaining means of reaching safety.

20.15 Helicopters remain the preferred method of evacuating an offshore installation as a safety precaution measure and in the limited instances in which they can be used in a developed emergency. They are quickly available on the North Sea, safe in all but the most adverse weather conditions and offshore personnel are accustomed to their use and discipline. The people evacuated are transferred directly to places of safety and are not left still at the mercy of weather conditions, as in evacuation by survival craft.

Evacuation by survival craft (TEMPSC)

20.16 Reg 5 of the Life-Saving Appliances Regulations requires that every normally manned offshore installation shall have TEMPSC of sufficient capacity in aggregate to accommodate 150% of the entire platform complement. In its statement of intent the DEn proposed increasing the required capacity of TEMPSC to accommodate twice the number (200%) of persons on the installation, "to enhance the safety of personnel on board an offshore installation". This proposal was evidently made in reaction to the disaster. I have 2 main difficulties with this proposal. Firstly, the non-availability of TEMPSC at the time of the disaster was not related to their number as such but to their location and distribution. Secondly, the proposal takes no account of the features of particular installations. On installations which have certain complexities and configurations it may be desirable to provide a wider distribution of TEMPSC to improve the range of circumstances in which a safe and full evacuation is likely to be achieved. I would favour the retention of the existing requirement to accommodate 150% of the entire platform complement. However I consider that it should be required that the TEMPSC provided should include TEMPSC which are readily accessible from the TSR and which have in the aggregate sufficient capacity to accommodate on board the number of persons on the installation. The exact number, location of any TEMPSC which may be required over and above these minima should be determined in the light of the Safety Case. It may, for example, be shown that additional TEMPSC should be provided near places where personnel may congregate or be trapped in an eventuality.

Davit-launched TEMPSC

20.17 The original design of offshore survival craft was a standard ship's lifeboat, with a full canopy and water deluge system added. A UKOOA witness, Mr I Wallace of Conoco (UK) Ltd, commented that the design of survival craft was and still is constrained by the International Maritime Organisation (IMO) standards; they were still seen as ship's lifeboats and had not been adapted to the requirements of the offshore oil industry. He said that a number of improvements more suited to the industry's specific needs had been put forward but the lifeboat manufacturers continued to design to IMO standards because the bulk of their business was concerned with ships.

Problems clearing the platform legs

20.18 A critical problem with a davit-launched TEMPSC is ensuring that it gets away from the vicinity of the installation after launching into the sea in severe weather conditions, when it would be in danger of being swept under the installation and destroyed. Also wind-induced motion could cause the TEMPSC to contact the installation during descent, if the overhang is less than 7m. The minimum weight of a TEMPSC is determined by this latter problem. The DEn's statement of intent acknowledged these concerns. Since 1985 a joint steering committee, with representation from Government departments, industry and contractors has been considering enhanced launching techniques for survival craft. Two passive devices, one using a hinged boom projecting from the side of the installation to rotate the TEMPSC outwards, called PROD, and the other using an air-launched sea anchor, are being tested. So also is a powered dolphin similar to a torpedo. The DEn and the industry have supported full-scale trials of the PROD concept and it is being developed into a commercial product. Joint work by an oil company and a contractor has led to the testing of another concept, in which an anchored buoy is used to direct the TEMPSC away from the installation, called TOES. No enhanced launching system has yet been proposed for an installation in the North Sea.

Problems with davit disconnection

20.19 All TEMPSC are boat-shaped and thus launched on 2 fall wires (bow and stern). It is essential that the hooks on both wires should release the TEMPSC simultaneously. Two basic release systems have been used, the "off-load" system which will only allow the hooks to release the TEMPSC when it is afloat, and the "on-load" system which allows the simultaneous release of both hooks. The on-load system must be used in conjunction with hydrostatic interlock, which allows hook release only when the hull reaches the water; premature release could be disastrous, as in the attempted evacuation of the Ekofisk A platform in 1975 (see para 20.4) when a loaded TEMPSC was accidentally dropped into the sea from deck level. The off-load system has the major disadvantage that in severe weather conditions it is difficult to achieve a condition whereby both hooks are off-load. This has now been resolved by IMO resolutions which specify that survival craft should be equipped with on-load release gear. However the difficulties experienced in North Sea operations with the premature release of davit fall wires contributes to the prejudice felt by oil workers offshore who, in the main, are inexperienced in marine matters.

Free-fall lifeboats

20.20 A new type of survival craft, the free-fall lifeboat, has been introduced into the Norwegian sector. The free-fall lifeboat is a TEMPSC designed to be used with a launching system which releases the TEMPSC at the point of embarkation on the platform (up to 30m above sea level) and allows it to fall, entering the water with a high momentum which together with the specially shaped hull will propel the craft away from the platform. The particular perceived advantage of the free-fall lifeboat over the davit-launched lifeboat is its ability to clear the installation in severe weather conditions.

20.21 Development of the free-fall lifeboat started in 1973 but this was accelerated after the Ekofisk Bravo blowout in 1979 when a large research project was funded by the NPD. A total of some 40 free-fall lifeboats had been or were being installed on Norwegian installations at the time of the Inquiry. Free-fall lifeboats are now considered in the Norwegian regime to be the established evacuation system. Conventional davit-launched lifeboats are accepted but their availability must be shown to match that of free-fall boats. The Norwegian witnesses explained that all factors, mechanical as well as weather, are taken into account in this. Free-fall boats have been model-tested in severe sea state conditions and their overall availability is estimated at 99%. The remaining 1% is attributable to technical and human considerations.

20.22 Norwegian offshore personnel on installations on which free-fall lifeboats are installed must undergo special training which involves at least one fall in a free-fall lifeboat at one of 3 training centres. As an example of their reliability, it was said that one free-fall lifeboat at a training centre had been dropped some 1200 times without an accident of any kind. The occupants of free-fall lifeboats lie on their backs on special contoured seats and are restrained by body and head straps. In the sea this position is not comfortable and can accentuate sea sickness but the benefits are considered to outweigh the discomfort. The standard capacity for free-fall boats installed on large integrated platforms is 74 people.

20.23 Free-fall lifeboats, apart from having the advantage over conventional lifeboats of safely clearing the installation when launched in severe weather conditions, have no davit hooks to be unlatched. The total time from the embarkation decision to water entry is about the same as for davit-launched boats; more time is needed to seat and strap in the occupants but time to the sea is much less. They are, however, much heavier and more expensive than davit-launched boats and retrofitting can be a major problem. They have not as yet been used in actual emergencies in severe weather but extensive model testing has made the Norwegian authorities confident of their high rated availabilities.

20.24 No legislation directly regarding free-fall lifeboats so far exists in the UK. Reg 5 of the Life-Saving Appliances Regulations entails that the means of launching lifeboats should be by lowering, but the DEn's statement of intent proposes that this be amended to allow the launching of TEMPSC by any safe launching system of a type which has been tested and is acceptable to the DoT. It was stated that this would permit consideration of free-fall TEMPSC without the need for exemption; and that exemptions had already been granted for free-fall TEMPSC on a small number of mobile installations in the UKCS. The DoT had advised the DEn that free-fall lifeboats are a viable method of evacuation. I see no reason why free-fall lifeboats should not be permitted in the UKCS, as they are in the NCS. The necessary amendment to the regulations should be made forthwith. There should be no statutory barrier to the use of free-fall lifeboats. It would still remain for the operator to justify its choice of TEMPSC as being appropriate in the particular conditions of its installation. Where davit-launched TEMPSC are proposed to be used they should be oriented so as to point away from the installation.

Escape to the sea

20.25 Reg 8 of the Life-Saving Appliances Regulations requires that alternative means of evacuation to the sea have to be provided, so that the fullest practicable evacuation can still be secured. Below I describe various means in common use and comment on some new means.

Life rafts

20.26 Life rafts are not considered by the DEn to be an acceptable substitute for the required provision of TEMPSC. They do, however, usefully complement TEMPSC. The DEn statement of intent proposes to amend Reg 5 of the Life-Saving Appliances Regulations to require that, in addition to TEMPSC, every normally manned installation should be provided with life rafts having sufficient capacity in aggregate to accommodate all the people on board. I have already recommended (see para 20.16) that the total TEMPSC capacity on an offshore installation should remain at 150% of POB and be more if required by the Safety Case for the installation. The proposal to require 100% POB life raft capacity seems to me to be a reasonable requirement, as life rafts can complement TEMPSC in the event of emergencies such as a sudden structural failure, keeling over or sinking, where access to TEMPSC is prevented or their use is impracticable. The location of life rafts would be a subject for the Safety Case for the installation. They should, however, be installed in close proximity to mechanical means of escape to the sea such as ladders, ropes and escape chutes.

20.27 After an examination of the life rafts recovered from Piper and in the light of evidence that survivors were unable to deploy them, the DEn issued a safety notice (9/89) emphasising the existing legal requirement that life raft launch procedures should be included in musters and drills and clarifying the position with regard to the length of painter rope (cf paras 8.29-33). Painters will be shortened to the minimum practical length to ensure successful deployment; and the length of painter to be provided at each life raft launch point is to be agreed with the DoT.

Ladders and stairs

20.28 In their statement of intent the DEn recommend the installation of permanent ladders or stairs to the sea at the corners of the installation. Mr Wallace noted that it had been the practice to have 2 or more constructed ladders or stairways leading to the sea but that these suffered from storm damage and the effect of waves. In view of the difficulties experienced by personnel in getting safely into the sea at the time of the disaster, I support the DEn's recommendations. These ladders or stairways could be extendable to allow for the effect of waves provided this is acceptable in the Safety Case.

Ropes and rope devices

20.29 Knotted ropes, rope ladders and scrambling nets are very basic means of descent to the sea and have long been used on offshore installations. However only knotted ropes would appear to be practical as they can be easily and economically stowed at all life raft installations. Scrambling nets and rope ladders are awkward and difficult to use. In the disaster approximately half of those who escaped to the sea did so by using ropes or small diameter hoses. The others jumped where haste was imperative and/or ropes were not available. Knotted ropes are, however, a primitive means of escape and physically very demanding. They are particularly difficult to use if the user is wearing a life-jacket and/or a survival suit. But they are almost foolproof, they offer a continuous line of escape and place a person outside the confines of the installation structure. They should be seen as a last means of escape to the sea. A new individual self-rescue device, based on abseil technology and much less demanding physically, the Donut system, has been accepted for use by both the DEn and the NPD. At least one UK operator is issuing it generally to offshore staff. Some training is required and it cannot be re-used. I recommend that such equipment should be specified in the regulations for escape equipment. Another rope-based system is the Surescue Descender, an escape line down which people can descend on light-weight supports in a controlled manner. It accommodates one person at a time and would not seem to offer rapid evacuation for a large number of people. The Surescue is, however, acceptable to the DoT and one such system is installed on an accommodation barge in the North Sea.

Escape chutes and collapsible stairs

20.30 A number of these devices were described at the Inquiry. One, the Skyscape, a collapsible tubular net which allows controlled free-fall descent to the sea, has been accepted for use by the NPD and has been installed on a Norwegian installation. It requires an overhang and may not be suitable for all installations. The GOTECH escape stair is at the conceptual and scale model stage and much work remains to be done on it. These chutes or stairs have potential advantages over fixed ladders or stairs in that they would offer direct escape to a large number of personnel; they are positioned away from the platform, hanging from an overhang or cantilever; and they appear to avoid the difficulties inherent in the use of knotted ropes. Other chute-type devices were briefly described, none apparently yet available for full scale testing. One operator, Shell Expro, considered chute escape devices in the design of their latest platform but decided that due to certain disadvantages they were not yet appropriate.

Other devices

20.31 Another operating company, Mobil, is developing 2 dry transfer devices with different manufacturers. One (GEMVAC) is similar to the system used by navies for the transfer of materials and men at sea. The other (ODELE) involves lowering an inflatable life raft with men on board on to a specially constructed SBV. Both are in the development stage. Other devices, all at early conceptual stages, include a sea haven and a self-launching accommodation module.

Personal survival equipment

Life-jackets and survival suits

20.32 Life-jackets for all personnel offshore are required by regulation. The DEn proposes in its statement of intent to amend the regulations to require that offshore installations are provided with at least twice as many jackets as the number of people on the installation. The provision of survival or immersion suits is desirable but not yet mandatory. It was stated in evidence that the DEn was seeking through further work with the DoT and other organisations to overcome certain practical difficulties about the wearing of life-jackets with survival suits which had been identified. When this work was complete it was expected that provision of survival or immersion suits on all offshore installations would be made mandatory. Mr Wallace described an integrated survival suit and life-jacket which he said was in use by his company, Conoco. In view of the comments by survivors on the difficulties of making escape while wearing conventional life-jackets and immersion suits I recommend that this planned work should be carried out with despatch.

20.33 The use of a standard orange colour for life-jackets and survival suits was criticised by many engaged in the rescue of men from the sea; other objects and equipment such as life rafts are of the same colour. Attention must be given to using a separate and distinct colour for easy and rapid identification of survivors in the water, particularly in the dark.

20.34 Comment was also made on the problems of locating survivors in the sea. Whistles and lights are supplied on most life-jackets but may not be effective in adverse weather conditions. The use of radio transmitters or detectors should be considered.

Smoke-hoods

20.35 The ability to move through a smoke cloud can be of vital importance in an evacuation or escape. The escapee will have to move from his location at the time of the incident to the TSR or directly to an embarkation point. Very large quantities of dense, and possibly toxic, smoke are likely to be generated from a fire on a hydrocarbon producing installation. Evidence heard on smoke-hoods generated some discussion on the period for which simple filter-type hoods would be effective before the breathed air is over-saturated with carbon dioxide. Expert evidence was to the effect that filter-type smoke-hoods could provide temporary respiratory protection against smoke and toxic gases. It was suggested that this could be for some 10-15 minutes after which the concentration of carbon dioxide could seriously debilitate the wearer. Oxygen donating hoods are complex; special training for use is required. They are also bulky and expensive but can be very useful for exploratory investigation of an accident by specially trained men. Simple, light, filter-type hoods should be issued as part of personal survival kits to be kept by all on board offshore installations (para 20.36) but training should emphasise that they provide protection only for a limited period to facilitate evacuation or escape. On-going research sponsored by the industry on the development of improved smoke-hoods should be expedited.

Survival packs

20.36 Some operating companies, among them Occidental, issue survival packs to those going offshore. Generally these packs contain a life-jacket, a survival or immersion suit, a torch and fireproof gloves. Such equipment packs should become standard issue offshore. The packs can be kept in the individual's living quarters and/or at work sites and regularly examined. A type of smoke-hood, as described above, should be added to the kit, as well as any other simple and personal survival aids that may become available. I recommend that survival packs containing at least a personal survival suit, a life-jacket and a smoke-hood should be issued to everyone on board an installation and that these are normally retained in their accommodation. Other survival packs for at least half the POB should be stored in containers placed at locations on the installation subject to what is shown necessary by the Safety Case.

Rescue from the sea

Standby vessel (SBV) legislation and code of practice

20.37 Having escaped to the sea, survivors have to be rescued and taken to a safe place where medical care is available. The means of rescue should be effective in the widest possible range of weather conditions. Reg 10 of the Emergency Procedures Regulations requires a SBV to be present within 5 nautical miles of every normally manned installation, ready to give assistance in the event of an emergency at or near the installation. These vessels carry FRCs which can be deployed rapidly to rescue persons from the sea. This regulation is supported by a DoT code of practice, for the assessment of the suitability of SBVs for attending offshore installations, setting out standards which are to be met as the condition of the issue of a certificate in respect of the vessel. The code was first prepared in 1974; its binding force is based on a voluntary agreement whereby members of UKOOA undertook to abide by the standards set out in the code. Mr B C Drew, a senior surveyor in the DoT, said that this voluntary agreement had been honoured; to his knowledge there had never been a case where a vessel which has not been certificated has been chartered by a member of UKOOA. The third and latest edition of this code was issued in draft in August 1989. It took account of lessons learnt from the disaster. It has not yet been ratified.

Requirements of the code of practice

20.38 Mr Drew explained that the first code of practice continued in use after the introduction of the Emergency Procedures Regulations.

The latest ratified version was issued in 1984. It required, *inter alia*:

1. Provision of FRCs.
2. Improvement to the accommodation.
3. Improvement to equipment and first-aid.
4. The provision of bridge control.
5. Special provisions for large SBVs and those operating north of 62° north and west of 15° west.

Work on the third edition was started in 1986. In it the functions of an SBV have been expanded to include the requirements that it should:

(a) Communicate with the installation, etc.

(b) Rescue persons from the water.

(c) Keep a monitoring watch in the safety zone.

(d) Attend closely to the installation during certain operations (helicopter movements, work over the side, etc).

As stated in the preceding paragraph, this edition has not yet been ratified.

Criticism of SBV legislation

20.39 UKOOA witnesses were critical of the existing legislation governing the requirements for SBVs. Mr C J Middleton, Chairman of the UKOOA Marine Committee, said that the SBV was only one part of the total evacuation and rescue package but nevertheless a whole regulation and a code of practice were devoted to it. The prescriptive requirements that the SBV should have accommodation on board for the total population of the installation and that the SBV should attend each individual installation; and the specification of vessels by broad geographical areas were particularly criticised. It was suggested that the regulations should instead require operators to propose a total evacuation and rescue package for each installation or group of installations. Mr D T Rudd, of BP, described BP's evacuation policy and plan for the Forties field. This was an assessment of the total evacuation and rescue requirements for the Forties complex of 5 fixed installations and proposed that 3 SBVs (or 2 SBVs and the emergency support vessel Iolair) would be adequate to ensure safe and full evacuation and rescue in an emergency in that complex; or 4 SBVs when a flotel was stationed in the area. This contrasted with a requirement of 8 SBVs if Reg 10 was interpreted in a strict manner, as the DEn had recently indicated should be done. BP presently employed 4 SBVs in the Forties field. Mr Middleton suggested that a remote drilling rig, say to the west of Scotland, which would have little back-up nearby, would require a high-capability SBV which could accommodate the total population but such vessels would not be required in a multi-platform field or in a developed area of the North Sea. The consideration of a total package of facilities and other arrangements for evacuation, escape and rescue rather than a simplistic prescription of standard requirements is in line with the approach which I have already recommended in this chapter (paras 20.8-9). I recommend that the required changes are made in the legislation and code of practice so that evacuation, escape and rescue can be the subject of an analysis submitted by each operator; and form part of the Safety Case for each installation. However, some prescriptive regulations on standards and quality of equipment, crewing and training would be required. These equipments and standards are discussed below.

Criticism of SBV standards and the UKCS SBV fleet

20.40 Criticism by survivors and other witnesses was levelled at the general standard of SBVs in the UKCS. Information provided by Mr J S Daniel, Chairman of the Standby Ship Operators Association, showed that of the 187 SBVs for which there were complete data, 162 (87%) were converted fishing trawlers. There were only 7 purpose-built SBVs and 18 multi-functional vessels operating in a standby mode, but not all full-time. Mr Daniel said that if fishing trawlers were properly converted they would meet the requirements of the code; a trawler hull provided a very good platform for rescue operations because of its good sea-keeping qualities. However Mr M Macey, a Director of Maritime Rescue Services Ltd, was doubtful whether trawlers were sufficiently manoeuvrable even with bow-thrusters fitted, or had the visibility to pick up persons easily from the sea because of their small bridges and high forecastles. Mr Middleton suggested that because of the requirement in the code that SBVs should be capable of accommodating the total population of an installation, innovation had been stifled and the use of aged trawlers had been perpetuated.

20.41 The only SBV about which the Inquiry heard detailed evidence was the *Silver Pit*. I described its performance on the night of 6 July in Chapter 9 in critical terms.

It was deficient in many respects, although the courage of its crew was outstanding. In the light of the evidence my impression was that a large part of the 162 converted trawlers in the UKCS SBV fleet were in no better position. Offshore operators were accused of taking the view that because SBVs make no contribution to profit, expenditure on them should be kept to a minimum, a view vigorously resisted by UKOOA. Mr Daniel said that the pressures put on charter rates after the fall in oil prices in 1985/86 had made it difficult to maintain standards. The Norwegian standby fleet is in large part purpose-built to the specifications required by Norwegian legislation. My understanding is that the 7 purpose-built SBVs operating in the UKCS waters were mainly, if not all, Norwegian-built. I accept the implication that the strictness of the regulation and the present code have discouraged some operators from doing other than the minimum necessary and have thus inhibited improvement of the SBV fleet; and that the cost of operating SBVs has not necessarily enjoyed a high priority in the operating budgets of oil companies in recent years. I strongly urge that the standard of the existing SBV fleet is improved with despatch, although it is obvious that this cannot be done at once. Basic standards should be introduced for existing vessels and a tight but realistic deadline for compliance set. Specifications for new vessels should be set which will ensure that they meet fully the requirements of the Safety Case.

SBV equipment quality and standards

20.42 In these circumstances there is a strong case for setting specific standards for SBVs in legislation to ensure that the vessels used are of consistent quality and reliability. The important mechanical standards for SBVs, apart from sea-worthiness, should include:

1. *Manoeuvrability* It should not be a requirement for an SBV to manoeuvre close to damaged installations. Rather it should maintain a safe distance and use its FRCs to pick up survivors from the installation if this is possible. It should be able to manoeuvre to pick up survivors from the water or clinging to wreckage. This requires it to be highly manoeuvrable and able to maintain its position.

2. *Visibility* The master should be able to keep the rescue areas in full view from the bridge, and be able to approach a person or object in the water while retaining total control of the vessel. The FRC launching area should be fully visible from the bridge.

3. *Lighting* At least 2 searchlights, covering the full 360°, and capable of being remotely controlled from the bridge, should be available. There should also be adequate local lighting in the pick-up and launching areas.

4. *Communication* The SBV must be able to contact its FRCs, the installation and nearby vessels and aircraft, as well as to maintain conversational contact between the master and the crew.

5. *Survivor recovery from the water* Scrambling nets or ladders are only suitable for use by fit and uninjured personnel. If an accident has caused the escape of people to the sea it is very likely that some will be injured, possibly severely. A number of recovery techniques were described to the Inquiry. At least 2 different methods other than ladders or scrambling nets should be available on the SBV.

6. *FRCs* Two FRCs should be carried on SBVs. FRC standards are discussed in para 20.46.

7. *FRC launching and recovery* A rapid launching facility for FRCs must be installed. Launching should not be in the critical path of emergency response, ie the FRC should be able to be put in the water with engine running as soon as the crew is ready. Consideration should be given to the need to recover an FRC with a badly injured survivor on board who would be in danger by conventional recovery.

These should apply independently of what may be shown by the Safety Case to be required: and accordingly should be prescribed by regulations which would otherwise be goal-oriented with regard to rescue facilities.

SBV usage in man overboard incidents

20.43 In practice the main use of SBVs has been in the rescue of men falling overboard from an installation, either when working over the side (scaffolders etc) or other accidents (knocked overboard, etc). Where men are working over the side, SBVs or larger FRCs are stationed in close proximity to the installation. Data presented to the Inquiry showed that 126 MOB incidents occurred in the 13 years from 1974 to 1986 inclusive. The most common means of recovering the MOBs was by FRCs deployed from SBVs. A total of 35 deaths resulted from these MOB incidents. An analysis of this data showed a survival rate of 95% for working over the side incidents, compared with survival rates of only 45% on other installation MOB incidents and 60% for MOBs from attendant vessels (the latter including 7 from SBVs themselves). Over the period there were an average of 9 MOB incidents per year involving 10 or 11 casualties of which approximately 3 were fatalities. In the 26 years since North Sea operations started in 1964, there has been only one incident in which men had to escape into the sea deliberately - namely the disaster. This emphasises the need to ensure that the requirements of the regulations allow for MOB incidents and do not concentrate solely on major disasters which are rare.

SBV usage on other duties

20.44 The code for assessment of SBVs indicates that an SBV can operate in a multi-purpose mode provided that its safety role takes precedence over all others. Mr Drew explained that, for example, a supply vessel with appropriate standby certification can carry cargo from port to an installation provided that sufficient cargo is unloaded and the rescue areas are maintained clear of all encumbrances before she becomes a dedicated SBV. Also, certain small quantities of cargo can be carried between installations without impairing the safety function of the vessel. It is for the master of the SBV to ensure that the vessel is ready to undertake the rescue role at any time when on standby duty. Mr Ognedal also explained that in Norway SBVs could undertake functions other than standby services provided that these did not hinder the standby tasks or affect response times. This does not appear to be an area of difficulty.

FRC equipment and performance standards

20.45 The code for assessment of SBVs lays down that at least one FRC is carried on SBVs, ready for immediate use and capable of carrying at least 9 people plus 2 crew, or 15 people and 3 crew in the larger specification. FRCs must be capable of being launched while the SBV is underway. Their engines can be either petrol or diesel driven and be capable of being maintained while the SBV is on station. Although not specifically recommended in the code, all FRCs are of the rigid hull inflatable type and are self-righting. The larger ones are fitted with an enclosed wheelhouse which allows their crew to continue on station for extended periods, as required by MOB and other duties of attendance. They are capable of a speed of at least 20 knots in average sea states.

20.46 The lessons drawn from the disaster show that the FRC is a very important part of the total rescue effort. It is particularly important that they are fully reliable mechanically. I consider that it is very important that there should be a very high standard in a number of areas including:-

1. Launching capability
2. Capacity
3. Speed
4. Crewing
5. Maintainability
6. Communication links
7. Search capability (lighting etc).

FRC reaction time

20.47 Evidence was heard that when someone fell into the North Sea in winter there was the danger that he might suffer from "cold shock", a stoppage of the heart. If he was recovered within 4-5 minutes he stood a chance of recovery without permanent brain damage. If he survived the initial immersion the average period he could survive before hypothermia caused death was about 30 minutes, but this varied considerably from person to person. No target times for MOB recoveries have been recommended in the code but it is accepted that in over-the-side work supervised by SBVs and/or FRCs a recovery time of less than 5 minutes is achievable. Captain Ginn said that it would be very difficult to match that performance by helicopters, which would have to be on the same platform, fully manned and equipped with search and rescue facilities. Data from the period 1974-1986 showed that of the 43 casualties recorded as being in the water for 1-5 minutes, only one died (2%). Of 14 casualties in the water for 6-10 minutes, 2 died (14%) and of 14 in the water for greater than 10 minutes, 5 died (36%).

FRCs on installations

20.48 FRCs can be deployed from offshore installations as well as from SBVs. This is common practice in the NCS where 48 rigs and platforms carry FRCs. They are installed on only 3 installations in the UKCS. Mr Wallace said that the industry was not encouraged by the regulations to install FRCs on installations; FRCs were required on the SBVs in attendance. However, if the regulations encouraged a flexible approach rather than rigid prescription, in the case of a cluster of installations FRCs on some installations could give better cover. They would be particularly useful in covering work over the side. There were problems with launching and recovery. These problems have apparently been overcome in the NCS although this took about 8 years. I would recommend that the opportunity to station FRCs on installations should not be constrained by regulation, as their use would probably be an attractive part of total evacuation and rescue packages for installations (see para 20.39).

20.49 FRCs are launched from installations either by using single-fall davits (normal in Norway) or by cranes, with or without special launching cradles. It was recommended by Mr Wallace that they should be mounted as low as possible, ie on the cellar deck (the module support frame) as they did not have to be sited at emergency embarkation points. Dr Side reported that the reaction times for MOB recoveries using installation-launched FRCs compared favourably with those from SBVs during periods of work over the side. The longest response time found in a study of MOB incidents was 7 minutes, with the average being 4-5 minutes. It might not be necessary to have a dedicated FRC crew available on the installation as they might be able to carry out other non-conflicting duties when not required for MOB cover.

SBV and FRC manning levels and requirements

20.50 The code for the assessment of the suitability of SBVs for attending offshore installations requires that the DoT states on the certificate of survey of the SBV the absolute minimum manning below which it is considered unsafe to operate. The owner of each vessel in association with the master prepares contingency plans covering the responsibilities and allocation of duties of crew members in the event of the occurrence of an incident. These plans also detail descriptions of the responsibilities of the SBV master and the installation OIM, and the responsibilities for the control of search and rescue operations. The minimum manning scales range from a crew of 7 to a crew of 15 depending on the size (ie survivor capacity) of the SBV. Mr Macey felt that the manning specifications in the code were too low with respect to the smaller size SBVs. Also when 2 FRCs were carried there should be crews for each of these on board (3 each). This was not allowed for in the code. It was also insufficient in not requiring a second mate, to alleviate over-long watches. I do not consider that the evidence before the Inquiry was such as to enable me to make definite recommendations on this matter.

I consider that the DoT should take this evidence into account when revising the code.

20.51 The proposals in the amended code require medical examinations before employment for all members of the crew. Crew members over 50 have to undergo annual medical examination, and be certified as fit to be employed on a vessel offshore for up to 28 days at a time. Except in special cases the age limit for crew members should be set at 60. I agree with these proposed standards.

20.52 The proposals also state that the periods of duty on SBVs should be limited to 28 days in summer and 21 days in winter, with an allowance of 2 days steaming to and from installations. No crew should serve 2 consecutive periods of duty with less than one week's leave of absence between them. Again I am in agreement. I consider that the changes referred to in this and the last paragraph should lead to an improvement in performance and the enhancement of safety.

SBV crewing problems

20.53 Low charter rates in an increasingly competitive market in recent years appear to have made it difficult to find and retain people with the appropriate knowledge, experience and mentality to crew SBVs. Mr Macey suggested that operating companies did not take sufficient interest in ensuring that crew standards and training were up to requirements; and that crews overstayed their prescribed tours of duty. (Mr Drew of the DoT said that this latter problem was being acted on.) Mr Daniel suggested that better conditions, more training and better pay (which would entail higher charter rates) would be needed to improve the manning situation. He said that Government, operating companies and vessel owners/operators should seek to engage in constructive discussion so that improvement can be achieved and fragmentation avoided.

20.54 The problems of crew motivation and boredom, and their feeling of being unappreciated by the installation and the industry were described by Mr Macey. He suggested that more contacts between SBV crews and operating company personnel, both offshore and onshore, would help. So also would more regular offshore exercises involving the SBVs and their crews. The different terms and conditions of SBV crews, who did not enjoy the equal time on and off duty that was common in operating companies, did not help their motivation. Crew accommodation and recreation facilities were obvious areas in which to seek improvements but stimulation by activities, exercises and close involvement with the platform were also important. It would appear to me that there are indeed real problems with the motivation of SBV crews who have the task of keeping station for weeks at a stretch with nothing to relieve the routine. This is not a matter for regulation but I consider the offshore operators and vessel owners should take steps to improve the situation. As a minimum there should be more contact between the SBVs and the installations and more realistic exercises. In this respect I would recommend that the position and status of SBVs offshore and their functions for the following week should be notified weekly to the regulatory body with a copy to the DoT. This would minimise the possible over-staying of tours of duty and would also keep the situation of the crews in focus for vessel owners and charterers.

SBV crew training

20.55 There is no current legislation covering the training of SBV crew members. The latest edition of the code sets out the certificates which have to be obtained by all crew members and gives guidance on the establishments and bodies where the training courses specified can be undertaken. Requirements for specialised training are laid down. Every member of the crew should have attended a course of basic first-aid. At least 2 of the crew (other than the master) should hold a certificate in advanced first-aid, one of whom should be nominated as the medic. For each FRC carried at least 3 crew members should be trained and hold certificates in all aspects of its handling and communications. Refresher courses must be attended regularly. The courses specified in the code appear to cover all the recommendations for training made in the course of evidence. The government departments, vessel owners and operators and operating companies should co-operate to ensure that all crew are fully trained in all aspects specified. I would emphasise the need to train and refresh the crews of SBVs, especially the coxswains and crews of the FRCs. All training should be documented and records of training held centrally, preferably by the OPITB. Probably the most important concern must again be to motivate the crews to take the benefit of the training. As Mr Macey, an expert on training, put it, "It does not matter how much training you give the crews, if the crew is not motivated then you are wasting your time.

Command in emergencies

The command structure

20.56 Evidence was heard from UKOOA on the command structure and organisation required to ensure effective response to an offshore emergency. Mr M R Baxendine, a Shell Expro OIM, said that in his company the general practice was to pre-select, train and drill at least 3 emergency response teams (operations, drilling and services), all with trained back-up support teams available in case these were required. All non-essential personnel, (ie those not in the command structure or the emergency response teams), assembled at predetermined muster stations, grouped by the lifeboat numbers to which they were assigned on arrival on the installation. The OIM was in overall charge of the installation; his replacement was pre-nominated to replace him if he was incapacitated or not contactable. Only the OIM or his replacement had the power to decide whether it was necessary to abandon the platform. His emergency command centre, normally the radio room, would receive progress information from the response teams and would direct them and communicate with nearby vessels and the shore as necessary. This appears to be the general pattern of emergency command followed on the UKCS. I comment on the criteria for OIM selection in the next paragraphs.

The OIM

20.57 The appointment of an OIM is required under the MWA (Secs 4 and 5). The regulations give the OIM general responsibility for safety, health and welfare and for maintaining discipline and order on the installation. Candidates for the post are nominated to and accepted by the regulatory authority. The Inquiry did not hear any evidence on the criteria applied to the acceptance of an OIM by the regulatory authority. In earlier chapters I expressed the view that there were significant shortcomings in the performance of certain of the OIMs on the night of the disaster. In particular I expressed the view that because of the lack of leadership on Piper the death toll was substantially greater than it would otherwise have been. A number of survivors said that in the galley, where the OIM was positioned, no one was in charge or giving instructions or advice.

20.58 Evidence on the abilities required in an OIM was given to the Inquiry by UKOOA and by the Institution of Mechanical Engineers. Mr K A J Ellice, a training manager with BP Exploration, said that they looked for exposure to the North Sea environment, experience in a related technical discipline and ability to command. Information on ability to command would normally be provided through the in-company staff appraisal systems. It was extremely difficult to judge a person's ability to command in a precise way; they could be provided with the "techniques and mechanisms". He said that leaders were found rather than trained. Mr Ellice was definite that BP would not and do not use psychological tests such as were practised in the Royal Navy and Merchant Navy. During experience and training leading up to the selection there would be the opportunity to assess individuals in a variety of situations and circumstances. Dr A A Denton, representing the Institution of Mechanical Engineers, listed 4 criteria that the OIM and at least one deputy should have, command ability, specifically tested in simulated circumstances; technical literacy to at least Higher National Diploma or equivalent standard; experience of at least 3 years offshore; and understanding of the sea/air environment by training and experience. Mr Baxendine, who gave separate evidence on the command structure, was a practising OIM with 14 years experience. He stated that in the vast majority of cases the OIMs in his company (Shell) had all previously commanded groups of men.

20.59 The failure of the OIMs to cope with the problems they faced on the night of the disaster clearly demonstrates that conventional selection and training of OIMs is no guarantee of ability to cope if the man himself is not able in the end to take critical decisions and lead those under his command in a time of extreme stress. While psychological tests may not appeal to some companies the processes used and proven successful by the armed forces or the Merchant Navy, who have to rely on their officers to lead under stress, should be seriously considered by operating companies. The post of OIM calls for decisions which may make the difference between the life and death of personnel on board. The remoteness of installations, the requirement for installations to be self-contained in the means of dealing with a rapidly developing incident, the need to obtain, verify and consider data communicated to him from various sources for immediate decision on which the lives of those on board depend demands a level of command ability which is not a feature of normal management posts. The command ability of the OIM and the command structure and organisation in emergencies should be factors in the Safety Case proposed by the operating company. They should be part of the safety management system of the company which I will propose in Chapter 21.

Emergency exercises

20.60 Mr Ellice described how operating companies tested their command structures, by regular emergency exercises held for each installation, by operating company exercises and by full-scale exercises involving outside authorities such as the coastguard, police etc. For these a major disaster such as a helicopter crash on a platform or an explosion and fire were simulated. BP employed emergency response trainers who regularly visited all installations and assisted installation management to conduct specialised emergency exercises. There were also nominated persons in their safety department who were totally responsible for the planning and instigation of large-scale emergency exercises carefully organised to require co-ordinated onshore and offshore response. They considered that full-scale exercises were very important, covering interconnected platforms as necessary. Larger-scale exercises effectively exercised the emergency systems as well as training those in command on the installation. UKOOA have published guidelines for offshore emergency exercises, to determine the effectiveness of the operators' emergency procedures. Both in-house and major exercises in conjunction with outside authorities are specified.

20.61 I consider that emergency exercises are essential means of ensuring that paper procedures work in practice. They also allow for the assessment and upgrading, as necessary, of the performance of the command structure. I recommend that emergency exercises are carried out in accordance with UKOOA guidelines and that command teams are given practice in decision-making. The operator's system for emergency exercises will form part of its safety management system (see Chapter 21).

Precautionary musters, drills and training

20.62 Precautionary musters are held on all North Sea installations. All the persons on board are assigned a TEMPSC number on arrival on the platform and, on the emergency alarm sounding, non-essential personnel assemble at the pre-determined muster station, by lifeboat groups. If the OIM decides that the platform should be wholly or partly evacuated they make their way either to the helicopter deck, if helicopters are used, or to the lifeboat station, where pre-selected coxwains command the individual lifeboats. Separate lifeboats are reserved for the emergency response teams to use if it becomes necessary to evacuate the installation completely. POB lists are maintained on installations but experience on the night of the disaster shows that it would be important for them to be updated for every movement of personnel, and copied immediately to shore. These lists should be maintained in alphabetical order and by contractor employer, to minimise confusion and delay in reacting to queries in emergencies. I recommend that all POB should attend at least one muster per tour of duty; and that the circumstances of all precautionary musters and evacuations should be reported to the regulatory authority.

20.63 If central control and a planned evacuation cannot be exercised, as in the case of Piper on the night of the disaster, the personnel would be expected to make their own way to the sea. Mr D S Kinloch of Conoco described the need to take individual action in these circumstances. Such action, if taken prematurely, could of course be detrimental to controlled and orderly evacuation but the emergency training given to offshore personnel should enable individuals to minimise the risks they take if this becomes inevitable.

20.64 Realistic and up-dated emergency training and regular drills are of vital importance to ensure that the risks of emergency evacuation, escape and rescue are minimised. They should never be neglected. I recommend that the UKOOA guidelines for offshore emergency safety training on installations should be a minimum requirement for emergency and related training. I recommend that records of personal details and safety training courses attended by all personnel seeking employment offshore should be maintained by operators until the central training register instituted by the OPITB is operational. As for emergency drills and training, the operator's systems for these should form part of the safety management system (see Chapter 21).

20.65 The responsibility to ensure that the reaction to an emergency is effective, safe and disciplined is primarily with the management of the installation, ultimately the OIM. Onshore management have important roles to play in this but the decisions have to be taken on the platform. The command structure must be tested and drilled regularly. This should be seen as an essential part of working offshore. The biggest difficulty arises where there is an attitude of indifference offshore, particularly in the case of the occasional worker who may be on the platform for only a few days. All on board should take part in training, drills and exercises. The abnormally high casualty rate among those on Piper who, for reasons of their employment were not fully familiar with the platform layout, was striking.

Chapter 21

The Future Offshore Safety Regime

Introduction

21.1 The discussion in this chapter is divided into 3 main parts in which I discuss:

(i) The importance of the management of safety by operators; and the need for the maintenance of a consistently high standard of performance if their responsibilities under the regime are to be discharged (paras 21.2-14),

(ii) the extent to which the present methods of control, allocation of responsibilities, regulations and guidance in the offshore regime are appropriate and effective (para 21.15-51), and

(iii) changes in the regime which, along with those recommended in Chapters 17-20, are in my view necessary if the regime is to fulfil its functions in an appropriate and effective way (paras 21.52-87).

The management of safety

The role of operators

21.2 The safety of personnel on installations is critically dependent on the management of safety by the operators, as the circumstances of the disaster clearly demonstrated. There is, of course, nothing new in the idea that safety requires to be managed. The reports of investigations into recent major incidents have shown the dangers posed by serious failings in the management of safety by large organisations.

21.3 The evidence before the Inquiry has served to demonstrate that an offshore installation presents a combination of features which make it unique from a safety point of view. The living quarters are relatively close to the plant, which itself is placed in a confined space. Evacuation may be difficult if not impossible in certain weather conditions. While a chemical plant has some of these characteristics, evacuation is always available and the operating crew are not confined to the immediate vicinity. Installations are designed to meet specific requirements and may be subject to modification. These considerations underline the need for an adequate system for the management of safety and the need for a suitably rigorous regime which ensures that this is maintained.

21.4 There are practical limits to the extent to which a safety regime can affect the manner in which safety is managed. Mr R E McKee, Chairman and Managing Director of Conoco (UK) Ltd, offered the following comments:

> "It is my fundamental belief that safety cannot be legislated, while recognising that enough legislation or regulation needs to exist to ensure that minimum standards are maintained. Such regulation should impose a duty on the operator to do everything reasonable to achieve a safe operation. By and large, safety has to be organised by those who are directly affected by the implications of failure. These people are in the best position to determine the detailed measures necessary on their own particular installation to achieve the safety objective. Imposition of detailed requirements cannot anticipate all the variances of differing practice, location, organisation and size that exist. In fact, prescriptive regulation or over-detailed guidance may at times result in the overall safety objective actually being compromised. Innovation, on-going improvement and objectivity will be stifled; and the more prescriptive the regulation the more unclear it is who has the responsibility for total safety. Compliance becomes the overriding objective. Sight is lost of the more realistic and overall intent that all reasonable steps should be taken to achieve the total safety of the installation. Finding the middle ground is difficult. The

> Government is faced in some ways with the same problems that upper management is. In other words, first, they must be confident that industry has in place facilities that are properly designed for safety, using a FSA approach, and then that organisations have generated a proper safety culture that will help result in excellent safety performance. Audits need to assume a far higher prominence as a means of checking the ability of the organisation to achieve safe designs, operations practices and systems to interrupt a chain of events leading to a Piper Alpha type accident. This will require more skilled personnel for operations to conduct specialist audits, for third parties to check them and for Government departments to review their success."

With the general thrust of those comments I find myself entirely in agreement. I should add that it is also plain that a regulator cannot be expected to assume direct responsibility for the on-going management of safety. There may be circumstances in which inspectors can and should take the relatively drastic step of interfering by means of statutory notices, but these are the exception. For all practical purposes the management of safety is and remains in the hands of the operators.

21.5 This approach may be compared with what Mr Rimington described as the HSC's approach to the principle of self-regulation:

> "For practical purposes, its essence is that while the regulator can and should, in consultation with those regulated, provide a framework of rules and the necessary impulses and disciplines, health and safety is principally a matter for management in-firm."

21.6 These considerations underline the importance in the offshore safety regime of the general duties of employers under the HSWA and measures which are directed to ensuring that these duties are performed in a demonstrably adequate manner. I regard this as a key part of the regime.

Changes in the regime discussed in earlier chapters

21.7 In Chapters 18-20 I have discussed a series of measures which should be put into effect in the interests of safety, primarily through goal-setting regulations and to some extent through more detailed provisions.

21.8 More fundamental than these, and different in kind, are the measures directed to the submission and acceptance of a Safety Case on certain aspects of safety which I have discussed in Chapters 17, 19 and 20. These are directed to ensuring that the potential major hazards of the installation and the risks to personnel thereon have been identified and appropriate controls provided; and that adequate provision is made for ensuring, in the event of a major emergency affecting the installation, a temporary safe refuge (TSR) for the personnel on the installation, and their safe and full evacuation, escape and rescue. The present chapter will consider whether further requirements should be imposed on operators with a view to their demonstrating that they have made and maintain adequate arrangements for the management of safety at large.

The means of achieving adequate management of safety by all operators

21.9 Management witnesses gave evidence to the Inquiry as to the importance of defining and communicating to the whole workforce an adequate safety culture or philosophy; and ensuring that they were fully motivated to implement it. Safety should not be treated as something which was separate from the conduct of business. Mr R A Sheppard, Vice-President of Production and a Director of Amoco (UK) Exploration Company said that "safe, prudent working practices and procedures are good business practices". The organisation of safety was a matter for line management at each successive level. Mr McKee said:

> "Philosophically we look to line management for safety performance, not to the safety department or to a government agency. If a safety programme is to have outstanding results, it is imperative that senior and then each progressively junior level of management exerts its leadership in establishing goals, demanding accountability for performance and providing the necessary resources. While top management sets the safety standards for the entire company, our first-line supervisors are the key link in actually making it happen. Each of them is personally involved in safety training, safety inspections and other safety activities. They make sure that all line employees and contractors reporting to them are trained to work safely: that not only must they know how to perform their jobs properly and safely but are convinced that they have a responsibility to do so."

21.10 Mr Rimington pointed out that the reports on recent major incidents had drawn attention to the importance of the chain of command for safety, and particularly to the significance of leadership from the top. They had also focused attention on the related aspect of in-firm safety culture, and particulary the influence of the human factor in accident causation. That close attention to the management of safety was effective in preventing accidents, and that it was compatible or even associated, with first rate commercial performance was clearly demonstrated. For this he cited the performance of Du Pont de Nemours (of which Conoco (UK) Ltd is a subsidiary). His inspectors had formed the unequivocal impression that the more successful firms usually adopted a more highly structured and effective approach to safety than others. He held the view strongly that it had a great deal to do with discipline. "If one adopts a disciplined and determined approach to one's commercial success, one is likely to adopt such an approach to other aspects of one's business." The establishment of a safety culture included, he said, the "systematic identification and assessment of hazards and the devising and exercise of preventive systems which are subject to audit and review. In such approaches particular attention is given to the investigation of error. The control of human error involves the assumption that people will make mistakes but that by thought, pre-design and proper motivation this can be made much more difficult and the consequences mitigated."

21.11 It is clear that a systematic approach is required if an operator is to ensure safety on its installations and compliance with the requirements of legislation, including the duties imposed under the HSWA. This involves a planned approach to the elimination of danger both in design and in operation. This may be illustrated by the evidence of Mr P Doble, Deputy Project Manager of the Kittiwake Project, who explained how its design proceeded through the stages of feasibility study, conceptual design and detail design. The design philosophy was documented so that in any subsequent audit or review it would be possible to judge what had actually been done against the design intent. Management procedures were based on the quality assurance specifications of BS 5750, supplemented by systematic hazard identification and analysis to provide a series of checks and balances as the design proceeded. These included hazard and operability studies, safety reviews, equipment criticality assessments and audits. Mr McKee said that Conoco traditionally had a formal quality assurance system in place for design and construction of new platforms and modifications to existing facilities. The extension of this philosophy to the technical aspects of their operations was a key objective for 1990. The objective was to have a regularised way of watching over work practices so as to interrupt the chain of events that resulted in an accident. Mr M Ferrow, Manager, Safety and Quality Assurance for Conoco said that safety could be regarded as a "sub-set of quality assurance". He described how quality assurance was used to "close out" study findings in the engineering safety plan for Conoco's "V Fields" in the southern North Sea. He believed that it would be impossible to have a fully safe operation without a quality assurance system which he described as "a mechanism by which managers and engineers and the company in general can be sure that what they are doing will be safe, operable and fit for purpose, and, bearing in mind the faults and errors which can occur, either technical or human, sets up systems which take reasonable precautions against that; and then, finally, imposes some sort of formal audit structure into that to ensure that these things are being done on a continual basis." The use of quality assurance had evolved in the North Sea industry from the early or middle 1970s, starting with structural matters, extending to systems and then into an all-embracing technique for ensuring that what was designed was in fact built to specification. It was now moving, or had moved, into the operating areas.

21.12 Mr Rimington described quality assurance in the promotion of safety as "absolutely essential" and established practice in all major industries. Mr Petrie was aware that most operators demonstrated some type of quality management system to a standard such as BS 5750 or ISO 9000.

21.13 Common sense and experience of what happened on Piper indicate that it is not enough to set up a systematic approach to safety and put it into operation. There is a plain need to review and up-date the system in the light of experience both of the operator and of the industry. It is also necessary to "audit" the extent and quality of adherence to the system and to "verify" that its results are in practice satisfactory. It is clear that companies with an outstanding safety record go to considerable lengths to audit the management of safety. Mr McKee explained that Conoco performed management and safety department audits and inspections on a frequent basis, amounting to several per month on all aspects of safety management from housekeeping to work permit usage. As chief executive he received safety audit reports and reacted by raising the issues which were involved with the relevant vice-president. He conducted his own informal audits on his frequent visits to the platforms. He specifically discussed the audit system with managers and employees. All operating managers and their staff conducted regular internal safety audits. First line supervisors conducted frequent safety inspections in their areas of responsibility. Company procedures required daily audits for compliance with the PTW system and weekly compliance reports. Experienced safety professionals carried out audits on a regular basis by means of inspections of the platforms, including the activities of contractors. In addition there was an annual management safety audit of the platforms, including all relevant onshore managements. There were also special safety audits including team members from outside consultants. Mr Sheppard observed that "simply looking at the way the equipment is operated and the operating conditions of the equipment is not a complete safety audit. It has to incorporate in it the operating procedures, the way safety is approached, upon that particular installation, and it cascades up into how it is approached generally by the company." If it was found that part of the safety philosophy or safety programme was not being followed or interpreted in the appropriate manner he would discuss his concern with the manager of the particular part of the company to find out whether he had the same impression. Contributions might also be sought from the safety specialists and other Amoco managers in order to see whether his assessment was confirmed. Together they would examine the available data and determine whether they were dealing with the root cause of the problem and not a symptom of some larger problem. Once that examination was complete they would collectively set about exploring ways of improving the situation. It could be a communication problem, a supervisory deficiency, a training issue or an organisational flaw.

Relationship to the regime

21.14 The need for a good and well maintained management of safety by all operators, and not merely the few, is plain. No doubt the prime responsibility for this lies with the operators. However it is also plain that the regime has a part to play in the achievement of that overall objective. Is the present regime appropriate and adequate for the purpose? I turn next to this question.

The existing regulatory approach

21.15 In this part of the chapter I will examine the present methods of control; the allocation of responsibilities; and existing regulations and guidance.

Methods of control - design

21.16 Since the Construction and Survey Regulations came into operation the examination of design and what has been constructed has effectively been in the hands of the certifying authorities. The Second Schedule to the regulations coupled to the guidance provided by the DEn require certifying authorities to consider whether various aspects of an installation meet and continue to meet specified standards, frequently related to establish codes. As I explained in para 16.27, certifying authorities are concerned with conceptual design of process plant only to a limited extent. In particular they are not required to review plant design in relation to major hazards. Their concern is with the end product or the proposed end product of the design or construction. They are not required to examine the management systems which lead to that design. As I have already stated in Chapter 19 while certifying authorities are concerned with passive fire protection, active fire protection is the concern of another body.

21.17 Under the present regime there are no other requirements which oblige operators to show that their management of safety is adequate for the purpose of safety in design.

Methods of control - operation

21.18 It is clear from the evidence that the DEn take the view that it is essential that the quality of management is assessed by them and found adequate. Mr Petrie's position was that over the years, as part of inspection activities and other activities with companies this assessment of management had occurred. He enlarged on these other activities by saying that there were management safety presentations "which start with the senior management of the company, where they describe their philosophy for safety and their control of safety in management terms, and how they implement that right through their structure to the relevant people on the installation - the managers, supervisors and other staff." That was one element. "From that follow discussions at different levels with my people in their appropriate levels within the company, and it is finally down to the assessment of inspectors in undertaking offshore inspections." He pointed out that the monitoring of management of safety was very similar to what was done onshore. His department had carried that forward with the concept of FSAs, which brought in all aspects of safety.

21.19 The PED's programme for 1988/89 which was submitted to the HSE in November 1987 shows that until the first half of 1987 the PED's ability to undertake safety presentations had been severely constrained by widespread over-loading of the staff in the safety branches, particularly at management level. What actually was done by way of safety presentations did not emerge clearly in the evidence, despite the attempts of various counsel to obtain elucidation. What seems to have happened is that presentations by senior management did not take place but that a number of companies gave presentations at middle management and working levels. As regards the slippage Mr Petrie explained that safety presentations involved a significant workload for his department and for himself in particular. However, prior to the disaster his department had carried out a pilot study based on presentations by a cross-section of companies, about 8 in number. This was, as Mr Petrie put it, "to see the way ahead and to see if it was of any benefit". The study had shown that the presentations, he said, "could be an effective method of assessing as well as stimulating operators' management commitment to safety, as well as providing valuable information for inspectors engaged in offshore inspections. A section to co-ordinate and service such audits in a way consistent with the safety management system requirements of the regime is being set up. Advice has been sought from the HSE's accident prevention and advisory unit and from others such as NPD on the audit of safety management systems." The disaster had caused the cancellation of further presentations. They would probably be reinstated in the Spring of 1990. Additional resources had been agreed for that.

21.20 I am bound to say that I see the system of inspections of the conventional type practised by the PED, when considered as a means of assessing or monitoring the management of safety by operators as suffering from a number of fundamental limitations. While inspections may lead to correction both at the time and for the future they address something which has already gone wrong. There is no systematic examination of the operator's system for the management of safety. In particular an examination of management onshore is not involved unless something comes to the attention of an inspector during a comparatively short offshore visit (reference may be made to para 15.50.). The obtaining and following up of safety presentations would be a means of the PED coming to grips with operators' safety management systems, but the progress in that direction has been extraordinarily slow and tentative. In any event it is still no part of the requirements of the regime that a safety management system should be demonstrated to be adequate and carried out in practice.

The PED's approach to the future

21.21 In considering the existing regulatory approach I should also take account of the regulatory body's approach to the future. Mr Petrie said that amongst the most important improvements that could be carried out in the regime in the next couple of years included taking forward the FSA approach as fast as possible and having it considered by operators. Another was the move towards goal-setting regulations, replacing prescriptive regulations which were over-inhibiting. Mr Priddle said that the most important area which he would identify for the future was that attention and a new focus required to be given to the development of the capability of the Safety Directorate to assess management systems.

21.22 Mr Petrie agreed that while no regulatory body can expect to employ permanently the full range of expertise which may be required for its work it ought to have most or all of the expertise needed to cover continuous requirements of its system of regulations. Within the PED there were people who had reasonable knowledge of management systems but assistance was being sought from the HSE. Mr E J Gorse who spoke to the DEn's discussion paper on FSA, made it clear that in the absence of in-house expertise the PED were employing consultants in addition to assistance from the HSE in formulating the Department's proposals. Mr Priddle said that while the Safety Directorate had a general competence in relevant engineering disciplines, he knew that there were some particular specialist disciplines which were not represented. A decision had not yet been made by him about the means by which the Department would increase the expertise. This would be the subject of proposals by Mr Petrie who had already made arrangements to devote part of his resources to the development of FSA. He would expect him to draw on the relevant expertise from the HSE. That was part of the integrated process which he was delighted to see in operation. In the context of expertise in the assessment of management systems he said: "I think there is certainly scope for increasing the expertise which exists but I would not wish to give the impression that there is no expertise." He had not yet seen Mr Petrie's proposals as to the new resources which should be introduced. He expected that in connection with the attracting of persons with the relevant expertise it would be necessary to supplement the training which the Department currently provided. As regards the timescale this should be related to the timescale within which FSA would be introduced. He thought it likely that the regulations would be made in the latter half of 1991. "The fact that the Department is not able yet to benefit from such things as formal safety assessment, which would go in greater depth into management systems, is something which we are working on, as you know, but I would not regard that as an indication that we are falling down on the job."

21.23 As regards the offshore inspectorate I have described in para 15.44 *et seq* the persistent shortfall in manning levels. Mr Petrie said that he had put in a bid to increase the total complement from 10 to 12 inspectors, which may be compared with 7 in post. In January 1990 this bid had not yet been put before the management board. At that time 9 specialists were being recruited. The divisional return which was to be submitted to the management board made provision for a further 8 specialists. The total of 17 would bring the total of specialist staff from 45 to 62. This took no account of administrators, including the safety policy branch where an increase in staff would help to take forward new regulations and assist generally with matters of policy. In the last few months there had been a "total rethink" of resources. A previous "fundamental rethink" in late 1986 had been implemented in 1987/88. Staff changes at that stage had given rise to many vacancies at the grade of Senior Inspector. Mr Priddle said, when giving evidence also in January 1990, that he was aware of the areas in which the Department had been unable to achieve because of lack of manpower. First attention had been given to the manning of the offshore inspectorate.

The HSE's approach to effective management of safety

21.24 It is of some interest to consider, by way of comparison, the approach adopted onshore. The HSE's approach to the management of safety as part of the Safety Case has been set out in Chapter 17. The HSC's plan of work for 1989-90 and beyond makes clear that the HSC and the HSE are intent on a vigorous promotion of the effective management of safety by industry. Leaving aside the premises to which the CIMAH regulations apply the HSE's approach is to insist on evidence that safety and particularly incidents are being properly monitored. The APAU, whom Mr Rimington described as "a sort of crack unit" carry out safety audits in co-operation with large companies and undertakings. Through this work they have acquired expertise in management systems and in packages for the monitoring of safety. They train other inspectors in management systems and increasingly take part in investigations of major incidents.

21.25 As regards inspectors' approach to onshore inspections reference may be made to what I have set out in para 16.37. Mr Rimington said that inspectors were trained particularly to concentrate on the management systems and attitudes in the course of their inspections. This was something for which they were most certainly trained. They could also call in the APAU if they had doubt.

The NPD's approach to the promotion of effective management of safety

21.26 Mr Ognedal said that safety could not be "inspected into a platform". Commenting on past experience of inspections he said: "In Norway it has had a tendency to create a situation where people do what they are told by these inspections and then wait more or less for the next inspection to come along and tell them what to do then." He elaborated this as follows:

> "We found that where we had identified a number of things on a platform requiring attention and had notified the operator of these, the operator would tend to react only to the matters drawn to his attention. We asked operators whether they were evaluating our comments on individual platforms across their platforms and fields and examining their systems in the light of the specific matters we were drawing to their attention. It appeared from the responses we received that this was not being done. We considered how we could focus on these issues with a view to motivating companies to do this themselves."

21.27 Mr Ognedal said that the main reason for starting to think along the lines of internal control was that NPD decided that the traditional way of supervising an activity was not effective. What was required was to get the operator to focus on the safety issue in a more systematic manner than was the case. He pointed out that even within the present system in Norway verification, including inspection, could only reveal what had gone wrong. This was the basic important point in auditing the procedures that controlled the activity. If weaknesses in these procedures were revealed, corrections could be made before they resulted in erroneous work performance or equipment failure.

21.28 He also expressed the view that it was a better use of resources to look at the framework that would produce safe activities than to find out only what had gone wrong. "I would say that my conviction is that my resources should be used to promote the operator and all his personnel, including contractors, etc, to be conscious in relation to the activities and the framework controlling the activities themselves, and to help and motivate that organisation which is present 24 hours a day. That is the best use of my resources."

21.29 As regards the implementation of internal control Mr Ognedal said that normally operators would base their method of management and control on accepted methods and standards for quality assurance. It had therefore been recognised that the duty of having an established internal control system was complied with by implementing integrated quality assurance systems, such as in accordance with ISO 9000. He preferred to see internal control integrated in this way.

21.30 Mr Ognedal said that 5 or 6 years ago consultants produced much of the documentation which was required for internal control. However operators had very quickly found out that they could not use documents which had been written by consultants. At the present time they produced the documents themselves and used consultants only to assist in defining what the scope and content of the document should be. Some operators had found the implementation of the system time-consuming. He was not sure if they found it difficult. It certainly took time to establish the system and go through the documentation which controlled the activity to see that it was coherent and that the system was implemented and properly understood in the organisation. His view was that without something similar in nature to internal control a company would be less safe. As regards contractors the operator would require to assess any contractor which it was going to use and check that there was some form of internal control activity within the contractor's organisation. The operator would also have a duty to audit that to see that it did what it was supposed to do and to correct any flaws that were found. While the licensee had a duty to see that there was a system of internal control the duty to participate in that system affected all who took part in work offshore in the petroleum industry.

21.31 Mr Ognedal agreed that in carrying out supervision the staff of NPD were now much more involved in making judgements; and had to have the ability not only to make them but to defend them in discussion with management. During the auditing process his staff were dealing much more with senior managers than was the case before. This meant that they required to understand the managerial role and the organisation that particular managers had under their control.

The allocation of responsibilities

21.32 The Burgoyne Committee recommended that the Government should discharge its responsibility for offshore safety through a single government agency whose task it was to set standards and to ensure their achievement (6.5). This was in distinction from the situation at the time of their report where 3 agencies namely the DEn, the HSE and the Department of Trade each had certain responsibilities for safety offshore. The committee envisaged that in the event of their recommendation being implemented the arrangement whereby the Department of Trade carried out examinations on an agency basis should be terminated and the DEn should assume that task (4.10). At the same time the committee firmly upheld what they called "the principle of independent certification of critical features of offshore structural and operational safety". They recorded that the practice of subjecting all aspects of the design and construction process to the independent scrutiny of a certifying authority had found general support and approval (4.25).

21.33 It is clear that the Burgoyne Committee did not perceive that there was any inconsistency between the concept of a single government agency and the role performed by a certifying authority, although the effect of that arrangement was that an important measure of discretion was entrusted to another body and that the process which led up to the issuing of the certificate of fitness was outside the direct knowledge of the government agency. It appears that the special expertise of the certifying authorities was seen as favouring this arrangement; and that their well-established standing provided a full assurance of independence. Since 1987 their work has been audited by the DEn. During the course of the Inquiry no criticism was made of their ability for, or their performance of, the work which has so far been entrusted to them. The attention of the Inquiry was drawn to the fact that they can undertake work as consultants in the design of installations. To carry out such a function would obviously be inconsistent with acting as a certifying authority in regard to the same matter. However, I am satisfied that in practice conflict would be avoided; and that the possibility of consultancy work should not affect the running of the certification system in any material way.

21.34 The DoT continues to act as the agent of the DEn in regard to fire-fighting equipment and life-saving appliances. Their work is also audited by the DEn.

21.35 During the course of the Inquiry a number of witnesses gave evidence that it was important that the work of regulation should be carried out by a single body. In Chapter 17 I have already discussed that point in relation to FSA. Mr M Ferrow, Manager, Safety and Quality Assurance for Conoco (UK) Ltd, spoke to UKOOA's position paper which advanced the view that it was "essential that the outside authority is competent in assessing both the engineering and management control aspects. Due to the integrated nature of the FSA there should be a single body responsible for the overall assessment." In that connection Mr Ferrow said: "We operators can direct our energies at safety and being safe more profitably by not being encumbered by a complex regime which requires us to interface with several bodies on specific matters. It would benefit everyone, in my belief, if operators could deal with one single authority who understood the overall issue at stake and could indeed help the operators to achieve their objectives."

21.36 Mr Ferrow also commented that the offshore safety regime had developed in such a way that offshore inspectorates were more fragmented than onshore. The pipelines inspectorate from his point of view appeared to be a relatively separate part of the DEn enforcing different sets of Acts and regulations. He disagreed that such separation was inevitable where special expertise was required. There was no single point of contact which looked at the overall issue.

21.37 In Chapter 19 I referred to the evidence of Mr Brandie, Safety and Compliance Manager, Chevron (UK) Ltd and the Chairman of the UKOOA Fire Protection Working Group, who maintained that the best technical solution to fire protection had been hampered by the splitting of the regulatory requirements for passive and active fire protection. Two sets of regulations were administered for the DEn by different authorities, namely the DoT and the certifying authorities. As a practical matter the latter tended to have a more continuous dialogue with operators. In connection with Chevron's own proposals it had been found necessary to have meetings with both the DoT and the DEn at the same time in order to make sure that they were not in conflict with the requirements of the Fire Fighting Equipment Regulations.

Regulations and guidance

21.38 After a review of the legislative and other controls exercised by the DEn for offshore safety the Burgoyne Committee came to certain conclusions as to the structure of the written controls. These were, *inter alia*, that an Act of Parliament "sets out main duties and obligations"; that regulations "detail mandatory objectives of controls"; and that guidance notes "relate to a set of regulations, give non-mandatory advice on methods of achieving objectives". (4.48). They recommended that: "Future regulations should specify objectives and avoid overlap. Methods of implementation should be advised as fully and flexibly as possible in guidance notes which should be recognised as being non-mandatory." (6.15).

21.39 From all sides during the Inquiry there was support for the proposition that the regime should be controlled by regulations which set objectives ("goal-setting regulations"). Mr Petrie agreed that where possible regulations should set objectives rather than lay down a series of prescriptive requirements, and that this was the way forward so far as the Department was concerned. This allowed for flexibility and the best practices to be used without inhibition. Goal-setting regulations were equally applicable in the area of mobile drilling platforms. The Department generally had the same approach as the HSE. He agreed completely that this placed a greater burden on the regulator in the sense that he must exercise his experience, judgement and discretion on areas which might be subject to debate. However, the distinction between a goal-setting regulation and a prescriptive regulation was very rarely clear-cut. Some existing regulations could be described as setting objectives. He did not wish to give up the tool of prescriptive regulation where it was appropriate in order to prescribe a minimum standard. Mr Priddle accepted that future regulations should in principle be goal-setting in their nature, but he observed: "Specific requirements seem to us very valuable in defining acceptable standards in certain well-defined cases." By way of comparison I may add that in Norway the NPD are currently moving away from a regime of detailed regulations and re-emphasising that the operator himself has to make the appropriate decisions based on objectives. Mr Ognedal stated that it was the intention of NPD to reduce prescriptive regulation to a minimum in all areas where it was possible to do so without affecting the safety level. It was foreseen that in some areas there would still have to be prescriptive regulations. One of the reasons for adopting the goal-setting approach was to make regulations that were more flexible, so that changing technology could be accommodated without the need for new legislation.

21.40 The movement towards goal-setting regulations would be in full accordance with the philosophy adopted by the Robens Committee for safety and health legislation. However, despite the statements of attitude made by witnesses from the DEn there has been virtually no progress towards the creation of new goal-setting regulations since the publication of the report of the Burgoyne Committee in 1980. Mr Petrie agreed that onshore the HSE had achieved this in certain areas. "We have not, as yet, managed that, although the target should have been reached." When asked for the reason for the lack of goal-setting regulations he said "I do not believe that our philosophy is that different from HSE. We have had difficulties with manpower to take forward this work, because of other work." Another factor was the task of considering the balance to be struck between goal-setting and prescriptive regulations. In the result the existing regulations under the MWA, most of which were made prior to the report of the Burgoyne Committee are different in their general approach from the type of goal-setting regulations which have been produced by the HSE on the basis of the HSWA.

21.41 Quite apart from this state of affairs it is clear that a number of the existing regulations under the MWA have already been recognised to be in need of up-dating. The PED's programme for 1988/89 stated that in view of the many changes in the offshore industry during the 10-15 years since many of the regulations had been made, it was intended to undertake a review of legislation with a view to up-dating, rationalising and streamlining regulations wherever possible. This was stated as one of the actions which the Safety Directorate intended to take with the overall objective of the improvement of safety standards offshore and the corresponding reduction in accidents. Mr Petrie explained that this project had reached the point of identifying priority areas. However, due to constraint on resources that existed even before the disaster it had been agreed that it was no longer feasible to consolidate and streamline the regulations in the way originally envisaged, as the programme for the following year makes clear. However that programme indicated a proposal to prepare a timetable for (i) the Operational Safety, Health and Welfare Regulations, which "are far too specific with the result that they have become out of date. Consequently a large number of requests for exemption from some detailed requirements of the regulations are received"; (compare para 7 of the DEn's submission to the Burgoyne Committee in 1979); (ii) the Life-saving Appliances Regulations and the Fire Fighting Equipment Regulations, where "technological changes in recent years mean that some up-dating is necessary"; and (iii) other regulations including the Emergency Procedures Regulations, which needed to address the question of one standby vessel supporting more than one installation.

21.42 During the course of his evidence Mr Ferrow advocated the approach that: "Efforts should be strongly directed at safety rather than compliance for its own sake." He explained: "It can be extremely expensive and disruptive to carry out certain specific precautions and buy very, very little or, in fact, even negative value in terms of safety, simply in order to comply with a regulation." He went on to say: "The problem with the regulations as they have existed is that they do not address the overall system whereby the individual components are connected together, so, whereas there are very particular design codes, etc for valves and pressure vessels and so on, the way in which all those particular components interact is in fact not the subject of any particular specific legislation that I am aware of for offshore platforms at the moment." The point made by Mr Ferrow is similar to one made by ICI Petroleum Services Ltd in their submission to the Burgoyne Committee which is printed at pages 239-240 of their report. They stated in the course of their submission:

> "Experience onshore since the introduction of the HSWA compared with the previous legislation seems to be that the principles of self-regulation and management control are resulting in a more responsible forward-looking attitude by companies. The present system of control by regulation in the North Sea could lead, it is believed, to an attitude on the part of some employers whereby there is a primary desire to comply with the regulations rather than exert maximum effort towards total safety. Moreover, regulations are slow to form and difficult to change; they are inappropriate for complex and rapidly changing technologies, and they are capable of being abused by encouraging the attitude typified by 'the plant must be safe because everything has been done that the regulations require'. What is needed for future projects is a more flexible system which can not only respond quickly to new problems - thereby generating improvements - but encourage a forward-looking attitude and put the initial responsibility for deciding what is safe where it belongs - with the employers."

At this point it is worth recalling the quotation from the evidence of Mr McKee which I gave in para 21.4, to which may be added the following quotation from his evidence: "Regulations need to be less prescriptive and detailed, more objective and broader based. Over time as you layer more and more prescriptive types of regulations on to the overall regime it probably takes away from the overall objective of total safety." By way of comparison I noted that Mr Rimington's evidence was that regulations under the HSWA normally address themselves to systems. He cited in that connection the provisions of the Pressure Systems and Transportable Gas Containers Regulations 1989 under which management were required to validate and confirm pressure systems in a systematic way. He went on to say: "Now accompanying those regulations, which principally address themselves to systems and responsibilities, are quite considerable codes that will go into all sorts of details, such as, for example, what you do if you come to a pressurised system which you can enter, as opposed to one that you cannot, and so on. Therefore, we proceed from the general to the particular, leaving varying degrees of latitude to an employer as to how he tackles the particular. That is our whole philosophy."

21.43 Mr Ferrow also put in a plea that the structure of Acts, regulations and guidance should, if possible, be made simpler. He said that there would be great benefit in a system of legislation which all, including engineers, operators as well as managers, would understand. He saw the potential for a simpler framework of legislation that did not remove previous legislation at a stroke but looked towards simplifying and incorporating it within that framework. He thought that the better way to go was to set up a requirement for assessments rather than attempting to identify all the particular hazards that there could be in all situations and then providing particular rules to address those particular points.

21.44 Mr Ferrow went on to say that it was an unsatisfactory situation where it was necessary to apply for exemptions to strict regulations. He would be happier dealing with guidance which could be discussed on a case by case basis. This point was supported by other witnesses who were concerned with various measures for safeguarding personnel in the event of an emergency. Thus Mr M Booth, Head of Operations Safety, Shell (UK) Exploration and Production Ltd who dealt with escape routes said that in view of the diversity of platforms it was undesirable to have a detailed prescriptive legislative approach. It stifled technology and advancement and at the end of the day it was counter-productive. A similar point was made by Mr I Wallace, Superintendent of Occupational Safety and Health, Conoco (UK) Ltd, and Dr J Side of the Institute of Offshore Engineering, Heriot-Watt University, who dealt with emergency evacuation, escape and rescue. The dangers of over-prescriptive regulation are I think clear from this evidence. It is unwise for any regulator to put much reliance on exemptions which take time and trouble to obtain and may discourage an operator from incorporating the benefit of improvements in technology. Further, as Mr Petrie accepted, the fact that any regulation requires a large number of exemptions may well indicate that the regulation has been badly framed.

21.45 As I stated above in para 21.38, the Burgoyne Committee recommended that guidance notes should be recognised as being non-mandatory. They further said that: "The guidance notes to regulations should be kept up to date on a continuous basis and their status as non-mandatory guidance should be clear." (6.17). Mr Petrie said: "There is frequently a misconception on the part of people who do use guidance notes that they are more than guidance notes. It will not be the first time that somebody has said to me they wanted to talk about regulations when in fact they were talking about guidance notes. We always point out that it is exactly guidance notes and the standing of them. Of course, it is explained in the front of the guidance notes that they are non-mandatory." On the other hand the PED saw guidance notes mainly as giving minimum standards. He did not agree that this represented the application of guidance notes in a prescriptive manner, because the same level of safety might be achieved in another way. "When I said minimum I mean meeting the guidance notes provides the minimum standard that we believe will comply with the regulations. There are other ways of achieving exactly the same thing - or potentially other ways of achieving the same thing. That is why the guidance notes are not mandatory to allow that flexibility." However, a number of witnesses spoke of the problems created by the fact that guidance notes tended to be treated as an obstacle to alternatives. Mr Ferrow said of the guidance notes which related to the Construction and Survey Regulations: "I can assure you that they are adhered to almost to the letter and are taken extremely seriously by engineers at all levels. It has become a working document for the method of construction and principally structural matters, and now extends into a wider variety of matters. As a guidance document it works almost too well in the sense that the certifying authorities seem unprepared to deviate from the written guidance without reference back to the DEn." Referring to the guidance notes relating to Reg 11(1) of the Fire Fighting Equipment Regulations he said: "The requirement to provide fire-water in process areas at the rate of 12.2 litres/m^2/minute is, in my view, off the point of providing fire-water to mitigate the consequences of a fire. If I think of the resources that are brought to bear in terms of trying to achieve those sort of objectives, I feel they would be better employed looking at and analysing what the likely fires would be and what the necessary rates of fire-water would be for that particular incident." cf para 19.66 for the evidence of Mr Brandie on this matter.

21.46 I turn now to examine the history of the extent to which regulations made under the HSWA have been extended to offshore as well as onshore application. The Burgoyne Committee noted that safety offshore was the subject of the MWA, the HSWA and the PSPA and regulations thereunder. They saw as the first task of the single agency for safety offshore to review the overlap between these Acts (4.24). They recommended that future regulations should avoid overlap (6.15). They commented that the further development of safety regulations could in theory be undertaken under either the MWA and the PSPA on the one hand or the HWSA on the other, although the wider application of the latter made it preferable (4.21). The agency agreement which was entered into by the HSC and the Secretary of State for Energy set out that it had been agreed between them that the Secretary of State would make adequate arrangements in accordance with such guidance as the HSC or the HSE might give for the development of health and safety regulations, approved codes of practice and other advisory material under the HSWA. The revised letter of implementation dated 23 March 1982 reflected this. The HSE seconded inspectors to the PED in the expectation that they would put forward regulations under the HSWA. There appears to have been no problem in framing regulations under the HSWA in such a way as to place duties on licensees and other specific categories of persons defined in the MWA. In the event no legislation under the HSWA has been promoted by the PED apart from the Offshore Installations and Pipeline Works (First Aid) Regulations 1989. Further, in the light of the attitude and advice on policy given by the PED the offshore application of sets of regulations prepared by the HSE in the modern form which is in line with the views of the Robens Committee and the policy of the HSWA has occurred only in a limited number of cases. It will also be recalled that whereas since 1977 the HSWA itself has applied to the UKCS, the legislation relating to the offshore industry such as the MWA and its regulations have not been made relevant legislation for the purposes of the HSWA and accordingly subject to replacement under that Act.

21.47 Mr Rimington explained that the procedure when the question of offshore application arose was that the HSE's policy branch asked the PED what advice it would give to the HSC. The policy on offshore application was not a matter in which the HSE played any direct part. This was done under the agency agreement. At a later stage it became a policy decision on the part of the HSC whether or not to accept whatever advice they received from the PED. Out of 27 occasions in which the PED's advice had been solicited the answer on 7 occasions was in favour of, and on 20 occasions was against, offshore application. In regard to those figures Mr Rimington observed: "That is a very limited way of perhaps looking at the matter. I have to repeat that I am not very familiar with the offshore situation. I also have to say that the Mineral Workings Offshore Acts are, though perhaps old-fashioned in form, really quite a modern set of provisions. They in general seem to have served the industry well in the estimation certainly of those who are regulated and also, in the view of the DEn, who are much closer to the matter than we are." The regulations in the case of which the PED advised against offshore application included proposals as to CIMAH Regulations in 1983; and Control of Substances Hazardous to Health COSHH Regulations in 1985. In Chapter 22 I will have some comments to make in regard to the PED's understanding of and attitude to the offshore application of those proposals. Mr Rimington said that it was clear from these and other examples that the response from the PED was identical. Since clearly some general factor was at work the HSC invited the PED to produce a view on the relative operation in the future of the HSWA and the MWA "because clearly there was a tension between the two". He explained that the overlap between the Acts was of the liveliest concern to him and, he believed, the HSC. As the HSWA regulations extended offshore, if indeed that was intended, the position of the HSE under the agency agreement automatically extended. "Given the fact that the HSWA in any case applies offshore, and is indeed used by the PED, very considerable difficulty arises in knowing precisely what the extent of the executive's responsibility is, or indeed the commission's responsibility ... so the commission wished to have the policy of the DEn set out much more clearly that it had been. Such a policy, when set out, could not obliterate the difficulty of 2 overlapping sets of legislation, but it would produce more stability in the situation." He also said that the HSE had always perceived in its relationship with the PED a very great sensitivity which he personally could understand, about the question of policy for anything that had to do with the structural integrity of offshore installations. He said that the PED "had a very important and comprehensive system going. It had been endorsed by the major committee that had sat on the subject. We took it that this was a very considerable bar to them feeling that some very substantial change involving legislation should be undertaken."

21.48 In 1986 the PED submitted a written review of offshore safety legislation in response to the request from HSC. It stated that there appeared to be no problems relating to the interaction between the PPA, the MWA, the HSWA and the PSPA as they affected health and safety. New regulations under the HSWA could be used as an "infill" to existing requirements, sometimes as an "addition" and on occasions as in "substitution" for existing standards. On the other hand it said that, however welcome such assimilations might be, this general rule could not be applied universally. Offshore there was a need to apply specific standards which might have no logical counterpart onshore, such as in the area of first-aid, emergency procedures, fire-fighting and life-saving. Further, certification had no direct onshore counterpart. Its efficacy had withstood the test of time and there was a clear need to continue with this concept. The review went on to say:

> "Whilst arguments could be advanced to make the 1971 and 1975 Acts relevant statutory provisions of the 1974 Act, it is believed that the present position is essential for current and foreseeable offshore needs. There are 2 overriding and salient features of mineral workings legislation: that of 'structural integrity' and that of exploration, including drilling and production licences and consents - matters which are not in themselves dependent on or relevant to the occupational health and safety of persons or directly affecting the public. It is self-evident that there is a need to ensure such standards whether persons are employed or not. Unmanned installations are likely to increase as is the number of sub-sea completion systems. There will therefore be a need for regulations under the 1971 and 1975 Acts to ensure the continuation and improvement of appropriate standards. With offshore safety policy clearly placed in the hands of the Secretary of State for Energy there would appear to be no conceivable reason to divest him of this responsibility as a paper exercise only to return it to him as part of a new agency agreement since the existing agreement and letter of implementation exhort him to develop health and safety legislation by utilising the HSWA. This paper acknowledges and accepts that occupational health and safety should, where ever appropriate, be made under the HSWA. The Offshore First-Aid Regulations are a prime example of this action and shows the co-operation between the executive in this department in their development as well as the acceptance of 5 other sets of HSWA regulations which have an offshore application."

Among the conclusions of the paper it was said that there was a need to retain specific regulations in such matters as life-saving, fire-fighting and emergency procedures. "Such regulations could be made under the HSWA: although historically having no onshore connotation it would seem logical to continue any future action under the 1971 and 1975 Acts for the sake of continuity."

21.49 Mr Rimington commented that the paper very largely confirmed his understanding as to the view which the PED took as to the scope for the use of regulations under the HSWA. "What it does not resolve is - given that regulation of anything has to be tackled from a certain philosophy - any conflict between the philosophies involved. In order to give a final answer to the question, how far are we entitled to form judgements of PED's effectiveness? Where does that judgement begin or end? Does it stop entirely with the 7 regulations, or does it extend somehow beyond that? If it extends beyond that, how do you cut them off?" Mr Rimington also added that the scope of the expression "occupational health and safety" was extremely difficult to define. However, he accepted that the paper achieved what the Burgoyne Committee had referred to (in 4.24) as the review of the overlapping Safety Acts. The PED had streamlined the situation in the sense of relying almost wholly on the MWA. In those circumstances he thought that they could very fairly claim to have simplified the situation and brought some order into it.

21.50 Mr Petrie explained the approach which the PED took when presented with proposed regulations. He said: "We look to see the purpose and intention of any proposed regulations, see how they are perhaps already covered by our existing regime. If they are not considered to be already covered or partially covered, then the decision has to be taken as to whether it is appropriate for that particular bit of legislation to apply offshore." As a matter of general policy he would not necessarily be against disturbing "the old regime". This had been done in a number of cases and he expected to do that on occasions. "But I think perhaps I should also make it clear that we assess the situation and put the case to the HSC, who are, if I can so call it, the final arbiter in that matter and advise the Secretary of State of their view after having heard evidence, information, views of the department." He added later: "I think it is a general view that we should not unnecessarily be amending and changing legislation. Indeed, in that same light, there are many onshore regulations that are still not assimilated in new regulations under the 1974 Act. Assimilation would certainly be striven for in the case of new regulations which have no existing counterpart in the offshore safety regime. But even if existing regulations were merely being amended the PED would look into the possibility of assimilation." Mr Priddle repeated the point that the HSC had the right to advise the Secretary of State of a contrary view from that expressed by the PED.

21.51 My general conclusions in the light of this evidence are that there has been virtually no progress towards the creation of new goal-setting regulations. Many existing regulations are unduly restrictive in that they are of the type which impose 'solutions' rather than 'objectives'; and are out of date in relation to technological advances. Guidance notes are expressed, or at any rate lend themselves to interpretation, in such a way as to discourage alternatives. This poses a clear danger that compliance takes precedence over wider safety considerations; and that sound innovations are discouraged. The PED have advised a policy - which the HSC has accepted - of reliance mainly on the MWA. Even if it is accepted that structural integrity is a special feature of what is required in the case of offshore installations and that it should not be forgotten that unmanned installations form part of the total number, there is a clear overlap between the field covered by the HSWA and that covered by Section 6 of the MWA. That section forms a basis for a number of the existing sets of regulations, including the Operational Safety Health and Welfare, Emergency Procedures, Life-saving Appliances and Fire Fighting Equipment Regulations. In the result, on the one hand the existing regulations under the MWA have stagnated; and on the other hand the effect of the policy advised by the PED has been to distance offshore regulations from the influence of the main stream of practice in modern regulations on health and safety. One outstanding example of the result of this policy was the rejection in 1983 of the offshore application of the proposed CIMAH Regulations. The same point applies whether one talks of the extension offshore of regulations which are to apply onshore or the creation of a parallel set of regulations which are adapted to conditions peculiar to offshore installations.

The future regulatory approach

21.52 In this part of the chapter I shall draw together a number of matters which have been discussed earlier and set out what I consider to be the changes which are required in the regime in addition to those already recommended on the basis of Chapters 17-20.

Ensuring the adequate management of safety by all operators

21.53 The earlier discussion shows that although operators' management of safety is of critical importance to the safety of personnel on installations the present regulatory provisions do not address it in any direct sense. They consist on the one hand of sets of regulations which are directed to specific and limited subjects (mainly 'hardware') and on the other hand the broad duties set out in the HSWA. Further, I am not convinced that under the present regime the regulatory body can monitor and support the operators' management of safety in more than a minor and incidental way. My views would remain unchanged even if the Safety Directorate were fully manned - which is far from being the case at present.

21.54 It is also clear to me that the offshore safety regime has fallen significantly behind the onshore regime in a number of respects in which thinking on safety matters has advanced over the last 10 years. The respect which is most relevant at this point is the concept of the Safety Case. The DEn's advice against not only the offshore application of the proposed CIMAH Regulations but also the facility of a Safety Case has set back the development of the offshore safety regime by many years. Even though the Safety Case has proved to be more successful than could have been predicted by the HSE its introduction was rightly regarded as a major advance in the technique of the regulation of safety.

21.55 Accordingly in my view a number of major changes in the offshore safety regime are long since due. These have implications both for operators and for the regulatory body. In previous chapters I have recommended the introduction of a requirement for submission of a Safety Case for various purposes which take account of the peculiar problems presented by offshore installations. In my view it is necessary to go one stage further in order to ensure that operators set out their system for the management of safety and demonstrate that it is adhered to.

21.56 I consider that operators should be required to set out formally the safety management system which they have instituted for their companies and to demonstrate that it is adequate for the purpose of ensuring that the design and operation of their installations and equipment are safe. For convenience of reference in this report I will refer to the safety management system as SMS. The SMS would be expected to set out the safety objectives of the operators, the system by which those objectives were to be achieved, the performance standards which were to be met and the means by which adherence to those standards was to be monitored. The SMS would be expected to contain a full demonstration as to how safety was to be achieved in both design and operation. Thus it would cover, *inter alia*, how safety was to be achieved through:-

— organisational structure
— management personnel standards
— training, for operations and emergencies
— safety assessment
— design procedures
— procedures, for operations, maintenance, modifications and emergencies
— management of safety by contractors in respect of their work
— the involvement of the workforce (operators' and contractors') in safety
— accident and incident reporting, investigation and follow-up
— monitoring and auditing of the operation of the system
— systematic re-appraisal of the system in the light of the experience of the operator and industry.

21.57 It would be appropriate that this demonstration should form a leading part of the Safety Case, for which much of the information would be required in any event in connection with major hazards. Along with the SMS would be any safety management system which was particular to the installation for which the Safety Case was prepared.

21.58 I have considered carefully whether or not I should recommend that the SMS should be set up in accordance with any particular type of system which is already in use. At the Inquiry Dr A A Denton, giving evidence on behalf of the Institution of Mechanical Engineers, advanced the view that operators should be required to adopt quality management systems (QMS) techniques. This would involve the application of QMS to the whole of a company's operations of which the management of safety formed part. Dr Denton defined quality management as all systematic actions which were necessary to ensure that the activity is planned, organised, executed and maintained according to requirements in, and pursuant to, laws and regulations, and in adherence to corporate policies, requirements and specifications. QMS control what must be done; who will do it; how it will be done; if it must be controlled by instructions, procedures or drawings; how the accomplishment of the task is to be documented; who will verify that the work was completed as planned; and what records must be kept, by whom, and for how long. QMS had 4 "prime indispensable and indivisable components", namely a corporate quality manual and subsidiary quality manuals for individual platforms; a requirement that the manual be followed; regular audits by an independent third party; and a response to deficiencies by appropriate corrective action. Dr Denton maintained that total quality could not be applied to safety alone. Hence if QMS were required by regulation to apply to safety it would force a company to apply QMS to every part of its activities. I have come to the conclusion that it would be going too far for me to recommend the imposition of a system which would apply to all operators and across the entirety of their operations. I take the view that the operators should have the freedom to choose the type of system which is appropriate for them, in the light of the regime's requirements and their own operations. However, in the light of the evidence which I have heard I consider that in the formulation of their SMS operators should draw on principles of quality assurance similar to those contained in BS 5750 and ISO 9000.

21.59 I should perhaps add that as part of his evidence Dr Denton proposed on behalf of the Institution of Mechanical Engineers that mandatory minimum standards of technical qualifications should be established for platform staff. cf para 20.58. For example, while accepting that the exact qualifications would depend on the size and complexity of a platform, the OIM should be technically literate at least to Higher National Diploma or equivalent standard and have at least 3 years offshore experience and an understanding of the sea/air environment. An operations superintendent should be a Chartered Engineer, process operators should be qualified to Higher National Certificate or equivalent standard, and each specialist maintenance trade should be led by someone with at least Higher National Diploma status. In any managing position the occupant required both a sound theoretical understanding and relevant practical experience, preferably offshore. UKOOA submitted that it was for the operator to decide the appropriate manning levels for an installation and the appropriate qualifications of personnel. Technical qualifications needed to be balanced against other desired capabilities, such as skills in man management and communications abilities. I am not persuaded that specifying standards of technical education for the generality of platform positions is a practical way forward, as platforms vary in size and complexity, as do the organisational systems of operators. However the competence, including the soundness of technical understanding, of those appointed to positions of authority is an issue critical to the safe operation of any platform and, while agreeing that this has to be for the decision of the operator, it should be set out for review by the regulator as part of the operator's SMS.

21.60 It is clearly essential that in addition there should be controls by means of which the regulatory body can be assured that the SMS is adhered to. It is clearly inappropriate and impracticable for the regulatory body to be made responsible for auditing in detail operators' compliance with their SMS. Accordingly, it should be part of the regime that operators are required to satisfy themselves by means of regular audits that their SMS are being adhered to. On the other hand the regulatory body should be required regularly to review operators' audits on a selective basis; and itself to carry out such further audits as it thinks fit; and by regular inspection verify that the output of the SMS is satisfactory.

21.61 What I have outlined in the last paragraphs involves a completely new approach to regulation in the UKCS. It is, however, totally consistent with the HSWA and the concept of self-regulation. It represents in my view a logical development from the requirement of a Safety Case for each installation. It is true that it has no current counterpart onshore. However, it can be seen as a further advance in the philosophy of a safety regime. Further, the evidence has shown that the industry consists of a relatively small number of companies running high technology operations where there is a strong need for a systematic approach to the management of safety. In any event its introduction offshore could have ultimate benefits for the onshore safety regime. The statutory assessment of the management of safety by the use of SMS offshore parallels the work of the APAU which is undertaken by agreement with employers onshore. In the light of evidence as to what operators are already accustomed to do in the UKCS and the NCS I am confident that operators will be able to adapt to this change in the regime. As regards the regulatory body, these and other changes will call for expertise and resources well beyond those presently enjoyed by the DEn.

The allocation of responsibilities under the regime

21.62 I am entirely satisfied that I should endorse the view which the Burgoyne Committee expressed that there should be a single regulatory body. (cf para 17.71.) While even within a single body there are inevitably separations due to differences in expertise and function there are clearly advantages in the co-ordination of the work of regulation. This is particularly important for the future in which a greater burden will be placed on the expertise, judgement and resources of the regulator, upon which his confidence and that of the industry will rely.

21.63 It is clear to me that, given the introduction of a requirement for a Safety Case, and the associated requirements for operators to demonstrate their SMS and audit compliance with it, the need for certifying authorities to continue to perform the same functions as before should be re-appraised. A number of parties to the Inquiry submitted on the basis of the introduction of FSA or 'internal control' that the present role of the certifying authorities should be brought to an end. For example UKOOA supported the submission that the certificate of fitness should in future be granted by the regulatory body on the basis of a survey and report by one of the existing certifying authorities or any other satisfactory body, subject to the inclusion of the operators themselves. The Contractors' Interest on the other hand submitted that certifying authorities should continue to be responsible for examination of 'hardware'; whereas the assessment of management systems should be the responsibility of the regulatory body.

21.64 Having considered those submissions in the light of the evidence I have come to the conclusion that it would be going too far and too fast for me to recommend particular changes in this area. I consider that it is not advisable or practicable for me to make a re-appraisal. This is a matter which should be carried out by the regulatory body. The other changes in the regime which I am recommending are in themselves major and will require a substantial amount of time and resources to plan, organise and implement. Their exact formulation is beyond the scope of a public inquiry. At present it is impossible to foresee all the considerations which may be of relevance and importance at these future stages. In these circumstances I consider that my best course is to recommend that the regulatory body should consider (i) after the introduction of requirements for demonstration of SMS and auditing of compliance with it; and (ii) after experience in the operation and effectiveness of such requirements whether and to what extent it will be appropriate to retain the present system of certification.

21.65 It remains for me to consider the position of the DoT. As will be seen from Chapter 19 I am strongly of the view that an integrated approach should be taken to fire protection so that both active and passive are considered together. To some extent this will be achieved through the Safety Case. I have, however, recommended that new regulations and guidance notes should promote such an integrated approach. In these circumstances it will be even more inappropriate than it is at present that different bodies should be concerned with separate consideration of active and passive fire protection. The ideal solution would be if these matters were considered wholly by the single regulatory body itself. This is of course complicated by the existence of the certification system. However as a first step I would advise that the regulatory body should assume direct responsibility for the functions which are presently discharged by the DoT. Further, I cannot see any sound reason for not adopting the same approach in regard to life-saving appliances.

21.66 As I am strongly in favour of a single regulatory body I consider that that body should discharge the regulatory functions in regard to standby vessels whether directly or through the agency of the DoT, save those which relate to the statutory responsibility of the DoT under the Merchant Shipping Acts.

Regulations and guidance

21.67 I am entirely satisfied that the principal regulations in regard to offshore safety should take the form of requiring that stated objectives are to be met rather than prescribing that detailed measures are to be taken. In relation to such regulations guidance notes should give non-mandatory advice on one or more methods of achieving such objectives without prescribing any particular method as a minimum or as the measure to be taken in default of an acceptable alternative. On these points I endorse the recommendations of the Burgoyne Committee at 6.15 and 6.17. However, I accept that there will be a continuing need for some regulations which prescribe detailed measures.

21.68 In connection with the proper development of offshore regulations it is in my view appropriate and necessary that the parts of the MWA and PSPA which have the same general purposes as those of Part 1 of the HSWA and any regulations made under those provisions should be made relevant statutory provisions for the purposes of the HSWA. The exact identification of the provisions in question is a matter which should be left to the regulatory body.

21.69 The replacement of the present sets of regulations with goal-setting regulations will obviously take some considerable time to execute. The regulatory body will have to decide what place this should occupy in the order of priorities, having regard to other major changes. There is clearly room for rationalisation of regulations, particularly having regard to the shape of the future regime. With those considerations in mind I consider that an appropriate form of replacement for the Construction and Survey Regulations, the Fire Fighting Equipment Regulations, the Life-saving Appliances Regulations and the Emergency Procedures Regulations would be:-

(i) Construction Regulations, covering *inter alia* the structure and layout of the installation and its accommodation.

(ii) Plant and Equipment Regulations, covering *inter alia* plant and equipment on the installation and in particular those handling hydrocarbons.

(iii) Fire and Explosion Protection Regulations, covering *inter alia* both active and passive fire protection and explosion protection, and

(iv) Evacuation, Escape and Rescue Regulations, covering *inter alia* emergency procedures, life-saving appliances, evacuation, escape and rescue.

The text of Chapters 19 and 20 provides a number of examples of regulations which it would be appropriate to incorporate in these sets of regulations.

21.70 Operators should be encouraged to specify standards to be used by the company with a view to demonstrating compliance with goal-setting regulations. Thus in the case of a given installation operators may demonstrate compliance by reference to such standards, the terms of guidance notes and what is shown by a safety assessment or a combination of one or more of such methods.

21.71 As regards existing guidance notes the regulatory body should consider whether and to what extent they should be treated without replacement or modification as giving non-mandatory advice in the sense set out in para 21.67; and should inform the industry accordingly.

21.72 In the light of representations made at the Inquiry by the contractors' interests I would also advise that in connection with the preparation of guidance notes the regulatory body should review the procedures for consultation so as to ensure that the views of representatives of employers and employees involved in work offshore are adequately taken into account.

Involvement of the workforce

21.73 In para 18.48 I referred to the involvement of the workforce as an important means of developing and maintaining an attitude to safety which is conducive to the prevention of accidents which may have harmful consequences. In para 21.56 I indicated that the operators' SMS, which is directed to demonstrating how safety is to be achieved, should include the way in which the total workforce is involved to that end.

21.74 Under the present regime, both onshore and offshore, specific requirements have been laid down for the appointment and functions of safety representatives of the workforce. At the Inquiry there was a clear controversy, which I will deal with below, as to the form which the requirements in the offshore safety regime should take. However, the need for such requirements, whatever form they take, would not, in my view, be affected by the implementation of the recommendations which I have made so far in this report. The representation of the workforce in regard to safety matters is important not merely for what it achieves on installations but also for the effect which it has on the morale of the workforce - in showing that their views are taken into account and that they are making a worthwhile contribution to their own safety. For this purpose it is clearly advisable to have statutory provisions which are well known, universally applied in similar circumstances and effective in operation.

Safety representatives and safety committees in the onshore safety regime

21.75 Under Sec 2 of the HSWA regulations may provide for the appointment by "recognised trade unions" of safety representatives whom the employer is bound to consult in regard to arrangements for co-operation in the promotion and development of measures to ensure health and safety at work and in the checking of the effectiveness of such measures. The employer may be required to establish a safety committee which has the function of keeping under review the measures taken to ensure the health and safety at work of his employees and such other functions as may be prescribed. So far as the onshore safety regime is concerned these provisions were implemented by the making of the Safety Representatives and Safety Committees Regulations 1977, which confer various functions on safety representatives including the making of investigations, inspections and representations. A "recognised trade union", which had the sole power to appoint safety representatives, meant an independent trade union which the employer concerned recognised for the purposes of negotiations relating to or connected with one or more of a number of specified matters - such as the terms and conditions of employment, or the physical conditions in which any workers are required to work; the allocation of work or the duties of employment as between workers or groups of workers; and facilities for officials of trade unions. Since 1977 there has been a growth in the extent to which trade unions have been "recognised". Mr Rimington said that safety representatives could play a valuable part in the promotion of safety and in relation to inspections. For those who were appointed safety representatives it was a very great strength that they were appointed by the unions. "The unions train them in quite a sophisticated way. They have the means of putting a great deal of power at the elbow of safety representatives where they care to do so." Where a union was weakly organised or not very strongly represented the usefulness of the safety representatives might be somewhat impaired.

Safety representatives and safety committees in the offshore safety regime

21.76 Although Sec 2 of the HSWA applied to the UKCS from 1977 the 1977 Regulations were not applied offshore. Diametrically opposed views were held by the trade unions and UKOOA. The latter objected to the offshore application of the 1977 Regulations on the ground that there were very few installations where there was a "recognised trade union". The Burgoyne Committee supported the view that on each installation there should be a safety committee which was representative of the workforce, including contractors' personnel, but did not consider it essential to embody this in regulations (6.50 and 5.97). However, 2 members of the committee, Mr R Lyons, then National Officer of ASTMS and Mr J Miller, then National Officer of the T & GWU dissented strongly on the latter point, urging that the 1977 Regulations be extended offshore forthwith.

21.77 In the event after years of discussion the DEn in 1987 were able to achieve a measure of general acceptance which led to the making of the Offshore Installations (Safety Representatives and Safety Committees) Regulations 1989. These were made under the provisions of the MWA and provide that the workforce is to be entitled to elect safety representatives and that where these have been elected a safety committee is to be established. This was clearly a step forward and an attempt to deal with a real problem. It still left as the bone of contention whether safety representatives should be appointed by trade unions, as was the case onshore.

The trade unions' evidence

21.78 The attitude of the trade unions on the matter of safety representatives was one of the principal subjects of the evidence given by Mr Lyons, since 1987 the Assistant General Secretary of ASTMS and latterly of MSF; Mr F Higgs, National Secretary of the Chemical, Oil and Rubber Group, T & GWU; and Mr A W T Cunningham, Occupational Health and Safety Officer, EETPU. Mr Lyons said that MSF had over 4000 paying members and represented in total about 6000 employees in North Sea activities. MSF members worked for both operators and contractors and performed a variety of jobs. According to the evidence of Mr Higgs T & GWU had about 3000 members offshore.

21.79 It was clear that the background to the evidence of these witnesses was a long-standing frustration as to the limited extent to which trade unions had been "recognised" offshore; whereas the unions had been recognised by many of the operating companies in relation to their operations onshore. As Mr Lyons put it: "There is a large trade union influence offshore. It has not got an adequate machinery through which it can be expressed." He complained that a memorandum of understanding as to the procedure for achieving recognition had not been adhered to or enforced. There were members of MSF on every platform in the North Sea, he thought; and there was a majority membership of MSF alone on quite a few of the platforms where no ballots as to recognition had been agreed. "In many of the platforms we have got 100% membership." The Inter-Union Off-shore Oil Committee (IUOOC) had been formed in order to eliminate inter-union disputes over representation offshore. On behalf of the IUOOC he had entered into a recognition agreement in 1978 with the Phillips Petroleum Company in regard to platforms in the Hewett field, the effect of which was that the 1977 Regulations should be treated as if they applied offshore. He said that this had led to an improvement in practices and an increase in confidence. It was hoped to extend that agreement to the Maureen field. MSF had also made many agreements with Shell on behalf of Shell Exxon which were supported by ballots of the workforce. MSF was the only trade union which held such agreements. However in each instance the agreement excluded health and safety. He claimed that there was no other country in the world in which there was a practice whereby a trade union which had been recognised by the employer was excluded from discussing health and safety.

21.80 Mr Lyons castigated the 1989 Regulations as contrary to the spirit of the HSWA. Without the offshore extension of the 1977 Regulations it was nonsense to say that the HSWA fully applied offshore. The 1977 Regulations had the advantage that safety representatives appointed by trade unions would have the back-up and facilities which a trade union is able to provide, including training and advice on health and safety issues. Unions held regular training schools at which a wide range of health and safety issues were discussed. These took place at regional, national and international levels. If a safety representative had difficulty in performing his or her function there was somebody for him or her to go to in order to get assistance. "For a safety representative to be effective he requires a supportive culture, structure, credibility, advice, training and recognition of the contribution that he can make on safety issues." For a number of years Shell had had a safety committee system which was similar to that provided for under the 1989 Regulations. However, despite the efforts of MSF the workforce were reluctant to stand or be represented. Where the trade union appointed the safety representatives "training and advice can be given openly without any 'fear factor' which unfortunately permeates the UK sector of the North Sea among the workforce. Workers do not want to put their continued employment in jeopardy through raising a safety issue that might be seen as embarrassing to management." As an example he said that contractors' employees suffer particularly from the "not-required-back" phenomenon. When asked whether a safety committee elected by the whole workforce might be seen to be more representative than one which was restricted to members of trade unions he said: "The quality of that committee bears no relationship to a trade union-based safety committee, and that is best borne out by looking at Shell onshore, where the committees do not cover all employees but are extremely positive in health and safety." The 1989 Regulations were perceived as favouring the operators. This was seen as part of the evidence of a conflict of interest which led to trade unions favouring the replacement of the DEn with the HSE as the regulatory body, as he and Mr Miller had also advocated in their dissent from the report of the Burgoyne Committee.

The submissions of UKOOA

21.81 UKOOA opposed the application offshore of the 1977 Regulations. It would have only a limited scope for operation in view of the limited extent to which there were "recognised trade unions". The 1989 Regulations were adequate. They did not prevent a trade union member becoming a safety representative and having trade union support. There was no suggestion that trade union members were more concerned than others with matters of safety. Where trade unions represented a minority of the workforce, if they were able to appoint the safety representatives they might effectively disenfranchise non-union members: or even union members who might wish to have a different representative.

Safety delegates in the Norwegian offshore safety regime

21.82 In this regime it appears that trade unions receive automatic recognition. The extent of union membership has grown over the years. The regime provides for the appointment of safety delegates upon whom a number of important powers are conferred, including the right to halt dangerous work. Mr Ognedal considered that union back-up could be beneficial to the work of safety delegates. However, they are elected by the whole workforce, rather than being appointed by the unions.

Observations

21.83 My remit does not extend to matters of industrial relations, whether or not the point at issue is a controversial one, as it is in the case of the offshore workforce. Accordingly I am not concerned with the merits of the recognition of trade unions offshore or with the means by which support for such recognition should be ascertained. I have to concern myself with the question of safety, and in doing so take account of the existing situation in the North Sea.

21.84 In the light of the evidence which I have heard, which admittedly came almost entirely from trade union witnesses, I am prepared to accept that the appointment of offshore safety representatives by trade unions could be of some benefit in making the work of safety representatives and safety committees effective, mainly through the credibility and resistance to pressures which trade union backing would provide.

21.85 However, the position offshore is complicated by a number of factors: trade union membership is still relatively limited in relation to the total offshore workforce; trade unions have been "recognised" only to a limited extent; and the employment of offshore workers is fragmented between a number of different employers, with a high proportion being employed by contractors. As matters stand it does not seem to me to be appropriate to replace the 1989 Regulations with the offshore extension of the 1977 Regulations. This would remove safety representatives from a very large part of the workforce and would undo the limited progress which was achieved in difficult circumstances by the making of the 1989 Regulations. Further those regulations have been in force for only a short period. Experience will show whether or not representatives elected under those regulations lack adequate credibility or resistance to pressures. In the meantime I consider that it would be inappropriate for me to recommend any change in the method by which safety representatives are chosen. I understand that the regulatory body intends to review the 1989 Regulations after 2 years' experience of their working. When carrying out that review the regulatory body may consider that there is room for improving the effectiveness of safety representatives; and putting the trade unions' contentions to the test for that purpose. For example, it may consider that it is appropriate to modify the existing scheme so as to require that safety representatives are appointed by trade unions in certain cases, such as where a trade union had achieved recognition in relation to a substantial aspect of labour relations and had a substantial membership on the installation in question.

21.86 For the present I am satisfied that it is appropriate that the type of protection provided in the case of trade union activities under Sec 58(1)(b) of the Employment Protection (Consolidation) Act 1978 should also be afforded to the activities of an employee as a safety representative. The Trade Union Group also submitted that intimidation and the breaking of a contract should become a criminal offence where it was directed against the raising or pursuing of a complaint relating to health and safety. As regards any wider measures I consider that the correct course in the first instance is to look to the safety representative as the channel through whom complaints in regard to health and safety should be expressed. I am also aware of the efforts which the Secretary of State for Energy and UKOOA have made in order to demonstrate that victimisation is not to be tolerated and that the reporting of incidents affecting safety is to be encouraged.

21.87 The Trade Union Group and other parties made a number of specific criticisms of the 1989 Regulations. Since these regulations have only recently been introduced I do not in general think that it is appropriate for me to recommend alterations. However, there is one exception to that. Reg 27 provides that it is to be the duty of the employer of a safety representative to ensure that he is provided with such training in aspects of the function of a safety representative as may be reasonable in all the circumstances and that the employer is to meet any reasonable costs associated with such training including travel and subsistence costs. In the light of the evidence I consider that the burden of providing the training and bearing its cost should fall not on the employer but on the operator of the installation where the safety representative serves. The operator has a knowledge and a responsibility for safety on an installation which is far wider than that of contractors working on it. In the case of smaller contractors who may have few personnel working on an installation they may, as Mr Lyons suggested, have great difficulty in providing training for any of their employees who may be elected as a safety representative. It is extremely important that the safety committee should include an adequate representation of contractors' employees.

Chapter 22

The Regulatory Body

Introduction

22.1 In this chapter I will give my views as to the body which should be the regulatory body for the future offshore safety regime.

22.2 This involves considering a question which was studied by the Burgoyne Committee who reached the conclusion that the DEn was capable of discharging the responsibility of a single government agency for offshore safety, provided that it was suitably strengthened and sought advice from other bodies on matters of common concern (6.6). Since 1980 this matter has not been reviewed. There have been important developments in regulatory techniques in both onshore and offshore regimes. There has been direct experience of the capabilities and approach of the DEn and the HSE. The industry is on the threshold of what on any view are major changes which have important implications for the qualities required of the regulatory body. In the light of these considerations and the evidence which I heard in Part 1 of the Inquiry I considered that it was appropriate that this question should be considered in Part 2.

22.3 It is right that I should emphasise at this point that the proper context for the question is the future offshore safety regime. Much of the evidence and submissions were concerned with what was said to be past failures or successes on the part of the DEn and the HSE. However, these are relevant only in so far as they throw light on the appropriate choice for the future. Further that choice should take into consideration the implications of change at this stage in the history of the offshore safety regime.

The reasons for the conclusions of the Burgoyne Committee

22.4 It is clear that the committee attached significance to the differences between the offshore industry and the rest of industry in the United Kingdom, particularly in respect of the differences in environment and the remoteness of operation. There was need for special treatment which called for "flexibility of approach, speed of reaction and individual treatment of each case" in dealing with the problems of the offshore industry. They said that speed of response and flexibility of approach were more likely from an organisation with only one industry whose safety matters were its concern (4.16-18). General satisfaction had been expressed with the way in which the PED had approached its task. This was attributed to the selection of well qualified and experienced personnel. The DEn (and its predecessors) had grown up with the offshore industry and was in the best position to understand it and its problems (4.13-15).

22.5 On the other hand there had been criticism of the HSE's involvement in offshore safety, apparently due to its "lack of expertise" in certain areas such as deep diving, petroleum engineering and structural engineering in a marine environment. The assimilation of the offshore inspectorate into the HSE would take some time to be achieved (4.13-14). An organisation with responsibility for the majority of industrial safety would tend to show greater rigidity and a slower response (4.18).

22.6 On the footing that the DEn was the chosen agency "it is unthinkable that DEn would ignore advice on general trends and practices onshore in formulating offshore safety policy" (4.11).

22.7 As noted earlier two members of the committee, Mr Lyons and Mr Miller, dissented, essentially on the ground that a government department which was substantially responsible for the direction and control of an industry should not in any way be responsible for the standards and enforcement of occupational health and safety in that industry.

The alternatives

22.8 I am in no doubt that as matters stand the choice lies between the DEn on the one hand and the HSE on the other, on the basis that in either case the body is suitably strengthened for the task ahead. I heard detailed closing submissions in regard to that choice. The Trade Union Group and the Piper Disaster Group submitted that the HSE should replace the DEn as the regulatory body. UKOOA made submissions as to the qualities which should be possessed by the regulatory body. It "should be a single authority which has appropriate competence and expertise". However UKOOA were neutral as to which body I should recommend. It may be noted that at the time of the Burgoyne Committee UKOOA supported the DEn as the regulatory body. The Contractors' Interests favoured the retention of the *status quo*. The DEn did not itself enter into this controversy but their counsel assisted me greatly by acting as *amicus curiae* at my request and set out full arguments against the proposal for replacement of the DEn by the HSE.

22.9 In what follows I will set out what I have derived from the evidence as to the nature and capabilities of each body; and as to the way in which each has approached the development and enforcement of regulatory control.

The Department of Energy

22.10 The DEn is in the position, which the Burgoyne Committeee considered to be of some significance, of being able to concentrate on the offshore industry which, has many special features. As one would expect the department has acquired a great deal of knowledge of the industry. It is regularly in contact with bodies which represent operators, contractors and the workforce. These bodies are consulted in regard to proposed legislation and participate in the discussion of future guidance and research.

22.11 On the other hand the comparatively small size of the Safety Directorate means that the prospects for promotion of its personnel are limited. This may well be a factor which has tended to affect recruitment and retention of personnel. It is clear from the evidence to which I have referred in Chapters 15 and 21 that in a number of areas the work of the Safety Directorate has been hampered by persistent under-manning. The problem does not seem to be due, at least in recent times, to a shortage of financial resources but to a difficulty in recruiting. Although I have noted the initiatives which are being taken, it seems unlikely that this chronic problem will be readily solved.

22.12 The comparatively small size of the Safety Directorate appears also to have been a factor restricting the scope of the in-house expertise which it could employ, with the result that it placed more reliance on the work of consultants and other bodies such as the HSE than it would have done if it were part of a larger body with greater shared resources. At the same time I should say that it was brought out clearly in evidence that the HSE is always ready to provide assistance to the Safety Directorate. The limitations on the Safety Directorate's own expertise have a practical significance, and particularly for the future. Three points may be mentioned. Firstly, I accept Mr Ferrow's comment that the inspectorate "do not seem to have such direct and straightforward access to all the areas of expertise that they might want". Secondly, these limitations are likely to affect the ability of the regulatory body to give prompt and authoritative responses. The Directorate appears to be short of in-house expertise in fire and explosion protection. I noted that Mr Brandie suggested that the apparent reluctance of the DEn to support a scenario-based approach to the design of fire protection stemmed from a shortage of expertise to assess such design. If goal-setting regulations are to be brought into existence there would require to be an entirely different level of expertise from the present. Thirdly, the present intention of the Safety Directorate is to rely on certifying authorities for the assessment of the hardware aspects of FSA; and as regards the assessment of management the directorate is clearly short of the required expertise (see para 21.22).

22.13 It was strongly represented by trade union witnesses, in line with the dissent from the report of the Burgoyne Committee, that the Safety Directorate lacked, or at any rate was perceived to lack, independence. Put another way, it was suggested that there was a conflict of interest between the objectives of the Safety Directorate on the one hand and the objectives of other parts of the DEn on the other. However, it was pointed out in response that in Norway a single body, the NPD, is in control of both exploitation of resources and of safety; although it was responsible to different Ministries in regard to those functions. It was also pointed out that in the case of the United Kingdom the PED had two reporting lines. One was to the Secretary of State for Energy, who was in turn responsible to Parliament. There is a clear Ministerial commitment to safety and the Safety Directorate exercise direct access to Ministers as occasion arises. The other was to the HSC, in accordance with the arrangements set up by the Government in the light of the views of the members of the Burgoyne Committee.

The DEn's approach to the development of regulatory control

22.14 I have already discussed in Chapter 21 the DEn's lack of progress on goal-setting regulations, the unduly restrictive nature of existing regulations and guidance notes and the restricted use of the HSWA for regulations (summarised at para 21.51). This does not show the "speed of response and flexibility of approach" which the Burgoyne Committee considered that the DEn were more likely to exhibit.

22.15 At para 17.22 I commented that prior to the disaster the DEn does not appear to have addressed the major hazards presented by hydrocarbon inventories. This is further illustrated by the history of its attitude to the CIMAH Regulations and the introduction of FSA. In October 1983 the HSE asked the DEn whether the requirements of the proposed CIMAH Regulations for the provision of a Safety Case and emergency plans would be appropriate for offshore situations. In reply Mr Petrie, as Head of Operations and Safety, in a letter dated 24 November 1983 stated that it was considered that existing legislation under the MWA already covered the proposed requirements. He went on: "Furthermore this department has policy initiation responsibility for all offshore oil and gas safety matters and advises the HSC on such policy matters. It is our intention to advise the HSC against any extension of onshore major hazard legislation to offshore installations, where the legal and practical provisions are considered satisfactory and are already far in advance of these contemplated by HSE." This was at a time when the Burgoyne Committee had already recommended that the DEn should encourage a systematic approach to safety assessments of structures and plant during design and construction, with the purpose of establishing agreed procedures (6.27); and when in the NCS risk evaluation on a quantitative basis was already required.

22.16 Questioned as to what was "already far in advance" Mr Petrie said that these words had been justified by the existence since 1975 of the Construction and Survey Regulations. He said that although certifying authorities did not deal with safety assessment as such they dealt with design and construction in accordance with codes. He also referred to a number of miscellaneous requirements of other offshore regulations, and said: "We know what the hazard is only too well with significant amounts of hydrocarbons offshore, so that, together with many other regulations that apply offshore, we broadly felt that the objective of the regulation was already in place, including the general requirement, under the general aegis of the HSWA, for employers to ensure that they have a safe place of work." However, in my view, the problem of major hazards is not one which can be dealt with simply by following codes; and the miscellaneous requirements were not components of a system which was intended to be able to handle such hazards. Mr Petrie did not appear to have realised from the CIMAH Regulations that the preparation of a Safety Case was valuable in imposing a discipline on manufacturers to show that they had identified the major hazards and created appropriate controls, although this was part of the background to the regulations and is explicitly set out in the guidance notes which relate to them. He did not appear to be certain whether it had been realised that management systems were an important element in the CIMAH Safety Case. He admitted that he had not kept up with the development of the Safety Case under the CIMAH Regulations.

22.17 The proposition that the offshore provisions were "far in advance" is at odds with the DEn's discussion document on FSA, work on which began in 1987. This stated, *inter alia*: "For some time the Safety Directorate has been concerned that reliance on good engineering practice, the application of approved standards and the certification and inspection regimes do not of themselves comprehensively identify and highlight the hazards and sequences of events that can lead to a major accident."; and referred to FSA as embracing "the whole spectrum of safety analysis techniques that can be brought together in a structured framework to make a major step forward in enhancing the overall safety of offshore installations." As I have already observed at para 17.26, the document makes no reference to the CIMAH Regulations.

22.18 The evidence demonstrates, in my view, a serious failure on the part of the DEn to address the regulatory requirements for dealing with the major hazards, whether they arose from collisions or from a failure in pressure systems or in some other way. The result, as I said in para 21.54, has been to set back the development of the offshore safety regime by many years. The DEn's attitude appears to have been based in part on a failure to realise that the existing offshore provisions were not enough; and in part on a failure to understand the CIMAH Regulations and the Safety Case - a failure which, at least in the case of Mr Petrie, persisted throughout his evidence.

22.19 In about 1985 the DEn advised against the offshore application of the COSHH Regulations on the basis that the provisions of the Operational Safety, Health and Welfare Regulations were adequate. The COSHH Regulations represented a major change onshore, described by Mr Rimington as the most important reform for 13 years. Their basic aim was to ensure that where employees might be exposed to toxic substances there should be formal procedures to ensure that their exposure was minimised and was in any case kept below the maximum exposure level. Mr Petrie said that probably the main offshore provision which was relevant was Reg 4 of the Operational Safety, Health and Welfare Regulations, but it is clear that there is no true similarity between them. There was no evidence that the COSHH Regulations were unsuitable for offshore application; and indeed Mr McKee gave evidence that Conoco (UK) Ltd had unilaterally applied them to their installations.

22.20 The approach of the DEn seemed to me to tend towards over-conservatism, insularity and a lack of ability to look at the regime and themselves in a critical way. From this certain practical results have followed; the introduction of improvements in safety has been hampered; and the development of legislation on the basis of the HSWA has been kept back.

22.21 It does not appear to be perceived by the DEn that a radical change of approach is already due. Nothing appears to have been learnt from the experience of the NPD with which the DEn were in regular contact. Despite arrangements which should have enabled the DEn to obtain a wider view of modern approaches to the regulation of industrial safety, such as their relationship with the HSC, their work on the OIAC and their opportunities for exchange of ideas and personnel with the HSE, the offshore approach to the management of safety seems to me to be a number of years behind the approach onshore.

The DEn's approach to enforcement of regulatory control

22.22 I have already commented in Chapters 15 and 21 on the type of inspection practised by the DEn; and the absence of any systematic approach to the scrutiny of systems for the management of safety. Their approach appeared to me to be at least in origin mainly reactive; moves towards a more pro-active approach appear to have been slow and tentative. Here again my remarks in para 22.21 apply.

The Health and Safety Executive

22.23 The HSE encompasses responsibility in regard to both general and specialised industry onshore. It represents the principal source of safety expertise in the United Kingdom. While it employs consultants in many areas it clearly regards in-house expertise as essential. This expertise includes the fields of major hazards, safety assessment and the assessment of management systems. Mr Ferrow described the HSE as being "a fairly comprehensive and diverse organisation that allows individual inspectors in the field relatively quickly to get very expert advice on almost any matter you can think of".

22.24 The HSE has, of course, no current expertise or experience in regard to offshore installations. However, while the environment and remoteness of offshore installations are unlike anything onshore, the nature of the operations carried on offshore are no more complex than what may be encountered onshore. Further, as I have already indicated in Chapter 17 I see no reason why the onshore approach to major hazards and safety assessment should not, *mutatis mutandis*, be capable of extension to the offshore. In passing I should note that Mr Rimington, when asked to comment on the HSE's "lack of expertise" (see para 22.5), pointed out that the HSE had had no involvement with offshore engineering and would not have questioned the expertise of the DEn in regard to deep diving.

22.25 The HSE has not been without difficulties in achieving adequate recruitment. In regard to specialist inspectors Mr Rimington said that following the Chernobyl disaster there had to be a substantial pay rise in order to recruit additional nuclear inspectors. There was a current difficulty in retaining specialist inspectors in the Technology Division but the HSE was acting on advice which had been obtained in order to deal with this. A result of the HSE being the principal source of expertise was the 'poaching' of experts by industry. He was heartened by the fact that for 3 successive years the Government had given the HSC their full bid for financial provision.

22.26 It is clear that the HSE has always encouraged upward mobility among its personnel. It has recently elaborated a strategy for the development of careers in its organisation. This has also benefited recruitment and the retention of personnel. Mr Rimington said that inspectors were transferred into the specialist inspectorate from other parts of the HSE if they were suitably qualified. "So certainly we have transferred people, and more particularly ideas, from one part of the executive to another."

22.27 Mr Rimington said that the HSE's 'clout' with industry was in part due to its independence and in part to the fact that both sides of industry were represented on the HSC and in the working groups with which the HSE was closely involved.

The HSE's approach to the development of regulatory control

22.28 As I have stated in para 16.36 the HSE has made substantial progress with the modernisation of existing onshore legislation relating to health and safety. Progress has necessarily been slow owing to the need to formulate a new style of regulations for industry at large or for cases in which a special regime was required; and owing to the need to carry out consultation with a view to arriving at a consensus. Latterly the speed of development of legislation has been increased. HSE has plainly built up a strong body of knowledge and experience in the formulation of legislation which fulfils the policy of the HSWA and make major advances in techniques for the regulation of safety.

The HSE's approach to enforcement of regulatory control

22.29 While one of the ways in which the HSE seeks to enforce a regulatory control is by inspection there appear to me to be significant differences in its approach to inspection compared with that of the DEn. It will be recalled that in para 16.37 I referred to the evidence of Mr Rimington that "an inspector's immediate purpose in visiting is to satisfy her or himself that systems exist that are likely to lead to the identification and prevention by management of significant faults and that the attitude of management is conducive to this." At para 21.24 I referred to the HSE's insistence on evidence of the monitoring of safety. This demonstrated a greater attention to the systems by which accidents can be prevented and mitigated. This effort is supported by the work of the APAU (see paras 16.39 and 21.61).

22.30 It was also clear from the evidence that the HSE have given a higher profile to the subject of safety both with the public and with industry. Plans and details of performance are published. Mr Rimington said: "If safety is cost effective, then in my view a high profile for it is cost effective."

Implications of change

22.31 In regard to the HSE, in view of its lack of existing expertise and experience in the offshore industry Mr Rimington was circumspect when commenting on the proposition that the HSE should become the regulatory body offshore - a change which had not been sought either by that body or the HSC. He emphasised the distinctive culture of the offshore industry and the importance that the regulated had confidence in the regulator. Such a change would call for flexibility and understanding on both sides. He pointed out the difficulties involved in organisational distribution and the care which would require to be taken to make sure that changes in the legislation occurred at no greater speed than they could be adapted to. On the other hand I am satisfied that there is no incompatibility between the offshore safety regime and the principles on which the onshore safety regime is presently organised. This includes the certification system which has no exact counterpart onshore. Further I have no doubt that the HSE has the necessary basic expertise for assuming responsibility offshore, although it is obvious that the HSE could not be expected to proceed without the assistance of PED inspectors and their accumulated knowledge and experience of the offshore industry. I should also point out that, as between these two bodies, I consider that the HSE would have the capacity to cope with the major management workload involved in the assumption of responsibility for offshore safety along with the other major changes which I have recommended for the future regime.

22.32 The transfer of responsibility to the HSE would bring to an end the agency agreement the operation of which has, in my view, a number of features which are not entirely satisfactory. Under that agreement the HSC as principal has no say in the quality or efficiency of the work of the DEn in regard to matters which fall within that agreement. In para 21.49 I pointed out Mr Rimington's comments on the difficulty of determining how far the HSC or the HSE were entitled to form judgements of PED's effectiveness. Finally this should assist in bringing to an end the tension between the MWA and the HSWA in the offshore safety regime.

22.33 In regard to the PED Mr Priddle pointed out that the transfer of responsibility from the PED to the HSE seemed likely to include some constraint on the free flow of information and some duplication of resources as between the Safety Directorate and other petroleum specialists in the PED. He thought that there would be some loss of career development opportunities and management flexibility.

Conclusion

22.34 I have considered carefully the factors which I have attempted to set out in the preceding paragraphs. I have come to the conclusion that the balance of advantage in the interests of the future offshore safety regime lies in favour of the transfer of responsibilities from the PED to the HSE. The decisive considerations in my mind arise from considering the differences in approach between these two bodies to the development and enforcement of regulatory control. These differences have been plain for some years and flow from differences in the way in which the bodies are directed and managed. I am confident that the major changes which I have recommended are ones which are in line with the philosophy which the HSE has followed. This alternative is clearly preferable to the PED even if it was given a higher level of manning with greater in-house expertise. I also attach importance to the benefits of integrating the work of the offshore safety regulator with the specialist functions of the HSE.

22.35 I am conscious that the change which I have recommended will take some time to implement and will inevitably involve disruption. Successful implementation will call for co-operation, flexibility and understanding at all levels between the industry and the existing and future regulatory bodies. Special treatment will be required in regard to certain functions which are presently discharged by the Safety Directorate. These include the planning, as distinct from the safety, functions in regard to offshore pipelines; and the function of administering well consents. It is appropriate that these functions should be retained by the DEn.

22.36 As regards the flow of information between specialists in the PED, I noted earlier that the Safety Directorate is consulted about and can express reservations on safety grounds in regard to important stages in the licensing process (see para 16.18). It is clear that in order to do this effectively they must be involved in and aware of the discussions between specialists in the EADU and operators in regard to both exploration and development. It is of major importance, in my view, that such links between the EADU and the regulatory body for safety be maintained in the transfer of responsibility for safety to the HSE.

22.37 While offshore safety stands to benefit by responsibility being transferred to the HSE it is important that the distinctive character and requirements of the offshore industry should be recognised in the administrative arrangements within the HSE. For this reason it is also my view that responsibility for offshore safety should be discharged by a discrete division of the HSE which is exclusively devoted to offshore safety and is able to respond promptly and authoritatively to its special needs. This division should employ a specialist inspectorate and should have a clear identity and strong influence in the HSE. It should be headed by a chief executive who should be responsible directly to the Director General of the HSE and should be a member of its senior management board. His function would include the development of the offshore safety regime, and in particular the implementation of its provisions for Safety Cases and SMS. The need for adequate resources in order to meet these changes is obvious.

22.38 In these circumstances there is little which I require to say in regard to the complaint that the Safety Directorate is not independent or perceived to be independent and accordingly is not well fitted to carry out the functions of the regulatory body in regard to safety matters. On the evidence I was not convinced that the Safety Directorate actually lacks independence or that its actions had been affected by considerations related to the exploitation of resources. On the other hand there is a perception, at least among some trade unionists, that it lacks independence. This is an unfortunate feature of the present scene. However, if my recommendations in this chapter are followed it will no longer be a live issue.

Chapter 23

Recommendations

In this chapter I will set out my recommendations in the light of the matters discussed in Chapters 17-22. Each recommendation is followed by reference to the paragraph in the earlier chapter to which it is directly related. The recommendations are arranged according to the following subjects:-

Subject	*Recommendations*
Safety Case	1-13
Auditing of the operator's management of safety	14-15
Independent assessment and surveys of installations	16
Legislation - General	17-22
The regulatory body	23-26
Safety committees and safety representatives	27-31
Permits to work	32-38
Incident reporting	39
Control of the process	40-42
Hydrocarbon inventory, risers and pipelines	43-46
Fire and gas detection and emergency shutdown	47-48
Fire and explosion protection	49-54
Accommodation, TSR, escape routes and embarkation points	55-61
Emergency centres and systems	62-70
Pipeline emergency procedures	71-72
Evacuation, escape and rescue - General	73-76
Helicopters	77
TEMPSC	78-81
Means of escape to the sea	82-84
Personal survival and escape equipment	85-87
Standby vessels	88-96
Command in emergencies	97-99
Drills, exercises and precautionary musters and evacuations	100-104
Training for emergencies	105-106

Safety Case

1. The operator should be required by regulation to submit to the regulatory body a Safety Case in respect of each of its installations. The regulation should be analogous to Reg 7 of the CIMAH Regulations, subject to recommendations 2–13 (paras 17.33-43).

2. The Safety Case should demonstrate that certain objectives have been met, including the following:-

(i) that the safety management system of the company (SMS) and that of the installation are adequate to ensure that (a) the design and (b) the operation of the installation and its equipment are safe (paras 17.36 and 21.56-57);

(ii) that the potential major hazards of the installation and the risks to personnel thereon have been identified and appropriate controls provided (para 17.37); and

(iii) that adequate provision is made for ensuring, in the event of a major emergency affecting the installation (a) a Temporary Safe Refuge (TSR) for personnel on the installation; and (b) their safe and full evacuation, escape and rescue (paras 17.37-38, 19.109, 19.157 and 20.8).

3. The SMS should be in respect of (a) the design (both conceptual and detailed) of the operator's installations; and (b) the procedures (both operational and emergency) of those installations. In the case of existing installations the SMS in respect of design should be directed to its review and upgrading so far as that is reasonably practicable (para 21.56).

The SMS should set out the safety objectives, the system by which these objectives are to be achieved, the performance standards which are to be met and the means by which adherence to these standards is to be monitored (para 21.56).

It should draw on quality assurance principles similar to those stated in BS 5750 and ISO 9000 (para 21.58).

4. In furtherance of the objectives set out in para 2 above, the operator should be required to set out the following in the Safety Case:-

(i) A demonstration that so far as is reasonably practicable hazards arising from the inventory of hydrocarbons

(a) on the installation, and

(b) in risers and pipelines connected to the installation both in themselves and as components of the total system of which they form part

have been minimised (paras 19.17 and 19.20).

(ii) A demonstration that so far as is reasonably practicable the exposure of personnel on the platform to accidental events and their consequences has been minimised (para 17.37).

(iii) A demonstration by quantified risk assessment of major hazards that the acceptance standards have been met in respect of risk to the integrity of the TSR, escape routes, embarkation points and lifeboats from design accidental events and that all reasonably practicable steps have been taken to ensure the safety of persons in the TSR and using escape routes and embarkation points (paras 17.38 and 19.157).

(iv) A demonstration that within the TSR there are facilities as specified by the operator which are adequate for the purpose of control of an emergency (para 19.182).

(v) A fire risk analysis, in accordance with recommendation 49 below (para 19.90).

(vi) An evacuation, escape and rescue analysis, in accordance with recommendations 73-75 below (para 20.9).

5. For the purposes of the demonstration referred to in para (iii) of recommendation 4, the accidental events are to be identified by the operator. A design accidental event is an event which will not cause the loss of any of the following:-

- the integrity of the TSR,
- the passability of at least one escape route from each location on the platform,
- the integrity of a minimum complement of embarkation points and lifeboats specified for personnel in the TSR, and
- the passability of at least one escape route to each of these embarkation points,

within the endurance period specified. Events more severe than this are referred to as residual accidental events (para 19.160).

The acceptance standards for risk and endurance time should be set before the submission of the Safety Case. Standards should be set by reference to the ALARP principle. For the time being it should be the regulatory body which sets these standards. The operator should define the conditions which constitute loss of integrity of, and the standards of protection for, the TSR and escape routes to the TSR and from the TSR to the embarkation points; and should specify the minimum complement of embarkation points and lifeboats for the TSR (paras 19.158-159).

6. The TSR should normally be the accommodation (paras 19.156 and 19.161).

In the case of existing installations any requirement for the upgrading of the accommodation, escape routes and embarkation points should be determined on the basis of the Safety Case (para 19.165).

7. In connection with the above the Safety Case should specify the following:-

In respect of the TSR-

- — its function
- — the conditions which constitute its integrity
- — the conditions for integrity of its supporting structure
- — the events in which and the period for which it is to maintain its integrity (paras 19.157-158).

In respect of escape routes to the TSR and from the TSR to the embarkation points-

- — the conditions which constitute their passability
- — the conditions for integrity of their supporting structure
- — the events in which and the periods for which they are to maintain their passability (*provided* that for each location on the platform there should be a minimum of two escape routes to the TSR, at least one of which should remain passable for the period) (para 19.164).

In respect of embarkation points and lifeboats-

- — the number and location
- — the conditions for their integrity and that of their supporting structure
- — the events in which and the periods for which they are to maintain their integrity
- — the minimum complement for the TSR (para 19.164).

8. No fixed installation should be established or maintained in controlled waters; and no mobile installation should be brought into those waters with a view to its being stationed there or maintained in those waters unless a Safety Case in respect of that installation has been submitted to and accepted by the regulatory body (para 17.41).

9. As regards existing installations the date for submission of the Safety Case should be laid down by regulation. There is an urgent need for the submission of Safety Cases, but the date should be selected by the regulatory body. The regulatory body should have the power, in the event of the failure of an operator to submit an acceptable Safety Case, to require the operator to take whatever remedial action it considered necessary, including requiring the installation to be shut down (paras 17.44-45).

10. A Safety Case should be updated:-

(i) After a period of years from its last assessment (not less than 3, not more than 5, years).

(ii) At the discretion of the regulatory body on the ground of a material change of circumstances, such as a change of operator, the occurrence of a major emergency (including one in which there is a precautionary evacuation), a major technological innovation or the discovery or better understanding of a major hazard.

However, provision should be made in order to avoid the need for more than one Safety Case to be updated by an operator at the same time; and to enable the regulatory body to postpone the automatic updating where it has recently required a discretionary updating (para 17.46).

11. As regards modifications to installations or their equipment or procedures, the operator should, before putting the modification into effect, ascertain what effect, if any, it has on the relevant components of the Safety Case. An operator should be required to report to the regulatory body all intended modifications which meet criteria set by the regulatory body, with a view to discussing with the regulatory body whether and to what extent a review of the Safety Case is required (para 17.47).

12. For the time being the acceptance by the regulatory body of Safety Cases should not be regarded as justifying the revocation of regulations or the withdrawal of guidance notes (para 17.67).

Where an operator proposes to meet the objectives of a Safety Case by means which are not in accordance with regulations or guidance notes the justification for such a course should be set out in the Safety Case. For the assistance of operators the regulatory body should publish as soon as possible, and thereafter update in the light of experience, a list of the individual regulations relating to an installation and its equipment in respect of which it is prepared to grant exemption in the light of a satisfactory demonstration in a Safety Case; and to do likewise in regard to guidance notes (para 17.67).

In due course the existing regulations of a detailed prescriptive nature should be reviewed with a view to their revocation or replacement by regulations which set objectives. However, it is anticipated that there will continue to be even in the long term a case for some detailed prescriptive regulations (paras 17.63, 17.67 and 21.67).

13. The regulatory body should discuss with the industry whether it is desirable and practicable that at the stage of the application for Annex B consent (or its equivalent) there should be a procedure for submission by operators of a preliminary assessment of matters relevant to a Safety Case and for the acceptance of this assessment being a prerequisite for the granting of Annex B consent (para 17.43).

Auditing of the operator's management of safety

14. The operator should be required to satisfy itself by means of regular audits that its SMS is being adhered to (para 21.60).

15. The regulatory body should be required regularly to review the operator's audit on a selective basis; and itself to carry out such further audit as it thinks fit; and by regular inspection verify that the output of the SMS is satisfactory (para 21.60).

Independent assessment and surveys of installations

16. The regulatory body should consider (i) after the introduction of requirements for the demonstration of SMS and auditing of compliance with it; and (ii) after experience in the operation and effectiveness of such requirements whether and to what extent it will be appropriate to retain the present system of certification (para 21.64).

Legislation - General

17. (i) The principal regulations in regard to offshore safety should take the form of requiring that stated objectives are to be met (referred to as "goal-setting

regulations") rather than prescribing that detailed measures are to be taken (para 21.67).

(ii) In relation to goal-setting regulations, guidance notes should give non-mandatory advice on one or more methods of achieving such objectives without prescribing any particular method as a minimum or as the measure to be taken in default of an acceptable alternative (para 21.67).

(iii) However, there will be a continuing need for some regulations which prescribe detailed measures (para 21.67).

18. The provisions of the Mineral Workings (Offshore Installations) Act 1971 and the Petroleum and Submarine Pipe-lines Act 1975 which have the same general purposes as those of Part 1 of the Health and Safety at Work etc Act 1974 (HSWA), and the regulations made under such provisions, should be made relevant statutory provisions for the purposes of the HSWA (para 21.68).

19. The Construction and Survey Regulations, the Fire Fighting Equipment Regulations, the Life-Saving Appliances Regulations and the Emergency Procedures Regulations should be revoked and replaced by-

(i) Construction Regulations, covering *inter alia* the structure and layout of the installation and its accommodation.

(ii) Plant and Equipment Regulations, covering *inter alia* plant and equipment on the installation and in particular those handling hydrocarbons.

(iii) Fire and Explosion Protection Regulations, covering *inter alia* both active and passive fire protection and explosion protection, and

(iv) Evacuation, Escape and Rescue Regulations, covering *inter alia* emergency procedures, life-saving appliances, evacuation, escape and rescue.

Each of the above sets of regulations should include goal-setting regulations as their main or primary provisions and should be supported by guidance notes giving advice which is non-mandatory in the sense set out in paragraph (ii) of recommendation 17 (para 21.69).

20. Operators should be encouraged to specify the standards which they will use to comply with goal-setting regulations. For a given installation compliance may be demonstrated by reference to such standards, the terms of guidance notes and what is shown by a safety assessment or a combination of one or more of such methods (paras 17.66 and 21.70).

21. As regards existing guidance notes the regulatory body should consider whether and to what extent they should be treated without replacement or modification as giving non-mandatory advice in the sense set out in paragraph (ii) of recommendation 17; and should inform the industry accordingly (para 21.71).

22. In connection with the preparation of guidance notes the regulatory body should review the procedures for consultation so as to ensure that the views of the representatives of employers and employees involved in work offshore are adequately taken into account (para 21.72).

The regulatory body

23. There should be a single regulatory body for offshore safety (para 21.62).

24. The single regulatory body should discharge the safety functions in relation to fire-fighting equipment and life-saving appliances. As regards standby vessels it should discharge all functions, whether directly or through the agency of the Department of Transport (DoT), save those which relate to the statutory responsibility of the DoT under the Merchant Shipping Acts (paras 21.65-66).

25. The functions of the Petroleum Engineering Division of the Department of Energy (DEn) which are concerned with the regulation of offshore safety should in future be discharged by a discrete division of the Health and Safety Executive (HSE) which is exclusively devoted to offshore safety (paras 22.34 and 22.37).

26. This division should employ a specialist inspectorate and have a clear identity and strong influence in the HSE. It should be headed by a chief executive who should be responsible directly to the Director General of the HSE and should be a member of its senior management board. His function would include the development of the offshore safety regime, and in particular the implementation of its provisions for Safety Cases and SMS (para 22.37).

Safety committees and safety representatives

27. The regulatory body, operators and contractors should support and encourage the involvement of the offshore workforce in safety. In particular, first line supervisors should involve their workforce teams in everyday safety (para 18.48).

28. The operator's procedures included in line management of operations which are aimed at involving the workforce in safety should form part of its SMS (para 21.56).

29. The DEn's intention to review the Offshore Installations (Safety Representatives and Safety Committees) Regulations 1989 after 2 years' experience of their working is endorsed (para 21.85).

30. Safety representatives should be protected against victimisation by a provision similar to Sec 58(i)(b) of the Employment Protection (Consolidation) Act 1978 (para 21.86).

31. The Offshore Installations (Safety Representatives and Safety Committees) Regulations 1989 should be modified to the effect that the training of safety representatives should be determined and paid for by the operator (para 21.87).

Permits to work

32. The operator's permit to work system should form part of its SMS (para 21.56).

33. Operators and the regulatory body should pay particular attention to the training and competence of contractors' supervisors who are required to operate the permit to work system (paras 18.17 and 18.29).

34. Standardisation of the permit to work system throughout the industry is neither necessary nor practicable. However, in view of the fact that there is much in common between the systems of different operators, the industry should seek to increase harmonisation, for example in the colours used for different types of permits to work and in the rules as to the period for which a permit to work remains valid (para 18.28).

35. While it is not inappropriate for contractors' supervisors to act as Performing Authorities, operators should be made responsible for ensuring that such supervisors are trained in the permit to work system for the installation where they are to act as Performing Authorities and that they carry documentary proof of having completed such training (para 18.29).

36. All permit to work systems should incorporate a mechanical isolation procedure which involves the physical locking off and tagging of isolation valves (para 18.29).

37. A permit to work and its consequent isolations, both mechanical and electrical, should remain in force until the work is sufficiently complete for the permit to be signed off and the equipment returned to operation (para 18.8).

38. Copies of all issued permits to work should be displayed at a convenient location and in a systematic arrangement such that process operating staff can readily see and check which equipment is under maintenance and not available for operation (para 18.8).

Incident reporting

39. The regulatory body should be responsible for maintaining a database with regard to hydrocarbon leaks, spills and ignitions in the industry and for the benefit of the industry. The regulatory body should:-

- (i) discuss and agree with the industry the method of collection and use of the data,
- (ii) regularly assess the data to determine the existence of any trends and report them to the industry, and
- (iii) provide operators with a means of obtaining access to the data, particularly for the purpose of carrying out quantified risk assessment (para 18.43).

Control of the process

40. Key process variables, as determined by the Safety Case, should be monitored and controllable from the Control Room (para 18.36).

41. The Control Room should at all times be in the charge of a person trained and qualified to undertake the work of Control Room operator. The Control Room should be manned at all times (para 18.35).

42. The training of Control Room operators should include instruction in an onshore course in the handling of emergencies (para 18.35).

Hydrocarbon inventory, risers and pipelines

43. The Emergency Pipe-line Valve Regulations should continue in force until they are subsumed in the Plant and Equipment Regulations. The provision in these regulations for there to be on each riser a valve with full emergency shutdown capability and located as close to sea level as practicable is endorsed (paras 19.34-35).

44. There should be no immediate requirement that a subsea isolation valve (SSIV) be fitted on a pipeline connected to an installation. The operator should demonstrate in the Safety Case that adequate provision has been made, including if necessary the use of SSIVs, against hazards from risers and pipelines (para 19.36).

45. Studies should be carried out with the following objectives:-

- (i) To explore the feasibility of dumping in an emergency large oil inventories, such as those in the separators, in a safe and environmentally acceptable manner, so as to minimise the inventory of fuel available to feed a fire (para 19.19).
- (ii) To minimise the pipeline connections to platforms (para 19.21).

46. Studies should be carried out with the following objectives:-

- (i) To achieve effective passive fire protection of risers without aggravating corrosion (para 19.22).
- (ii) To improve the reliability and reduce the cost of SSIVs so that it is more often reasonably practicable to install them (para 19.37).

Fire and gas detection and emergency shutdown

47. The arrangements for the activation of the emergency shutdown valves (ESVs), and of SSIVs if fitted, on pipelines should be a feature of the Safety Case (para 19.42).

48. Studies should be done to determine the vulnerability of ESVs to severe accident conditions and to enhance their ability to survive such conditions (para 19.43).

Fire and explosion protection

49. Operators should be required by regulation to submit a fire risk analysis to the regulatory body for its acceptance (para 19.90).

50. The regulations and related guidance notes should promote an approach to fire and explosion protection:-

(i) which is integrated as between -
  - — active and passive fire protection
  - — different forms of passive fire protection, such as fire insulation and platform layout, and
  - — fire protection and explosion protection (paras 19.87-95);

(ii) in which the need for, and the location and resistance of, fire and blast walls is determined by safety assessment rather than by regulations (para 19.96);

(iii) in which the function, configuration, capacity, availability and protection of the fire water deluge system is determined by safety assessment rather than by regulations (paras 19.97 and 19.99);

(iv) which facilitates the use of a scenario-based design method for fire protection as an alternative to the reference area method (paras 19.91 and 19.98); and

(v) which provides to a high degree the ability of the fire water deluge system, including the fire pump system, to survive severe accident conditions (para 19.100).

51. The ability of the fire water deluge system, including the fire pump system, to survive severe accident conditions should be a feature of the Safety Case (para 19.100).

52. The regulatory body should work with the industry to obtain agreement on the interpretation for design purposes of its interim hydrocarbon fire test and other similar tests. If in the view of the regulatory body there exists a need for an improved test, such as a heat flux test, it should work with the industry in order to develop one (para 19.101).

53. The DEn discussion document on Fire and Explosion Protection should be withdrawn (para 19.102).

54. The regulatory body should ask operators which have not already done so to undertake forthwith a fire risk analysis, without waiting for legislation (para 19.103).

Accommodation, TSR, escape routes and embarkation points

55. Provisions should continue to be made by regulations supported by guidance notes as to the construction of the accommodation; and as to escape routes and embarkation points (para 19.166).

56. The regulations and the related guidance notes should promote an approach to protection of the accommodation:-

(i) in which external fire protection is provided both to prevent breach of the accommodation and to maintain breathable air within it (para 19.170); and

(ii) in which an integrated set of active and passive measures is provided to prevent ingress of smoke and other contaminants into the accommodation and to maintain breathable air within it (paras 19.170-171).

57. For the purpose of maintaining breathable air within the accommodation, it should be required by regulation that the ventilation air intakes should be provided with smoke and gas detectors and that on smoke or gas alarm the ventilation and dampers should shut down (para 19.172).

58. The regulations and related guidance notes on escape routes should recognise that it may not be practicable to protect escape routes against all physical conditions; and accordingly should be based on the objective that they should remain passable (para 19.174).

59. It should be required by regulation that escape routes are provided with adequate and reliable emergency lighting and with photoluminescent direction signs (para 19.175).

60. The regulatory body should ask operators which have not already done so to carry out forthwith an assessment of the risk of ingress of smoke or gas into the accommodation; and to fit smoke and gas detectors and implement ventilation shutdown arrangements as in recommendation 57, without waiting for legislation (para 19.173).

61. Studies should be carried out with the objective of assisting designers in predicting the breathability of air in a TSR where its external fire wall is subjected to a severe hydrocarbon fire (para 19.163).

Emergency centres and systems

62. It should be required by regulation that there should be available within the TSR certain minimum specified facilities for the monitoring and control of an emergency under hostile outside conditions (paras 19.178 and 19.182).

These facilities should be in the Control Room, which should be located in the TSR (para 19.179).

On existing installations where the Control Room is not in the TSR, these facilities should be in an Emergency Control Centre located in the TSR. In such a case the Control Room should be protected against fire and explosion as determined by safety assessment (paras 19.180-181).

63. It should be required by regulation that a Radio Room with facilities for external communications should be located in the TSR (para 19.179).

On existing installations where the Radio Room is not in the TSR, these facilities should be in an Emergency Radio Room located in the TSR (para 19.180).

64. The regulations and related guidance notes should promote an approach to emergency systems:-

(i) which provides to a high degree the ability of these systems to survive severe accident conditions (paras 19.188-189); and

(ii) which applies to communications systems the fail-safe principle (para 19.193).

The emergency systems include the emergency power supplies and systems, the emergency shutdown system and the emergency communications systems. Severe accident conditions include fire, explosion and strong vibration (para 19.188).

65. The ability of emergency systems to survive severe accident conditions should be a feature of the Safety Case (para 19.189).

66. The regulatory body should work with the industry to promote the use of status light systems (para 19.192).

67. The regulatory body should work with the industry to achieve standardisation of status lights and of alarm systems for emergencies (para 19.194).

68. Studies should be done to determine the vulnerability of emergency systems to severe accident conditions and to enhance their ability to survive such conditions (para 19.190).

69. The regulatory body should ask operators which have not already done so to review forthwith the ability of emergency systems to withstand severe accident conditions (para 19.191).

70. Where a regulation imposes a requirement for a major emergency or protective system, such as a fire deluge system, it should be required that the operator should set acceptance standards for its availability (para 19.199).

Pipeline emergency procedures

71. Operators should be required by regulation regularly to review pipeline emergency procedures and manuals. The review should ensure that the information contained in manuals is correct, that the procedures contained are agreed with those who are responsible for executing them and are consistent with the procedures of installations connected by hydrocarbon pipelines (para 19.196).

72. Operators should be required by regulation to institute and review regularly a procedure for shutting down production on an installation in the event of an emergency on another installation which is connected to the first by a hydrocarbon pipeline where the emergency is liable to be exacerbated by continuation of such production (para 19.197).

Evacuation, escape and rescue - General

73. Operators should be required by regulation to submit to the regulatory body for its acceptance an evacuation, escape and rescue analysis in respect of each of its installations (para 20.9).

74. The analysis should specify the facilities and other arrangements which would be available for the evacuation, escape and rescue of personnel in the event of an emergency which makes it necessary or advisable in the interests of safety for personnel to leave the installation (para 20.9).

75. In particular the analysis should specify:-

(i) The formal command structure for the control of an emergency affecting the installation;

(ii) The likely availability and capacity of helicopters, whether in-field or otherwise, for the evacuation of personnel;

(iii) The types, numbers, locations and accessibility of totally enclosed motor propelled survival craft (TEMPSC) available for the evacuation of personnel from (a) the TSR and (b) other parts of the installation from which access to the TSR is not readily available;

(iv) The types, numbers and locations of life rafts and other facilities provided as means of escape to the sea;

(v) The specification (including speed, sea capability and accommodation), location and functions of the standby vessel and other vessels available for the rescue of personnel;

(vi) The types, numbers, locations and availability of fast rescue craft, whether stationed on the installation or on the standby or other vessels; and

(vii) The types, numbers and locations of personal survival and escape equipment.

(All in para 20.9).

76. The regulatory body should ask operators which have not already done so to undertake an evacuation, escape and rescue analysis forthwith, without waiting for legislation. The timetable for completion of this analysis should be agreed between the regulatory body and the industry but should not exceed a total of 12 months, and that only for operators of a large number of installations (para 20.9).

Helicopters

77. Operators should adopt a flight following system for determining at short notice the availability and capacity of helicopters in the event of an emergency. This system could be either a system operated by the individual operator or a North Sea-wide system (para 20.11).

TEMPSC

78. The requirement by regulation that each installation should be provided with TEMPSC having in the aggregate sufficient capacity to accommodate safely on board 150% of the number of persons on the installation should be maintained (para 20.16).

Such provision should include TEMPSC which are readily accessible from the TSR and which have in the aggregate sufficient capacity to accommodate safely on board the number of persons on the installation (para 20.16).

79. On new installations where the provision of davit-launched TEMPSC is acceptable to the regulatory body they should be oriented so as to point away from the installation (para 20.24).

80. The regulatory body should work with the industry to develop equipment and methods to enable TEMPSC to be launched clear of the installation including where, as on existing installations, they are oriented so as to point along the side of the installation (para 20.18).

81. Reg 5 of the Life-Saving Appliances Regulations should be amended or replaced so as to enable free-fall TEMPSC to be installed on new and existing installations. It should remain for the operator to justify its choice of TEMPSC as being appropriate in the particular conditions of its installation (para 20.24).

Means of escape to the sea

82. It should be required by regulation that each installation should be provided with life rafts having in the aggregate sufficient capacity to accommodate safely on board at least the number of persons on board the installation; along with suitable ropes to enable those persons to obtain access to the life rafts after they have been launched and deployed (para 20.26).

83. A variety of means of descent to the sea should be provided on all installations. In accordance with recommendation 75 the types, numbers and locations of facilities for this purpose should be specified in the evacuation, escape and rescue analysis; but such facilities should include:-

- fixed ladders or stairways
- personal devices for controlled descent by rope (paras 20.28-29).

84 The regulatory body should work with the industry to determine the practicability and safety of escape chutes and collapsible stairways (para 20.30).

Personal survival and escape equipment

85. Each individual on board an installation should be provided with:-

(i) a personal survival (or immersion) suit;

(ii) a life-jacket;

(iii) a smoke hood of a simple filter type to exclude smoke and provide protection for at least 10 minutes during escape to or from the TSR;

(iv) a torch; and

(v) fireproof gloves.

These articles should be kept in the accommodation (para 20.36).

Other survival suits, life-jackets and smoke hoods for at least one half of the number of persons on the installation should be stored in containers placed at suitable locations on the installation (para 20.36).

86. The use of small transmitters or detectors on life-jackets in order to assist in the finding of personnel in the dark should be considered. Luminescent strips should be of a colour other than orange (paras 20.33-34).

87. Work should be carried out with the objective of combining the functions of a survival suit and a life-jacket in one garment (para 20.32).

Standby vessels

88. Changes in the regulations and the code for the assessment of standby vessels should be aimed at an improvement in the quality of standby vessels, introducing basic standards for existing vessels and higher specifications for new vessels (para 20.41).

89. It should be required by regulations that each standby vessel should comply with the following standards:-

(i) It should be highly manoeuvrable and able to maintain its position;

(ii) It should provide full visibility of the water-line in all directions from the bridge;

(iii) It should have at least two 360° searchlights capable of being remotely controlled;

(iv) It should have two fast rescue craft. One of the 2 fast rescue craft should be able to travel at 25 knots in normal sea states. The smaller fast rescue craft (9 person capacity) should be crewed by 2 persons; the larger by 3 persons. Fast rescue craft should be equipped with adequate means of communicating with the standby vessel by VHF radio; and carry an adequate portable searchlight;

(v) It should have the means of rapid launching of its fast rescue craft;

(vi) It should have adequate means of communication by radio with its fast rescue craft, the installation, nearby vessels and the shore; and

(vii) It should have at least two methods of retrieving survivors from the sea.

(All in para 20.42).

90. Reg 10 of the Emergency Procedures Regulations should be revoked (para 20.39).

91. Sec 3 of the code for the assessment of standby vessels (areas of operation) should be withdrawn (para 20.39).

92. The owners of standby vessels should be required to notify the regulatory body weekly as to the locations and functions of their vessels in the ensuing week. A copy of such notification should also be given to the DoT (para 20.54).

93. As regards the appropriate numbers for the crew of standby vessels, the DoT should take into account the evidence given in the Inquiry when reviewing the code in this respect (para 20.50).

94. The proposals in the amended code as to age limit, medical examination and certification of fitness of members of the crew of standby vessels; and as to their periods of duty are endorsed (paras 20.51-52).

95. The regulatory body should work with the industry to obtain agreement as to adequate training packages for the crew of standby vessels. Such training should be administered, and records of training kept by the Offshore Petroleum Industry Training Board (OPITB) (para 20.55).

96. The coxwain and crew of fast rescue craft should receive special training for their duties, along with regular refreshers (para 20.55).

Command in emergencies

97. The operator's formal command organisation which is to function in the event of an emergency should form part of its SMS (para 20.59).

98. The operator's criteria for selection of OIMs, and in particular their command ability, should form part of its SMS (para 20.59).

99. There should be a system of emergency exercises which provides OIMs with practice in decision-making in emergency situations, including decisions on evacuation. All OIMs and their deputies should participate regularly in such exercises (para 20.61).

Drills, exercises and precautionary musters and evacuations

100. The operator's system for emergency drills and exercises should form part of its SMS (paras 20.61 and 20.64).

101. Offshore emergency drills and exercises should be carried out in accordance with the UKOOA guidelines for offshore emergency drills and exercises on installations (paras 20.61 and 20.64).

102. All offshore staff should attend one muster per tour of duty (para 20.62).

103. The circumstances of all precautionary musters and evacuations should be reported by operators to the regulatory body (para 20.62).

104. Operators should maintain lists of personnel on board by alphabetical order and also by reference to the names of contractors whose personnel are represented on board. These lists should be updated for every movement of personnel and copied immediately to the shore (para 20.62).

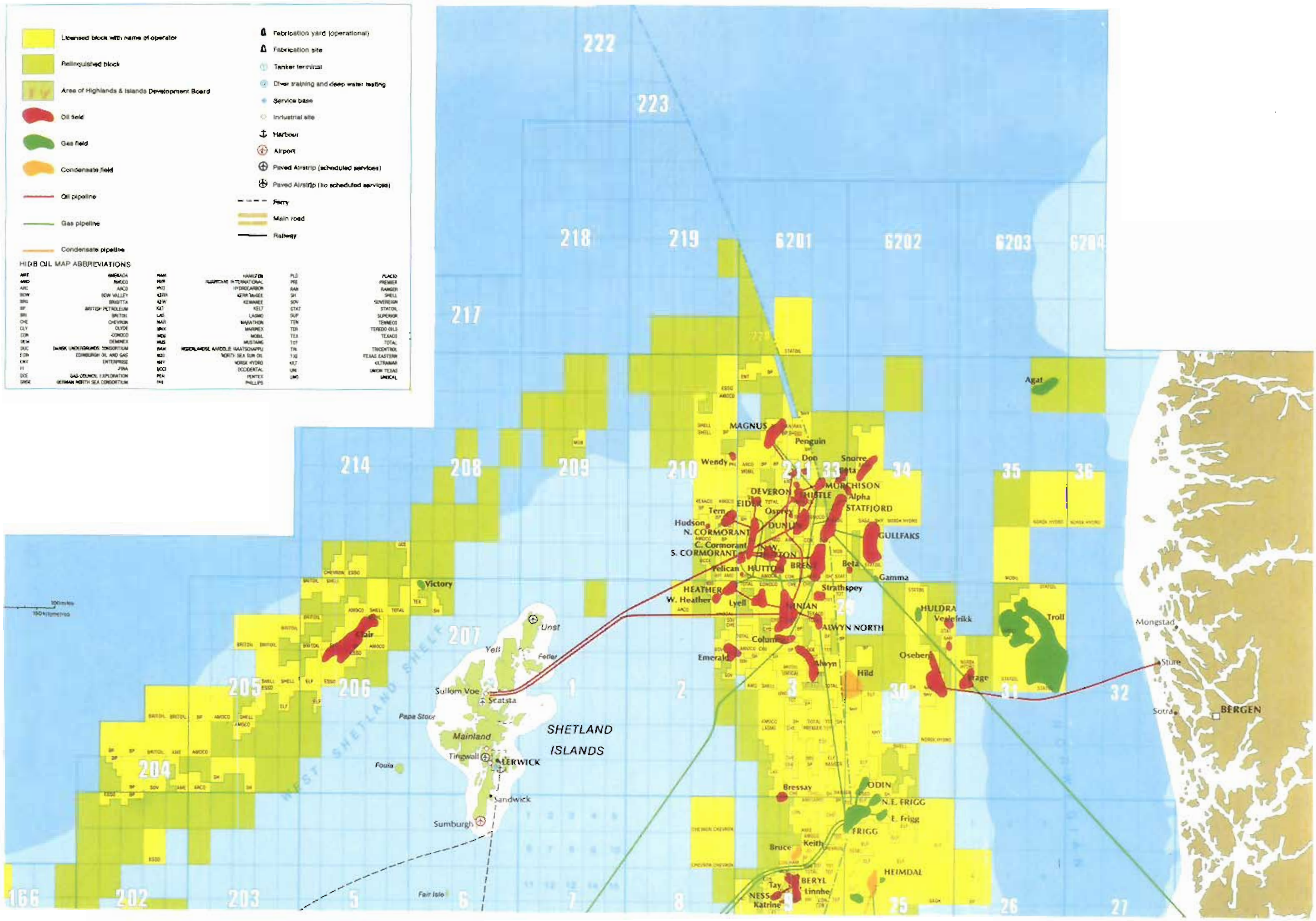
Training for emergencies

105. The UKOOA guidelines for offshore emergency safety training on installations should be a minimum requirement for survival, fire-fighting and other forms of training detailed therein for the relevant personnel employed offshore. Personnel who have not met the requirements of these guidelines should not be permitted to work offshore (para 20.64).

In order to ensure that these guidelines are complied with operators should be required to devise and maintain a system for the purpose, pending the date when the central training register instituted by OPITB for recording the personal details and safety training courses attended by all personnel seeking employment offshore is fully operational (para 20.64).

106. The operator's system for emergency training and its enforcement should form part of its SMS (para 20.64).

Overleaf – Plates 1 & 2 Oil and Gas fields in the northern North Sea.

Licensed block with name of operator
Relinquished block
Area of Highlands & Islands Development Board
Oil field
Gas field
Condensate field
Oil pipeline
Gas pipeline
Condensate pipeline
Fabrication yard (operational)
Fabrication site
Tanker terminal
Diver training and deep water testing
Service base
Industrial site
Harbour
Airport
Paved Airstrip (scheduled services)
Paved Airstrip (no scheduled services)
Ferry
Main road
Railway
HIDB OIL MAP ABBREVIATIONS
AMF AMERADA
AMO AMOCO
ARC ARCO
BOW BOW VALLEY
BRG BRIGITTA
BP BRITISH PETROLEUM
BRI BRITOIL
CHE CHEVRON
CLY CLYDE
CON CONOCO
DEM DEMINEX
DUC DANSK UNDERGRUNDS CONSORTIUM
EDIN EDINBURGH OIL AND GAS
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GNSC GERMAN NORTH SEA CONSORTIUM
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HUR HURRICANE INTERNATIONAL
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MAX MARINEX
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Tern
Osprey
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N. CORMORANT
DUNLIN
GULLFAKS
C. Cormorant
S. CORMORANT
NW. HUTTON
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Beta
Gamma
HEATHER
W. Heather
Lyell
Strathspey
NINIAN
HULDRA
Veslefrikk
Troll
ALWYN NORTH
Columba
Emerald
Alwyn
Hild
Oseberg
Brage
Victory
Clair
Unst
Yell
Fetlar
Sullom Voe
Scatsta
Papa Stour
Mainland
SHETLAND ISLANDS
Tingwall
LERWICK
Foula
Sandwick
Sumburgh
Fair Isle
WEST SHETLAND SHELF
Bressay
ODIN
N.E. FRIGG
E. Frigg
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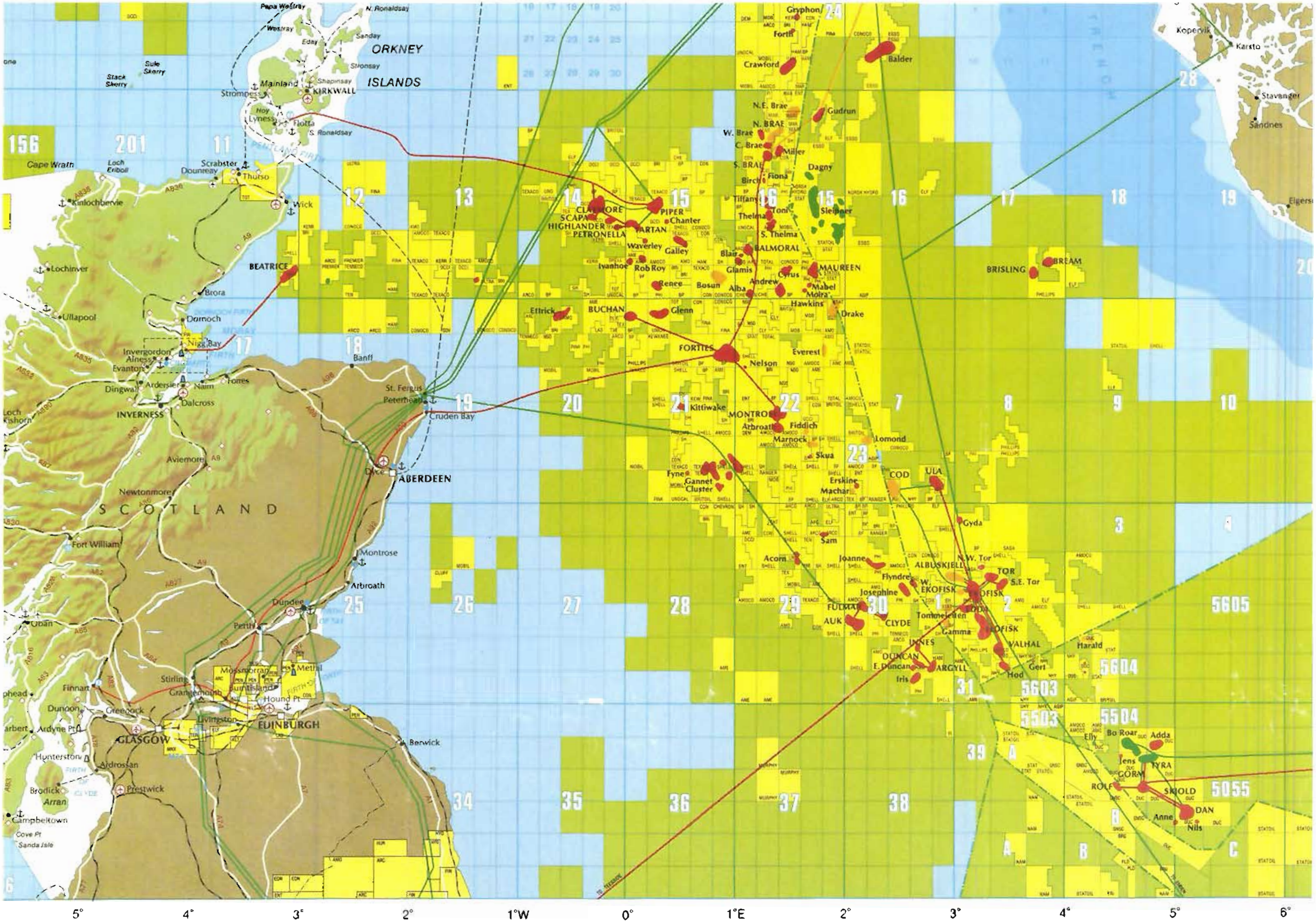
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Lyness
Flotta
S. Ronaldsay
Pentland Firth
Sule Skerry
Stack Skerry
Cape Wrath
Loch Eriboll
Scrabster
Dounreay
Thurso
Wick
Kinlochbervie
Lochinver
Ullapool
Brora
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Moray Firth
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Dingwall
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Aviemore
Newtonmore
SCOTLAND
Fort William
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Banff
St. Fergus
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Montrose
Arbroath
Dundee
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Perth
Methil
Mossmorran
Burntisland
Hound Pt
Firth of Forth
Stirling
Grangemouth
Livingston
EDINBURGH
Finnart
Greenock
Dunoon
Ardyne Pt
GLASGOW
Hunterston
Ardrossan
Prestwick
Brodick
Arran
Firth of Clyde
Campbeltown
Cove Pt
Sanda Isle
Berwick
Kopervik
Karsto
Stavanger
Sandnes
Egersund
TRENCH
BEATRICE
CLAYMORE
SCAPA
HIGHLANDER
PETRONELLA
PIPER
Chanter
TARTAN
Waverley
Galley
Ivanhoe
Rob Roy
Renee
Ettrick
BUCHAN
Glenn
FORTIES
Nelson
Kittiwake
MONTROSE
Arbroath
Fiddich
Marnock
Fyne
Gannet Cluster
Bosun
Alba
Andrew
Glamis
Blair
BALMORAL
S. Thelma
Thelma
Toni
Tiffany
Birch
Fiona
S. BRAE
C. Brae
W. Brae
N. BRAE
N.E. Brae
Miller
Dagny
Sleipner
Gudrun
Crawford
Forth
Gryphon
Balder
MAUREEN
Cyrus
Mabel
Moira
Hawkins
Drake
Everest
Lomond
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COD
ULA
Gyda
Sam
Acorn
Joanne
Flyndre
Josephine
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Harald
BRISLING
BREAM
Elly
Bo Roar
Adda
Jens
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Plate 3 The Piper Alpha platform: view from the north-west.

Plate 4 The Piper Alpha platform: view from the south-east.

Plate 5 The Piper Alpha platform: west face and pipe deck.

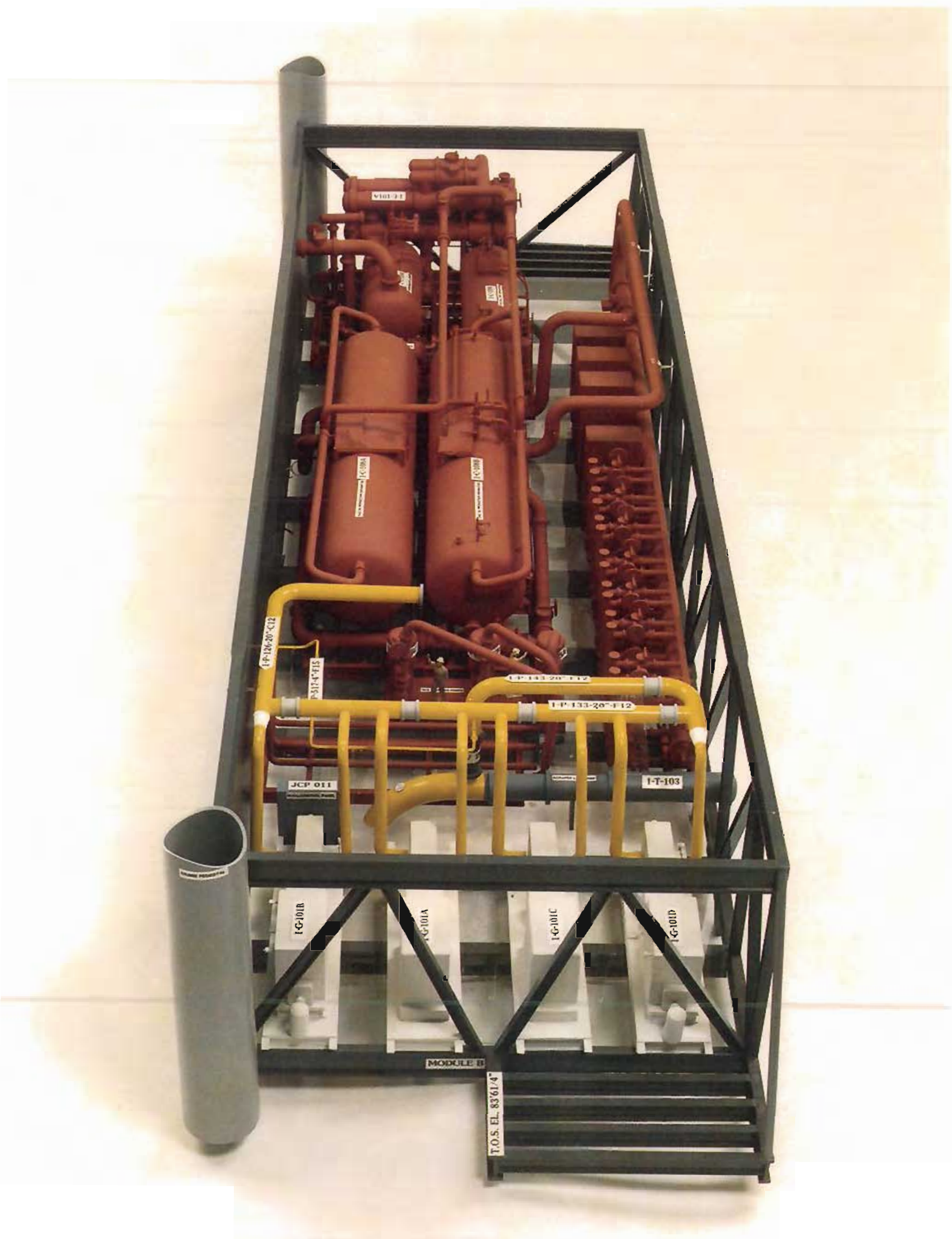

Plate 6 Model of the production modules (1: 33 scale): B Module looking east.

Plate 7 Model of the production modules (1: 33 scale): C Module looking east.

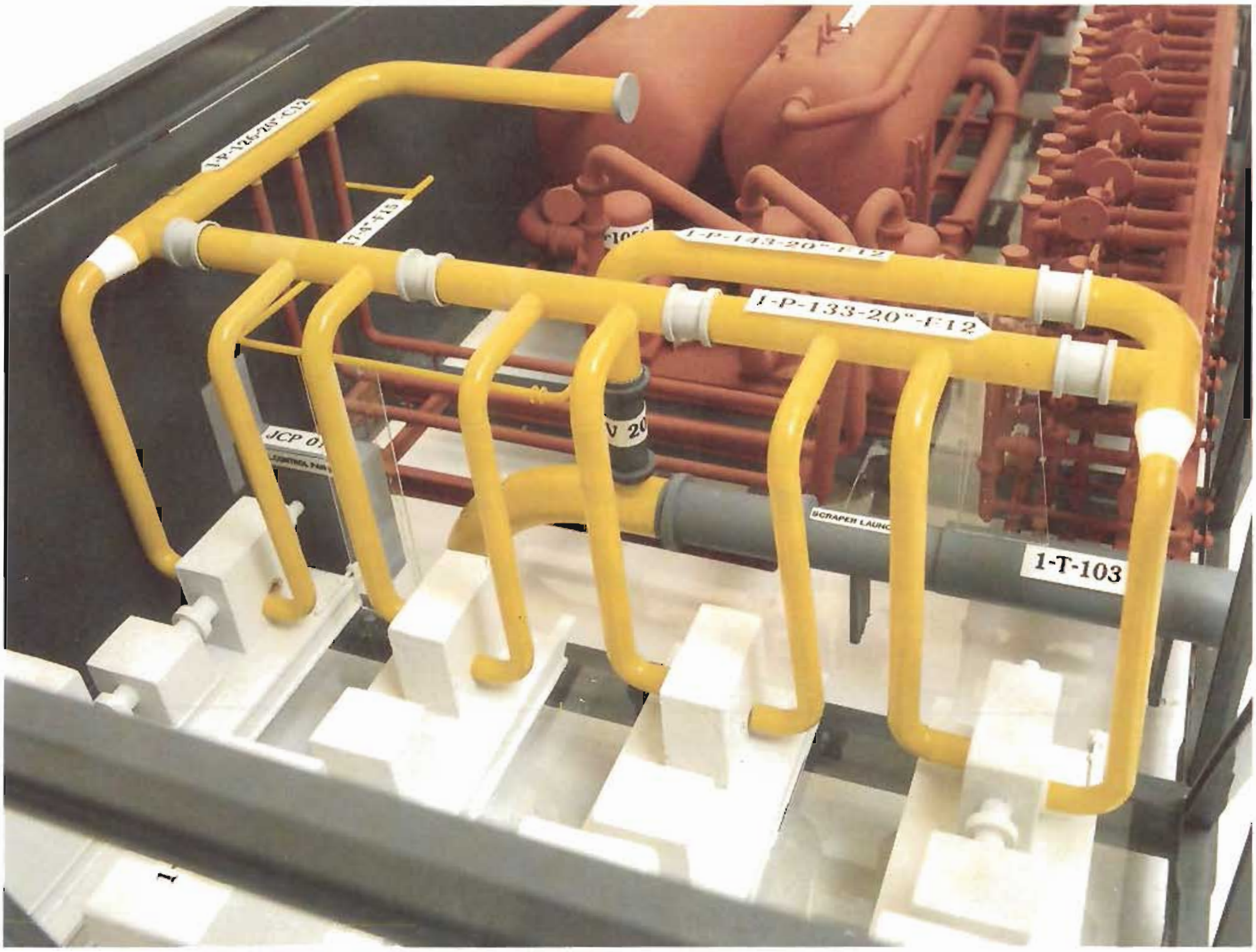

Plate 8 Model of the production modules (1: 33 scale): the main oil line pumps at the west end of B Module. The 4 inch condensate injection line is the small yellow line 2–P–517–4"–F15 coming through the B/C firewall and entering the MOL pump discharge header 1–P–143–20"–F12.

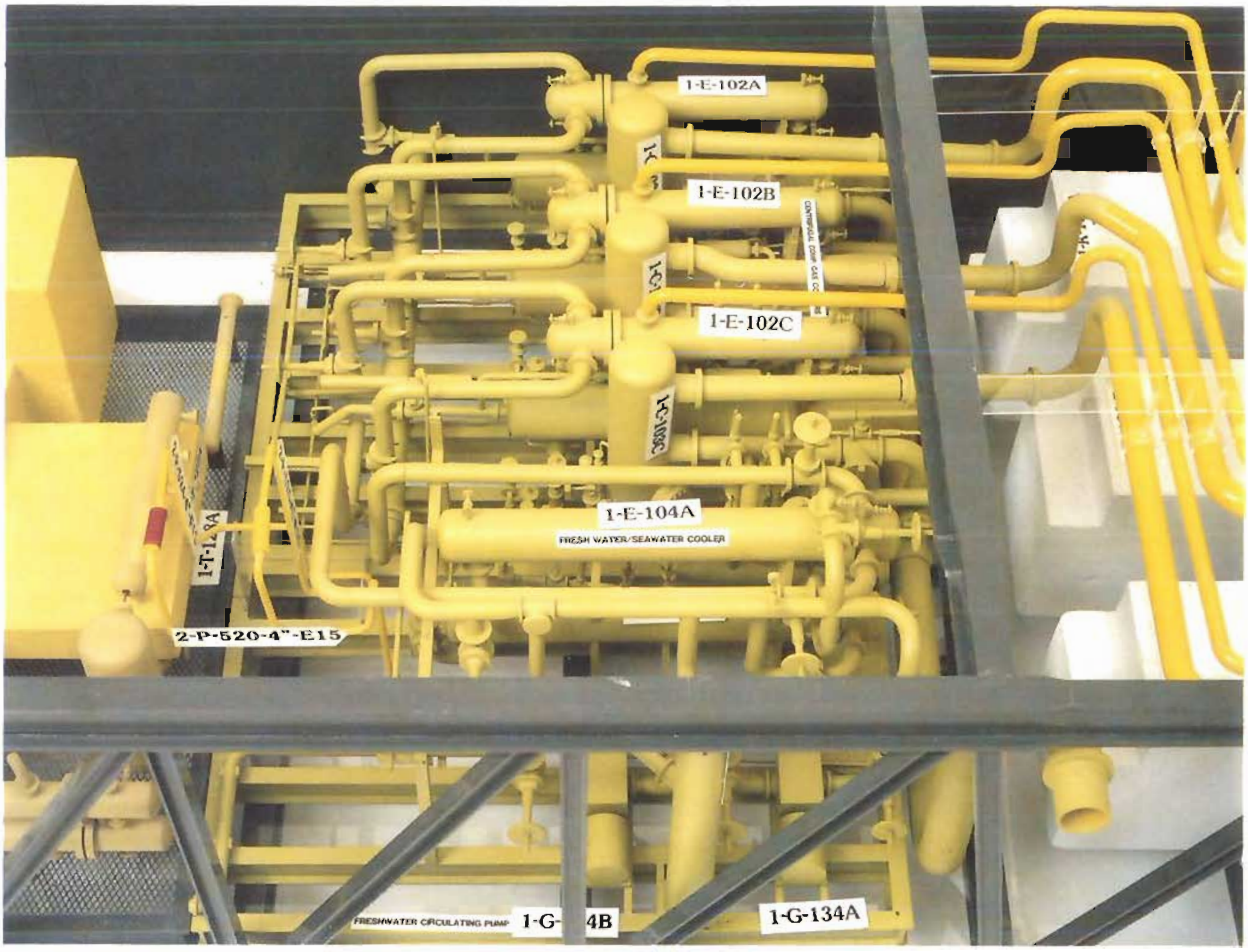

Plate 9 Model of the production modules (1: 33 scale): the centrifugal compressor skid towards the east end of C Module. The location of PSV 504 is marked in red.

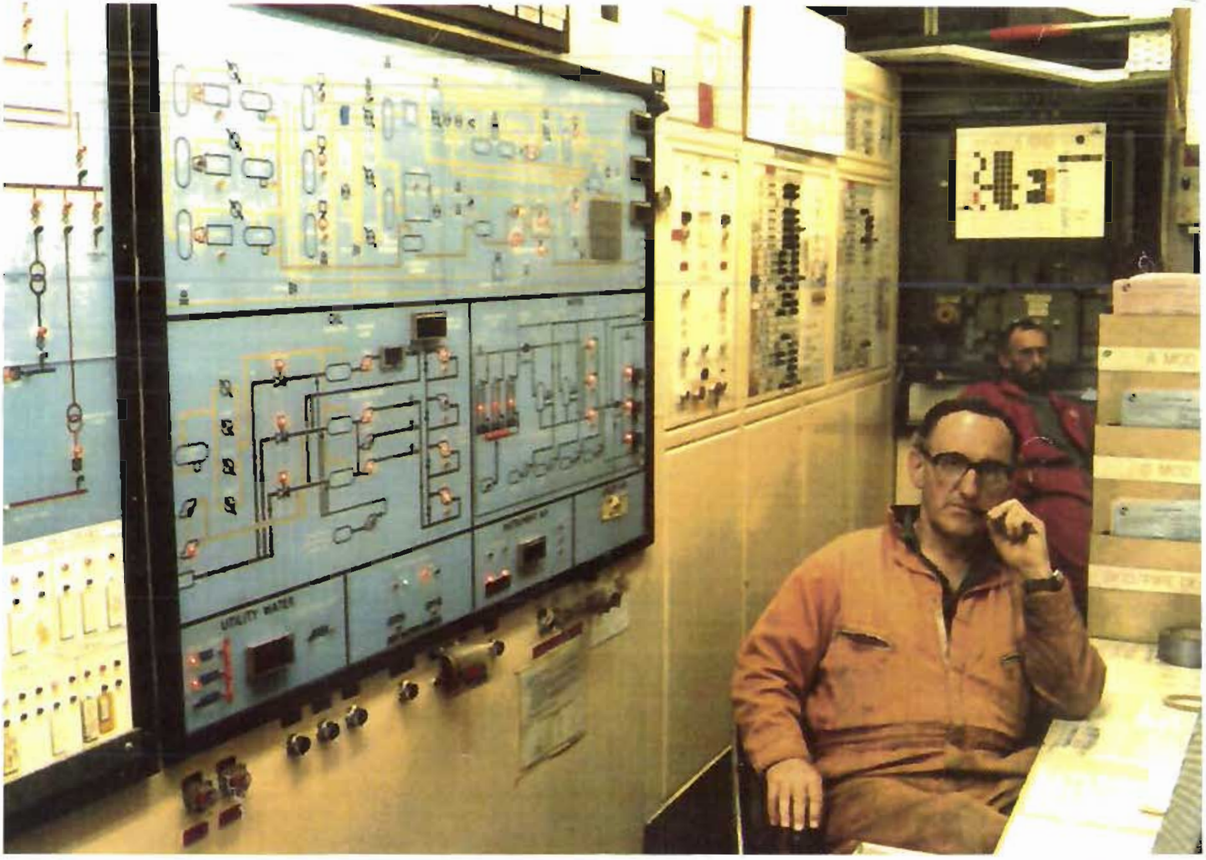

Plate 10(a) Control panels and control desk in the Control Room. The view is of the space between the control desk and the main process control panel, looking south (see Fig.J.4(c)). The operator is sitting with his left elbow on the control desk. To the east and going from south to north are the main fire and gas control panel and then the main process control panel.

Plate 10(b)
The north-west corner of the platform, showing the Chanter riser gantry. The gantry is the two structures, one ending in a triangular shape and the other in a rectangular one, projecting from the 68ft level. Also shown is the 20ft level and the navigation aid platform at the north-west corner of the 68ft level.

Plate 11(a) The *Tharos.*

Plate 11(b) The *Silver Pit.*

Plate 12(a) An Atlantic 21 fast rescue craft (FRC).

Plate 12(b) A Piper liferaft on its launching platform.

Plate 13 The east flare before the initial explosion. The photograph was taken by Mr Macdonald from the *Lowland Cavalier* some 1-2 minutes before the initial explosion.

Plate 14(a)

Plate 14(b)

The early fire in B Module: (a) Mr Miller's first photograph; and (b) his second photograph. The first photograph was taken from the *Tharos* some 15 seconds after the initial explosion. The next five photographs were taken in quick succession at intervals estimated as 2-3 seconds.

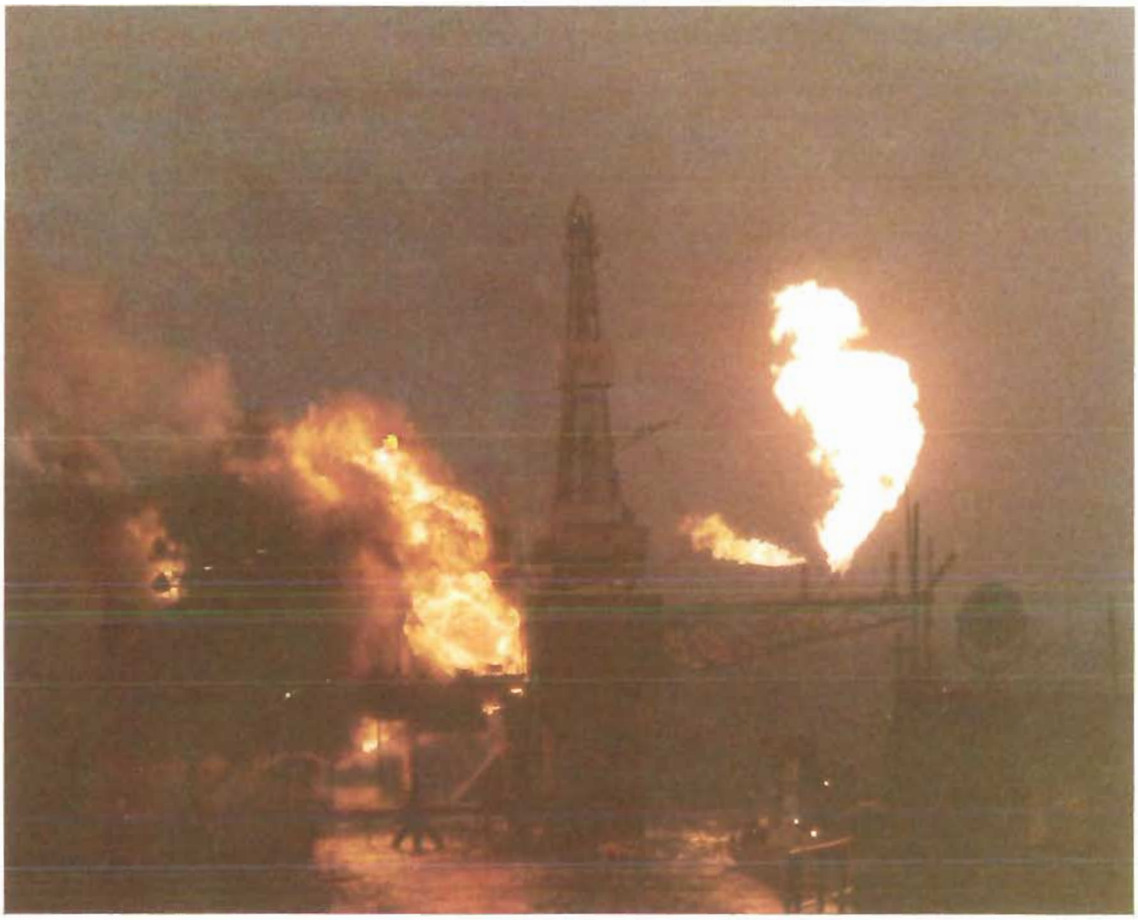

Plate 15(a)

Plate 15(b)

The early fire in B Module: (a) Mr Miller's third photograph; and (b) his fourth photograph.

Plate 16(a)

Plate 16(b)

The early fire in B Module: (a) Mr Miller's fifth photograph; and (b) his sixth photograph.

Plate 17(a) The early fire in B Module: photograph taken by Mr Macdonald from the *Lowland Cavalier* at a time estimated as some 30 seconds after the initial explosion.

Plate 17(b) The fires on Piper before riser rupture: Mr Miller's thirteenth photograph.

Plate 18(a) The fires on Piper before riser rupture: Mr Miller's nineteenth photograph.

Plate 18(b) The fires on Piper before riser rupture: photograph taken from the *Maersk Cutter*.

Plate 19(a) The fires on Piper before riser rupture: photograph taken by Mr Ritchie from the *Lowland Cavalier*

Plate 19(b) The fires on Piper just after rupture of the Tartan riser: photograph taken by Mr Gibson from the *Lowland Cavalier* at a time estimated as 22.20–22.22 hours.

Plate 20(a) The fires on Piper some time after riser rupture: photograph taken from the *Tharos* helicopter.

Plate 20(b) The fires on Piper some time after riser rupture: further photograph taken from the *Tharos* helicopter.

Plate 21 The remains of A Module on the morning of 7 July.

Plate 22(a)

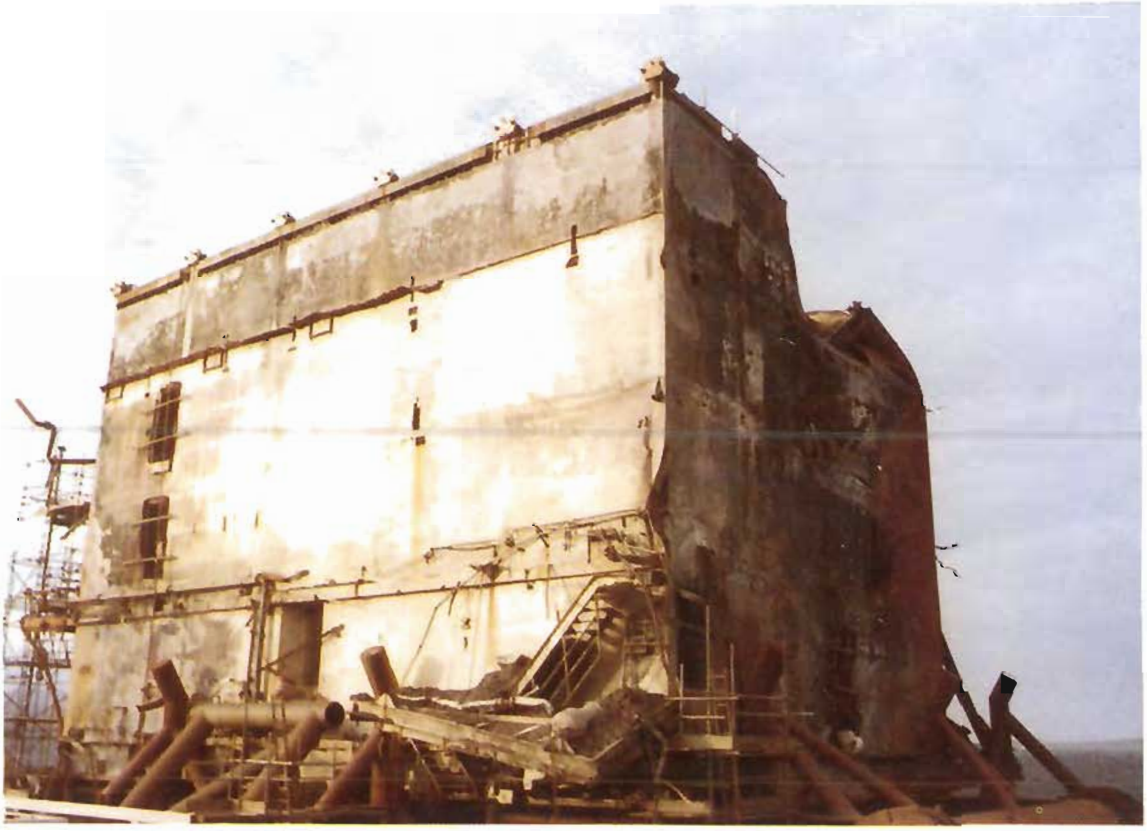

Plate 22(b)

Accommodation modules at Flotta after recovery from the seabed — 1: (a) the East Replacement Quarters (ERQ); and (b) the south face of the ERQ.

Plate 23 Accommodation modules at Flotta after recovery from the seabed — 2: the Additional Accommodation West (AAW).

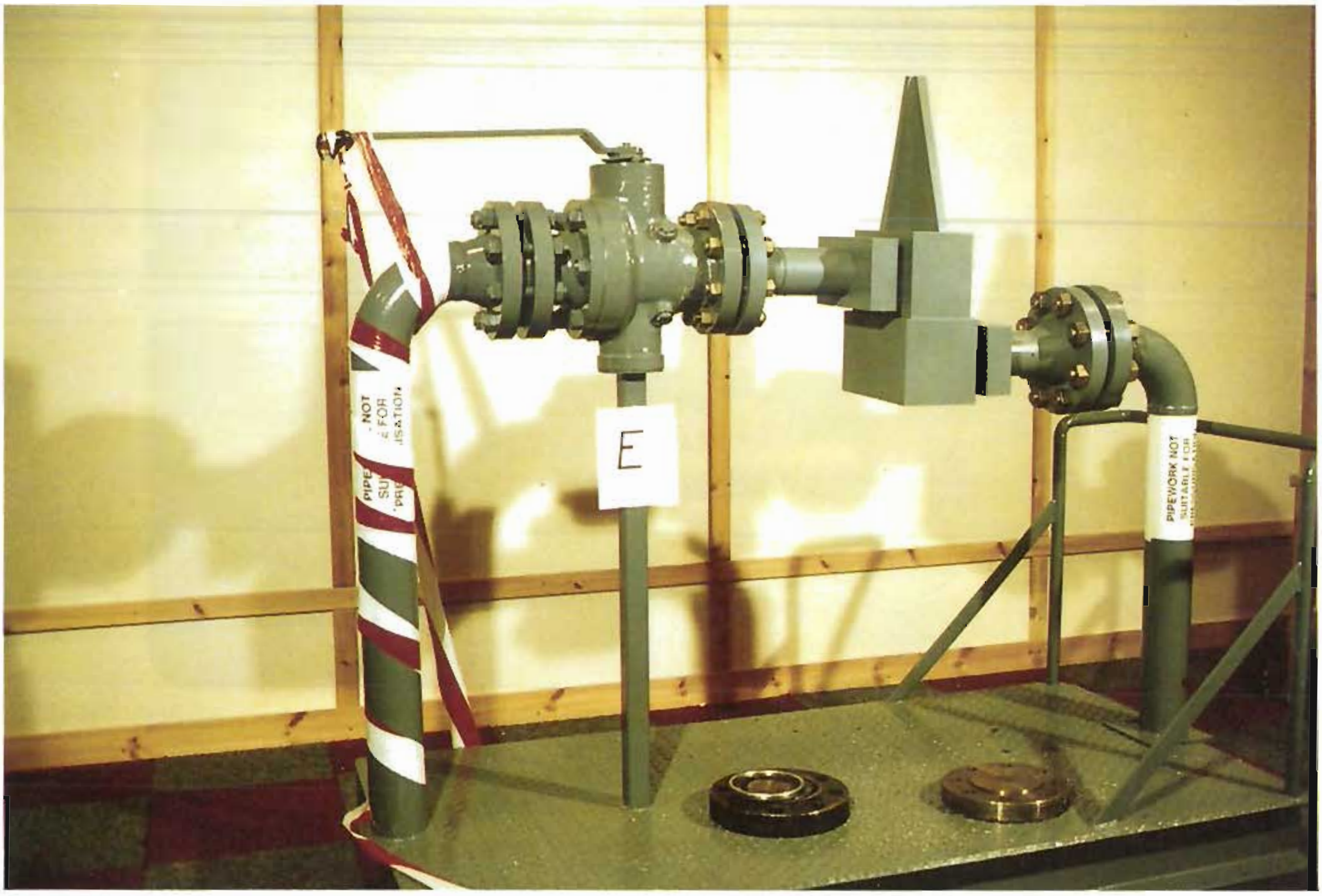

Plate 24(a)

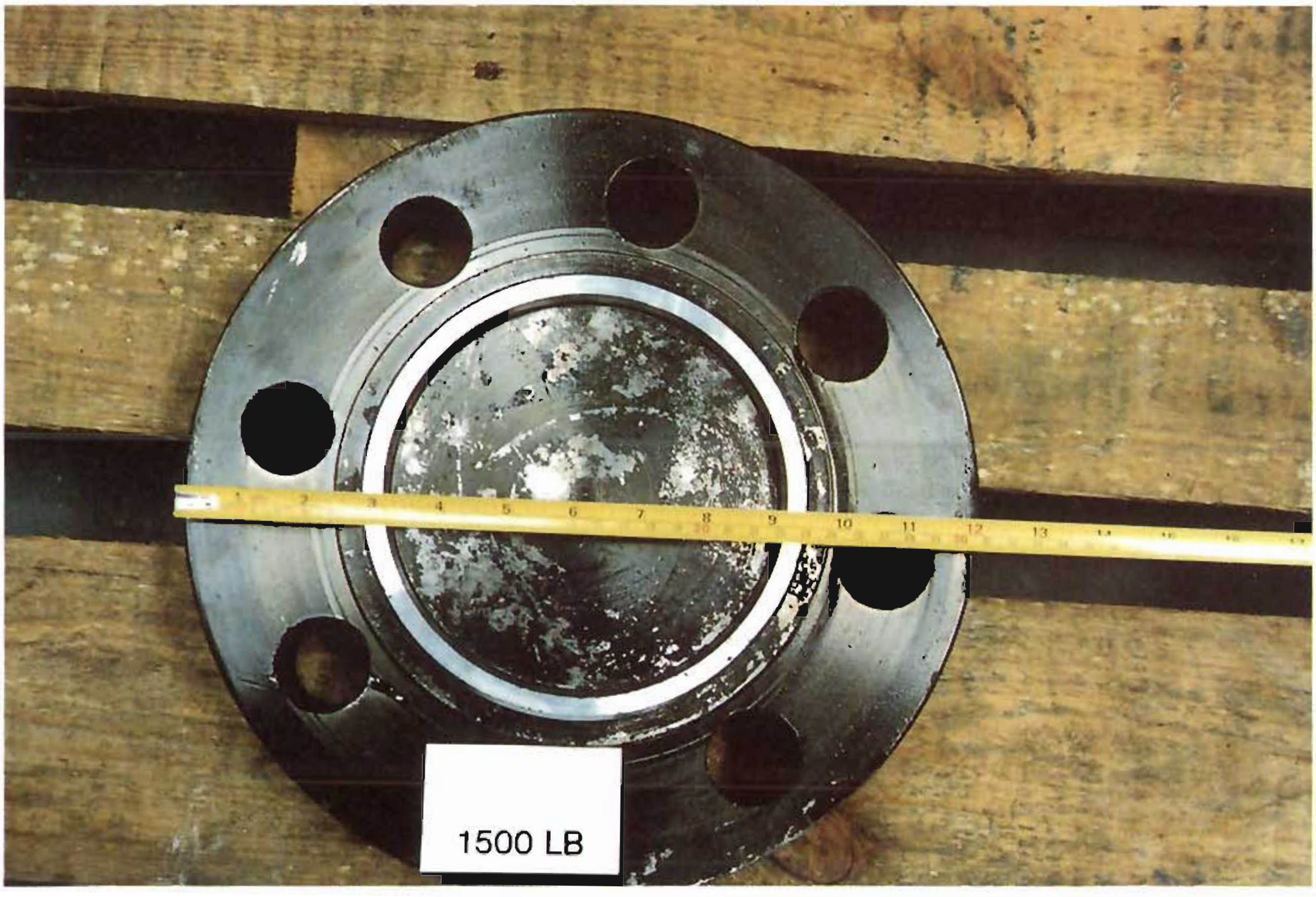

Plate 24(b)

The pipework at the site of PSV 504 in C Module: (a) model of the PSV and pipework; and (b) a 1500 lb flange with ring. The PSV is the wooden mock-up. Its inlet is on the right hand side.

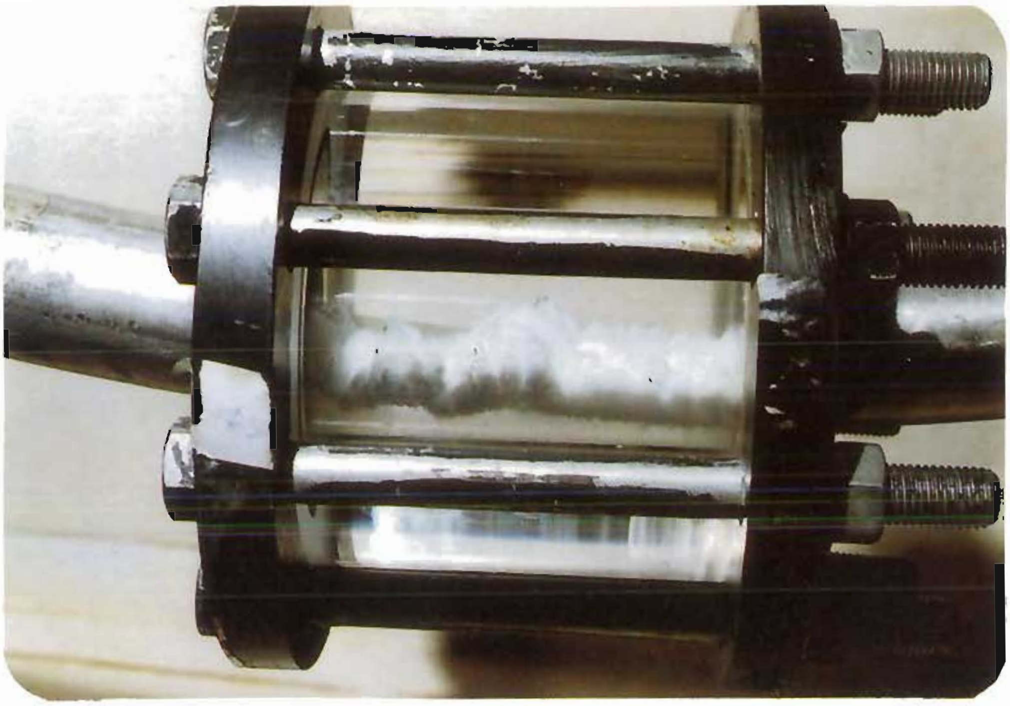

Plate 25(a) Hydrate formation in an observation window of the rotating wheel test rig in the tests conducted by Petreco.

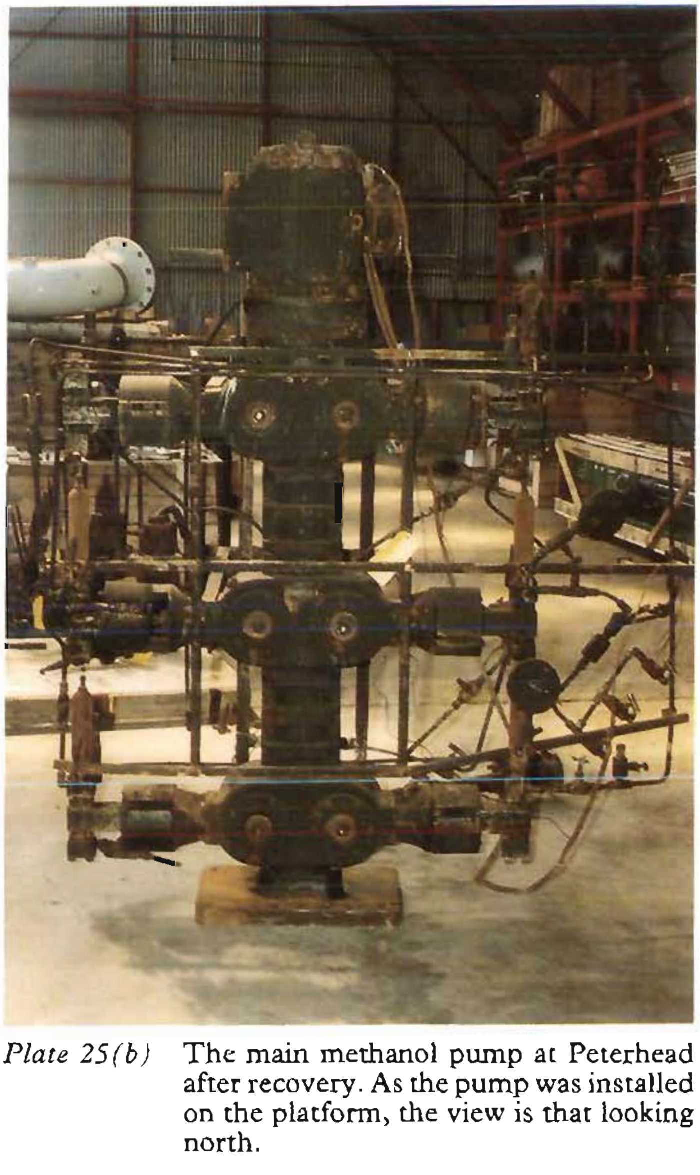

Plate 25(b) The main methanol pump at Peterhead after recovery. As the pump was installed on the platform, the view is that looking north.

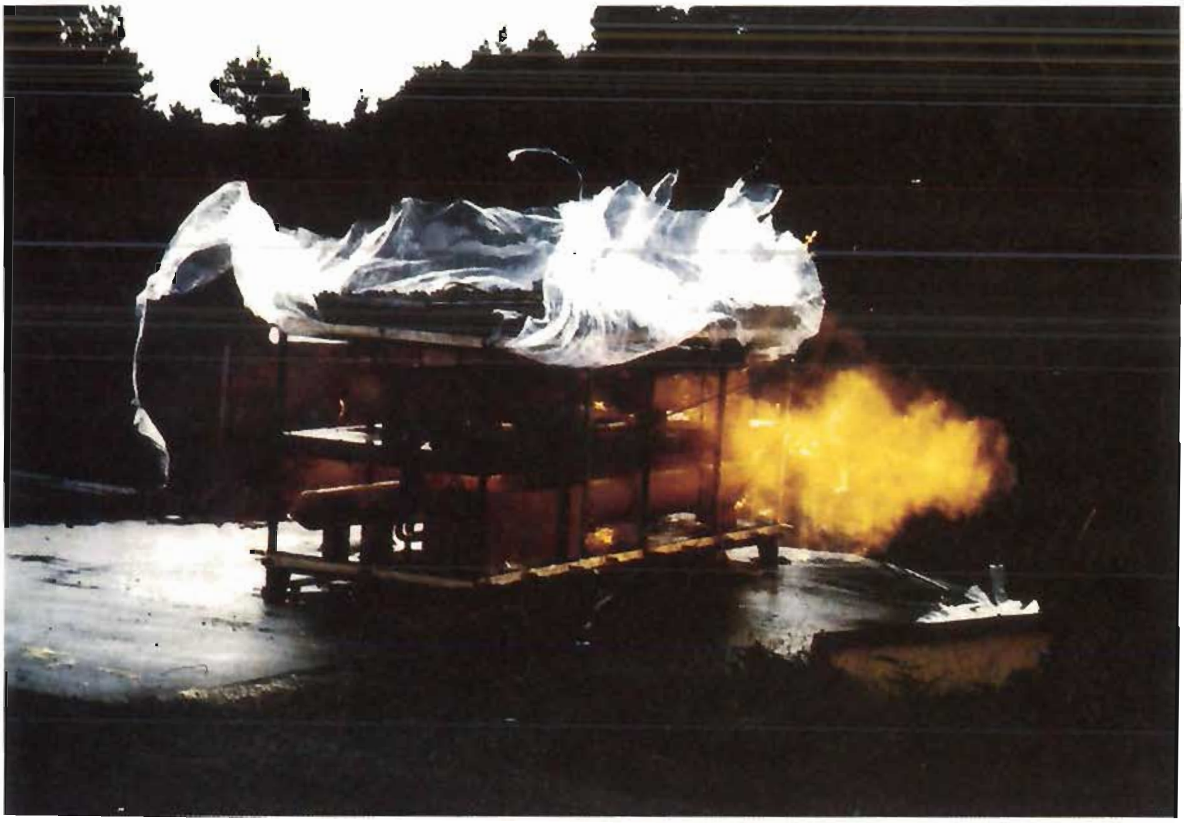

Plate 26(a) Explosion in a scaled down module typical of those conducted by CMI to validate its explosion model.

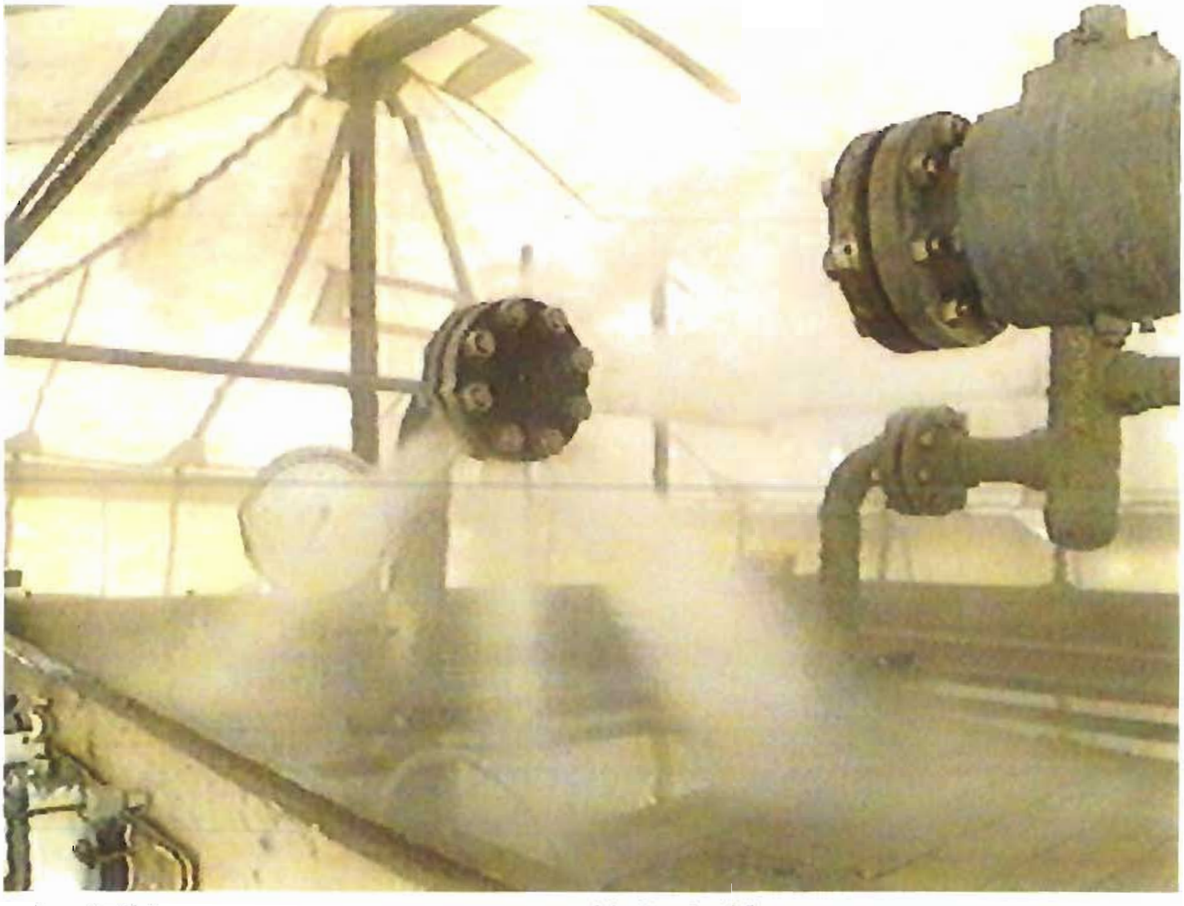

Plate 26(b) Leak from a blind flange assembly in the Nowsco tests.

Appendix A

Procedural History

Preliminary Hearings

A.1 A Preliminary Hearing was held at the Aberdeen Exhibition and Conference Centre, Bridge of Don, Aberdeen, on 11 November 1988. The date was selected in order to enable potential parties to have an adequate opportunity to consider the implications of The Petrie Report. At this hearing I disposed of applications by persons to be parties to the Inquiry and dealt with various matters of procedure and programming. I permitted persons to be parties to the Inquiry if they were able to show an interest, which required to be a reasonably direct interest, in some aspect of the subject matter of the Inquiry which as a matter of fairness required protection by such representation. I required that persons who had a similarity of interests should be jointly and not separately represented. Appendix B contains a list of the parties to the Inquiry.

A.2 Parties who intended to attach blame or criticism to someone else, whether or not already a party to the Inquiry, were required to give advance notice to the Secretariat which was then responsible for informing the other parties and any other person who had been so named. This procedure was carried out satisfactorily.

A.3 A second (and final) Preliminary Hearing was held in Edinburgh on 9 January 1989. This meeting was concerned solely with the progress which had been made in the recovery of documents by agreement.

The Inquiry

A.4 Part 1 of the Inquiry opened on 19 January 1989 and closed on 1 November 1989. It sat for 130 days. Part 2 of the Inquiry opened on 2 November 1989 and closed on 15 February 1990. It sat for 50 days. The whole proceedings of the Inquiry were held in public. No opening submissions were made. At the end of Part 1 closing submissions were made by the parties and Counsel to the Inquiry in writing, extending to over 1300 pages, and briefly highlighted orally. Copies of the written submissions were made available to the press and the public. At the end of Part 2 parties who intended to invite me to make recommendations submitted written lists of them in advance of making their closing submissions. Copies of these lists were likewise made available to the press and the public. During the course of the Inquiry a committee of experts under the chairmanship of the Assessors met on 2 occasions. The first of these was on 20 February 1989 and the second on 27 June 1989. These meetings were concerned respectively with (i) the involvement of the contents of pipelines with which Piper was connected; and (ii) expert opinion in regard to the scenario that condensate had been ingested into the reciprocating compressors.

Witnesses

A.5 196 witnesses gave evidence in Part 1 of the Inquiry. 14 of them who required to give evidence on a number of different matters gave evidence on 2 or more occasions. 64 witnesses gave evidence in Part 2 of the Inquiry. 9 of them gave evidence on 2 occasions. Lists of the witnesses are contained in Appendices C and E; and a list of experts' reports in Part 1 is contained in Appendix D. After I had decided that the evidence of a witness would be of assistance to the Inquiry copies of his precognition were circulated by the Crown Office to the parties. This served to avoid any risk of the Inquiry being delayed. Each witness gave evidence after being put on oath or affirming; and was subject to cross-examination by the parties to the Inquiry and, where applicable, by Counsel to the Inquiry, subject to the extent which I considered to be of assistance to the Inquiry. In certain instances I permitted legal representation to be provided in support of witnesses whose interests were not represented by any of the parties to the Inquiry.

A.6 At the Preliminary Hearing on 11 November 1988 the Lord Advocate (The Lord Cameron of Lochbroom) attended in the public interest and explained the assistance which he had arranged that the Crown Office should provide to the Inquiry. He also made the following statement:

> "Further, to assist the Inquiry, I wish to state that I undertake that in the case of any witness who appears before this Inquiry, neither his evidence before the Inquiry nor evidence given before the Inquiry by any person by reference to or incorporating the whole or any part of any documents which that witness is required to produce to the Inquiry, shall be used against him, or any other person who could be held criminally responsible on account of his actings in any subsequent criminal proceedings, except in criminal proceedings in which the charge is one of having given false evidence before the Inquiry or having conspired with or procured others to do so."

Documents

A.7 A large number of documents were recovered for examination in order to see whether they might be of assistance to the Inquiry. The principal sources were Occidental, Score (UK) Ltd, the DEn and Lloyds Register of Shipping. The documents recovered from Occidental included a number of logs and other records which had been recovered from the bed of the North Sea when the ERQ was raised in October 1988. As the result of remarkable work which was done by specialists at Flotta virtually all of these documents were still legible. In order to receive the large volume of recoveries a library was set up and administered by Messrs Cremer and Warner in order that all parties might have access to them. From the contents of the library Messrs Cremer and Warner assembled a collection of core documents which form the first instalment of the productions before the Inquiry. These were copied and circulated to all the parties. Thereafter additional documents were produced from the library and elsewhere as the need for the Inquiry to refer to them was identified.

A.8 Due to the co-operation of the havers of the documents it proved unnecessary for me to exercise my power under Reg 7(a) of the Public Inquiries Regulations to require production of documents considered necessary for the purposes of the Inquiry. The sole exception to this was the interim report of the Occidental board of inquiry into the disaster which counsel for the Contractors' Interests asked me on Day 78 to require Occidental to produce. This motion was opposed by Occidental on a number of grounds. Having heard counsel I considered that the appropriate course of action in the first instance was to pronounce such an order for the limited purpose of enabling Counsel to the Inquiry to advise me as to any grounds which there might be upon which the Court might consider it necessary for the purposes of the Inquiry to examine the report. I pronounced that order on 13 June 1989. On 16 June I was advised by Counsel to the Inquiry that the report did not contain information which would add materially to what was already available to the Inquiry. In these circumstances I made no further order in regard to the interim report.

A.9 As regards all documents circulated to the parties by the Crown Office, such as witness statements and productions, the representatives of all parties entered into an agreement with Counsel to the Inquiry that these were provided solely for use by the parties and their agents, experts and representatives in connection with the preparation for and conduct of the proceedings; and gave various undertakings including not to publish their contents beyond the extent to which they had already been made public in the proceedings.

Costs and expenses

A.10 On 9 November 1989 I issued the following Opinion in connection with an application by the Trade Union Group for a direction as to their expenses:-

> The Piper Alpha Trade Union Legal Group, which I shall refer to as "the Group", have applied to me for a direction that the expenses of the Group so far as properly attributable to its participation in Part 1 of the Inquiry should be paid by Occidental. This application, which is opposed by Occidental, was made in reliance on Reg 9(2) of The Offshore Installations (Public Inquiries) Regulations 1974, under which the Inquiry is held. That provides as follows:- "The court may direct that the costs of an inquiry shall be paid in whole or in part by any person who in the opinion of the court, by reason of any act or default on his part or on the part of any agent or servant of his, caused or contributed to the casualty or other accident the subject of the inquiry."
>
> Written submissions in regard to this application have been presented to me by the Group and by Occidental. The Department of Energy and the Department of Transport have also submitted observations in writing. On Day 130 of the Inquiry I heard counsel for these parties and had the benefit of observations by Counsel to the Inquiry.
>
> Counsel for the Group sought to satisfy me that the application was competent; and, if so, that it was made at an appropriate time. He further submitted that it was appropriate for me to make the direction in due course in the light of the view which he had earlier asked me to take as to Occidental's responsibility for what happened in the disaster.
>
> The question of competency, upon which I have had full submissions from counsel, is logically the first point which requires to be addressed and it is appropriate that I should deal with it at the present stage. The short point is whether the expenses of a party such as the Group fall within the meaning of the expression "the costs of an inquiry".
>
> Counsel for the Group submitted that when given its ordinary meaning, which involved eschewing "artificial refinement or subtle distinctions", the expression covered all the costs which were properly incurred by any party whose representation before the Inquiry had been permitted by the court. He pointed out that under Reg 4 the court is to hold the inquiry "in such a manner and in such conditions as the court thinks most effectual for enabling it to make the report required by Reg 9". One of the ways in which it did so, he said, was by scrutinising applications by persons to be represented as parties before the Inquiry. Where permission was given, the basis for that must have been that the court was satisfied that representation of that party before the Inquiry would be of assistance to it. He went on to submit that whereas the remuneration of the court and the assessors was specifically dealt with in Reg 3(2) it was clear that a number of items of expense which were not mentioned in the Regulations but must have been considered by the court to be of assistance to it, were covered by the expression "the costs of an inquiry". He gave as examples the cost of secretarial assistance, accommodation for the Inquiry and the services of Counsel to the Inquiry. By similar reasoning the expression would cover the expense incurred by a person who had been permitted to be a party to the Inquiry. In support of his arguments counsel founded on the decision of Lord Ross in *Holburnhead Salmon Fishing Co. v Scrabster Harbour Trustees*, 1982 SC 65. In that case, he held that the words "all costs, charges and expenses of and incidental to the preparing and obtaining of this Order and otherwise incurred in reference thereto shall be paid by the Trustees" in a provisional order which had been confirmed were wide enough to cover expenses incurred by the company in pursuing its petition against the order. Counsel drew attention to the fact that at page 66 Lord Ross described this language as very wide, adding that he could see no reason why the section should be construed in a narrow sense. Counsel also founded on the terms of certain orders made by the Hon Mr Justice Sheen as Wreck

Commissioner in the Zeebrugge Inquiry under section 56(5) of the Merchant Shipping Act, 1970, which provides that "The Wreck Commissioner or Sheriff may make such order with regard to the costs of the investigation as he thinks just ....". In a supplementary report on costs the Wreck Commissioner stated, *inter alia*, that "the statutory power of a Wreck Commissioner to make an order for costs is laid down in the most general terms". He went on to refer to the principle that an order for costs was used as the only method of penalising which was competent to the court as against parties other than certificated officers. The orders made by him in that inquiry included orders for various payments by Townsend Car Ferries Ltd to representatives of the National Union of Seamen and of certain members of the crew or their dependants, all as orders "with regard to the costs of the investigation".

The above arguments make it necessary for me to examine the true significance of the fact that a person has become a party to the present inquiry. It is to be noted that the 1974 Regulations do not compel, or empower the court to compel, any person to be a party to the inquiry. Further they do not require the court to accept any person as such a party. On the other hand the terms of Reg 7(b) and (d) refer to "any person appearing" at the inquiry and plainly imply that the court has the power to permit persons to appear as parties before the inquiry. That is a power which I exercised in the present inquiry at the Preliminary Hearing on 11 November 1988 by granting permission in the exercise of my discretion and on cause shown. The words in which I expressed what required to be shown, the substance of which would in any event have been implied, were that "I must be satisfied that the person has an interest, and that is a reasonably direct interest, in some aspect of the subject matter of the Inquiry which, as a matter of fairness, requires protection by such representation." Accordingly the basis for giving permission was the possession by a person of such an interest and not the expectation on the part of the court as to the assistance which was expected from him. It is not essential to an inquiry such as the present for any particular persons to be parties to it. In these circumstances I consider that the attempt to make a comparison between the cost of various items which have been provided at the request of the court or those acting on its behalf and the cost of a party's representation before the inquiry is ill-founded.

When the provisions of the 1974 Regulations are further considered a number of other important points emerge. At no point in the Regulations is there any explicit reference to expenses attributable to a person appearing before the inquiry or any mechanism by which a test is provided in order to ensure that the expenses were justified or reasonable. On the other hand express provision is made by Reg 8 for the payment and taxation of the expenses of witnesses. Turning again to Reg 9, para (3) provides that any costs which a person is ordered to pay under para (2) may be recovered from him by the Secretary of State. No provision is made for recovery by any other person, as one would have expected if "the costs of an inquiry" included the expenses attributable to a party's appearance before the inquiry. Para (5) provides that "The costs of an inquiry, other than any costs paid by any person pursuant to a direction of the court under para (2), shall be treated as expenses of the Secretary of State under the Act". There is nothing to suggest that in para (5) the meaning of "the costs of an inquiry" is different from the meaning of that expression where it appears in para (2). If the submissions of the Group are correct it means that, apart from any direction under para (2), the expenses of all parties to the inquiry which are attributable to their participation are to be treated as expenses of the Secretary of State under the Mineral Workings (Offshore Installations) Act 1971, and accordingly by virtue of section 13(1)(a) of that Act, to be paid out of money provided by Parliament. It should also be noted that this would be regardless of whether as matters turned out their representation before the inquiry, which could have involved little or no active participation, was of any assistance to the inquiry. Further, unlike the situation in para (2), there would be no question of any exercise by the court of a discretion which the Group submit can and should be exercised in their favour. These considerations reinforce the views which I have expressed above as to the unsoundness of the Group's submissions.

As regards the two examples of the approach to expenses cited by counsel for the Group I do not find them to be of any real assistance since they depend upon the statutory provisions to which each was related. In *Holburnhead Salmon Fishing Co. v Scrabster Harbour Trustees* it is clear that Lord Ross attached particular importance to the words "and otherwise incurred in reference thereto" which have no parallel in the present case. As regards the orders made at the Zeebrugge Inquiry, there does not appear to have been any dispute as to the competency of making such orders. Further, as counsel for the Department of Energy and the Department of Transport pointed out, it may well be of significance that in terms of the Merchant Shipping (Formal Investigations) Rules 1985, under which that Inquiry was held, certain persons could be made parties to the formal investigation by service of a notice of investigation upon them.

I should add that counsel for the Department of Energy and the Department of Transport also drew to my attention the way in which the Civil Aviation Review Board which was concerned with the Chinook helicopter accident at Sumburgh approached the question of expenses under Reg 14(7)(a) of the Civil Aviation (Investigation of Accidents) Regulations, 1983. In that case the Board, of which the Chairman was Sheriff P G B McNeill, QC, took the view that "the expenses of the review board" included the expenses of persons who were obliged by the Regulations to render assistance to the Review Board but did not include parties who appeared by virtue of Reg 14(2). While this decision is of some interest within its own context, I attach no importance to it for present purposes.

For the reasons which I have set out above I have come to the conclusion that the Group's attempt to bring their expenses within the scope of the expression "the costs of an inquiry" is ill-founded and accordingly I reject their application as incompetent.

A.11 At the end of the Inquiry counsel for the Trade Union Group invited me to make a recommendation on an extra-statutory basis that "payment of the costs incurred by ... MSF and the T & GWU should be made out of central funds." In support of this he pointed out that members of these unions were among the deceased and the survivors. The unions had sought to represent the interests of their members in seeking the reasons for the toll of deaths and injuries: and to promote safety in a number of specific areas of the safety regime, including by its alteration in a number of respects. He suggested that the Inquiry had been assisted by that representation, in particular in cross-examination of the Occidental management and those responsible for the operation of the safety regime. The unions had borne a heavy burden of expenditure. There were considerations of public policy in favour of not discouraging trade unions and other bodies and persons of limited resources from participation in public inquiries into matters of safety. He also drew my attention to recommendations which the inspector had made in the investigations into (i) the King's Cross Underground Fire (in favour of the Fire Brigade's Union and ASLEF); and (ii) the Clapham Junction Railway Accident (in favour of the NUR, TSSA and ASLEF). I have carefully considered these submissions. In my view these submissions have merit, particularly when it is borne in mind that, in regard to the opening up of matters of possible criticism, Counsel to the Inquiry adopted a neutral position. Accordingly the burden of exploring such matters fell to a large extent to the trade unions. On the other hand not all the points which they sought to explore proved to be of assistance to the Inquiry. While the matter of any payment out of public funds is entirely at the discretion of the Secretary of State I recommend that these trade unions should receive a contribution towards their costs. Having considered all the relevant factors I recommend that 40% would be an appropriate proportion. If the Secretary of State is disposed to make a payment out of public funds I recommend, in line with the course proposed by counsel for the Trade Union Group, that the costs should be taxed, failing agreement, by the Auditor of the Court of Session.

Appendix B

List of Parties and their Representatives

The Inquiry

The Solicitor-General for Scotland (Mr A F Rodger QC), Mr T C Dawson QC, Advocate-depute, Mr A P Campbell and Miss M Caldwell, Advocates; Mr A D Vannet, Solicitor, Crown Office, Edinburgh.

Piper Alpha Trade Union Legal Group (comprising 2 firms of solicitors for the representatives of 23 deceased and 8 survivors; and MSF and T & GWU).

Mr H H Campbell QC, Mr I Truscott, Advocate; Messrs Robin Thompson and Partners and Messrs Allan McDougall & Co, SSC, both of Edinburgh.

Piper Disaster Group (comprising 154 firms of solicitors for the representatives of 142 deceased and 49 survivors; and the EETPU).

Mr R N M MacLean QC, Mr C M Campbell, Advocate; Messrs Balfour and Manson, SSC, Edinburgh.

Occidental Petroleum (Caledonia) Ltd, Occidental Petroleum Corporation, Occidental Petroleum (Great Britain) Inc, Texaco Inc, Texaco Britain Ltd, Union Texas Petroleum Holdings Inc, Union Texas Petroleum Ltd and LASMO (TNS) Ltd

Mr J L Mitchell QC, Mr D G Monaghan and Mr D W Batchelor, Advocates; Messrs Paull and Williamsons, Advocates in Aberdeen.

Contractors' Interests (representing the interests of 25 offshore contractors - Aberdeen Offshore Services Ltd, Aberdeen Scaffolding Ltd, Bawden International Ltd, British Telecom PLC, Caleb Brett International Ltd, Eastman Christensen, Exploration Logging Ltd, W R Grace Ltd, Halliburton Manufacturing & Services Ltd, Inspectorate (UK) PLC, Kelvin Catering Ltd, Leuven Services (Aberdeen) Ltd, London Bridge Engineering Ltd, Macnamee Services Ltd, MI Great Britain Ltd, M B Services, McPherson Associates, Neyrfor UK Ltd, N L Petroleum Services (UK) Ltd, Northern Industrial & Marine Services Ltd, Orbit Valve Company Europe, Stena Offshore Ltd, Testwell Services Ltd, Wood Group Engineering Offshore Ltd, Wood Group Valve & Engineering Services Ltd).

The Dean of the Faculty of Advocates (Mr A C M Johnston QC), Mr R S Keen and Mr H W Currie, Advocates; Mr D M G Russell of Messrs Simpson and Marwick, WS, Edinburgh.

*Score (UK) Ltd**

Mr M S Jones QC; Messrs McClure Naismith Anderson & Gardiner, Solicitors, Glasgow.

*Ingersoll-Rand Co Ltd**

Mr G N H Emslie QC, Mr P Atherton, Barrister and Mr J R Campbell, Advocate; Messrs Lace Mawer, Solicitors, Manchester.

*Dresser Rand (UK) Ltd**

Mr D J D Macfadyen QC; Mr J R Foster QC (of the English Bar), Mr J G Reid, Advocate; Messrs Elliott & Co, Solicitors, Manchester.

*Allison Gas Turbine**

Mr F H Bartlit of Messrs Kirkland & Ellis, Attorneys, Chicago; Miss S Mason, Attorney; Messrs Dundas and Wilson, CS, Edinburgh.

Department of Energy and Department of Transport

Mr J M McGhie QC, Dr Lynda Clark QC; Mr A Williams of the Office of the Solicitor to the Secretary of State, Scottish Office, Edinburgh.

United Kingdom Offshore Operators Association Limited#

Mr A R Hardie QC; Messrs McGrigor Donald, Solicitors, Glasgow.

Notes:

The symbol * denotes that the representation was during Part 1 only of the Inquiry. The symbol # indicates that the representation was during Part 2 only.

In addition to the above the following were permitted to appear at the Inquiry:-

Miss Verity Jenner of Messrs Raeburn Christie & Co, Advocates in Aberdeen, on behalf of NUMAST, on day 56 for the interests of Mr J W Sabourn; and Mr N F Davidson, Advocate and Mr C R R Cowie of Macroberts, Solicitors, Edinburgh, on days 64, 65, 66 and 129 for the interests of Texaco North Sea (UK) Co Ltd.

Appendix C

List of Witnesses in Part 1

1.	AMAIRA, E Z	Diver (Survivor)
2.	ANSTOCK, C	Detective Inspector, Identification Bureau, Grampian Police
3.	ASHBY, A R	Former Deputy OIM, MSV Tharos
4.	ATKINSON, F H	Manager, Offshore Division, Lloyds Register
5.	BAGNALL, G H	Lead Maintenance Technician, Occidental
6.	BAKKE, J R DR	Manager, Explosion Research Laboratories, Christian Michelsen Institute, Norway
7.	BALFOUR, D DR	Director, Sieger Ltd
8.	BALLANTYNE, R H	Electrician (Survivor)
9.	BARCLAY, R W	Mechanical Fitter, formerly with Wood Group Valve and Engineering Services Ltd
10.	BARR, J	Diving Supervisor (Survivor)
11.	BARRON, W P	Chargehand/Foreman Painter (Survivor)
12.	BERRIFF, P	Independent Television Producer
13.	BETT, K E DR	Senior Lecturer, Department of Chemical Engineering, Imperial College, London
14.	BLAIR, D I	First Mate/DP Operator, MSV Tharos
15.	BODIE, A	Offshore Safety Superintendent, Occidental
16.	BOLLANDS, G	Production Operator (Survivor)
17.	BRADING, J E	Chairman, Occidental Petroleum (Caledonia) Ltd
18.	BRADLEY, M J	Rigger (Survivor)
19.	BRUCE, A C	Valve Technician, formerly with Score (UK) Ltd
20.	BURNS, J	Shift Supervisor - MCPO1, Total Oil
21.	BUSBY, F	Driller (Survivor)
22.	CALDER, H J	Helicopter Landing Officer (Survivor)
23.	CAREY, R F	Instrument Technician (Survivor)
24.	CARR, W H	Director, John Wood Group PLC and Wood Group (Engineering) Ltd
25.	CARROLL, A M	Inspection Diver (Survivor)
26.	CARSON, G	Second Engineer/Medic, MV Silver Pit
27.	CASSIDY, N G	Instrument Technician (Survivor)
28.	CLARK, A G	Maintenance Leadhand (Survivor)
29.	CLARK, M R	Chief Process Engineer, Occidental
30.	CLAYSON, P G	Former Safety Superintendent, Occidental
31.	CLAYTON, W F	Scaffolder (Survivor)
32.	CLEGG, M	Master, MV Lowland Cavalier
33.	COMMON, R M	Site Administrator (Survivor)
34.	CORMACK, E J	Police Constable, Grampian Police
35.	COTTER, J E	Production Operator, Occidental
36.	COX, R A DR	Consultant, formerly Chief Executive, Technica Ltd, Consulting Scientists and Engineers
37.	CRAIG, J A	Valve Technician (Survivor)

38.	CROSS, J H	Managing Director, RGIT Survival Centre Ltd, Aberdeen
39.	CUBBAGE, P A	Consultant Scientist, Cremer and Warner Ltd, Consulting Engineers and Scientists
40.	CUNNINGHAM, K	Diver (Survivor)
41.	DAVIDSON, J	Operations Superintendent - Claymore, Occidental
42.	DAVIE, R A	Senior Consultant, Yard Ltd
43.	DAVIES, M E DR	Managing Director, BMT Fluid Mechanics Ltd
44.	DIXON, J P	Painter, formerly of Wood Group Engineering
45.	DRYSDALE, D D DR	Lecturer, Unit of Fire Safety Engineering, University of Edinburgh
46.	DRYSDALE, J	Production Operator, Occidental
47.	DUGUID, I	Lead Roustabout (Survivor)
48.	DUTHIE, D	Detective Sergeant, Grampian Police
49.	ELLINGTON, D	Rigger (Survivor)
50.	ELLIOTT, D	Foreman Rigger (Survivor)
51.	ELLUL, I R	Consultant Engineer, Scientific Software-Intercomp (UK) Ltd
52.	ENNIS, S O	Master, MV Sandhaven
53.	FERGUSON, I	Mechanical Technician (Survivor)
54.	FLAWS, W J	Deck Foreman, MSV Tharos
55.	FOWLER, I N	Joiner (Survivor)
56.	GIBSON, R	Construction Engineer, Coflexip (UK) Ltd - MV Lowland Cavalier (Photographs)
57.	GOODWIN, B	Chargehand Rigger (Survivor)
58.	GORDON, I M	Chief Inspector, Grampian Police
59.	GORDON, R McG	Manager, Loss Prevention Department, Occidental
60.	GORDON, T D	First Mate/DP Operator, MSV Tharos
61.	GRANT, P M	Manager of Human Resources, Bawden International Ltd
62.	GRIEVE, E C	Production Operator (Survivor)
63.	GRIEVE, J H K DR	Head of the Department of Forensic Medicine, University of Aberdeen
64.	GRIFFITH, I L	Helicopter Pilot, British International Helicopters
65.	GROGAN, G E	Vice President Engineering, Occidental
66.	GUIOMAR, D	OIM -MCPO1, Total Oil
67.	GUTTERIDGE, J L	Toolpusher (Survivor)
68.	HAFFEY, C A	Seaman, MV Silver Pit
69.	HENDERSON, J S	Commandant, Offshore Fire Training Centre, Montrose
70.	HENDERSON, T A	Lead Operator, Occidental
71.	HENDRY, W T DR	Former Head of the Department of Forensic Medicine, University of Aberdeen
72.	HILL, D J	Crane Operator (Survivor)
73.	HODGSON, S A	Flight Lieutenant - 202 Squadron, RAF Lossiemouth
74.	HUTCHISON, E	Nautical Surveyor, Maritime Directorate, Department of Transport
75.	JACKSON, B	Rigger (Survivor)

76. JEFFREY, P G	Consultant Engineer, Plessey Assessment Services Ltd
77. JENKINS, R D	Senior Inspector, PED, Safety Inspectorate, Department of Energy
78. JENNINGS, M H G	Flight Information Logistics Officer (Survivor)
79. JOHNSEN, H K DR	Managing Director, Petreco A/S, Norway
80. JONES, J M CAPT	Managing Director, London Offshore Consultants
81. KERR, E R	Radio Officer, British Telecom International, Wick Radio Station
82. KHAN, M R	Chemist (Survivor)
83. KILOH, A J	Deckhand, MV Silver Pit
84. KINRADE, D H	Radio Operator (Survivor)
85. KONDOL, J M	Deputy OIM, MSV Tharos
86. LAMB, C W	Mechanical Fitter (Survivor)
87. LAMBERT, D	Scaffolder (Survivor)
88. LEEMING, J	Former OIM - Tartan, Texaco
89. LETHAM, I	Former Deck Hand, MV Sandhaven
90. LETTY, A D MacK	OIM, MSV Tharos
91. LLOYD, P	Senior Electrical Engineer, Occidental
92. LOBBAN, W J	Water Blaster (Survivor)
93. LOCKWOOD, C	Lead Production Operator, Occidental
94. LYNCH, J	Lead Production Operator, Occidental
95. MACALLAN, J L	Production and Pipeline Manager, Occidental
96. MCDONALD, A G	Head of Telecommunications - North Sea, Occidental
97. MCDONALD, J McG	Rigger (Survivor)
98. MACDONALD, L M T	Electronic Technician, UDI Group Ltd -MV Lowland Cavalier (Photographs)
99. MCGEOUGH, F	Safety Training Co-Ordinator, Occidental
100. MCGREGOR, R J	Mechanical Technician (Survivor)
101. MACKAY, A J	Electrician (Survivor)
102. MACKAY, I F	First Mate, MV Lowland Cavalier
103. MCLAREN, W McI	Electrical Engineer Surveyor, Lloyds Register
104. MACLEAN,R MacK C	Master, MV Loch Carron
105. MACLEOD, S R	Diving Superintendent (Survivor)
106. MCNEIL, D A DR	Senior Scientific Officer, National Engineering Laboratory
107. MCNEILL, J P	Former Coxswain, MV Silver Pit
108. MACPHERSON, C A	Master, MV Loch Shuna
109. MCREYNOLDS, A D	Vice President - Operations, Occidental
110. MARSHALL,J G DR	Consulting Scientist, formerly with Burgoyne and Partners
111. MAY, D J McD	Senior Engineer for Pipelines and Structures, Marine Department, Occidental
112. MEANEN, J S	Scaffolder (Survivor)
113. MENZIES,J A R H	Scaffolder (Survivor)
114. MIDDLETON, A H	Noise and Vibration Consultant/Director, Anthony Best Dynamics Ltd
115. MIDDLETON, S J	Diver (Survivor)

116. MILLAR, A J	General Secretary, Professional DiversAssociation
117. MILLER, C A	Mobile Diving Unit Pilot, Aberdeen Offshore Services - MSV Tharos (Photographs)
118. MILLER, D A	Security Manager, Occidental
119. MITCHINSON, W	Former Mate, MV Silver Pit
120. MOCHAN, A H	Superintendent Engineer (Survivor)
121. MORETON, M D	Production Supervisor - Tartan, Texaco
122. MORTON, C I	Master, MV Maersk Cutter
123. MUIR, I F	Former Second Mate, MV Loch Shuna
124. MURPHY, P J	First Engineer, MSV Tharos
125. MURRAY, J	Helicopter Engineer, British International Helicopters
126. MURRAY, J	Production Operator, Occidental
127. NAYLOR, D E	Driller (Survivor)
128. NIVEN, C I	Diver (Survivor)
129. PALMER, A C DR	Managing Director, Andrew Palmer andAssociates Ltd, Consulting Engineers
130. PARRYDAVIES, G P	Diver (Survivor)
131. PATERSON, E A MRS	Former Process Chemical Engineer, Occidental
132. PATERSON, R E	Welder (Survivor)
133. PATERSON, W N	Chief Engineer, MSV Tharos
134. PATIENCE, J A	Lead Safety Operator, Occidental
135. PETRIE, J R	Director of Safety, PED, Safety Directorate, Department of Energy
136. PILLANS, G P	Senior Electrical Surveyor, Lloyds Register
137. PIRIE, A	Service Engineer, Wood Group Valve and Engineering Services Ltd
138. PLUMMER, C D	Chief Engineer, Atkins Oil And Gas Engineering Ltd
139. POUNTNEY, R J	Winchman - 202 Squadron, RAF Lossiemouth
140. POWELL, A C M	Crane Operator (Survivor)
141. PUNCHARD, E T R	Diving Inspection Controller (Survivor)
142. RAE, S	Electrician (Survivor)
143. RALPH, N E	Foreman Rigger (Survivor)
144. RANKIN, A D	Valve Technician (Survivor)
145. REID, M A	Lead Foreman (Survivor)
146. RICHARDS, G	OIM(Back to Back) - Piper Alpha, Occidental
147. RICHARDSON, S M DR	Senior Lecturer, Department of Chemical Engineering and Chemical Technology, Imperial College, London
148. RITCHIE, A	Detective Superintendent, Grampian Police
149. RITCHIE, A A	Civil Engineer, Ritchie Sub-sea Engineering - MV Lowland Cavalier (Photographs)
150. RITCHIE, C B	Managing Director, Score (UK) Ltd
151. ROBERTS, G D	Squadron Leader, RAF - Rescue Co-ordination Centre, Edinburgh
152. ROBERTS, K	Facilities Engineer - Tartan, Texaco
153. ROBERTSON, G G	Safety Supervisor, Occidental

154. ROBINSON, D T	Barge Clerk/Helicopter Landing Officer, MSV Tharos
155. ROGERS, T	Facilities Engineer, Occidental
156. ROWAN, C J	Senior Diving Superintendent, StenaOffshore
157. RUSSELL, J B	Mechanical Fitter (Survivor)
158. RUTHERFORD, J	Rigger, Wood Group Engineering Offshore Ltd
159. SABOURN, J W	Former Master, MV Silver Pit
160. SANDLIN, S B	OIM - Claymore, Occidental
161. SAVILLE, G DR	Department of Chemical Engineering and Chemical Technology, Imperial College,London
162. SCANLON, T J	Offshore Superintendent, formerly with Wood Group Engineering Offshore Ltd
163. SCILLY, N F DR	Principal Specialist Inspector, Technology Division, Health and Safety Executive
164. SCOTHERN, E	Instrument Technician, Occidental
165. SEDDON, R H	Senior Maintenance Superintendent, Occidental
166. SKIDMORE, M	Senior Facilities Engineer, Occidental
167. SLAYMAKER, J M	Production Operator, formerly with MB Services
168. SMYLLIE, R J	Senior Engineer, Cremer and Warner Ltd, Consulting Engineers and Scientists
169. SNEDDON, R G	Operations Superintendent, Occidental
170. STANDEN, R	Senior Physicist, NOWSCO Well Services Ltd
171. STICKNEY, M E DR	Senior Systems Engineer, Hughes Aircraft Corporation
172. STOCKAN, L W	Lead Process Operator, Flotta Terminal, Occidental
173. STRACHAN, R DR	Consultant, Aberdeen Industrial Doctors
174. STREET, W R	Director, Hollobone Hibbert and Associates Ltd
175. SWALES, V	Derrickman (Survivor)
176. SYLVESTER-EVANS, R	Associate Director, Cremer and Warner Ltd, Consulting Engineers and Scientists
177. TAIT, J	Service Engineer, Score (UK) Ltd
178. TEA, D C	Instrument Technician, Occidental
179. THOMPSON, D McR	Rigger (Survivor)
180. THOMSON, M S	Senior Engineer Surveyor, Lloyds Register
181. THOMSON, R G	Industrial Cleaner (Survivor)
182. THORNTON, P G	Assistant Firemaster, Grampian Fire Brigade
183. TODD, A C B	Maintenance Superintendent, Occidental
184. TUCKER, D M	Fire and Loss Consultant/Senior Partner, Tucker Robinson, Consulting Scientists
185. TURNER, D J	Managing Director, Camera Alive Ltd
186. WATT, A	Valve Technician, Score (UK) Ltd
187. WATTS, P C A	Chief Process Engineer, Kaldair Ltd
188. WELLS, J V	Diver (Survivor)
189. WHALLEY, D	Team Leader, Score (UK) Ltd
190. WILLIAMSON, R	Service Technician, Bran and Leubbe (GB) Ltd, Pump Manufacturers
191. WOOD, A L	Fitter (Survivor)
192. WOOD, J O	Diving Technician (Survivor)

193. WOOD, W P	Ship Surveyor, Marine Directorate, Department of Transport
194. WOTTGE, K R	Facilities Engineering Manager, Occidental
195. WYNN, J P A	District Staff Officer, HM Coastguard, Aberdeen
196. YOUNG, W H	Instrument Technician (Survivor)

(Note: Three witnesses, MACKENZIE, I H - Scaffolder (Survivor), MILLER, H J - Rigger (Survivor) and PAYNE, A G - Diver (Survivor), did not give evidence at the Inquiry but their statements were read out by Counsel to the Inquiry at the end of Part 1.)

Appendix D

List of Reports by Experts Submitted in Evidence in Part 1

1. **Andrew Palmer and Associates Limited**

   "Damage to 4 inch condensate line in Module B of Piper Alpha Platform" - May 1989 - spoken to by Dr A Palmer

2. **Anthony Best Dynamics Limited**

   "Investigation of noises heard prior to the first explosion" - September 1989 - spoken to by Mr A H Middleton

3. **Atkins Oil and Gas Engineering Limited**

   "Study of Piper Alpha liquid carry-over to compressors scenario" - June 1989 - spoken to by Mr C D Plummer

4. **BMT Fluid Mechanics Limited**

   "Airflow and gas dispersion study" - August 1989 - spoken to by Dr M E Davies

5. **Bran and Leubbe**

   "Investigation of the stroke settings of the six-head methanol injection pump" - September 1989 - spoken to by Mr R Williamson

6. **Camera Alive Limited**

   "Report on analysis of polaroid photograph of flange" - August 1989 - spoken to by Mr D J Turner

7. **Christian Michelsen Institute**

   7.1 "Simulation of gas explosions in Module C, Piper Alpha" - November 1988 - spoken to by Dr J R Bakke

   7.2 "Gas explosion simulation in Piper Alpha Module C using FLACS" - September 1989 - spoken to by Dr J R Bakke

8. **Cremer and Warner**

   8.1 "Preliminary review of potential causation scenarios" - January 1989

   8.2 "Possible explanations for the prolonged flaring and venting on the Piper Alpha platform after the initial explosion" - June 1989 - spoken to by Mr R Smylie

   8.3 "Report on scenarios put forward by the Department of Energy from scenario C" - August 1989 - spoken to by Dr R Sylvester-Evans

   8.4 "Review of evidence relating to the initial explosion on the Piper Alpha platform on 6 July 1988" - spoken to by Dr P Cubbage

9. **Department of Chemical Engineering and Chemical Technology, Imperial College**

   9.1 "An appreciation of the operation of the reciprocating compressors used on the Piper Alpha oil platform" - June 1989 - spoken to by Dr K E Bett

   9.2 "Hydrate formation on Piper Alpha" - June 1989 - spoken to by Dr S M Richardson

9.3 "Analysis of flows in Piper Alpha gas import and export lines" - June 1989 - spoken to by Dr S M Richardson

9.4 "Autoignition in line to site of PSV 504 on Piper Alpha" - August 1989 - spoken to by Dr S M Richardson

9.5 "Gas and liquid leakage from line 2-P-524-4"-F15" - September 1989 - spoken to by Dr S M Richardson

9.6 "Repressurisation of lines associated with condensate injection pump 2-G-200A on Piper Alpha" - June 1989 - spoken to by Dr G Saville

9.7 "Leakage from line 2-P-524-4"-F15 to site of PSV 504 on Piper Alpha" - August 1989 - spoken to by Dr G Saville

9.8 "Hydrate/ice formation and occurrence of low temperatures in flare, vent and recycle lines on Piper Alpha" - September 1989 - spoken to by Dr G Saville

9.9 "Hydrate formation downstream of Joule-Thomson valve PCV 721" - September 1989 - spoken to by Dr G Saville

9.10 "Overpressurisation of condensate injection pump 2-G-200B and associated lines on Piper Alpha" - September 1989 - spoken to by Dr G Saville

9.11 "Failure pressures in discharge and safety valve lines from pump 2-G-200B" - September 1989 - spoken to by Dr G Saville

10. **Department of Fire Safety Engineering, University of Edinburgh**

"Review of evidence relating to the development of the fire which followed the initial explosion in module C" - August 1989 - spoken to by Dr D Drysdale

11. **Department of Forensic Medicine, University of Aberdeen**

"Statement by Head of Department of Forensic Medicine, University of Aberdeen" - August 1989 - spoken to by Dr W T Hendry

12. **Dr J G Marshall**

"The Piper Alpha disaster - a preliminary report on the potential sources of ignition" - spoken to by Dr J G Marshall

13. **Health and Safety Executive**

13.1 "An assessment of the explosion effects, and conditions likely to give rise to such effects, on the Piper Alpha production platform" - August 1988 - spoken to by Dr N F Scilly

13.2 "An assessment of the explosion effects, and conditions likely to give rise to such effects, on the Piper Alpha production platform - Supplementary report" - May 1989 - spoken to by Dr N F Scilly

14. **Hollobone Hibbert and Associates Limited**

"Feasibility of the recovery of subsea wreckage from Piper Alpha" - January 1989 - spoken to by Mr W R Street

15. **Hughes Training and Support Systems Group**

"Report of photograph processing and enhancement" - July 1989 - spoken to by Dr M F Stickney Jr

16. **Kaldair**

"Technical study of the flare performance during the Piper Alpha incident" - February 1989 - spoken to by Mr P C A Watts

17. **London Offshore Consultants**

"Preliminary report on the adequacy of the investigation and subsequent report by Hollobone Hibbert and Associates Ltd entitled "Feasibility of the recovery of subsea wreckage from Piper Alpha" " - February 1989 - spoken to by Captain J M Jones

18. **National Engineering Laboratory**

18.1 "Leakage evaluation tests on a weld-neck flange and blind flange assembly in connection with the Piper Alpha Public Inquiry investigation" - July 1989 - spoken to by Mr R A Davie

18.2 "Assessment of the NEL flange leakage experimental results taken in connection with the Piper Alpha Inquiry" - September 1989 - spoken to by Dr D A McNeil

19. **Nowsco Well Service (UK) Limited**

"Leakage and related effects from a pipe under pressure" - spoken to by Mr F Standen

20. **Petreco**

"Investigation into hydrate properties and their possible formation within the Piper Alpha production process" - September 1989 - spoken to by Dr H K Johnsen

21. **Plessey Assessment Services**

"Piper Alpha liferaft investigation" - April 1989 - spoken to by Mr P G Jeffrey

22. **Scientific Software-Intercomp**

"Hydraulic study of pipelines associated with the Occidental Piper Alpha platform" - December 1988 - spoken to by Dr I Ellul

23. **Sieger Limited**

"Report on gas detection" - spoken to by Dr D Balfour

24. **Technica, Consulting Scientists and Engineers**

24.1 "Investigation of blast resistance of firewalls" - August 1988 - spoken to by Dr R A Cox

24.2 "Investigation of blast resistance of firewalls - Supplementary Report" - May 1989 - spoken to by Dr R A Cox

24.3 "Extent of damage caused by the initial explosion and probable effects on critical systems" - June 1989 - spoken to by Dr R A Cox

24.4 "Projectile effects of firewall disintegration" - June 1989 - spoken to by Dr R A Cox

24.5 "Investigation of failure times of Tartan gas riser due to varying heat loads" - June 1989 - spoken to by Dr R A Cox

25. **Tucker Robinson**

"Report on the examination of the fire and smoke damage in Piper Alpha accommodation modules, east replacement quarters and additional accommodation west" - June 1989 - spoken to by Mr D M Tucker

Appendix E

List of Witnesses in Part 2

(and the subject matter of their evidence)

1.	ADAMS, A J	Principal Pipeline Inspector, Safety Directorate of PED, Department of Energy	Pipeline Isolation Systems including Subsea Valves
2.	ALLEN, C S	Head of Alwyn Safety, Total Oil Marine PLC	Application of Computers to Permit to Work Systems for Offshore Installations
3.	ASHWORTH, M	Senior Control Engineer, BP International	Process Control and Emergency Shutdown Systems
4.	BANKS, R P	Supervisor of Engineering Design and Construction, Chevron (UK) Ltd	The Qualifications and Qualities required in an Offshore Maintenance Supervisor
5.	BAXENDINE, M R	Offshore Installation Manager, Shell (UK) Exploration & Production Ltd	Command Structure in an Emergency
6.	BOOTH, M J	Head of Operations Safety, Shell (UK) Exploration & Production Ltd	Escape Routes to the Survival Craft and the Helideck on Offshore Installations
7.	BRANDIE, E F	Safety and Compliance Manager, Chevron (UK) Ltd, Chairman of UKOOA Fire Protection Working Group, representative of CBI on OIAC	Factors for Enhancing the Integrity of Offshore Safe Haven Areas. An Alternative to Standard Firewater System Designs for UK Sector Offshore Installations
8.	BROADRIBB, M P	Central Safety Engineering Superintendent, BP Exploration	Subsea Isolation Valves - The BP Approach
9.	CHAMBERLAIN, G A DR	Technical Leader of Explosion Protection Review Task Force, Shell (UK) Exploration & Production Ltd	The Nature and Mitigation of Vapour Cloud Explosions
10.	COX, R A DR	Consulting Engineer, formerly Chief Executive of Technica Ltd	Overview of Quantified Risk Assessment
11.	CUNNINGHAM, A W T	Occupational Health and Safety Officer, EETPU	Safety Representatives
12.	DALZELL, G A	Fire and Safety Engineer, BP International, Member of UKOOA Fire Protection Working Group	The Prevention of Smoke Ingress into Offshore Accommodation Modules

13.	DANIEL, J J S	Director, Hollobone Hibbert & Associates Ltd, Chairman of the Standby Ship Operators Association Ltd Standby Vessels
14.	DAVIES, G H	Area Director, Health and Safety Executive, Merseyside & Cheshire Area Permits to Work
15.	DAY, J	Head of Electrical Engineering, Shell Exploration & Production Ltd, Member of UKOOA Electrical Sub-committee Electrical Power for Emergency Systems
16.	DE LA PENA, M	Divisional Director, Environmental & Safety Products Division, Dowty PLC Smoke Hoods
17.	DENTON, A A DR	Chairman, Noble Denton International Ltd, Vice President of the Institution of Mechanical Engineers Quality Management Systems
18.	DOBLE, P A C	Deputy Project Manager, Kittiwake Project, Shell (UK) Exploration & Production Ltd The Means of Preventing and Mitigating the Effects of an Explosion - Kittiwake Project
19.	DREW, B C	Chief Surveyor, Marine Directorate, Department of Transport Code for Assessment of the Suitability of Standby Vessels
20.	ELLICE, K A J	Training Manager, BP Exploration Training of Offshore Installation Managers
21.	ELLIS, A F DR	Deputy Chief Inspector, Technology Division, Health & Safety Executive Quantified Risk Assessment - HSE's View
22.	EVANS, J D	Research & Development Manager, MSA (Britain) Ltd Smoke Hoods
23.	FERROW, M	Manager, Safety & Quality Assurance, Conoco (UK) Ltd The Offshore Safety Regime and Formal Safety Assessments
24.	FLEISHMAN, A B	Senior Safety Technologist, Group Safety Centre, BP International Gyda Safety Evaluation
25.	GILBERT, R B DR	Chief Engineer, Nelson Project Team, Shell (UK) Exploration & Production Ltd Subsea Valves
26.	GINN, M C CAPT	Principal Air Transport Officer, British Gas PLC, Chairman of UKOOA Aircraft Committee The use of Helicopters in Offshore Evacuation
27.	GORSE, E J	Principal Inspector, Safety Directorate of PED, Department of Energy Formal Safety Assessments
28.	HEIBERG-ANDERSON, G	Platform Manager, Gullfaks C, Statoil, Norway The Means of Ensuring Safe and Full Evacuation - The Statoil Approach, The Control of the Process

29.	HIGGS, F	National Secretary of the Chemical, Oil & Rubber Group, Transport & General Workers' Union The Offshore Safety Regime
30.	HODGKINS, D J	Director of Safety and General Policy Division, Health and Safety Executive The Agency Agreement between the Health and Safety Commission and the Department of Energy
31.	HOGH, M S DR	Manager Projects and External Affairs, Group Safety Centre, BP International Overview of Use and Value of Quantified Risk Assessment
32.	JONES, M J	Training Officer, Central Training Division, BP Exploration Development of Craft Training Scheme
33.	KEENAN, J M	Assistant General Secretary, Banking Insurance & Finance Union, formerly District Officer, Transport & General Workers' Union, Aberdeen Standby Vessels
34.	KELLEHER, T W	Fire and Safety Engineer, Shell Exploration & Production Ltd, Project Manager of Department of Energy/UKOOA Research Projects on Evacuation by TEMPSC Survival Craft and Free Fall Lifeboats
35.	KINLOCH, D S	Offshore Installation Manager, Conoco (UK) Ltd Independent Actions during Emergencies, Permit to Work Procedure
36.	KYLE, S R	Environment and Safety Co-ordinator, Brae Operations, Marathon Oil (UK) Ltd, Chairman of UKOOA Working Group on Permits to Work Permit to Work Procedure
37.	LIEN, E	Technical Director, Selantic Industrier as, Norway Skyscape Offshore Emergency Evacuation System
38.	LITTLEJOHN, I J	Process and Maintenance Engineering Group Supervisor, Amoco (UK) Exploration Ltd The Qualifications and Qualities Required in an Offshore Supervisor
39.	LYONS, R A	Assistant General Secretary, Manufacturing, Science & Finance Union The Offshore Safety Regime
40.	MCINTOSH, A R	Principal Inspector, Safety Directorate of PED, Department of Energy Protection against Fire and Explosion
41.	MCKEE, R E	Chairman and Managing Director, Conoco (UK) Ltd Managing Safety
42.	MACEY, M	Director, Maritime Rescue Services Ltd Standby Vessels - Training of Personnel
43.	MATHESON, A B MR	Consultant in Accident and Emergency Care, Aberdeen Royal Infirmary The Offshore Specialist Team
44.	MARSHALL, V C DR	Chartered Engineer, Formerly Director of Safety Services, Bradford University Safety Cases and Safety Assessments

45.	MIDDLETON, C J	Marine Superintendent, Marathon (UK) Ltd, Chairman of UKOOA Marine Committee Standby Vessels
46.	NORDGARD, T	Vice President, Projects Division, Statoil, Norway The Location and Protection of Accommodation on Integrated Drilling and Production Platforms on the Norwegian Continental Shelf
47.	OGNEDAL, M	Director, Safety and Working Environment Division, Norwegian Petroleum Directorate The Norwegian Offshore Safety Regime
48.	PAPE, R P DR	Head of Major Hazards Assessment Unit, Health and Safety Executive Quantified Risk Assessment - HSE's Experience
49.	PERROTT, I R	Assistant Chartering Manager, Maersk Co Ltd Skyscape
50.	PETRIE, J R	Director of Safety, PED, Department of Energy Life-Saving Appliances, The Offshore Safety Regime
51.	PRIDDLE, R J	Deputy Secretary, Department of Energy The Offshore Safety Regime
52.	RIMINGTON, J D	Director General, Health and Safety Executive The Onshore Safety Regime
53.	RUDD, D T	Marine Superintendent, BP Exploration Evacuation Policy and Plan for Forties Field
54.	SCANLON, T J	Mechanical Piping Engineer (formerly Offshore Superintendent, Wood Group Engineering Offshore Ltd) Permit to Work Systems
55.	SEFTON, A D DR	Leader of the Hazardous Installations and Transport of Dangerous Substances National Interest Group, Health and Safety Executive The Control of Industrial Major Accident Hazards Regulations 1984, Safety Reports
56.	SHEPPARD, R A	Vice President (Production) and Director, Amoco (UK) Exploration Co Ltd Managing Safety
57.	SIDE, J DR	Senior Policy Scientist, Institute of Offshore Engineering, Heriot-Watt University Offshore Emergency Rescue and Evacuation
58.	SPOUGE, J R	Consulting Senior Engineer, Technica Ltd Comparative Safety Evaluation, Arrangements for Accommodating Personnel Offshore
59.	TAYLOR, B G S DR	Director of Technical Affairs, UKOOA The Development and Future of the Offshore Oil Industry
60.	TVEIT, O J	Senior Engineer, Statoil, Norway Risk Assessment, The Norwegian Offshore Safety Regime
61.	VAN BEEK, A W	Head of Offshore Structures Engineering, Shell (UK) Exploration & Production Ltd Blast Walls

62.	VASEY, M W DR	Manager, Safety Modelling and Offshore Safety, British Gas PLC Midlands Research Station Possible Mitigation of Module Explosions on Offshore Platforms
63.	WALLACE, I G	Superintendent of Occupational Safety and Health, Conoco (UK) Ltd, Member of UKOOA Safety Committee and Chairman of Department of Energy Emergency Evacuation Steering Committee Emergency Evacuation and Escape/TEMPSC, Methods of Emergency Escape to Sea
64.	WILLATT, R	Senior Pipeline Engineer, BP Engineering Piplines Group Functional and Safety Aspects of Offshore Pipeline Connections

Appendix F

Supplementary Material on Chapter 3

F.1 A description of the Piper Alpha platform was given in Chapter 3. Further information on certain detailed features is given here.

Centrifugal compressors

F.2 There were 3 parallel centrifugal compressor trains. The A train consisted of a suction scrubber, a centrifugal compressor, 1-K-105A, a gas cooler, and a discharge scrubber; the B and C trains were similar. Each compressor together with its turbine was housed in its own separate compartment at the extreme east end of C Module and the associated equipment was located on the centrifugal compressor gas skid inboard of the compressors themselves.

F.3 The function of the suction scrubber was to remove any condensate droplets not removed in the condensate knockout drum and carried forward. In normal operation there would be virtually no condensate removed at this point. Condensate would be formed, however, following compression and cooling and this condensate was removed in the discharge scrubbers. There was a level controller on each discharge scrubber.

F.4 Each compressor was driven by its own gas turbine. Air entering the first section, the gas generator, was compressed, fuel gas was then injected and the resultant mixture burnt and then expanded through 2 sets of turbines, the first to drive the air compressor just referred to, and the second, the power turbines, to drive the centrifugal compressors. The exhaust gases from these turbines were vented through tall exhausts at the east face of the module. The turbines were supplied with fuel gas from the fuel gas system. The fuel gas line within the turbine compartment included a hose section.

F.5 The compressor trains were equipped with gas operated valves (GOVs) to allow them to be shut in. There were a considerable number of trips on the turbines or the compressors themselves, including high gas discharge temperature; high suction and discharge scrubber levels; high and low fuel gas pressure; enclosure high temperature, fire and gas (50% LEL); seal and lube oil systems; and vibration. There was a seal oil system on each compressor to prevent gas escaping. On shutdown of the compressor the seal oil system would also shut down, though after a time delay. If the compressor was still pressurised, gas could escape and therefore on shutdown the compressor was automatically vented. There were recycle loops on the compressors and anti-surge controls to maintain the flow of gas through the machines by recycling and thus preventing them going into surge conditions.

F.6 Each compressor set was housed in an individual enclosure, made of steel sheet, the gas turbine and the compressor being in separate compartments of the enclosure, separated by a bulkhead, with the turbines outboard. The turbine compartment had double doors on the south side and the compressor compartment a single door also on the south side. The controls for the compressor, and its turbine, were on a local control panel, which was situated on the west side of the enclosure.

F.7 The turbine air intakes and exhausts and the enclosure ventilation are shown in Fig F.1. Air was drawn in to the turbine intakes through filter-silencer units with inlets located on both north and south sides at the east end of the turbine compartment. Burnt gas passed out through the exhausts, the outlets of which were high up, facing east, on the east side. Air for the ventilation of both turbine and compressor compartments was taken in at a south-facing intake at the east end of the enclosure. The source of this air was outside the module and from a safe area. Ventilation air from the turbine compartment passed out through a duct which terminated on the east side, while air from the compressor compartment passed out into the module through louvres on that compartment.

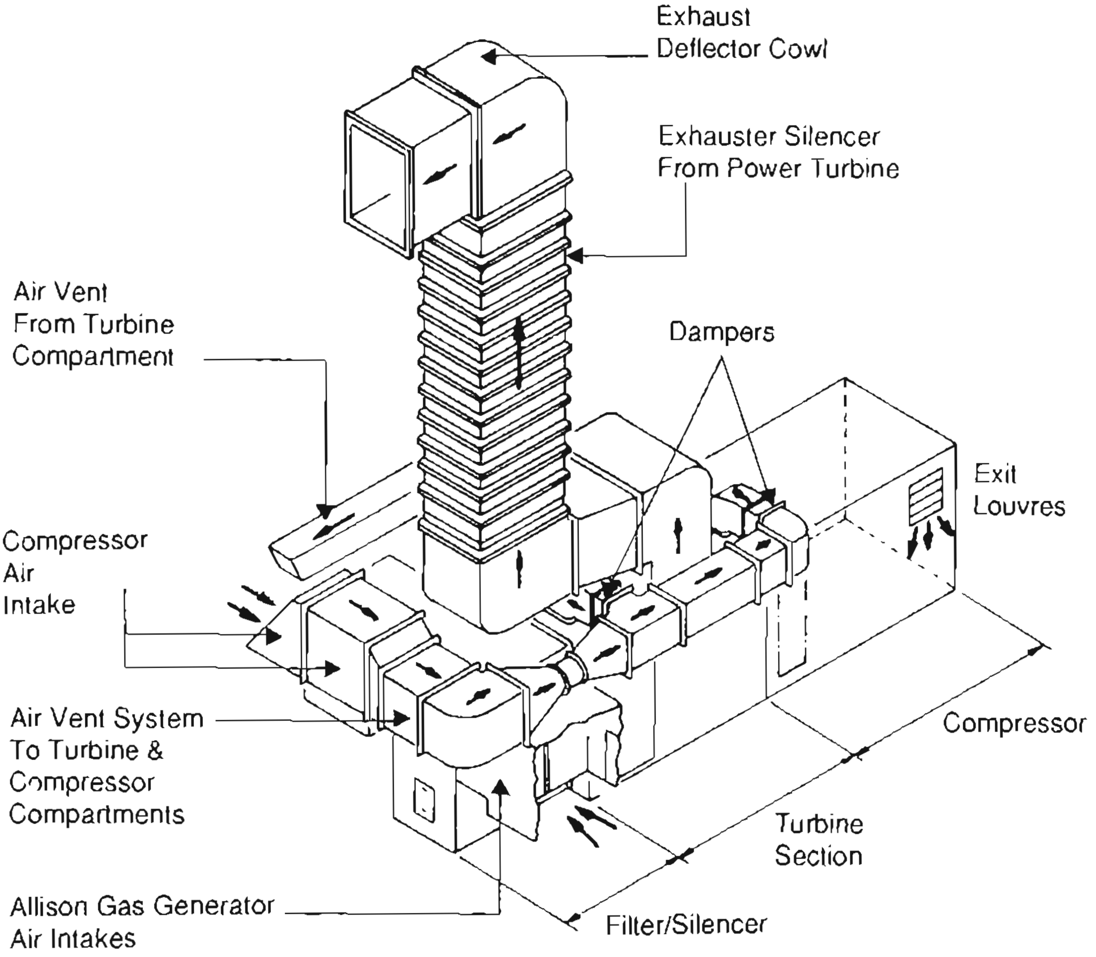

Fig. F.1 Ventilation system of the centrifugal compressor and gas turbine enclosures.

F.8 The ventilation system was designed to trip if the compressors stopped, but it was fitted with a time delay relay which permitted the ventilation to continue running for 2 hours after the turbine and compressor were shut down. However, if the gas detector at the ventilation air inlet registered a high gas alarm, both the compressor and ventilation systems would shut down immediately. The setting of this alarm was said to be 50% LEL, as for the turbine and compressor compartments, but this was not confirmed.

F.9 The compressor enclosures were about 10 ft high and stood on the solid deck of the module. There was a grating 2 ft above the deck and around the compressor set enclosure. About 5 ft to the west of the centrifugal compressor enclosure the solid deck sloped up and joined the grating. It then ran at that level until it reached the reciprocating compressors, after which it dropped 2 ft again and continued thus to the west side. There was no connection through which gas could flow at deck plate level from the east to the west side, because of the rise part way through the module. There was a half-door, starting at 3 ft and ending at 10 ft up, between the compressor enclosure and firewall on compressor C and between the 2 enclosures of C and B compressors, at the east end of the turbine filter-silencers and another door at the west end of these; the arrangements between the other compressors were not explored.

Reciprocating compressors

F.10 There were 2 parallel trains of reciprocating compressors with first and second stage compression. The first stage of the A train consisted of a suction scrubber, a reciprocating compressor, 1-K-103A and a gas cooler. The second stage of the A train consisted of a suction scrubber, and a reciprocating compressor, 1-K-103A (again); there was no gas cooler. The B train was similar. These compressors were located in the middle of C Module.

F.11 Following first stage compression the gas followed different paths, depending on whether the operational mode was phase 1 or phase 2, but in both cases it then entered the suction of the second stage.

F.12 The 2 stages of compression in each train were performed by a single machine. These were large machines: the motor and machine together were said to be about 35 ft long and the machine itself weighed some 70 tons. The associated equipment was located around the compressors. Each compressor was driven by an electric motor. The compressor consisted of 6 cylinders: 3 on the first stage and 3 on the second; the cylinders were double-acting. Each machine was oriented with its frame end to the south.

F.13 On each compressor train there were GOVs to allow it to be shut in and a number of trips which would operate to shut down and isolate the machine. There was a recycle loop around the first stage of each compressor and 2 recycle loops around the second stage, one through GOVs 903 and 905 and one through PCV 746. Some of the cylinders on each compressor were fitted with an unloader, a device which holds open one of the valves and thus prevents compression occurring. On the first stage the ends of the cylinder near the frame could not be unloaded but the outboard ends could. On the second stage 2 of the 3 cylinders could be unloaded on the outboard ends, but 1 cylinder could not be unloaded at all. The ability to unload and recycle gas around the compressors gave the flexibility to operate at low gas flows and to reduce the flow of gas going forward and the condensate produced. The controls for unloading and recycling were beside the machines in C Module. Unloading a compressor and putting it on recycle involved switching 7 switches: 3 unloaders and a recycle valve for the first stage, 2 unloaders and a recycle valve for the second.

F.14 In phase 2 operation the first stage reciprocating compressor capacity could be boosted by the use of the reciprocating compressor, 4-K-803, the SEPCO, or Worthington, compressor, located in the GCM, which was operated in parallel with the other 2 machines. Gas was taken to this compressor from the centrifugal compressor discharge and was discharged by it to the inlet of the molecular sieve driers, where it joined the gas from the first stage of the other 2 reciprocating compressors. The SEPCO compressor was used mainly as a back-up.

JT flash drum and other condensate collecting vessels

F.15 Condensate in the gas leaving the separators was knocked out in the condensate knockout drum and pumped back to the separators by 2 condensate transfer pumps. There was a high level trip on the drum, which would shut the ESVs at the inlet of the separators, to prevent carryover of condensate into the flare system. The condensate knockout drum was located north of the test separator at the east end of B Module and the condensate transfer pumps were next to the drum.

F.16 The condensate suction vessel, 2-C-202, collected condensate from the centrifugal compressor suction scrubbers. The level of condensate in the vessel was controlled by level control valve LCV 725. The condensate passed to the JT flash drum, entering the inlet pipe just downstream of the JT valve. The condensate suction vessel was located at the 68 ft level between the JT flash drum and the condensate injection pumps. The vessel was positioned as close to the ceiling of this level as possible in order to provide maximum net positive suction head to the condensate booster pumps. There was a balance line from the top of the condensate suction vessel to the header for the centrifugal compressor discharge scrubbers. The JT valve was in the ceiling of the 68 ft level at the extreme east side.

F.17 The JT flash drum, 3-C-701, located on the 68 ft level, was a condensate knockout and surge vessel which had somewhat different functions in the 2 modes of operation. In phase 1 operation it operated at a pressure of 665 psia and received condensate from the JT valve, PCV 721, and from the condensate suction vessel. The gas from the drum then passed to the suction of the second stage reciprocating compressors and the liquid to the condensate pumps. Somewhat more than half the condensate entering the drum came from the JT valve. A pressure differential of some 30 psi was maintained between the condensate suction vessel and the JT flash drum by differential pressure control valve DPCV 723A,B which controlled a flow of gas to flare. The pressure differential allowed condensate to flow from the condensate suction vessel to the JT flash drum. This vessel acted as a surge tank supplying the condensate pumps. The level of condensate in the drum was maintained by a level controller which controlled the speed of the condensate injection pump. There was a low level trip on the drum which stopped the condensate injection pumps to protect them against operation without any liquid intake. There was also a high level alarm, but no trip. This alarm was displayed on the local control panel and also as a common alarm in the Control Room.

F.18 In phase 2 operation the JT flash drum acted simply as a surge vessel for the condensate pumps and operated at a lower pressure, about 260 psia, and at 57°F. The JT valve was closed but served as a pressure relief valve to flare. DPCV 723A,B was set up in a different mode to act as a pressure control valve rather than as a differential pressure control valve.

Condensate injection pumps

F.19 Condensate from the JT flash drum was pumped into the MOL by a pair of condensate booster pumps in series with a pair of condensate injection pumps. The 2 condensate booster pumps, 3-G-701A,B, were centrifugal pumps; they raised the pressure to 670 psia and discharged to a common header. There was normally one pump operating and one on standby.

F.20 The condensate then entered the condensate injection pumps, 2-G-200A,B, shown in Fig J.9. The condensate injection pumps were single-acting, reciprocating, positive displacement pumps driven by an electric motor through a variable speed drive. They were supplied by Thyssen Maschinenbau Ruhrpumpen. The pump package consisted of an injection pump, an electric motor, a torque converter, a reduction gearbox, a control panel and a lubricating oil system; the torque converter was also referred to as the Voith coupling. The pumps had common suction and discharge headers.

F.21 Each condensate injection pump consisted of 3 horizontal cylinders, pistons, inlet and outlet valves, and suction and discharge manifolds. The reciprocating action alternately raised and lowered the pressure in each cylinder, causing it to fall below that in the suction header and draw in condensate through the suction valve and then raising it above the pressure in the discharge line into which it then flowed through the discharge valve; the 2 valves were spring-loaded to close.

F.22 The pump motor was a 500 hp constant speed induction motor with a nominal full load speed of 1725 rpm. The output shaft of this motor entered a torque converter. The output shaft from this converter passed into a gearbox which effected a 12.5:1 reduction in the rotational speed. The output shaft from this gearbox then drove the crank on the pump. The maximum pump speed was therefore 138 rpm. The torque converter, or Voith coupling, was a device by which power was transmitted from a driven input shaft to an output shaft by transfer of fluid between an impeller on the input shaft and a turbine wheel on the output shaft. The amount of torque transmitted was controlled by guide vanes which adjusted the flow of the fluid.

F.23 The pump speed, and hence pumping rate, was controlled by level controller LIC 720 on the JT flash drum. There was a selector switch on condensate control panel JCP 057 which allowed control to be exercised instead by the level controller of the condensate suction vessel, but it appeared to have fallen into disuse. The level controller altered the set point of the speed controller SC 501 on pump A or SC 502 on pump B; the speed controller then altered the guide vane setting of the torque converter. Panel JCP 057 was located just to the east of A pump.

F.24 Each pump was provided with an isolation or shutdown GOV on the inlet and another on the outlet, the suction and discharge valves on A pump being GOV 5005 and GOV 5006 and those on B pump being GOV 5007 and GOV 5008, respectively. On the suction side there was a manual isolation valve upstream of the GOV and a pulsation dampener downstream of it. On the discharge side there was a pulsation dampener, a high pressure trip and then an NRV upstream of the GOV.

F.25 The function of the GOVs was to effect automatic isolation of the pump. The valves were pneumatically operated ball valves, the suction valve being 8 inch and the discharge valve 6 inch. Each valve was an air-to-open valve which would close on loss of air pressure. The pumps had a number of trips which would cut off power to the motor. There were trips on low suction pressure, high discharge pressure, lube oil failure, seal failure, high motor winding temperature, high motor or pump bearing temperature and high vibration. A pump trip would also cause closure of the GOVs, thus isolating the pump. If a pump trip occurred so that the GOVs closed, it was necessary in order to restart the pump to reset the GOVs. This was done from panel JCP 057.

F.26 The function of the pulsation dampeners was to smooth out the pressure fluctuation caused by the reciprocating action of the pumps. They were essentially spherical vessels divided by a rubber diaphragm, which in normal operation was precharged on the upper side with nitrogen. Both suction and discharge dampeners had a volume of 75.7 litres.

F.27 There were 2 methods of electrical isolation of the pumps: locking off and racking out. Locking off involved locking off the isolation switch for the pump; the power from the 120 V AC UPS to panel JCP 057 remained on. Racking out involved pulling out the switchgear rather like opening the drawer of a filing cabinet; this cut off power to the panel. There was a manual pilot latch valve, or push-pull button, supplied by the power supply to JCP 057, which could be used to open the GOV. If there was power to the panel, the pilot latch valve when pulled would remain out, whilst if there was no power, it would not, and would need to be held out.

F.28 The pump local control panels JCP 043 and 044 were located at the north-east corner of each pump. The pump start buttons were at these panels. The suction and discharge GOVs on each pump were both on its south side, the discharge valve to the west of the suction valve, the 2 valves being about 2 ft apart. The push-pull buttons for the 2 valves were near the discharge GOV. Each pump had a lube oil package. Local alarms for the lube oil system on each pump were given on its local control panel.

F.29 There was no local alarm indication for low suction pressure or for high discharge pressure, either on panel JCP 057 or the local pump panels.

F.30 The discharge manifold was integral with the pump itself. The discharge line was taken off one side and the relief line off the other. In the original design the pressure safety valve was mounted on the pump itself, but as installed the PSV was on a relief line, as described below.

F.31 The pressure safety valves PSV 504 and 505, on pumps A and B respectively, were located in C Module. It was understood that the PSVs had been arranged in this way to prevent water reaching the valve and causing corrosion. There were manual isolation valves on the discharge lines from the PSVs. These lines then entered a common line, which had another manual isolation valve on it and which returned to the condensate suction vessel.

F.32 The relief line from the A pump to PSV 504 was line 2-P-524-4"-F15. The line coding indicates that the pipe was 4 inch diameter and pressure rating F15, which was the Bechtel code for a 900 lb rating. The corresponding working pressure was 2160 psi. The rating of the pipework flange on the upstream side of PSV 504 differed between drawings, being in some cases F15 and others G15, corresponding to 900 lb and 1500 lb rating, respectively.

F.33 Condensate from the discharge header of the condensate injection pumps passed through PCV 511. The purpose of this valve was to maintain a pressure sufficient to prevent flashing off of the condensate if the pressure in the MOL fell, essentially a pressure greater than that in the JT flash drum. PCV 511 was located towards the west end of the 68 ft level.

F.34 The volume of the pump system when shut in by the GOVs, taking account of the volume of the pulsation dampeners, comprised the volume of the pipe between the suction GOV and the pump, that of the pump itself, that between the pump and the discharge GOV (or strictly the NRV) and that of the relief line, and was some 400 litres. For a condensate density of 500 kg/m^3, the mass of condensate shut in would be 200 kg.

Methanol injection system

F.35 The main methanol injection pump, 3-G-702, was a 6-head injection pump and was located on the skid deck to the east of the drilling derrick and north of the deoxygenation towers. Plate 25(b) shows a photograph of the front view of the pump taken at Peterhead. For the installed pump this was the view looking north. The methanol supply came from a methanol tank, 2-C-201, which had a capacity of about 600 gallons and was kept filled from transportable containers. There was in addition an air-driven methanol pump, 2-G-201, the so-called "windy" pump, which supplied a further set of injection points. There were also 2 pneumatic pumps, the Williams pumps, which could be connected for use as back-ups. The location of the methanol injection points on the plant is shown in Fig J.8. On 6 July there were 2 injection points upstream of the JT valve, one the normal injection point fed from the main methanol pump head D and one a temporary injection point fed by a hose from head F.

Gas flaring

F.36 Gas between the production separators and the inlet of the centrifugal compressor system could be sent to flare through PCV 51/1,2. Gas from the outlet of that system could be sent to flare through PCV 1000A,B. There was at the same point a take-off of gas for fuel gas. Gas between the JT flash drum and the second stage reciprocating compressor system could be sent to flare through DPCV 723A,B. Gas from the second stage reciprocating compressors went 3 ways; to serve as lift gas, to MCP-01 and through PCV 945 to flare.

Control Room

Condensate injection pump displays and alarms

F.37 The status of the condensate injection pumps was indicated in the Control Room by lights on the mimic panel. There were 2 status lights, a red running light and a green shutdown light, and normally one or other of these lights would be on.

There was also on the mimic panel an amber alarm light which came on whenever there was a change in the status of a pump. For example, the amber light would come on if the pump was running and then stopped. In this case the green stop light would also come on. If the operator accepted the alarm, the buzzer would cease and the amber light would stop flashing. If he tried to reset the alarm, the amber light would still remain on because the alarm condition still existed. The amber light might remain on even if equipment was electrically isolated, because it had a separate electrical supply. The effect of stopping the pump and effecting electrical isolation by locking off a pump would be that the red running light would go out and the amber stop light would appear on the mimic panel. The effect of stopping the pump and effecting isolation by racking out would be to extinguish both red and green lights. The amber light would be illuminated when the pump stopped but would go out if the alarm were accepted and reset. An amber light on a pump could mean one of 3 things: that the pump had stopped; that it had been isolated by locking off; or that it had been isolated by racking out and that the alarm had not yet been reset.

Electrical supply system

Uninterrupted power supplies

F.38 Tables of the items supplied by the UPS systems were given in the Petrie Report (Tables 1-4). These had been reviewed by Occidental and were confirmed to be comprehensive. The items supplied by the D Module 125 V DC UPS are shown in Table F.1. They included emergency lighting in the accommodation and the HVAC system and dampers. They also included post lube oil pumps which supplied lubrication during the rundown period of certain items of rotating equipment. Table F.2 lists the items supplied by the D Module 120 V AC UPS. They included the general alarm/personal address (GA/PA) system and emergency telephones as well as the F&G system, which also included the solenoid valves for automatic activation of the fire water deluge sets. There were 2 further UPSs in the Utility Module, a 125 V DC and a 120 V AC UPS. The items supplied by these are listed in Table F.3.

Hazardous area classification

F.39 For the purposes of hazardous area classification the codes define 3 zones:

Zone 0 - A zone in which an explosive atmosphere is continuously present or present for long periods.

Zone 1 - A zone in which an explosive atmosphere is likely to occur in normal operation.

Zone 2 - A zone in which an explosive atmosphere is not likely to occur in normal operation and if it does will only exist for a short time.

A safe area is one in which an explosive atmosphere is not expected to occur. Hazardous area classification does not fully protect against ignition of a large leak, which may find an ignition source beyond the classified area.

F.40 Electrical equipment for use in Zones 1 or 2 is designed so that it does not constitute a source of ignition. The standard of safeguarding applicable to Zone 2 is lower than that applicable to Zone 1, because risk of a flammable mixture being present is less.

F.41 Diagrams showing the hazardous area classification of the platform were presented. On the production deck A-C Modules were Zone 2 areas, except for a small Zone 1 area in B Module near the production header, but for C Module the walkways at both the west and east ends and the air intakes of the centrifugal compressor turbines at the latter side were safe areas. D Module was a safe area. Most of the 68 ft level was a Zone 2 area, except for small safe areas at the north landing on the west side, the north-west corner, the north-east corner, and for part of the produced water area on the east side.

Gas detection system

F.42 The gas detection system is described in outline in Chapter 3. Further details are given here on the gas detection system in C Module with special reference to the information necessary to interpret the evidence on the gas alarms, including that bearing on the time delay of the detectors and the possibility of a detector not registering the gas cloud. Evidence on the gas detectors was given by 2 of the Occidental technicians responsible for the F&G detection system, Mr E Scothern and Mr D C Tea, and a representative of the gas detector manufacturers, Sieger Ltd, Dr D Balfour.

Location of gas detectors

F.43 The location of the gas detectors in C Module is shown in Fig J.10 and in Table F.4. On the height of gas detector G101/2 there was a conflict between the evidence of Mr Scothern and Mr Tea, the former putting it near the roof and the latter some 2-3 ft above floor level. Counsel to the Inquiry submitted that in so far as Mr Scothern had not been dealing with the system since 1987, whereas Mr Tea had, the latter's evidence was to be preferred.

Types of gas detector

F.44 The gas detectors were Sieger detectors types 770, 780 and 910. Type 910 was the most modern type and it was policy to replace any detector which fell to be replaced with this type. The features of the types 780 and 910 detectors were described by Dr Balfour. The principle of operation of the sensor was the catalytic oxidation of the hydrocarbon gas on a catalyst bead and the measurement of the change in resistance of the bead caused by the heat evolved in the reaction. The gas passed to the sensor through a sinter filter. The detector was held in a weather protection housing.

Composition and LEL of potential gas leaks

F.45 The streams which had potential to leak into the module were essentially natural gas and condensate. These are often approximated by methane and propane, respectively. The LELs of methane and propane are 5% and 2.1%. The actual compositions of the hydrocarbon streams at the suction of the first stage of the reciprocating compressors and of the second stage of the reciprocating compressors and at the discharge of the condensate injection pumps as given by Dr Balfour are shown in Table F.5. The LEL of a gas mixture may be estimated using the Le Chatelier equation. Dr Balfour's estimates using the Coward and Jones form of this equation were 3.54%, 3.81%, 2.16% and 2.34%, for streams at positions 170, 220 and 350, cases A and B, respectively. It may be noted that the LEL 2.16% for the stream at position 350 for case A is very close to the LEL of 2.1% for propane.

Gas detector settings

F.46 The gas detectors were calibrated for methane but were used to detect other hydrocarbons also. The low alarm setting was 15% of the LEL for methane and the high alarm setting 75% of the LEL. For methane these settings therefore correspond to concentrations of 0.75% and 3.75%, respectively. On a gas detector calibrated to read 100% full scale for 100% LEL of methane, the gas stream at position 350 would read 64.5% and 69.3% full-scale for cases A and B, respectively.

Gas detector dynamic response

F.47 There is a small time lag before a gas detector registers the gas concentration to which it is exposed. This lag is often characterised by the response time, the time for the reading to rise to 90% of its final value when subjected to a step change in the concentration. Dr Balfour gave the response times of the type 780 sensor as 19 and 24 seconds for methane and butane and those of the 910 sensor as 22 and 27 seconds for these 2 gases, respectively. An alternative parameter used to characterise the dynamic lag is the time constant. Taking from the above an estimate of the response time for propane of 23 seconds, the corresponding time constant is some 10 seconds. The actual response of the detector to a gas cloud depends on the way in which the concentration changes with time. If what the detector sees is a sudden step change, it responds rapidly. For a change in concentration from zero to 15% LEL the times to low gas alarm given by Dr Balfour for both types of detector on both gases were less than 2 seconds. If the detector sees a ramp, or linearly increasing, input of concentration, then, after an initial transient, its output lags its input by a time equal to the time constant. The figures given by Dr Balfour apply to new detectors. Dr Balfour stated that detectors brought back from the field and tested again in laboratory conditions had behaved as did new detectors, but neither he nor the Occidental witnesses questioned were able to give any information on the dynamic response of detectors tested in the field.

F.48 Since the principle of operation of the detectors used was the measurement of the heat evolved consequent on the catalytic combustion of the hydrocarbon gas with air, there was a theoretical possibility that if the detector were flooded with pure gas, so that the concentration passed almost instantaneously from zero to 100%, the detector might not register an alarm. Dr Balfour stated that in fact there is a delay introduced by the diffusion of the gas through the filter and that the detectors do respond even when flooded. The effect of a jet of liquid condensate was also considered. In this case Dr Balfour believed that the detector would be protected by its weather protection housing.

Gas detector reliability and disabling

F.49 The reliability of the gas detectors was explored both with Dr Balfour and with Occidental personnel. Dr Balfour referred to the blocking of the filters by salt crystals, wind-borne particles, water or even fire-fighting foam, and to contamination of the catalyst by silicon and other chemicals. Silicon poisoning had been a problem, but steps had been taken and the problem much reduced. Any failure of the detectors would be unrevealed and it was therefore necessary to test them periodically. Some field data which his company had obtained showed a mean time to failure of about 10 years. Mr Tea had experienced deterioration of detectors in the turbine enclosures due to heat and in the accommodation due to silicone polish sprays. Usually when a detector was out of calibration, it was possible to make a small potentiometer adjustment. Outright failure was rare, but he could not put a figure on it. The interval between calibration tests was 4 months.

F.50 Mr Tea explained that it was possible to disable individual gas detector zones by "pinning out", which involved inserting a pin into the module for that zone at the back of the control panel. This was not itself logged, though the work being done in the zone would be.

Emergency shutdown system

F.51 Various terms were used to describe a complete ESD of the platform, including platform emergency shutdown (PESD) and overall emergency shutdown (OESD), the latter being used particularly in the phrase "electrical OESD". The 2 had essentially the same meaning and are referred to here as PESD.

Activation of PESD

F.52 Although there were separate pneumatic and electrical ESD systems, activation of one resulted in activation of the other so that the final effect was the same. Pneumatic PESD was initiated by loss of pressure in the pneumatic pressure loop due to melting of a fusible link. It was also activated by the action of the electrical ESD system. De-energisation of the latter caused depressurisation of the pneumatic pressure loop by activation of solenoid valves. A third way in which the pneumatic loop might be activated was loss of instrument air pressure. The electrical OESD, or PESD, system consisted of a bank of relays in the Control Room which were held energised when the plant was operating. They were de-energised by loss of power from the 125 V DC system. The electrical OESD was also activated by the action of the pneumatic ESD system by de-energisation of the relays. It was stated that loss of the main power supply would cause a PESD, but the mechanism by which this occurred was not clearly established.

F.53 PESD was activated automatically by a limited number of major process upsets. An example given was high pressure on the MOL, caused perhaps by closure of a valve at Flotta, which would trip the MOL pumps and lead to a PESD. On the other hand shutdown of a major item of equipment did not necessarily involve a PESD. High level in one separator would cause shutdown of that separator and of its associated wells, but not shutdown of the platform.

F.54 As far as concerns fire, there was no mechanism other than the fusible links by which fire would activate the PESD. Neither a gas alarm nor a fire alarm would in itself initiate an ESD.

F.55 Detection of gas at equipment located in a safe area activated shutdown of that equipment. This applied to the main generators and in this case the loss of main power would lead to a PESD.

F.56 PESD could be activated manually from the Control Room or from manual push-buttons (break-glass time switches) at 20 locations on the platform. The procedure was that anyone aware of a possible hazard should contact the Control Room, but the purpose of having manual ESD points distributed around the platform was so that personnel could effect shutdown without having to communicate with anyone else and all operating personnel had the authority to initiate a PESD.

Effects of PESD

F.57 One effect of an electrical PESD was to depressurise the pneumatic pressure loop and so initiate a pneumatic PESD also. Likewise, one effect of a pneumatic PESD was to de-energise the electrical PESD system.

F.58 On PESD the wells were shut down by closure on each well of the downhole safety valve (DHSV), the hydraulic master valve (HMV) and the wing valves; the first 2 closed on loss of hydraulic pressure and the latter on loss of pneumatic pressure. A PESD involved the shutdown of all major items of process equipment such as production separators, gas compressors and pumps and closure of all the process ESVs. A PESD caused closure of the ESV on the MOL but closure of the ESVs on the gas pipelines was by manual push-button.

Blowdown on PESD

F.59 Although PESD initiated blowdown of inventories from equipment by opening blowdown valves to the flare system, there were exceptions. Some major items such as the centrifugal compressors were designed so that on tripping they would isolate and blow down automatically. Other items such as the reciprocating compressors did not blow down on tripping, but did blow down on PESD. The production separators would blow down automatically only if the air pressure to the blow down valve on the separators was lost. The reason for not making this blowdown automatic on PESD was concern for carryover of liquids into the flare. The same applied to blowdown of the JT flash drum. The GCM blowdown had to be initiated manually, the reason being that this system contained a good deal of condensate and there was concern about dumping this to flare.

Other features of PESD

F.60 During the PESD the main generators remained on line but switched automatically to diesel firing on falling fuel gas pressure. Other systems which continued in operation were the instrument air compressors, the electrically driven utility and utility/fire pumps and other utility and safety systems.

F.61 On the other hand, the main generators were provided with gas detectors which would shut them down on detection of gas at the high alarm level. The shutdown of the main generators would de-energise the electrical system and thus result in a PESD.

F.62 The fact that the system was designed so that the instrument air compressors continued in operation in a PESD meant that there would not normally be a loss of air to those valves which were pneumatically operated and that the fail-safe action which would cause valves to open or close on loss of air pressure would not come into play.

ESVs on pipelines

F.63 Of the 4 pipeline ESVs, ESV 208 on the MOL was located in B Module and was an electrically operated MOV powered from the emergency switchboard. It had pneumatic back-up to close it on loss of electrical power and further back-up of nitrogen from an accumulator to close it on loss of air. These arrangements were a retrofit. Evidence on the retrofitting of this valve and that on the Claymore line was given by Mr A C B Todd, the maintenance superintendent. The valve was completed, tested and commissioned on 25 April 1988. There was outstanding the fitting of an "Add-on pack" to provide an interlock to shut down the MOL pumps if both valves were less than 75% open. However, the valve had not been formally handed over from construction by 6 July. Mr Wottge stated that the valve had operated satisfactorily in its shutdown mode when a faulty relay in the ESD system caused closure of all the pipeline valves. ESV 501, the ESV on the Claymore pipeline, was also an electrically operated valve with a pneumatic back-up to close it on electrical power failure and a further nitrogen back-up to close it on loss of air. This valve too had been retrofitted in early 1988. Mr Todd said that it was completed, tested and commissioned on 9 April 1988, but had not been formally handed over by 6 July. In early July a new ball valve was fitted to ESV 501. The Tartan pipeline ESV, ESV 6, was a hydraulically actuated valve with nitrogen back-up. The MCP-01 pipeline ESV, ESV 956, was also a hydraulically actuated valve with nitrogen back-up.

Pipeline depressurisation facilities

F.64 There were on the 4 platforms facilities for depressurising the 3 gas pipelines by flaring the inventories, but they were limited by the gas flows which could safely be flared and such depressurisation normally took days rather than hours. All 3 pipelines could be depressurised at the Piper end by making the necessary connections and opening hand valve HCV 961 (see Fig 3.10). This valve was located near the pig traps. It was understood that about 100 MMSCFD could be passed through this valve. The Piper-MCP-01 line could be depressurised at MCP-01 by opening pressure control valves PCV 4353A,B to the blowdown skid. The depressurisation of the Piper-Claymore line could be effected at Claymore by opening hand control valve FCV 970. The Tartan-Piper line could be depressurised at Tartan through a valve. The normal rate of depressurisation was said to be about 12 MMSCFD with a maximum of 30 MMSCFD.

Phase 1 operation and GCM changeout

F.65 Preparations for the GCM changeout were made by Mr A Carter assisted by Mr T A Henderson, a lead production operator. Between 28 June and 5 July the 2 were on the platform together. Mr Henderson left on 5 July, but Mr Carter stayed on to oversee the changeover. No comprehensive work pack for the changeover was recovered, but Mr Henderson assembled a number of documents which he said Mr Carter had prepared. The latter had produced documentation covering the changeover from phase 2 to phase 1, operation in phase 1 mode, work to be done during the changeover period, advice to operators on this work and restoration of phase 2 operation. The work pack included lists of valves to be closed and of spades to be inserted. The pipes into the molecular sieve driers in the GCM were to be spaded off, since men would be working in the driers, but the GCM itself was not to be spaded off. The work pack also included instructions on depressurisation of equipment and on methanol injection. There were also several control loops which needed to be adjusted for operation in phase 1 mode. The setpoint on the JT valve, PCV 721, had to be changed so that it would control at the different pressure. The transmitter on DPCV 723A,B required to be switched so that the loop would operate to control differential rather than absolute pressure.

F.66 The GCM was taken out of service on Sunday 3 July. The gas plant was shut down and the compressors depressurised. The equipment and pipework in the GCM were then depressurised with the exception of the line to the SEPCO compressor; valves 30 and 62 on this line were closed. The teams carrying out the isolations were led by Mr Carter and Mr Henderson. The work programme for the GCM was scheduled for the period 3-15 July. One major item was the changeout of the beds of the molecular sieve driers. Since the beds adsorbed hydrogen sulphide as well as water, this was an operation liable to give rise to gas smells. There were various planned maintenance jobs and work on orbit valves.

Status of certain structural features

F.67 The status of certain structural features on the platform in early July is relevant in that it bears on the possibilities for the spread of flammable gas and of fire.

F.68 One such feature was the possible existence of apertures in the firewall between B and C Modules. It was alleged that part of the firewall near the door had been removed in order to allow work to be done on pipes passing through the wall. Several passages of evidence were heard on the point. It was agreed that a hole had been made in the firewall to allow painters to do needle-gunning work. However, whereas it was originally stated that there was a hole 5m x 4m in the firewall above the door towards the west end of the module, the final outcome was that the wall had been largely restored, although by 6 July an annular gap of perhaps 1-2 inch remained around at least one of the pipes penetrating the wall and over an area of uncertain size the fireproofing had not been remade.

F.69 There was also a door in the firewall opposite the MOL pig trap (see Fig J.3(c)); the door had a self-closing mechanism in the form of a weight on a chain enclosed in a tube. Evidence on this reduced to the allegation that on one occasion it was difficult to shut. There was a proposal to put a new access door in the wall to give access to the middle metering stream to allow removal of the turbine meter, but this work had not started by 6 July.

F.70 Evidence that the prover loop had been completely removed and other evidence that there was some scaffolding at the 68 ft level more or less below the area of the prover loop led to exploration of the possibility that some of the deck plates on the floor of B Module may have been missing. However, removal of the prover loop would not in itself create a gap in the deck plates and no evidence was given that such a gap existed on 6 July.

F.71 Some of the drawings of C Module (eg Fig 9.21 of the Petrie Report) showed a partitioned area at the west end of the module. The evidence was that there was no such partition at the main 84 ft level in the module.

Table F.1 - Items supplied by 125 V DC UPS in D Module mezzanine level

1. Emergency lighting for GCM, Utility Module, distribution boards EL 1, 2, 3 and 4, AAE, ERQ and LQW.
2. Turbine generator panels.
3. SPEEM + AAW distribution board.
4. Centrifugal compressors lube oil system.
5. High voltage and low voltage switchgear.
6. Main process control panel and MOL control panel.
7. HVAC panel and dampers.
8. Fire protection units P102A,B.

Note:
Based on Table 1 of Petrie Report (following para 4.3.6.1).

Table F.2 - Items supplied by 120 V AC UPS in D Module mezzanine level

1. General alarm and personal address system.
2. Main fire and gas panel.
3. Emergency telephones.
4. UPS shutdown contactor panels.
5. Divers' communication system.
6. Main control panel, MOL and gas separation panels.
7. Turbine and generator panels.
8. Drilling module fire alarm panel.
9. SPEEM PESD panel.
10. Turbine gas detection (1-P-102A,B).
11. Discharge scrubbers D/P valve (1-K-105C).
12. Condensate control panel JCP 057.
13. Metering and pig launcher and receiver local panels.

Note:
Based on Table 3 of Petrie Report (following para 4.3.6.1).

Table F.3 - Items supplied by 125 V DC UPS and 120 V AC UPS in Utility Module

A. 125 V DC UPS

1. 13.8 kV closing, tripping and indication supplies for 4-P-801 switchboards.
2. 4.16 kV closing, tripping and indication supplies for 4-P-802 switchboards.
3. 440 V tripping and indication supplies for 4-P-803 switchboards.

B. 120 V AC UPS

1. Fire and gas panel.
2. GCM local control panels.
3. Solartron telemetry system.
4. General alarm system.
5. Reciprocating compressors control panel.
6. HVAC control panel.
7. Flare control panel.
8. Depressurisation valves and solenoid valves.

Note:
Based on Tables 2 and 4 of Petrie Report (following para 4.3.6.1).

Table F.4 - Gas detectors in C Module

Area	Detector	Height	Location
C1	G22	3 ft down(a)	
	G23	3 ft down	
	G24	3 ft down	
	G25	3 ft down	
	G100/1	6 ft up(b)	
	G100/2	7-8 ft up	
C2	G101/1	12-13 ft up	
	G101/2	2-3 ft up	
	G101/3	15 ft up	
C3	G26		At ventilation fan inlet
	G27		Outside turbine compartment(c)
	G28		In compressor compartment
	G102/1	Roof level	At turbine intake
	G103/1	Below grating	At fuel gas valve
	G102/2(d)	Roof level	At turbine intake
C4	G29		At ventilation fan inlet
	G30		Outside turbine compartment(c)
	G31		In compressor compartment
	G102/2(e)	Roof level	At turbine intake
	G103/2	Below grating	At fuel gas valve
	G102/3(f)	Roof level	At turbine intake
C5	G32		At ventilation fan inlet
	G33		Outside turbine compartment(c)
	G34		In compressor compartment
	G102/3(g)	Roof level	At turbine intake
	G103/3	Below grating	At fuel gas valve
	G102/4	Roof level	At turbine intake

Notes:

(a) Down from ceiling.
(b) Up from floor.
(c) Detector outside compartment but with sample tube into compartment.
(d) Detector shared with area C4.
(e) Detector shared with area C3.
(f) Detector shared with area C5.
(g) Detector shared with area C4.

Table F.5 - Calculated composition of gas from selected potential leak points in C Module

Position Gas	Composition (% v/v) 170	220	350 (case A)	350 (case B)
Methane	65.7	71.6	20.0	21.4
Ethane	17.1	16.0	18.9	20.1
Propane	12.4	9.9	31.3	33.4
Butane	3.5	2.1	17.3	18.5
Pentane	1.1	0.5	10.0	6.1
Fraction 125-127	0.2	0.0	2.4	0.5
Fraction 175-365	0.0	0.0	0.1	0.0

Notes:

(a) Positions 170, 220 and 350 are at the first stage reciprocating compressors suction, the second stage reciprocating compressors suction and the condensate injection pumps discharge, respectively.

(b) Case A is for stream completely vaporised and case B for stream partially vaporised.

Appendix G

Supplementary Material on Chapters 5 and 6

Firewall failure

G.1 The analysis by Dr Cox of the over-pressures required to destroy the firewalls in C Module was described in Chapter 5. Further details of this analysis are given here.

G.2 The B/C firewall was a single-layer 4.5 hour integrity wall. The wall extended along the length of C Module from east to west and vertically from the production deck to the truss upper beam at a height of 6.35m. It consisted of an array of rectangular panels of 9.5 mm thick Durasteel 3DF2. The panels were of 2 main sizes and were each bolted into a rectangular frame which was a welded fabrication of 50 mm x 50 mm angle-section steelwork. Adjacent frames were bolted together, forming a "lattice". The lattice was typically 3 frames high. The lower edge of the bottom frame was continuously fillet-welded to the production deck and the upper edge of the top frame was attached to the underside of the upper truss beam by an arrangement of bolted and welded joints. The wall was further supported by clamping to the truss columns, the clamps being simple straps bearing on cleats which were site-welded to the lattice. The firewall is illustrated in Fig 5.2; the figure is schematic and is not to a consistent scale. The panelling is on the near side of the lattice. The figure shows 2 bays of the firewall with 3 vertical and 2 inclined members, all part of the truss, with lattice work and with panels, 3 high, bolted to it. The view in the figure is that seen from the inside of C Module looking south.

G.3 Information on the strength of the Durasteel panels and of the panel bolts was sparse and it was necessary to make assumptions. Durasteel 3DF2 is a composite material consisting of 0.5 mm perforated steel skins around a fibre reinforced cement core, with a total panel thickness of 9.5 mm. It was treated in the analysis as a homogeneous material with the same bulk properties as the composite sheet. A physical test was carried out at Aberdeen University and numerical modelling of this test gave reasonable agreement. Throughout the firewall 3/8 inch Whitworth bolts were specified but the steel grade was not known. The ultimate tensile strength of the grade assumed as representative of mild steel bolts was 432 MPa and a failure strength of 260 MPa was assumed throughout, this being representative of mild steel bolts. Further consideration led to a revision of the bolt strength. The assumed tensile and shear strengths were revised to allow for the thread form. The revised capacity of the bolts was calculated as 11.7 kN under tensile load and 6.7 kN under shear load. The maximum spacing allowed between panel bolts was 15 inches and between frame bolts 24 inches. The number of bolts was calculated from these figures. It would not be usual for there to be drawings and so the bolt spacings were subject to some uncertainty. The strength of the clamps was taken as 23 kN per clamp.

G.4 The C/D firewall was a triple-layer 6 hour integrity wall. The wall extended along the length of C Module from east to west and vertically from the production deck to the truss upper beam at a height of 6.38m. This wall differed from the single-layer wall in that the panels consisted of 3 identical Durasteel 3DF2 plates each 9.5 mm thickness and separated by 45 mm thick of dense mineral wool; the frames were smaller, being 7 rather than 3 high; there was a complex offset bolting arrangement; and the arrangement of the panel and frame bolts was different in detail. The firewall was clamped to truss 6 only by light duty hook clamps quite different from the clamps used on the single-layer wall. The triple-layer firewall is illustrated in Fig 5.3; the figure is again schematic but in this case the panelling is on the remote side of the lattice. The view in the figure is that seen from the inside of D Module looking south.

G.5 In the analysis of failure of the single-layer firewall the following failure modes were considered: panels, panel bolts, lattice framework, frame bolts, clamps and welds to the deck and to the truss. Failure of the panels was studied using both static and dynamic finite element techniques. Depending on the assumptions made, failures of a large panel (2.34m x 1.42m) under static loading were found to occur at 0.10-0.22 barg and under dynamic loading at 0.15-0.36 barg. The panel bolts were found to fail in shear loading at a pressure of about 0.1 barg and the frame bolts in tensile loading at a similar pressure. The clamps would fail at a pressure of about 0.12 barg. The lattice would collapse by formation of plastic hinges at about 0.53 barg. Failure of the welds was calculated to occur only when the pressure on the firewall was 4.7 barg. A similar analysis was made on the triple-layer firewall.

Wind tunnel tests

Gas detectors and gases tested

G.6 A brief account of the gas detection system in C Module is given in Chapter 3 and a fuller description in Appendix F. The location of the gas detectors in this module is shown in Fig J.10 and Table F.4. The description of the gas detection system in Appendix F covers the types of detector used; the gas mixtures which might occur as a result of leaks; the LELs of such gas mixtures; the settings of the detectors; their dynamic response; their reliability; and disabling of detectors. Attention is drawn to 3 points discussed more fully in that Appendix: the conflict of evidence on the height of gas detector G101/2; the time lag in the response of the detectors; and the practice of disabling gas detector zones by pinning out. No evidence was heard that any zone was pinned out on 6 July.

G.7 The gases the dispersion of which was simulated in the wind tunnel tests were propane and a neutrally buoyant mixture of methane, ethane and propane. The gas detector setting data used in the wind tunnel test experiments were as follows:

Gas	Concentrations (%)		
	LEL	Gas detector settings	
		Low alarm	High alarm
Methane	5.0	0.75	3.75
Propane	2.1	0.5	2.5

Background to tests and preliminary tests

G.8 The wind tunnel tests were performed by BMT Fluid Mechanics Ltd. at their wind tunnel at Teddington. A wind tunnel is used to perform small scale experiments on fluid flow. The object of interest is placed in the wind tunnel, the flow of air through the tunnel is set in accordance with principles of scaling, and the flow patterns are observed. It is a powerful and versatile device for studying flow of fluids around objects of complex geometry. Two wind tunnels were used, the main Environmental Wind Tunnel, and a smaller wind tunnel. The tests were performed on the 1: 100 and 1: 33 scale models used in the Inquiry, Models A and B, respectively, the models being taken away to the wind tunnel facility for the purpose.

G.9 The main series of tests were conducted on the 1:33 scale model, but as a preliminary to these tests, it was necessary to establish the ventilation air flow corresponding to the conditions at Piper on the evening of 6 July. This was done as follows. First, the flow-pressure drop characteristics of the 1:33 scale model were determined. The 1:100 scale model was then modified. On the original model the modules at the 84 ft level were represented by solid walls. For B and C Modules these were replaced by models of the modules similar to but simpler than the modules in the 1:33 scale model. The flow resistance of the C Module model in the 1:100 scale model was then adjusted to correspond to that measured on the 1:33 scale model. The 1:100 scale model so modified was placed in the larger wind tunnel and the air flow was adjusted to simulate the conditions at Piper. The wind conditions were based on those recorded by the *Lowland Cavalier* (see paras 3.138; also 3.3) and were taken as wind direction 207° and wind velocity 8.2m/s and for these conditions the ventilation rate through the module was 46 m^3/s. This corresponds to an air change rate of 39 air changes/h and to average air velocity of 0.5m/s. Other wind conditions were also studied and ventilation rates obtained as shown in Table G.1. With the ventilation rate thus established, the main tests were then performed using the 1:33 scale model in the smaller wind tunnel. A video of the tests on both models in the 2 wind tunnels was shown to the Inquiry. The flow through the model represented a speeded-up version of the flow in the actual module, 10 seconds on the model corresponding to 50-60 seconds at full scale. Propane was simulated in the tests using a mixture of argon and Halocarbon 12 and neutrally buoyant gas using a mixture of helium and carbon dioxide. Concentration measurements of these gases were taken at suitable sample points in the model using fine thermal conductivity aspirating probes. The number of sample points used varied between 5 and 27 per series.

G.10 Two sets of experiments were carried out. The first set investigated a number of different leaks, with emphasis on leaks from the area of PSV 504. The second set was concerned with leaks of neutrally buoyant gas. The tests conducted and the results of the first and second set of tests are given in Tables G.2-G.4, respectively. For each set of leak conditions a series of runs was performed, but the number of runs varied. For some conditions it was desired to take samples at 20 or more points, but in order to avoid excessive disturbance to the flow pattern the number of probes was limited to 5 in a given run. Thus it was often necessary to perform 4 or 5 runs to obtain the coverage of sample points required. The results for each condition were therefore referred to as a series.

Limitations of, and uncertainties in, tests

G.11 There are several sources of potential inaccuracy in wind tunnel tests. The most fundamental is the scaling process itself. Other sources include possible deficiencies in the models tested or in the meteorological conditions specified for the test and inaccuracies in measurement. In wind tunnel testing the system of interest is studied using a scale model. The scaling process involved in extrapolating the results to full scale involves some inaccuracy. However, there is wide experience with wind tunnel tests conducted on this basis. Making a very rough estimate of possible errors in average concentration, time and mass of fuel, Dr Davies indicated that they might be some plus or minus 20%. The 1:33 model was not an exact model of the equipment in C Module. For example, the compressors were modelled as "boxes" whereas in reality they were complex items of machinery with pipework, valves, etc. Dr Davies did not believe this was a significant source of error; it might alter a time interval from 20 to 25 seconds.

G.12 In the experiments measures were taken using aspirator probes. The response time of these probes was about half a second to a second, in full scale time units. Some typical traces of the concentrations measured in the experiments are shown in Fig G.1. Several features are noteworthy. Firstly, there was an appreciable difference in the final steady-state values. For example, for the 2 runs in series 25 for sensor G103/1 the steady-state values are approximately 2.6 and 3.1, while for sensor G101/2 they are 1.8 and 3.2. The lateral spread of the cloud, and hence the readings of sensor G101/2 tended to show a greater variability. Secondly, there was a high level of noise on the final steady-state value, so that an alarm might be triggered even though the smoothed steady-state value was below the alarm limit. This occurred in series 28. Thirdly, the initial part of the curves constitutes effectively a ramp, rather than a step, forcing function. On the full scale the concentration measured by the gas detector would, after a short initial transient, tend to lag the actual concentration by a time equal to the time constant of the detectors, estimated as 10 seconds. This would apply particularly to the low level alarms. The lag would be rather greater where the high level alarm limit was close to the final steady-state value.

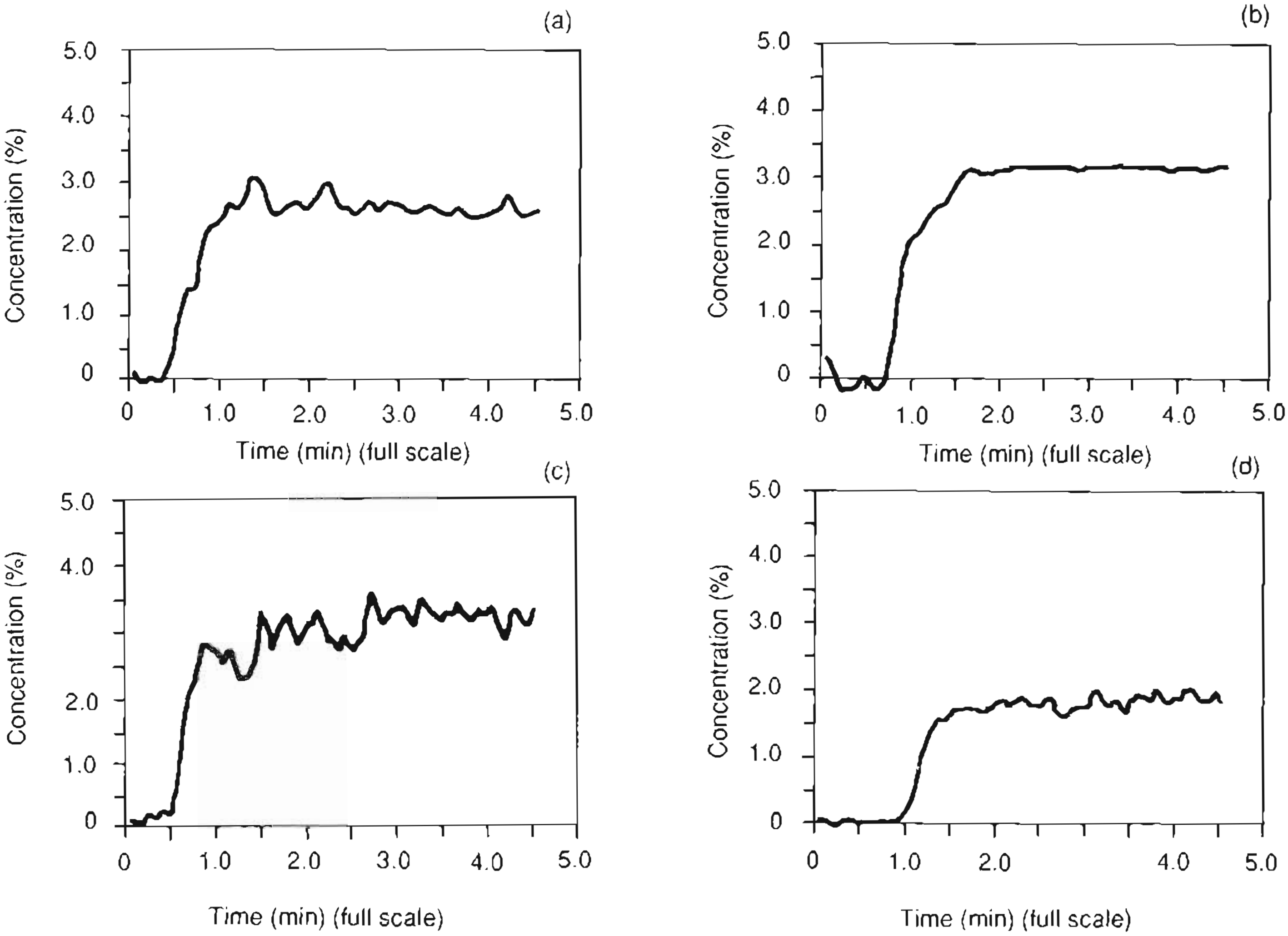

Fig. G.1 Gas concentration-time traces for sensors in repeated runs in series 25 in the BMT wind tunnel tests: (a) and (b) sensor G103/1; and (c) and (d) sensor G101/2.

G.13 It was possible that one or more of the gas detectors in C Module might not have been operational. In particular, the apparent failure of the 2 C2 detectors G101/1 and G101/2 to activate first constrained the interpretation of the test results. The possibility was explored that G101/1 might have been pinned out while work was done on PSV 504. However, there was no evidence that any detector was in fact pinned out.

Explosion simulations

G.14 Explosion simulations using the FLACS computer code were commissioned by the DEn and by Technica and a further run was commissioned by the Inquiry. The results of this work were described in Chapters 5 and 6. Further details are given here of the FLACS code itself, of the explosion simulations, and of the limitations of, and uncertainties in, these simulations.

The FLACS code

G.15 The FLACS code is designed to solve the fundamental equations of fluid flow taking into account turbulence and combustion. The 3-dimensional Navier-Stokes equations, suitably amplified to include the effects of turbulence and combustion reactions, are cast in discrete form, employing a finite volume technique, and are solved implicitly. Turbulence is modelled in terms of eddy viscosity and combustion in terms of turbulent, mixing-limited reaction. The space modelled is divided into a grid of "boxes" of volume one cubic metre. Normal assumptions are that the flammable gas cloud is a quiescent homogeneous stoichiometric mixture so that the effects of any concentration differences within the gas cloud, of any ventilation air flow or of a continuing leak source are neglected. Ignition is modelled as a weak ignition by assuming that at time zero half of the flammable mixture in one of the boxes has undergone combustion so that the temperature of the gas in the box is correspondingly increased. Details of the structure of the module and of the equipment contained in it are captured by a front-end code CASD. A further program is then used to process this information into a form in which it can be utilised by the FLACS code. The principal output of the code of interest in the present context is the explosion pressure generated, but the code also produces profiles of the concentrations of the unburnt fuel and the combustion products and of the gas velocities.

G.16 The effect of obstacles in the module is to enhance turbulence and this may have a strong influence on the pressures generated. Another important influence on these pressures is that of venting. Venting at open or partially open ends of a module is automatically taken into account in the code, but it is also necessary to allow for venting by wall failure. This is handled in the code as follows. The pressure at which a wall will fail is determined. It is assumed that the wall starts to move when this pressure is reached. The movement of the wall is then calculated from the mass of the wall and the pressure on it. It is further assumed that the distance which the wall travels will be limited by obstructions in the adjacent module. The movement of the wall opens up a gap between the wall and the floor and ceiling of the module and this vent area is expressed as an effective wall porosity. There is therefore an interaction between the pressure generated and the venting due to wall failure; the pressure causes wall failure and the wall failure acts to reduce the pressure.

G.17 The FLACS code has been validated by comparison of results obtained from the code with measurements made in experiments on explosions in scale models of modules. The models used were on scales of 1:33 and of 1:5. A typical explosion experiment is shown in Plate 26(a). The over-pressures predicted by the code lie within plus or minus 30% to a confidence level of some 95% of those measured experimentally. The variability of model experiments themselves is of the same order. It was Dr Bakke's expectation that the measured over-pressures would tend to be greater in full scale tests. The work at CMI has been sponsored by a number of organisations and a number of studies have been conducted on gas explosions in modules of offshore platforms.

Simulations performed for the DEn

G.18 Soon after the disaster the DEn commissioned CMI to carry out a series of simulations of explosion of idealised flammable gas clouds in C Module. Their report was issued as Annex 3 to the Petrie Final Report. The report, though dated October 1988, was based on the information available in August. CMI was provided with information on the geometry of C Module in the form of drawings and photographs. The plan view of C Module produced is shown in Fig 5.1. This figure also shows the pressure recording points, flammable gas clouds and ignition points. The Control Room was located in the mezzanine level of D Module and thus on the upper part of the C/D firewall at a point corresponding approximately to recording point 5. The firewall failure pressures were specified as 0.138 bar for the B/C firewall and 0.25 bar for the C/D firewall. The mass of the walls was given as 63 kg/m^2. It was agreed to assume a wall porosity of 20% for the B/C firewall and a 40% porosity for the C/D firewall. (In the original report and evidence it was stated that the porosity of both firewalls in this work was 20%, but this was corrected in the later report and evidence.) The compositions of the 2 fuels used in the simulations, natural gas and condensate vapour, are given in Table G.5, Sec A. For simplicity, the compositions used in the code are the equivalent mixtures given in Sec B of the table.

G.19 Five simulations were performed in this work. The simulations specified (cases 1-5) and the results obtained are shown in Table 6.2. Pressures were recorded at 8 points as shown in Fig 5.1. Points 1-4 are along the south wall and points 5-8 along the north wall. The points are at a height just over halfway up the module. For case 1 the pressures generated were sufficient to cause failure of both firewalls at all the recording points P1-P8. The pressures in case 2 were appreciably higher, those in case 3 higher than in case 2, and those in case 5 higher still, so that all these cases would cause failure of both firewalls at all the recording points. For case 4 the pressures were on the borderline of those required to cause failure, exceeding the firewall failure pressure only at points P2-P4 on the south wall. In particular, the pressure point 5 near the Control Room was below the failure pressure. Although this work was in large part superseded by that commissioned by the Inquiry, the apparent trends which it illustrates are important. One is that the pressures generated by a cloud of condensate as opposed to natural gas are somewhat higher (case 3 v case 2). Another is that an ignition source located at the centre of the module gives appreciably higher pressures than one located at the end (case 2 v case 1). A third is that the pressures occurring in the absence of venting by firewall failure are much higher (case 5 v case 3). And finally there is the not unexpected result that a smaller gas cloud gives rise to lower pressures (case 4 v case 1).

Limitations of, and uncertainties in, simulations

G.20 The simulation of an explosion in a module is a complex undertaking and the technology has been developed only recently. The model used in the simulation involves a number of idealisations and assumptions. There are some potential sources of inaccuracy in the model itself and in the solution of the model equations. Questions also arose concerning the input data for the particular scenario modelled for the Piper explosion. The idealisations made were those normally used in the code and have already been described. The flammable gas cloud had an idealised rectangular geometry and was assumed to be homogeneous. No account was taken of air flow through the module, of the effect of a continuing gas leak or of any upwind movement of the cloud. Some work has been done by CMI on gas cloud homogeneity. A high-momentum, quite large release tends to fill the module with a cloud which is relatively homogeneous and which rises in concentration as the release proceeds. With regard to the effect of ventilation, the air velocity in C Module was of the order of 0.5m/s, some 2-3 orders of magnitude below the highest velocities occurring in the explosion. Some inaccuracy is introduced during the process of integrating the differential equations of the model. The model used includes some parameters that can be "tuned" to fit experimental results obtained at small or medium scale. In such a case, however, there must always be some uncertainty when the model is extrapolated to full scale. Another idealisation was the modelling of the process of failure of the firewalls, which assumes that once the failure pressure is reached failure is effectively total and instantaneous. In fact processes such as shearing of the bolts must take some finite time. There remained some uncertainty concerning the extent to which the model took into account phenomena such as an external explosion. These were described by Dr Chamberlain in Part 2 of the Inquiry but were not explored with Dr Bakke in Part 1. To some extent the tuning process mentioned may allow for such phenomena, but since they tend to be more important at full scale, the allowance may not be fully adequate.

G.21 Questions concerning the input data for the Piper explosion centred particularly around the location of the ignition source, the porosity of the firewalls and the behaviour of the ducting around the centrifugal compressors. The selection of the location of the ignition source was not based on any information but was made to give something close to a worst case, ie one which would generate the highest pressures. By selecting this worst case it was possible to explore the smallest size of flammable cloud to give an explosion. The effect of the porosity of the firewall was somewhat reduced by the fact that according to the model only a small fraction of the ultimate porosity is developed at the time when the pressure reaches its peak. Thus although the treatment of porosity was very approximate, provided some reasonable allowance is made, the effect on the final results may not be great. The available vent area may also be increased by the destructive effect of the high wind velocities generated in an explosion. In particular, the ducting of the centrifugal compressors at the east end of C Module would be vulnerable to such winds. Loss of this ducting was not allowed for in the simulation.

Rating of upstream flange on PSV 504

G.22 As described in Chapter 6, there was uncertainty about the rating of the upstream flange on PSV 504. A summary of the evidence on this is given here.

G.23 A large number of drawings and other documents which bore on the question were produced by Mr M Skidmore, a Senior Facilities Engineer with Occidental. Many of these were documents related to the original design and pre-dated the construction of the condensate injection system. They showed that the original specification of the upstream flange was 900 lb. However, there were a pair of "as-built" drawings which for PSV 505 gave both on the drawing and the material code a 1500 lb rating and for PSV 504 a 1500 lb rating on the drawing but a 900 lb rating in the materials list. Mr Skidmore also produced documents relating to later modifications to features such as the pulsation dampeners which gave a 900 lb rating. There was in addition a telex dated 22 August 1977, and thus in the construction phase of the condensate system, calling for urgent action on shortage of materials, including 900 lb flanges. It was put to Mr Skidmore that in this situation a 1500 lb flange might have been fitted to progress the work, but he discounted this as poor practice.

G.24 Another source of information on the flange rating was the safety relief valve (SRV) test certificates for the periodic recertification work. A collection of certificates for PSVs 504 and 505 was examined. A summary of these certificates is given in Table G.6. Valve technicians who had worked on these PSVs since 1985 were called, namely Mr J Tait, a service engineer with Score (UK) Ltd, Mr A Pirie, a service engineer with Wood Group Valves and Engineering Services Ltd, Mr R W Barclay, formerly a valve technician with the same company, and Mr A C Bruce, formerly a valve technician with Score. Mr Tait described the sources from which a flange rating for an SRV, or PSV, might be obtained. There were history cards, test certificates, and site inspection. The flange rating might be obtained from the nameplate, if that was still legible. Alternatively, the flange could be measured and the rating looked up in flange tables. There was also an Occidental printout of the valves, but while this gave the pipe diameter, it did not necessarily give the flange rating.

G.25 As Table G.6 shows, the first entry of the upstream flange on PSV 504 as 1500 lb was on 29 October 1985. This was a rush job which Mr Pirie did alone, making the adjustment on the scaffolding using test flanges, and filling in and signing the test certificate No 3825. The job was too short to fit blind flanges. He did a similar job on PSV 505, recorded on test certificate No 3826. In both cases he recorded the upstream flange rating as 1500 lb. He could not remember how he established this; he did not think he had the previous test report available. He must have been sure of the rating or he would not have put it down, but he could have been mistaken. The next overhauls of PSV 504 and 505 were done by Mr Barclay and Mr J McDonald. The test certificate No 0101 for PSV 504 dated 16 September 1986, filled in and signed by Mr Barclay, again showed a 1500 lb rating. Mr Barclay said he would not have completed any part of the certificate before doing the job. He could not recollect how the flange rating was determined, but it would have been necessary to know it to do the job; in fact in this particular case it was necessary to improvise a test flange. When he came to sign the certificate he must have thought the rating entered was correct. The next day PSV 505 was overhauled, the overhaul being done by Mr McDonald and the test certificate No 0104 being filled in by Mr Barclay and signed by Mr McDonald; again an upstream flange rating of 1500 lb was entered. On 24 March 1988 PSV 505 was overhauled by Messrs Tait, Bruce and Sutton. The certificate

No 2607 is signed by Mr Bruce, though both he and Mr Tait said that it was filled in by the latter. Mr Bruce said that he and Mr Sutton measured the upstream flange rating on both PSVs and found it to be 1500 lb. They also checked against the certificates for the previous tests, that for PSV 505 being No 0104 on 17 September 1986. They had taken out both certificates, since they did not know which of the 2 PSVs was to be worked on and there was no difference in the flange ratings, both were 1500 lb. He believed that to get ahead with the paperwork the box on the certificate containing the entry on the flange rating was filled in before the work was done. Mr Tait, who filled in the certificate, was unsure where he obtained the flange rating. It was his practice to read the previous test reports and write notes in a notebook. He could have transferred information from his notebook to the new certificate, though if any inconsistency had been noticed he would have gone and measured the flange. He also stated that there could have been several valves being done that day and that since this overhaul itself was completed only about 22.00 hours, the certificate was probably signed the next day. It was put to Mr Skidmore that these test certificates showed that the flange rating was 1500 lb, but he maintained his belief that the flange had been originally specified as 900 lb and had not been changed. He agreed that if the 1500 lb flange rating on these certificates was a mistake, it was a separate one from that on the as-built drawings.

G.26 Photographs of PSV 504 and 505 were available to the Inquiry. The photographs were provided by Mr T Rogers, Facilities Engineer with Occidental, and were believed to have been taken about 1978. An attempt was made to determine the flange sizes from these photographs by Mr D J Turner, Managing Director of Camera Alive Ltd, using computer matching. Mr Turner stated that he obtained a good fit assuming the downstream flange to be 600 lb and the upstream one to be 900 lb, but a poor fit assuming the latter to be 1500 lb. Counsel to the Inquiry indicated that he did not accept this evidence, but did not pursue the matter by cross-examination.

G.27 The evidence on the rating of the upstream flange on PSV 504 was therefore contradictory. Fitters who had done the most recent work on the flange had entered it as 1500 lb on the test certificates. Although in principle this evidence might be preferred to that of the original design documents showing it to be 900 lb, there was doubt whether the entries were based on the immediate knowledge of those working on the flanges rather than transferred from previous test certificates. It is conceivable that the 1500 lb rating was entered in error during the work in October 1985 and then perpetuated. On the other hand the shortage of 900 lb flanges during construction and the rating shown in the "as-built" drawing are possible pointers to a 1500 lb rating.

Autoignition in relief line on A pump

G.28 In their third report Drs Richardson and Saville explored the possibility of rupture by autoignition in the relief line on A pump. The report included a detailed study of the possible effects of the estimated maximum explosion pressure of some 300 bara, which is described here. The effects studied were those on the pipe and, for a blind flange, on the flange itself and on the bolts and the ring.

G.29 The authors drew attention to the fact that if the time taken to reach the final pressure was substantially less than the response time of the container, the walls of the container would experience a transient stress double that experienced in a slow application of pressure, but stated that the response time of a rigid metallic container would be much less than the duration of the explosion and so no enhancement would take place. However, such enhancement would apply to bolts which were slack; in this case the maximum stress would be double that for tight bolts.

G.30 The relief pipe was 4 inch nominal bore. Since there was doubt about the pipe ratings, both 900 lb and 1500 lb ratings were considered. The Occidental specification for both ratings was for material to standard ASTM-A106, which gives a yield strength of 35000 psi and a minimum tensile strength of 60000 psi. The actual wall thickness was required to be at least 0.875 of the nominal thickness. When determining schedules Occidental made a corrosion allowance of 0.125 inch. Thus there were also 2 cases to consider with respect to pipe wall thickness. One was the nominal thickness and the other 0.875 x nominal thickness less the 0.125 inch corrosion allowance. The piping specifications considered and some results of the work are given in Table G.7. The specification C1D corresponds to Bechtel F15 rating and 900 lb flanges and C1E to G15 rating and 1500 lb flanges. Sections A and B of Table G.7 give, respectively, the maximum working pressures (MWPs) of the pipe and its yield and burst pressures. They show that the explosion pressure would exceed the MWP for the C1D but not for the C1E pipe. For the C1D pipe it would just exceed the yield pressure for the thin wall case, but not the burst pressure for either wall thickness. For the C1E pipe neither yield pressure nor burst pressure was exceeded for either wall thickness. The authors concluded that since the combination of less than nominal wall thickness and loss of corrosion allowance was improbable, it was unlikely that even the C1D pipe would yield, let alone burst. Both C1D and C1E rated pipes should have had no difficulty in containing the explosion.

G.31 For the flanges the Occidental specification was again to ASTM-A106, which requires a yield strength of 36000 psi and a minimum tensile strength of 70000 psi. Sec C of Table G.7 gives the MWP for the 2 ratings of flange. It shows that the explosion would overstress the 1500 lb flange only marginally, but the 900 lb flange severely. Further work would be required to determine what effect this would have. For the stud bolts and nuts it was found that the former would fail before the latter and therefore only the former were considered. The Occidental specifications for the bolts were to ASTM A193-B7. The required material has a yield strength of 105000 psi and a minimum tensile strength of 125000 psi. Sec D of Table G.7 gives for the 2 classes of bolt the bolt thicknesses and the tensile load for yielding. It was assumed that the bolts were initially tight. Sec D also shows the total tensile load resulting from the explosion. It can be seen by comparing the last 2 columns of this section that for both classes 2 bolts are sufficient to prevent yielding. Yielding would take place only if undersized bolts had been used. This is illustrated in Sec E of Table G.7, which shows the combinations of bolt size and number for failure just to occur. If the bolts were slack, twice as many bolts or bolts with diameter larger by the square root of two would be needed to prevent yielding. With regard to the meaning of slackness in this context, Dr Richardson said that it did not matter how tight the bolts were, provided there was no movement. For the ring the Occidental specification was for soft iron octagonal rings. The authors took for these a yield strength of 19100 psi and a tensile strength of 42200 psi. For properly matched flanges, the gap between the raised faces would be 4 mm. The authors found it difficult to envisage failure of the ring in this case. They thought a very small gap might perhaps open up but it would close again when the explosion pressure decayed. If mis-matched flanges were used, the ring would be confined at only one end. Calculations based on the simplification of treating the ring as an infinitely long cylinder gave a large deformation at 200 bara and bursting at 300 bara. The authors found it difficult to predict whether failure would occur in this case. The report also considered bending of the blind flange. If only 2 diametrically opposed bolts were used, it would be possible for the flange to bend about the line joining these bolts. It was estimated that for an explosion of 300 bara a gap 0.1 mm might open up, but it was expected that it would close again when the pressure decayed.

G.32 As far as concerns passage of any flame to the outside, this is determined by the gap available. The parameter generally quoted is the maximum safe gap, which is the maximum width of gap through which a flame will not propagate. The report quoted for lower hydrocarbons a maximum safe gap of less than 1 mm. The equivalent orifice diameter consistent with a gap of this size was 15 mm. Dr Richardson pointed out that the value quoted was for a standard apparatus with a gap length of 1 inch and for atmospheric pressure. The length of the gap on the holes envisaged on the flange assembly would be less and therefore the gap width to just prevent passage of flame would be less; he was unsure of the effect of pressure.

Hydrate formation and behaviour

G.33 The possibility of hydrate formation at various parts of the plant was examined by Drs Richardson and Saville and by Dr Johnsen. The latter also described experimental work on hydrates and discussed hydrate behaviour. An account was given in Chapter 6 of this evidence in so far as it bears on the formation of hydrates at the JT valve and their subsequent behaviour. Further details are given here of the evidence on the formation and behaviour of hydrates both at the JT valve and at other points on the plant.

Hydrate formation

G.34 Evidence on the equilibrium conditions for formation of hydrates at certain critical points was given by Drs Richardson and Saville in their first report and was presented by Dr Richardson. For formation of hydrate to occur it is necessary for the process conditions to lie within a certain envelope of pressure and temperature. If within this envelope the system comes to thermodynamic and phase equilibrium, hydrates will form. The approach to equilibrium may, however, be slow. Thus whether hydrates will actually form depends also on the rate at which equilibrium is approached. There are 2 types of method for the prediction of the equilibrium conditions for hydrate formation. The traditional method is based on K-values for the solid-vapour equilibrium. The other method utilises more fundamental thermodynamics. Drs Richardson and Saville made use of the computer program EQUIPHASE based on the latter method. They estimated the errors in this method as approximately 10-15% in the pressure, plus or minus 3°F in the temperature and 3% w/w in the quantity of methanol required in the aqueous liquid phase. Dr Richardson put the overall error in the amount of methanol to be added to inhibit hydrate formation at about 5% w/w. For example, if the proportion of methanol required was calculated at 28% w/w, the amount needed would lie between 23 and 33% w/w.

Hydrate formation on plant

G.35 The methanol injection points on the plant are shown in Fig J.8. Drs Richardson and Saville calculated first the hydrate formation temperatures assuming no methanol injection. They then calculated the flow rates of methanol required (i) to reduce the hydrate formation temperature to that of the stream exactly and (ii) to reduce it to 5°F below the stream temperature, thus giving a safety margin. The results are shown in Table G.8. From these results the authors concluded that if the methanol injection schedule specified was adhered to, the quantities injected were sufficient to give a safety margin of 5°F between the stream temperature and the hydrate formation temperature. In fact the only point where the margin was as low as 5°F was the JT valve. Additional evidence on the equilibrium conditions for hydrate formation was given by Dr Johnsen. Fig G.2 shows his set of hydrate formation curves for conditions representative of Piper.

Hydrate formation at JT valve

G.36 The possibility of formation of hydrate at the JT valve was considered by Drs Richardson and Saville in their first report on hydrates in general and in their eighth on hydrates at this valve. In their first report, presented by Dr Richardson, they calculated that the hydrate formation temperature just downstream of the JT valve was 62.5°F. They took the temperature at the JT valve as 52.5°F. They estimated that the methanol in the aqueous liquid phase just necessary to prevent hydrate formation at this temperature was 12% w/w. For a temperature of 28-30°F the amount of methanol required in the aqueous liquid phase to inhibit hydrate formation was calculated as 35% w/w. They estimated that given the prescribed methanol injection rates the amount of methanol in that phase would have been 25% w/w. The concentration of methanol would not have been sufficient to prevent hydrate formation.

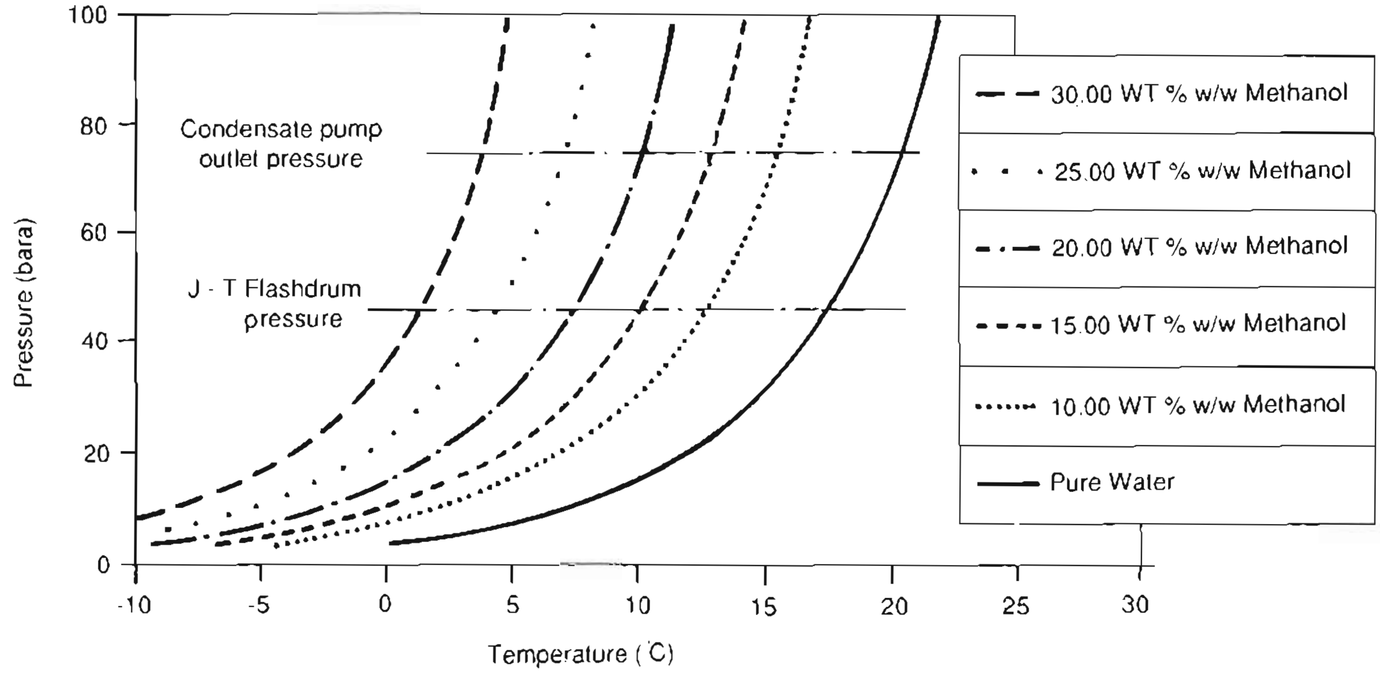

Fig. G.2 Typical hydrate curves for conditions representative of those on Piper given by Dr Johnsen. Hydrates can form if conditions are above and to the left of the relevant curve.

G.37 In their eight report, spoken to by Dr Saville, they presented a graph showing the relation between the hydrate formation temperature and the proportion of methanol in the aqueous liquid layer. At temperatures of 52.5°F and 48.0°F the concentrations of methanol required were 12 and 17% w/w, respectively. At 52.5°F methanol injection rates of 18.0, 19.9 and 37.9 US gal/h gave methanol concentrations in the aqueous liquid phase of 13, 14 and 25% w/w and at 48.0°F methanol concentrations of 14, 16 and 28% w/w. At a temperature of 50.0°F the methanol on the aqueous liquid phase required to prevent hydrate formation was 15% w/w. By interpolation of the above figures, this corresponded to a methanol injection rate at the JT valve of 19.9 US gal/h. This flow corresponds to that to the valve during the interruption of methanol supply.

Hydrate tests

G.38 Dr Johnsen carried out a number of experiments on hydrate formation and behaviour under conditions typical of those on Piper. All the tests were done using a wheel-shaped flow simulator. Condensate was formed in the wheel by admitting a suitable mix of gases and was then brought to equilibrium at the required pressure and temperature by rotating the wheel at 0.5 m/s. Water was then admitted and the behaviour of any hydrates formed was observed. Plate 25(a) shows hydrates formed at the observation window on the wheel. A video of some of the experiments was shown to the Inquiry. One test showed that, for simulated conditions at the JT valve of 639 psia (43.5 bara) pressure, 50.2°F (10.1°C) temperature and 15% w/w methanol in the aqueous phase, hydrates formed rapidly. The conclusions from the tests are described in Chapter 6.

Hydrate behaviour

G.39 Dr Johnsen outlined the conditions most favourable for hydrate formation, given that the system is in the hydrate forming region. If water and gas are simply left to stand, the process of hydrate formation may take weeks. If, however, water is sprayed into gas, near ideal conditions occur for hydrate formation. Hydrates can form long before a stoichiometric equilibrium has formed between the water and gas molecules. In some situations not all the water will be converted to hydrates and water and hydrates will co-exist. In light condensate streams with velocities of less than 1 m/s the water is hardly dispersed at all. It moves along the bottom of a horizontal pipe and gathers in pools in low points in the pipework or ahead of upward pointing bends.

G.40 Hydrates formed in streams with poor pipe-wetting or water-dispersing properties present the most problems, sticking on any mechanical obstructions such as welded joints, pipe seams, tappings, branches, bends and valves or even smooth surfaces. Hydrate plugs form in 2 ways. One mechanism is where sticky hydrates adhere to a wall and provide an anchor for other hydrates as they arrive. The hydrates may then pack and form an ice-like structure. The other is where the hydrates are not sticky but form a soft plug, covering perhaps 10% of the cross-section of the pipe. Upon hitting an obstruction the hydrate "train" will start compacting so that within a few seconds a plug is formed. Hydrates which have adhered to a pipe wall may loosen upon a slight temperature increase and form a soft travelling plug which on hitting an obstruction may compact into a hard plug. Hydrates formed at one point may give rise to problems at another point.

G.41 Once hydrates are formed, their dissolution tends to require quite a lot of heat, and therefore time. The mechanism of heat transfer for dissolution (conductivity) is different from those for formation (convection and turbulence as well as conductivity). The dissolution of hydrates requires considerable amounts of heat. Thus hydrates tend to dissolve only slowly and they may survive for several hours after being transported into parts of the process which have pressures and temperatures outside the hydrate region. Hydrates may be removed by increasing the temperature, adding methanol or decreasing the pressure. If the temperature is raised or methanol is added, this is liable to loosen hydrates from the pipe walls, but not to form water again quickly, so that a hydrate slurry moves down the pipe. This slurry may then compact into a hard plug. If the pressure differential across a hydrate plug is increased and as a result the plug moves, it may travel at the velocity of a rifle bullet. While this is not a likely mode of failure for small pipes, it may be for larger pipes.

Source of ignition

G.42 A brief account was given in Chapter 6 of the review of sources of ignition by Dr J G Marshall. Further details of this review are given here. Ignition of a hydrocarbon vapour cloud may occur either by deposition into the cloud of a small quantity of energy, such as that from a spark, or by heating up the bulk gas until it reaches its autoignition temperature. Dr Marshall emphasised the small amount of energy required to ignite a hydrocarbon vapour cloud. He gave minimum ignition energies of 0.29 mJ for methane and energies in the range 0.24-25 mJ for ethane, propane and butane. The energy needed is therefore very small, equivalent to the energy dissipated by a 5W torch bulb in 50 microseconds. Ignition sources considered by Dr Marshall included electric arcs and sparks, static electricity, flames and hot gases, hot surfaces, hot particles and chemical energy.

Electric arcs and sparks

G.43 Electrical equipment is a potential source of ignition. Equipment for use in hazardous areas is of 2 main types, flameproof and intrinsically safe. The latter is designed to be incapable of giving an incendive spark. Other electrical equipment might in principle give arcs and sparks. It should not do so if correctly selected, installed and maintained, but might if it had suffered damage or deterioration. Mr W N MacLaren, an Electrical Engineer Surveyor with Lloyds Register, described the electrical equipment which would be found in B and C Modules. It included electric motors, instrumentation and controls, junction boxes, cables, light fittings, telephone and public address systems, and trace heating. He had noted in one of his reports a number of bolts missing on an explosion-protected enclosure and other instances of bolts and screws missing, but he considered that the incidence of such missing bolts and screws was low and consistent with that on a well maintained installation. In 1979 a hydrocarbon gas leak occurred in C Module when a valve was inadvertently left open. The source of ignition was identified by the DEn inspector as a junction box.

Electrostatic sparks

G.44 The conditions under which an electrostatic charge builds up and then discharges were reviewed by Dr Marshall. The 2 situations which he highlighted were static discharge from an isolated conductor and from the human body. A jet of vapour containing fine liquid droplets tends to generate an electrostatic charge. A release of liquid condensate from high pressure would give such a jet. If a jet of such vapour impinges on a body which is a conductor but which is insulated from earth, it can cause that body to become charged. If the insulation from earth is sufficiently good, the charge will not dissipate by simply leaking away, but will build up. When a sufficient charge has accumulated, a spark discharge to earth may occur. The spark may have sufficient energy to ignite any flammable gas mixture which is present. Dr Marshall quoted a Shell expert, Mr Strawson, with regard to static discharge from an isolated conductor to the effect that "this mechanism has been responsible for all the explosions known to have resulted from charged liquid sprays". Examples of isolated conductors given by Dr Marshall were the nozzle on the end of a rubber or plastic hose or a spanner not in direct contact with the ground but lying on a piece of rag. The possibility was considered that under certain conditions, the metal scaffolding at the site of PSV 504 might have acted as an isolated conductor; there was no requirement to earth the scaffolding. Dr Marshall thought that the electrical capacity of the scaffolding would probably be too great and the resistance of the path to earth through the wooden planks on which it stood would probably be too low to prevent dissipation of the charge, while if even a high potential did build up the path around the wooden plank to earth would probably be too long to permit incendive discharge.

G.45 Another source of static discharge considered was the human body. Mr Richard had gone into C Module to investigate the first gas alarm and may have entered a flammable cloud. Dr Marshall stated that a prerequisite for the build-up of a significant static charge on a human being would be that he is wearing rubber or other insulating boots; with leather or antistatic footwear any charge would leak rapidly away to the metal deck. According to Mr Richards, the OIM, all personnel, Occidental and contractors, wore leather toe 'tector boots.

Flames and hot gases

G.46 The flare was a large open flame, and was thus the strongest and most obvious source of ignition on the platform, but ignition by this source requires that the flammable gas cloud actually reaches the flare. Hot work activities such as cutting and welding that night were described in Chapter 3. Mr Bollands had no recollection of any hot work permits out that evening for A, B or C Modules and the deluge systems were on automatic, but there was one out for the 68 ft level. There were hot work permits out for the pump room area and an area described as the "habitat" at the east end of D Module. However, construction work would normally finish by 21.00 hours.

G.47 The painters' air compressor, a diesel-driven machine, was situated at the north-west corner of the 68 ft level just to the west of the paint store and, evidently, just outside the boundary of the Zone 2 area of that level. The compressor was used to provide compressed air for the painters, who also did needle-gunning work. In addition, it provided compressed air for the divers' air winches, including that for the divers' bell. According to Mr J P Dixon, a painter, it was the practice for a colleague, Mr S Glendinning, to stay on in the evening to fill up the compressor with diesel, an operation which usually took him from about 18.00 to 21.00 hours. He was fairly sure that Mr Glendinning would not be working as late as 22.00 hours; he was unsure whether it was Mr Glendinning's practice to run the compressor to check it before leaving the job. Mr Punchard, the diving inspection controller, stated that some weeks before he had noticed sparks being emitted from this compressor. He had reported it and believed remedial action had been taken. On the night as he passed by the compressor making his return to the north-west corner it occurred to him that the compressor might act as a source of ignition for any escaping gas and he decided to shut it down. He could not find the shutdown button and asked Mr Elliott, who was passing, to assist him. Mr Elliott stated that it was he who shut the machine down; he had no idea who had asked him to do it. If the painters' air compressor had been running and had been sparking, it could have acted as a source of ignition for any gas cloud at the north-west corner of the 68 ft level or perhaps one falling down from the 84 ft level and being blown north, but there was no evidence that it was sparking on the night of 6 July.

G.48 Both a cigarette and the materials used to light up, such as matches or lighters, are in principle potential sources of ignition. Dr Marshall stated that it is quite difficult to ignite a hydrocarbon cloud with a lit cigarette and that in experimental trials it is usually necessary to do quite a large number of tests before ignition is achieved. Matches and lighters, however, give ignition much more easily. In general, there is a no smoking rule in hazardous areas and the rule is strictly enforced. The rule applied on Piper.

Hot surfaces

G.49 If a flammable mixture is heated up, it eventually ignites spontaneously. The minimum temperature at which this occurs is the autoignition temperature (AIT). Whilst it is convenient for the purposes of science and engineering to utilise the concept of an AIT, this is no more than a way of getting a handle on what are in reality quite complex combustion phenomena. Further, there is no established method of determining the AIT of a mixture of fuel gases. Dr Marshall gave a table of AITs, ranging from 595°C for methane to 285°C for pentanes. A flammable gas mixture can be ignited by a hot surface. In engineering design the temperature at which this occurs is frequently, but conservatively, taken as the AIT. Thus BS 5345 sets the AIT as the maximum for the temperature of a hot surface. In practice, there is a considerable but variable excess of the hot surface ignition temperature over the autoignition temperature. Dr Marshall quoted the statement of Mr Powell that "the case of ignition of gases and vapours bears little or no relation to their ignition temperatures". The lowest excesses shown in a tabulation given by Dr Marshall for small surface areas (not exceeding 108 mm^2, were 302°C for methane, 470°C for propane and 720°C for pentane. The excess also varied with the type of metal constituting the hot surface. Dr Marshall also quoted experiments showing various degrees of temperature excess.

G.50 The casings of the gas turbines on the centrifugal compressors in C Module ran hot. The possibility was explored that such a casing might have been the ignition source. For hot surface ignition to occur due to this source, it would be necessary for a flammable mixture to have access to the surface and for the surface to be sufficiently hot to cause ignition. Mr J Murray, an operator, stated that under normal running conditions the engine casing glowed red, a dull red. One of the checks carried out by the operator was for uneven glow on the engine. Asked to interpret "dull red" in terms of temperature, Dr Marshall referred to a table given by Dr Drysdale, according to which the first visible red glow would be at about 550°C and a dull red at about 700°C. Another operator, Mr J E Cotter, related an incident some 6 or 7 years before in which in the course of his inspection of a turbine he observed a dull red glow from the casing of the machine. He informed Mr Smith, the maintenance lead hand, but was told there was no cause for concern. This evidence suggests it would need experimental work to determine whether in normal operation the temperature of the engine casing might be high enough to cause hot surface ignition of a flammable gas mixture.

G.51 For this to occur, however, it would be necessary for the gas to gain access to the turbine. There are in principle 3 ways in which this might occur. One is for it to enter through an open door, another for it to be drawn in through the ventilation intake and the third for it to be ingested into the turbine air intakes. These 2 intakes were in areas classified as safe, but this does not rule out the presence of gas under more extreme accident conditions. The turbine compartments were maintained under positive pressure by the ventilation fan. There were doors on the compartments which should normally have been closed. The possibility was explored that they might have been open. Several witnesses gave evidence that the doors of both compartments were always kept closed; this was necessary to maintain a proper circulation for cooling. In any case, according to Mr Murray, there was a good air flow, normally sufficient to maintain positive pressure even with the door open.

G.52 Entry of gas through the ventilation system would have required that there was a flammable concentration at the ventilation air intake and that the ventilation system kept running. The ventilation intake was some 11 ft above the deck grating, some 2-3 ft east of the east crane pedestal and therefore projecting outside the module. Dr Davies stated that in his wind tunnel tests he had sensors near the ventilation intake and that though some flammable concentrations might just get in, he thought it unlikely that significant flammable masses would have been ingested. The ventilation system was designed to continue running for 2 hours after compressor shutdown, though if a high alarm were registered on the gas detector at the ventilation system inlet, the system would shut down immediately. The third compressor tripped before the final set of gas alarms. It is likely that the high gas alarm level was not reached in the ventilation intake on any compressor but if it was, the ventilation system should have shut down.

G.53 The combustion air intakes were some 6 or 7 ft up. Again Dr Davies stated that the wind tunnel tests showed that some flammable concentration might just enter. However, there was information from Occidental quoted by Dr Davies to the effect that no more than 25% of the air drawn into these intakes was from the module, the rest being from outboard of it. From Table G.3 the maximum steady-state concentration of gas in the air leaving the module for a leak of 100 kg/min (series 42) is 3.7%. A stream diluted by a factor of 4 would have a concentration of 0.9%, which is below the LEL of 2.1%. Flashback out through the turbine air intakes was not explored nor was entry of gas into these intakes after compressor shutdown.

G.54 If an explosion had occurred within the turbine compartment, the latter would have sustained massive damage. Such damage would probably have been obvious to Captain Morton on the *Maersk Cutter*. Further, this scenario requires that there was then a second explosion in the module itself. The witness evidence is against this.

Hot particles

G.55 Hot particles mentioned by Dr Marshall included hot soot and molten metal from welding and cutting. Sources of hot soot were heaters and engines and the flare. The possibility was raised that closing of a door after inspection of the centrifugal compressor or turbine compartment, such as Mr Richard may have made in seeking to detect the gas leak, might give rise to a mechanical spark of sufficient strength to ignite a flammable gas cloud but insufficiently conspicuous to have been noticed on other occasions. Dr Marshall agreed that with a heavy metal door, shut vigorously and making a glancing contact with the door jamb, this was possible.

Chemical energy

G.56 There are various ways in which energy release by chemical reaction can act as a source of ignition. Dr Marshall referred to 2 in particular, catalytic reactions on gas detector heads and self-heating of oil-soaked lagging or rags. The principle of operation of a gas detector is that the flammable gas is made to react by the catalytic element in the detector and the resultant temperature rise is then measured. In order to guard against ignition from this source, the detector head is equipped with a flame arrester. If the detector head were damaged, protection would be lost.

Probability of ignition and of identifying its source

G.57 Dr Marshall was asked his view of the probability that a gas leak in a module would be ignited. He regarded ignition of a violent release as probable but ignition of a release which was not violent as possible rather than probable.

G.58 At the end of his evidence Dr Marshall was asked how likely he thought it was that it would be possible to identify with reasonable certainty a source of ignition for the leak on Piper. He stated that in his experience of some 10 to 20 explosion investigations the principal guidance is from information available prior to the incident, debris and eye-witness observations, and that only in some one third of cases had he been satisfied that the source of ignition had been found. He agreed that in general in the absence of the debris evidence the chances of identifying the source of ignition were low, that this was so in the case of Piper and that probably the most which could be expected was to narrow the number of possibilities.

Table G.1 - Ventilation rates obtained for C Module on 6 July 1988 in wind tunnel tests on 1: 100 scale model

Wind direction relative to platform north(°)	Ventilation rate (m^3/s)		
	Wind speed (m/s)		
	7.2	8.2	9.2
200	31	35	39
207	40	46	52
218	51	58	65
228	57	65	73

Table G.2 - Complete list of wind tunnel tests conducted

Series		Leak			Ingestion & exhaust		
	Location	Type	Angle (°)	Rate (kg/min)	In (cfm)	Location	Out (cfm)
First set							
10	1	J	150	50	—	—	—
11	1	J	120	50	—	—	—
12	1	C	—	50	—	—	—
13	1	C	—	50	—	—	6000
14	1	C	—	50	19000	C	—
15	1	C	—	50	19000	C	6000
16	1	J	150	50	19000	C	6000
17	1	J	150	50	6800	C	6000
18	1	J	120	50	6800	C	6000
19	1	J	90	50	6800	C	6000
20	1	J	150	50	6800	A	6000
21	1	J	150	25	6800	C	6000
22	1	J	90	25	6800	C	6000
23	1	J	60	25	6800	C	6000
24	1	J	90	37	6800	C	6000
25	1	J	150	37	6800	C	6000
26	1	J	180	37	6800	C	6000
27	1	J*	180	37	6800	C	6000
28	1	C,2	180	37	6800	C	6000
29	1	C,1	120	37	6800	C	6000
30	1	C,1	120	37	—	—	6000
31	1	C,1	120	37	6800	A	6000
32	1	C,1	120	37	18200	C	6000
33	1	C,1	120	37	7000	C	6000
34	1	C	—	12	7000	C	6000
35	1	C,1	120	10	7000	C	6000
36	1	C,1	120	4	7000	C	6000
37 Aborted							
38	1	C,1	120	1	7000	C	6000
39	1	C,1	90	10	7000	C	6000
40	1	C,1	150	10	7000	C	6000
41	1	J	150	10	7000	C	6000
42	1	C,1	120	100	7000	C	6000
43	2	C,1	120	37	7000	C	6000
44	3	C	—	50	7000	C	6000
Second set							
45	1	J	150	100	7000	C	6000
46	2	J	150	100	7000	C	6000
47	3	J	150	100	7000	C	6000
48	4	J	150	100	7000	C	6000
49	1	J	150	1	7000	C	6000
50	2	J	150	1	7000	C	6000
51	3	J	150	1	7000	C	6000
52	1	P	—	100	7000	C	6000

Notes:

Series: Group of runs at the same conditions.

The following applies to the first set of tests (series 10-44):

Type: J — jet (small hole in horizontal pipe)
J* — jet impinging on nearby plate (separation 1m)
C — circumferential leak
C,n — circumferential leak with n x 120° sectors open

Angle: Orientation of jet
0° vertically upward
90° horizontal to east
180° vertically downward, etc.

Gas: All series used propane at -42°C except series 44 which used a cold natural gas, ethane and propane mixture

Ventilation: Wind induced ventilation was 46 m^3/s in all series

Ingestion: Volume of air drawn from within C Module

Location: intake of A or C centrifugal compressor

Exhaust: Total exhaust volume of vent air from all 3 centrifugal compressors

The following applies to the second set of tests (series 45-52):

Type: P — Release from an open horizontal pipe 3½ inch in diameter directed towards south wall

Gas: All series a cold natural gas, ethane and propane mixture

Otherwise as for first set tests.

Table G.3 - Concentrations and times to alarm obtained for selected wind tunnel tests: first set

		Series								
		15	16	19	26	27	32	35	36	42
Leak rate (kg/min)		50	50	50	37	37	37	10	4	100
Leak type		C	J	J	J	J*	C,I	C,I	C,I	C,I
Leak angle		—	150	90	180	180	120	120	120	120
A - Steady-state concentrations (% v/v)										
Sensor	Area									
G101/1	C2	1.7	0	0	0	0.6	0.2	0	0	0
G101/2	C2	1.6	2.3	2.5	2.2	2.5	2.0	0.9	0.8	3.1
G101/3	C2	1.2	1.1	0	0	1.1	0	0.2	0	0.3
G103/1	C3	2.7	3.4	2.6	2.7	1.5	2.4	1.2	1.2	3.7
G103/2	C4	1.6	2.5	x(a)	2.4	x	1.7	0.9	0.8	1.9
G103/3	C5	1.0	0.7	x	1.5	x	0.9	0.3	0.3	2.2
G27	C3	2.2	1.8	2.9	1.1	1.6	2.8	0.5	0.5	3.3
G30	C4	1.5	2.8	x	1.4	x	1.9	0.6	0.7	1.8
G33	C5	1.0	0.8	x	0.6	x	0.7	0.2	0	2.0
B - Time to low level alarm(s)										
Sensor	Area									
G101/1	C2	5	—	x	—	15	—	—	—	—
G101/2	C2	40	40	25	45	30	40	60	65	15
G101/3	C2	45	25	x	—	30	—	—	—	—
G103/1	C3	15	15	10	30	55	15	30	30	5
G103/2	C4	60	20	x	30	x	30	70	85	20
G103/3	C5	105	120	x	55	x	55	—	—	30
G27	C3	15	15	15	40	45	15	85	80	10
G30	C4	70	15	x	60	x	25	85	80	25
G33	C5	110	100	x	75	x	120	—	—	25
C - Time to high level alarm(s)										
Sensor	Area									
G101/1	C2	—	—	x	—	—	—	—	—	—
G101/2	C2	—	—	140	85	140	—	—	—	40
G101/3	C2	—	—	x	—	—	—	—	—	—
G103/1	C3	125	35	25	75	—	—	—	—	10
G103/2	C4	—	180	x	155	x	—	—	—	—
G103/3	C5	—	—	x	—	x	—	—	—	—
G27	C3	80	—	40	—	—	30	—	—	20
G30	C4	—	55	x	—	x	—	—	—	—
G33	C5	—	—	x	—	x	—	—	—	—
D - Area showing first alarm										
		C2	C3/C4	C3?	C3/C4	C2?	C3	C3	C3	C3
E - Time from first to second area alarm(s)										
		10	0	?	0	15?	10	30	35	10

Notes:

(a) x indicates that there was no sensor at this point in this series.

(b) For key to leak type and leak angle see notes to Table G.2.

Table G.4 - Concentrations and times to alarm obtained for selected wind tunnel tests: second set

		Series						
		43(a)	44	45	46	47	48	52
Gas		P	NG	NG	NG	NG	NG	NG
Position		2	3	1	2	3	4	1
Leak rate (kg/min)		37	50	100	100	100	100	100
Leak type		C,1	C	J	J	J	J	P
Leak angle		120	—	150	150	150	150	—
A - Steady-state concentrations (% v/v)								
Sensor	Area							
G101/1	C2	0	0.6	0.5	0	0	5.1	5.5
G101/2	C2	3.0	2.5	2.6	4.2	3.1	1.6	2.6
G101/3	C2	0	1.9	3.7	4.7	4.5	3.1	2.8
G103/1	C3	2.0	2.5	3.7	3.1	4.8	4.2	4.0
G103/2	C4	2.0	2.5	3.4	3.0	3.1	2.9	2.9
G103/3	C5	1.9	1.0	2.0	3.5	1.3	1.4	1.1
G27	C3	1.4	1.8	3.5	3.3	5.1	4.3	3.2
G30	C4	1.8	3.5	2.8	2.4	3.4	3.2	2.9
G33	C5	1.4	1.7	2.4	4.0	1.4	1.4	1.4
B - Time to low level alarm(s)								
Sensor	Area							
G101/1	C2	—	115	—	—	—	31	7
G101/2	C2	10	30	35	2	19	84	61
G101/3	C2	—	50	22	5	12	61	25
G103/1	C3	30	40	15	22	35	65	38
G103/2	C4	25	35	14	24	24	76	58
G103/3	C5	25	60	36	16	32	79	112
G27	C3	30	45	22	22	21	73	34
G30	C4	25	30	35	38	31	32	67
G33	C5	25	30	19	11	31	76	77
C - Time to high level alarm(s)								
Sensor	Area							
G101/1	C2	—	—	—	—	—	59	18
G101/2	C2	35	120	—	25	—	—	—
G101/3	C2	—	—	—	11	36	—	—
G103/1	C3	—	180	—	—	46	79	118
G103/2	C4	—	120	—	—	—	—	—
G103/3	C5	—	—	—	—	—	—	—
G27	C3	—	—	—	—	33	121	—
G30	C4	—	180	—	—	—	—	—
G33	C5	—	—	—	35	—	—	—
D - Area showing first alarm								
		C2	C2,C4,C5	C4	C2	C2	C2	C2
E - Time from first to second area alarm(s)								
		15	0	1	9	9	1	27

Notes:

(a) For convenience series 43 and 44, which are for locations other than position 1, are included in this table rather than in Table G.3.

(b) Gas: P = propane; NG = natural gas

(c) For key to position, leak type and leak angle see notes to Table G.2.

Table G.5 - Compositions of process streams used in the FLACS code explosion simulations

Component	Composition (% v/v) Natural gas	 Condensate
A		
Methane (C1)	67.75	19.86
Ethane	15.76	18.98
Propane (C3)	9.34	31.06
Butanes	1.97	17.16
Pentanes	0.45	9.94
Carbon dioxide	0.45	0.27
Nitrogen	4.23	0.46
B		
Equivalent C1	87.66	40.04
Equivalent C3	12.34	59.96

Table G.6 - Work on PSVs 504 and 505 in the period 1980-1988 spoken to by witnesses

Date	PSV	Test certificate No	 Flange rating (lb)	 Signature for valve overhaul
9.4.1980	505	-	None	Whalley
30.4.1980	504	-	None	Black
17.9.1981	505	-	None	Smith
7.6.1984	505	3046	None	Cowie
8.6.1984	504	3045	None	Cowie
22.6.1984	504	3049	900	Reid
15.9.1985	504	0018	None	Thom
19.9.1985	505	0033	None	Ritchie
29.10.1985[a]	504	3825	1500	Pirie
29.10.1985[a]	505	3826	1500	Pirie
16.9.1986	504	0101	1500	Barclay
17.9.1986	505	0104	1500	McDonald
24.3.1988	505	2607	1500	Bruce

Note:

(a) This work was resetting of the cold test pressure, which was done with the PSV on the scaffolding, and did not involve fitting a blind flange.

Table G.7 - Conditions for failure of condensate injection pump A pipework, blind flange and flange bolts under explosion pressure

A - Pipework: maximum working pressures

Rating	Pipe schedule	MWP (bara)
C1D	120	180
C1E	XXS	320

B - Pipework: yield and burst pressures

Rating	Yield pressure (bara)		Burst pressure (bara)	
	Nominal	Minimum wall	Nominal	Minimum wall
C1D	420	280	890	540

C - Flange

Rating	Class	MWP (bara)
C1D	900 lb	153
C1E	1500 lb	255

D - Bolts: tensile loads on bolts

Rating	Bolt diameter (in)	Tensile load for yielding per bolt (lbf)	Total tensile load for explosion pressure of 300 bara (lbf)
900 lb	1.125	83000	116000
1500 lb	1.250	105000	139000

E - Bolts: bolt diameters and numbers for failure just to occur

Rating	Bolt diameter (in)		
	2 bolts	4 bolts	8 bolts
900 lb	0.875	0.625	0.437
1500 lb	1.000	0.625	0.500

Table G.8 - Hydrate formation temperatures and methanol concentrations to prevent hydrate formation for selected streams in phase 1 operation

Stream	200	210	211	330	340	350
Pressure (psia)	635	635	635	635	670	1100
Temperature (°F)	52.5	55.6	55.6	55.6	55.9	60.2
Hydrate formation temperature (HFT) (°F)	62.5	62.4	62.0	>55.6	>55.9	>60.2
Methanol concentration (a) (% w/w)						
(a) to reduce HFT to stream temperature	12	8	8	5	6	1
(b) to reduce HFT to 5°F below stream temperature	17	14	14	11	11	7
Methanol concentration (a,b) from specified injection rates (% w/w)	17	28	28	28	28	36

Notes:

(a) In aqueous liquid phase.

(b) Calculated from the methanol injection rates specified by Mrs Paterson.

Appendix H

Schedule of Information Relating to the Deceased

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
1.	ADAMS, ROBERT McINTOSH (39) 70 Rowan Road Aberdeen	Rigger	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
2.	ANDERSON, GEORGE ALEXANDER J (45) 12 Dundonnie Street Boddam Peterhead	Baker	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
3.	ANDERSON, IAN GEDDES (29) 39 Dunnydeer Park Insch	Dual Service Operator	Halliburton Manufacturing & Services Ltd Howe Moss Crescent Dyce Aberdeen	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
4.	ANDERSON, JOHN (33) 4 Dunure Place Kirkcaldy Fife	Catering Manager	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Recovered 7.7.88 on surface of sea near Platform	Inhalation of smoke and gas
5.	ASHTON, MARK DAVID (19) 23 Townhead Drive Inverurie	Trainee Technician/Cleaner	Macnamee Services Ltd Burnside Works Kennerty Mills Road Peterculter Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
6.	BAIN, WILSON CRAWFORD A (34) 8 Pineview Fraserburgh	Valve Technician*	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Missing: LKW – in Accom. between 22.00 and 22.20	N/A
7.	BARBER, BARRY CHARLES (46) Annanbank Lewis Street Stranraer	Diving Consultant*#	Aberdeen Offshore Services Ltd Union Buildings 15 Union Street Aberdeen	Recovered 10.11.88 Track 8 by *Heather Sprig*: LKW – in water between B3 and B4 Legs shortly after 22.20	Drowning

	Deceased	*Occupation*	*Employer*	*Recovery LKW*	*Principal Cause of Death*
8.	BARCLAY, CRAIG ALEXANDER (24) 11 Park Avenue Dundee	Welder	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
9.	BARR, ALAN (37) 20 Carronvale Road Larbert	Electrical Technician	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Missing	N/A
10.	BATCHELOR, BRIAN PHILIP (44) 2 Allen Close Fleetwood	Seaman	Haven Shipping Co. Queens Road Great Yarmouth	Recovered 7.7.88 on surface of sea near Platform: LKW – in FRC of *Sandhaven* on W side of Platform about 22.50	Drowning
11.	BORG, AMABILE ALEXANDER (51) "Ithaca" The Drive Bassleton Lane Thornaby Cleveland	Non-Destructive Tester	Testwell (Ultrasonics) Ltd Unit 27 Murcar Industrial Est. Bridge of Don Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
12.	BRACKENRIDGE, HUGH WALLACE (47) 34 Kirk Street Leith Edinburgh	Roustabout	Bawden International Ltd Wellheads Road Dyce Aberdeen	Missing	N/A
13.	BREMNER, ALEXANDER ROSS COLVIN (38) "San Mar" 2 Edward Avenue Banff	Production Operator*	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Missing: LKW – on NW Navigation Aid Platform shortly before 22.20	N/A
14.	BRIANCHON, ERIC ROLAND PAUL (32) Rue de L'Oiseau Bleu Saint Wandrille Rancon France	Technician	Coflexip SA Rue Jean Hure Le Trait France 76580	Died in hospital on 19.7.88	Extensive Burns

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
15.	BRISTON, HUGH (40) 7 Curran Avenue Whinney Banks Middlesbrough	Scaffolder	Aberdeen Scaffolding Company Ltd Harness Road Aberdeen	Recoveed 6.9.88 in Galley of ERQ	Inhalation of smoke and gas
16.	BROWN, HENRY (39) 11 Derwent Drive Coatbridge	Welder	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
17.	BROWN, STEPHEN (27) 73 Dame Dorothy Crescent Roker Sunderland	Assistant Chef/Baker	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
18.	BRUCE, GORDON CRAIB (51) 55 Great Northern Road Aberdeen	Helicopter Landing Officer	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
19.	BRUCE, JAMES (42) 12 Beech Road Stockethill Aberdeen	Logger	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 11.7.88 50m, 245 degrees from Leg A5: LKW – Climbing up ladder to Drilling Tea Hut about 22.15	Inhalation of smoke and gas
20.	BUSSE, CARL WILLIAM (31) 408 Johnson Navasota Texas 77868 USA	Directional Drilling Supervisor	Eastman Christensen Ltd Murcar Commercial Pk Denmore Road Bridge of Don Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
21.	CAMPBELL, DAVID (23) 1 Hill Street Lossiemouth Morayshire	Cleaner	Macnamee Services Ltd Burnside Works Kennerty Mills Road Peterculter Aberdeen	Recovered 23.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
22.	CAMPBELL, DAVID ALLEN (29) 2 Ash Grove The Hillock Portlethen Aberdeen	Scaffolder	Aberdeen Scaffolding Company Ltd Hareness Road Aberdeen	Recovered 7.7.88 on surface of sea near Platform: LKW – jumping off Helideck about 22.50	Inhalation of smoke and gas

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
23.	CARGILL, ALEXANDER WATT (39) 17 Howard Street Arbroath	Electrician	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
24.	CARROLL, ROBERT (34) 40 Coronation Road Peterculter Aberdeen	Safety Operator*	London Bridge Eng Ltd Aberdeen Business Centre Willowbank House Willowbank Road Aberdeen	Missing: LKW – on NW Navigation Aid Platform shortly before 22.20	N/A
25.	CARTER, ALAN (43) 30 Dixons Bank Marton Middlesbrough	Lead Production Operator	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
26.	CLELAND, ROBERT (33) 89 Cairngorm Gardens Eastfield Cumbernauld	Derrickman	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 10.7.88 GMR 340062E 6484135N	Inhalation of smoke and gas
27.	COLE, STEPHEN COLIN (40) 10 Milson Road Keelby Lincolnshire	Radio Officer	Inspectorate UK plc Unit 3 Wellheads Way Dyce Aberdeen	Recovered 7.7.88 on surface of sea near Platform: LKW – possibly at entrance to Offices from pipe deck after 22.20	Inhalation of smoke and gas
28.	CONNOR, HUGH (35) 6 Corse Street West Kilbride	Instrument Technician/Lecturer	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 7.7.88 on surface of sea near Platform: LKW – leaving Instrument Workshop at about 22.00	Drowning
29.	COOKE, JOHN EDWARD SHERRY (59) 18 Castle Road Greenock	Plater	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Missing	N/A
30.	COOPER, JOHN THOMAS (37) 6 Haswell Avenue Hartlepool	Instrument Technician	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Missing: LKW – leaving Instrument Workshop at about 22.00	N/A

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
31.	COUTTS, WILLIAM NUNN (37) 2 Morangie Road Tain	Chef	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
32.	COWIE, WILLIAM JOHN (32) "Trevear" South Pringle Street Buckie	Steward	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
33.	COX, MICHAEL JOHN (26) 43 Pentland Crescent Aberdeen	Scaffolder	Aberdeen Scaffolding Company Ltd Hareness Road Aberdeen	Recovered 17.7.88 130m, 030 degrees from Leg A.5: LKW – on top of Radio Room at about 22.35	Drowning
34.	CRADDOCK, ALAN IRVIN (31) 10 Devanha Terrace Aberdeen	Drilling Supervisor#	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
35.	CROWDEN, EDWARD JOHN (47) 100 Thistle Drive Portlethen Aberdeen	Electrical Technician*	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
36.	CURTIS, BERNARD (45) 21 Tayside Street Carnoustie	Deputy Production Supt#	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
37.	DA SILVA, JOSE HIPOLITO (26) 40 Invercauld Place Aberdeen	Steward	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
38.	DAWSON, JOHN STEPHEN (38) 7 Bruce Walk Nigg Aberdeen	Telecom Engineer	Inspectorate UK plc Unit 3 Wellheads Way Dyce Aberdeen	Recovered 22.11.88 Track 19 by *Janeen*: LKW – at N doors of Galley after 22.00	Not Ascertained

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
39.	DEVERELL, ERIC (51) "Walescot" Bruntland Road Portlethen Aberdeen	Production Clerk	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 15.8.88 GMR 340023E, 6483933N	Death in fire
40.	DUNCAN, ALEXANDER (51) 21 Dalmahoy Drive Dundee	Steward	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Recovered 7.7.88 on surface of sea near Platform: LKW – outside Galley near ladder to Helideck about 22.40	Chest and abdominal injuries
41.	DUNCAN, CHARLES EDWARD (29) 31 Cairnwell Drive Aberdeen	Floorman*	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 31.10.88 in A Deck of ERQ at Flotta	Inhalation of smoke and gas
42.	DUNCAN, ERIC (49) 10 Dales Road Peterhead	Drilling Materials Man*	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 7.11.88 GMR 340111E, 6484145N: LKW – trapped in Materials Room after 22.00	Inhalation of smoke and gas
43.	DUNCAN, JOHN (33) (FORMERLY WALKER) 26 Balgownie Drive Bridge of Don Aberdeen	Engineer	Northern Industrial & Marine Services Company Ltd Unit 15 Woodlands Road Dyce Aberdeen	Recovered 18.7.88 144m, 011 degrees from Leg A5	Drowning
44.	DUNCAN, THOMAS IRVINE (39) 40 Langdykes Drive Cove Bay Aberdeen	Roustabout*	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 14.7.88 84m, 260 degrees from Leg B5: LKW – possibly in Mechanical Workshop after 22.00	Inhalation of smoke and gas
45.	DUNCAN, WILLIAM DAVID (38) 106 Hawick Drive Dundee	Crane Operator	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 20.7.88 205m, 054 degrees from Leg A5: LKW – in corridor of-C Deck after 22.00	Abdominal injury
46.	ELLIS, DAVID ALAN (28) 14 Carrhouse Lane Moreton Wirral Merseyside	Steward	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
47.	FINDLAY, DOUGLAS NEWLANDS (38) Errol Cottage Blackhills Elgin	Supervisor Mechanic	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
48.	FLOOK, HAROLD EDWARD GEORGE (51) 2 Fotheringham Drive Monifieth Dundee	Production Operator	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
49.	FOWLER, GEORGE (40) 14 Kilnwick Close Owington Farm Billingham Cleveland	Electrical Technician	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 7.7.88 on surface of sea near Platform	Inhalation of smoke and gas
50.	FREW, ALEXANDER PARK (41) 1 Linn Road Ardrossan Ayrshire	Plater	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
51.	GALLACHER, SAMUEL QUEEN (30) 29 Regent Street Greenock	Pipe Fitter	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
52.	GALVEZ-ESTEVEZ, MIGUEL (36) 7 Braehead Drive Cruden Bay Peterhead	Assistant Chef	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
53.	GIBSON, ERNEST (45) 498 Hylton Road Sunderland	Mud Engineer	Magcobar Imco GB Ltd Pocra Quay Aberdeen	Recovered 7.7.88 on surface of sea near Platform: LKW – on S side of pipe deck after 22.20	Drowning
54.	GILL, ALBERT STUART (32) 10 Swannay Road Aberdeen	Roustabout	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 6.9.88 in Galley of ERQ	Inhalation of smoke and gas

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
55.	GILLANDERS, IAN (50) 21 Lodgehill Park Nairn	Instrument Pipe Fitter	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Missing: LKW - going towards SW corner of Platform shortly after 22.40	N/A
56.	GILLIGAN, KEVIN BARRY (35) 6 Philip Grove Sutton St Helens Merseyside	Steward	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Recovered 12.7.88 GMF 340090E, 6484252N	Head and chest injuries
57.	GLENDINNING, SHAUN (24) 40 Hillview Brechin	Painter	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
58.	GOLDTHORP, JOHN EDWARD THOMAS (37) 10 Craigmill Gardens Carnoustie	Motorman*	Bawden International Ltd Wellheads Road Dyce Aberdeen	Missing: LKW - in Mechanical Workshop after 22.00	N/A
59.	GOODWIN, STEPHEN ROBERT (22) 112 Fitzwilliam Street Swinton Rotherham South Yorkshire	Geologist	Exploration Logging North Sea Ltd Walton Road Dyce Aberdeen	Recovered 5.11.88 in B Deck of ERQ at Flotta	Inhalation of smoke and gas
60.	GORDON, JAMES EDWARD GRAY (38) 72 Thistle Court Aberdeen	Floorman*	Bawden International Ltd Wellheads Road Dyce Aberdeen	Missing: LKW - on Drill Floor after 22.00	N/A
61.	GORMAN, DAVID LEE (41) 7 Forth Wynd Port Seton East Lothian	Safety Operator	London Bridge Eng Ltd Aberdeen Business Centre Willowbank House Willowbank Road Aberdeen	Missing: LKW - in Reception after 22.00	N/A
62.	GRAHAM, KENNETH (40) 2 Pevensey Close Preston Grange North Shields	Mechanical Technician	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Missing: LKW - on pipe deck shortly before 22.20	N/A

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death* ·
63.	GRANT, PETER JOHN (31) Naeview 20 Drumsmittal Road North Kessock Inverness	Production Operator	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 23.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
64.	GRAY, CYRIL JAMES (49) 171 Heathryfold Circle Aberdeen	Safety Operator	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 7.7.88 on surface of sea near Platform: LKW – on S side of pipe deck after 22.20	Drowning
65.	GREEN, HAROLD EUGENE JOSEPH (44) 2 Newburn Court South Shields	Rigger	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Missing: LKW – on top of Accom. W shortly before 22.20	N/A
66.	GROVES, MICHAEL JOHN (44) 10 Maidlands Edinburgh Road Linlithgow West Lothian	Production Operator	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 18.7.88 126m, 076 degrees from Leg A5	Inhalation of smoke and gas
67.	HACKETT, JOHN (49) 7 Brook Road Lymm Warrington Cheshire	Electrical Technician*	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 7.7.88 on surface of sea near Platform: LKW – at Reception about 22.05	Inhalation of smoke and gas
68.	HAY, IAN (31) 25 Boston Close Battlehill Wallsend Tyne and Wear	Steward	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Recovered 17.7.88 92m, 03 degrees from Leg A5	Inhalation of smoke and gas
69.	HAYES, THOMAS ALBERT (39) 223 Mosslands Drive Wallasey	Rigging Supervisor	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
70.	HEGGIE, JAMES (45) 18 Viewforth Gardens Kirkcaldy Fife	Project Services Supt.#	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
71.	HENDERSON, DAVID WILLIAM (28) 42 Hazlehead Place Aberdeen	Lead Floorman	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
72.	HOUSTON, PHILIP ROBERT (35) 4 Dixon Terrace Pitlochry Perthshire	Geologist	NL Sperry Sun/MWD/Baroid Logging Systems Wellheads Road Dyce Aberdeen	Recovered 25.9.88 GMR 340342E, 6484113N	Inhalation of smoke and gas
73.	JENNINGS, DUNCAN (28) 42 Drewett Close Shinfield Reading Berkshire	Geologist	Exploration Logging North Sea Ltd Walton Road Dyce Aberdeen	Recovered 16.7.88 66m, 211 degrees from Leg A5	Drowning
74.	JONES, JEFFREY GRANT (37) 2 Heol Brynhyfryd Woodlands Park Llantwit Fardre	Assistant Driller*	Bawden International Ltd Wellheads Road Dyce Aberdeen	Missing: LKW – on pipe deck after 22.20	N/A
75.	KAVANAGH, CHRISTOPHER (49) 71 Lomand Road Wemyss Bay	Plater	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 29.7.88 116m, 327 degrees from Leg A5	Multiple injuries
76.	KELLY, WILLIAM HOWAT (43) 10 Summerfield Road Condorrat Cumbernauld	Electrical Technician	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
77.	KILLINGTON, IAN (33) 5 Fulmar Drive Blyth Northumberland	Steward	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
78.	KIRBY, JOHN BRIAN (51) 3 Wheatlands Drive Easington Saltburn Cleveland	Production Operator	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
79.	KNOX, STUART GORDON CHARLES (37) 119 Morrison Street Edinburgh	Roustabout	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
80.	LAING, ALEXANDER RODGER (38) 43 Portree Avenue Broughty Ferry Dundee	Steward	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Missing	N/A
81.	LARGUE, TERENCE MICHAEL (34) 24 Beale Close Ingleby Barwick Stockton Cleveland	Scaffolder	Aberdeen Scaffolding Company Ltd Hareness Road Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
82.	LAWRIE, GRAHAM (39) 146 Faulds Gate Aberdeen	Roustabout	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
83.	LEGGAT, FINDLAY WALLACE (37) (formerly CAMPBELL) 15/8 Bernard Terrace Bridgeton Glasgow	Scaffolder	Aberdeen Scaffolding Company Ltd Hareness Road Aberdeen	Missing: LKW – in White House, possibly after 22.45	N/A

	Deceased	Occupation	Employer	Recovery/LKW	Principal Cause of Death
84.	LITHGOW, BRIAN (34) 25 Falcon Avenue Edinburgh	Photographic Technician	Stena Offshore Stena House Westhill Industrial Estate Westhill Aberdeen	Recovered 2.6.89 GMR 340152E, 6484085N	Not ascertained
85.	LITTLEJOHN, ROBERT RODGER (29) 9 Otterson Grove Dalgety Bay Fife	Pipe Fitter	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
86.	LONGSTAFFE, MARTIN GEORGE (22) 903 Ecclesall Road Sheffield	Logger	Exploration Logging North Sea Ltd Walton Road Dyce Aberdeen	Recovered 6.9.88 in Galley of ERQ	Inhalation of smoke and gas
87.	MAHONEY, WILLIAM RAYMOND (60) 255 Girdleness Road Aberdeen	Steward	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
88.	MARTIN, JOHN MORRISON (33) 56 Firhill Alness	Rigger	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
89.	McBOYLE, SIDNEY IAN (36) 24 Stensall Road Huntingdon York	Motorman*	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
90.	McCALL, ROBERT BORLAND (39) 56 Mauchline Road Hurlford Ayrshire	Chief Electrician	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
91.	McCULLOCH, JAMES (51) 4 Gregness Gardens Torry Aberdeen	H.V.A.C. Technician	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 6.9.88 in Galley of ERQ	Not ascertained

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
92.	McDONALD, ALISTAIR JAMES (33) 16 First Avenue Stepps Glasgow	Mechanical Technician	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
93.	McELWEE, ALEXANDER (45) 29 Westwood Quad Clydebank	Plater	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Missing	N/A
94.	McEWAN, THOMAS O'NEIL (38) 32 Maple Court Abronhill Cumbernauld	Electrical Chargehand	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
95.	McGREGOR, WILLIAM GEORGE (48) 11 Johnston Gardens West Peterculter Aberdeen	Leading Steward	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Recovered 7.7.88 on surface of sea near Platform	Chest injury
96.	McGURK, FREDERICK THOMAS SUMMERS (51) 131 Fintry Drive Dundee	Rigger	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Missing	N/A
97.	McINTOSH, WILLIAM HUGH (24) 80 Highfield Walk Turriff	Floorman	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
98.	McKAY, GORDON (33) 231 West Road Fraserburgh	Valve Technician	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 14.7.88 80m, 044 degrees from Leg A5	Inhalation of smoke and gas
99.	McLAUGHLIN, CHARLES EDWARD (46) 1 Unity Place Woodside Glasgow	Electrician	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 7.7.88 on surface of sea near Platform: LKW – going towards SW corner of Platform shortly after 22.40	Drowning

Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
100. McLEOD, NEIL STUART ROSS (41) Doleygate Farm Gnosall Stafford	Quality Assurance Inspector	Leuven Services (Aberdeen) Ltd 3 Albert Street Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
101. McPAKE, FRANCIS (49) 54D Woodside Road Raploch Stirling	Steel Erector/Rigger	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
102. McWHINNIE, DAVID ALLISON (36) 3 Carey Road Saltcoats Ayrshire	Production Operator	M B Services Ltd Unit 4E Wellheads Industrial Estate Dyce Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
103. McWILLIAMS, DUGALD McLEAN (31) 29 Mearns Street Greenock	Welder	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
104. MEARNS, CARL (20) 173 Marshall Wallis Road South Shields	Rigger	Stena Offshore Stena House Westhill Industrial Estate Westhill Aberdeen	Recovered 23.8.88 GMR 340104E, 6484116N	Inhalation of smoke and gas
105. MILLAR, DEREK KLEMENT MICHAEL (32) 8 Salters Terrace Dalkeith Midlothian	Supervisor*	Macnamee Services Ltd Burnside Works Kennerty Mills Road Peterculter Aberdeen	Recovered 22.7.88 104m, 091 degrees from Leg A1: LKW – at Reception after 22.00	Inhalation of smoke and gas
106. MILLER, ALAN DAVID (31) 6 Reid Crescent Kirkwall Orkney	Industrial Chemist	Caleb Brett International Wellheads Crescent Dyce Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
107. MILLER, FRANK (33) 6 Train Terrace Rosyth Fife	Scaffolder	Aberdeen Scaffolding Company Ltd Hareness Road Aberdeen	Recovered 6.9.88 in Galley of ERQ	Inhalation of smoke and gas

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
108.	MOLLOY, JOHN HECTOR (32) 67 Marlborough Park South Belfast	Engineer	NL Sperry Sun/MWD/Baroid Logging Systems Wellheads Road Dyce Aberdeen	Missing	N/A
109.	MORRIS, LESLIE JAMES (38) Pine Lodge Mill of Lumphart Oldmeldrum	Platform Supt.#	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 7.7.88 on surface of sea near Platform: LKW – going towards SW corner of Platform shortly after 22.40	Drowning
110.	MUNRO, BRUCE ALEXANDER FERGUSON (29) 96 Auchmill Road Bucksburn Aberdeen	Floorman	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
111.	MURRAY, GEORGE FAGAN (37) 8 Ravensby Road Carnoustie	Steward	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
112.	NIVEN, JAMES COWIE (27) 34 Chisholm Place Grangemouth	Roustabout	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
113.	NOBLE, GRAHAM SIM (37) 25 Broomhill Fraserburgh	Materials Man	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 3.11.88 in C Deck of ERQ at Flotta	Inhalation of smoke and gas
114.	O'SHEA, MICHAEL (30) 1 Millview Terrace Neilston Glasgow	Electrician	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 17.7.88 146m, 67 degrees from Leg A5	Inhalation of smoke and gas
115.	PEARSTON, ROBERT RENNIE (25) 63 Colthill Circle Milltimber Aberdeen	Mechanic	Macnamee Services Ltd Burnside Works Kennerty Mills Road Peterculter Aberdeen	Missing: LKW – in Cinema about 22.00	N/A

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
116.	PIPER, IAN (38) 26 Hillswick Road Sheddocksley Aberdeen	Motorman	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 26.10.88 in Reception of D Deck of ERQ at Flotta	Inhalation of smoke and gas
117.	POCHRYBNIAK, WASYL (37) 2 Westbourne Park Urmston Manchester	Lead Roustabout*	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
118.	PRICE, RAYMOND LESLIE (59) 57 Stanhope Drive Bromborough Wirrall	Production Operator	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Missing: LKW – in Electricians' Workshop and possibly White House between 22.00 and 22.20	N/A
119.	PYMAN, NEIL (32) 3 Strathburn Gardens Inverurie	Engineer	Eastman Christensen Ltd Murcar Commercial Park Denmore Road Bridge of Don Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
120.	QUINN, TERENCE STEPHEN (28) 2 Roseville Road Hayes Middlesex	Service Engineer	Orbit Valve Co Europe Orbit House Swallowfield Way Hayes Middlesex	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
121.	RAEBURN, WILLIAM WALLACE (38) 2 Papes Cottages Roseburn Edinburgh	Maintenance Controller	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 31.10.88 42m, 300 degrees from Leg A5	Inhalation of smoke and gas
122.	REID, DONALD (44) 4 Greenbrae Gardens South Bridge of Don Aberdeen	Chargehand Engineer	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 7.7.88 on surface of sea near Platform	Inhalation of smoke and gas
123.	REID, ROBERT WELSH (27) 37 Grant Road Arbroath	Roustabout	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
124.	RENNIE, GORDON MacALONAN (52) 162 Avontoun Park Linlithgow West Lothian	Process Operator*	M B Services Ltd Unit 4E Wellheads Industrial Estate Dyce Aberdeen	Missing	N/A
125.	RICHARD, ROBERT MILLER (45) 16 Polmont Park Polmont Falkirk	Production Operator*	M B Services Ltd Unit 4E Wellheads Industrial Estate Dyce Aberdeen	Missing: LKW – leaving 68 ft level for C Module shortly before 22.00	N/A
126.	RIDDOCH, ALAN (44) 22 Morven Crescent Findochty Buckie	Steward	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Recovered 6.9.88 in Galley of ERQ	Inhalation of smoke and gas
127.	ROBERTS, ADRIAN PETER (28) 2 Coed-y-Llwyn Gellilydan Gwynedd North Wales	Roughneck	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 25.7.88 31m, 245 degrees from Leg A5: LKW – at door leading from Reception at 22.05	Inhalation of smoke and gas
128.	ROBERTSON, ALEXANDER JAMES (50) 14 Ritchie Place Crieff	Lead Production Technician#	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
129.	ROBERTSON, DONALD NICHOLSON (54) 31 Sinclair Drive Largs Ayrshire	Mechanical Technician	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
130.	ROSS, GARY (29) 27 Stafford Street Aberdeen	Roustabout*	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 2.11.88 GMR 340107E, 6484109N: LKW – in Gymnasium after 22.00	Inhalation of smoke and gas
131.	RYAN, MICHAEL HECTOR (23) 819 Great Northern Road Aberdeen	Roustabout	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 7.7.88 on surface of sea near Platform	Chest injury

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
132.	SANGSTER, STANLEY (56) 52 Cummings Park Drive Aberdeen	Foreman Scaffolder	Aberdeen Scaffolding Co Ltd Hareness Road Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
133.	SAVAGE, JAMES JOHN DEARN (41) 8A Millfield Drive Polmont Falkirk	Electrical Technician	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 2.11.88 GMR 340107E, 6484109N	Inhalation of smoke and gas
134.	SCORGIE, MICHAEL HUGH BRODIE (28) 43 Turnberry Drive Kirkcaldy Fife	Lead Floorman*	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 19.7.88 111m, 086 degrees from Leg A5	Inhalation of smoke and gas
135.	SCORGIE, WILLIAM ALEXANDER (46) 11 Brimmond Way Westhill Aberdeen	Pipe Fitter	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
136.	SCOTT, JOHN FRANCIS (26) 1 Crew Loan Edinburgh	Scaffolder	Aberdeen Scaffolding Co Ltd Hareness Road Aberdeen	Missing: LKW – leaving Cinema shortly after 22.02	N/A
137.	SEATON, COLIN DENIS (51) Lee Croft Kilburn Thirsk North Yorkshire	Offshore Installation Manager#	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
138.	SELBIE, ROBERT HENDRY (32) 1 Newburgh Circle Bridge of Don Aberdeen	Turbo Drill Engineer	Neyrfor (UK) Ltd Hareness Circle Aberdeen	Recovered 23.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
139.	SERINK, MICHAEL JEFFREY (26) 7481 Gatineau Place Vancouver British Columbia Canada	Logger	Exploration Logging North Sea Ltd Walton Road Dyce Aberdeen	Recovered 31.10.88 in A Deck of ERQ at Flotta	Inhalation of smoke and gas

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
140.	SHORT, MICHAEL BERNARD (41) 23 Alfred Road Buckhurst Hill Essex	Foreman Rigger	Stena Offshore Stena House Westhill Industrial Estate Westhill Aberdeen	Recovered 11.7.88 GMR 340066E, 6484188N	Inhalation of smoke and gas
141.	SKINNER, RICHARD VALENTINE (41) 27 Baillie Norrie Crescent Montrose	Assistant Driller	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 14.7.88 GMR 340205E, 6484311N: LKW – on top of Accom. W shortly before 22.20	Drowning
142.	SMITH, WILLIAM HAMILTON (43) "Crammond" 10 Nobel View Reddingmuirhead Falkirk	Maintenance Lead Hand	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 23.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
143.	SPEIRS, JAMES (42) 31 MacFarlane Place Uphall West Lothian	Mechanical Technician	John Wood Group plc John Wood House Greenwell Road Bridge of Don Aberdeen	Missing	N/A
144.	STEPHENSON, KENNETH STUART (37) 26 Claudius Court South Shields	Rigger	Stena Offshore Stena House Westhill Industrial Estate Westhill Aberdeen	Recovered 12.7.88 150m 260 degrees from Leg B5	Inhalation of smoke and gas
145.	STIRLING, THOMAS CUNNINGHAM BOSWELL (27) 6 Burnbank Gardens Maryhill Glasgow	Cleaner	Macnamee Services Ltd Burnside Works Kennerty Mills Road Peterculter Aberdeen	Recovered 18.7.88 109m 072 degrees from Leg A5: LKW – in Galley after 22.00	Inhalation of smoke and gas
146.	STOREY, MALCOLM JOHN (38) 22 Coul Park Alness Ross-shire	Seaman	Haven Shipping Co Queen's Road Great Yarmouth	Recovered 7.7.88 on surface of sea near Platform: LKW – in FRC of *Sandhaven* on W side of Platform about 22.50	Drowning
147.	STOTT, JAMES CAMPBELL (40) 3 Newburgh Circle Bridge of Don Aberdeen	Plumber	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 6.9.88 in Galley of ERQ	Not Ascertained

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
148.	STWERKA, JURGEN TILO (36) 6843 Biblis 1 Beethoven Strasse 5 Hessen West Germany	Research Chemist	Grace G.M.B.H. Postfach 1445 In Der Hollerhecke D-6520 Worms West Germany	Recovered 26.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
149.	SUTHERLAND, STUART DOUGLAS (21) 9 Marchbank Road Bieldside Aberdeen	Student/Cleaner*	Macnamee Services Ltd Burnside Works Kennerty Mills Road Peterculter Aberdeen	Missing: LKW – in White House after 22.20	N/A
150.	SUTTON, TERRENCE JOHN (28) 18 Clinton Drive Sandhaven Fraserburgh	Mechanical Fitter	Score (UK) Ltd Glenugie Engineering Works Invernettie Peterhead	Missing: LKW — in White House after 22.20	N/A
151.	TAYLOR, ALEXANDER RONALD (57) 29 Gairnshiel Place Aberdeen	Roustabout	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 24.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
152.	THOMPSON, ALISTAIR ADAM (45) 10 Whitestripes Way Bridge of Don Aberdeen	Telecom Engineer	British Telecom New Telecom House College Street Aberdeen	Recovered 29.7.88 152m, 310 degrees from Leg A5	Inhalation of smoke and gas
153.	VERNON, ROBERT ARGO (51) 3 The Orchard Brightons Falkirk	Production Operator*	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Missing: LKW — on NW Navigation Aid Platform shortly before 22.20	N/A
154.	WAKEFIELD, JOHN EDWARD (35) 38 Chadwell Springs Waltham Grimsby Humberside	Instrument Technician	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 17.10.88 GMR 340106E, 6484112N adjacent to Leg B5: LKW - leaving Instrument Workshop shortly before 22.00	Drowning
155.	WALKER, MICHAEL ANDREW (24) 12 Dunnottar Road Castlepark Ellon	Technician	Wimpol Ltd Offshore Navigation Surveys Unit 6 5 Wellheads Industrial Centre Dyce Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas

	Deceased	Occupation	Employer	Recovery/LKW	Principal Cause of Death
156.	WARD, BRYAN THOMAS (49) 168 Clarendon Street Hull	Rigger	Stena Offshore Stena House Westhill Industrial Estate Westhill Aberdeen	Recovered 7.7.88 on surface of sea near Platform	Inhalation of smoke and gas
157.	WATKIN, GARETH HOPSON (42) 22 Bain Road Mintlaw Aberdeenshire	Offshore Medical Attendant#	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 14.7.88 50m, 245 degrees from Leg B5: LKW – in Accommodation, going to Medics' Room with injured man after 22.00	Inhalation of smoke and gas
158.	WATSON, FRANCIS JOHN (38) 67 Highfield Road Longlands Middlesbrough	Head Chef	Kelvin Catering Camps Ltd 5 Queen's Terrace Aberdeen	Missing	N/A
159.	WHIBLEY, ALEXANDER (28) 1 Crookmore Cottages Montgarrie Alford	Roustabout*	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
160.	WHITE, KEVAN DENNIS (42) 17/18 Everingham Orton Brimbles Peterborough	Maintenance Supervisor#	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 20.7.88 110m, 246 degrees from Leg A5	Chest Injury
161.	WHITELEY, ROBERT (39) 17 Queen Margaret Drive Glenrothes Fife	Roustabout	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Recovered 19.7.88 89m, 078 degrees from Leg A5: LKW – at Reception at 22.05	Inhalation of smoke and gas
162.	WHYTE, GRAHAM GILL (42) 17 Carron Place Aberdeen	Aerial Rigger	British Telecom New Telecom House College Street Aberdeen	Recovered 23.7.88 65m, 79 degrees from Leg A5	Death in fire
163.	WHYTE, JAMES GILBERT (53) 14 Cramond Park Edinburgh	Aerial Rigger	British Telecom New Telecom House College Street Aberdeen	Recovered 20.7.88 174m, 050 degrees from Leg A5	Inhalation of smoke and gas

	Deceased	*Occupation*	*Employer*	*Recovery/LKW*	*Principal Cause of Death*
164.	WICKS, ALAN (40) 72 Chapman Drive Carnoustie	Safety Supervisor#	Occidental Petroleum (Caledonia) Ltd 1 Claymore Drive Bridge of Don Aberdeen	Recovered 20.7.88 80m, 278 degrees from Leg A5: LKW – near W door on C Deck shortly before 22.20	Death in fire
165.	WILLIAMSON, PAUL CHARLES FERGUSON (24) 8 Fairview Wynd Danestone Aberdeen	Floorman*	Bawden International Ltd Wellheads Road Dyce Aberdeen	Recovered 23.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke and gas
166.	WISER, DAVID (65) 140 Drayton Park Highbury London	Survey Technician	UDI Group Ltd Offshore Instrumentation Denmore Road Bridge of Don Aberdeen	Recovered 25.10.88 in D Deck of ERQ at Flotta	Inhalation of smoke
167.	WOODCOCK, JOHN RICHARD (29) 9 Claremont Street Aberdeen	Technical Clerk	John Wood Group plc John Wood House Greenwell Road East Tullos Aberdeen	Missing: LKW — in Tea Hut above pipe deck after 22.20	N/A

NOTES: No 10 (Brian Batchelor) and No 146 (Malcolm Storey) were members of the crew of the Fast Rescue Craft of the *Sandhaven*.

The symbol * denotes that the deceased was on night shift. The symbol # indicates that he was on 24 hours call.

The column "Recovery/LKW" sets out information as to the recovery of the body of the deceased where this was achieved. In the case of those missing and those recovered from elsewhere than the wreckage of the accommodation it sets out the last known whereabouts (LKW) of the deceased in the period from about 22.00 on 6 July in the light of the evidence available to the Inquiry.

Appendix I
List of Abbreviations

Acronyms

AAE	Additional Accommodation East
AAW	Additional Accommodation West
AC	Alternating current
ACMH	Advisory Committee on Major Hazards
AFE	Authorisation for expenditure
AIT	Autoignition temperature
ALARP	As low as reasonably practicable
APAU	Accident Prevention Advisory Unit (of HSE)
ASTM	American Society for Testing and Materials
BA	Breathing apparatus
BOP	Blowout preventer
BS	British Standard
BST	British Standard Time
CAA	Civil Aviation Authority
CBI	Confederation of British Industry
CIMAH	Control of Industrial Major Accident Hazards (Regulations)
COSHH	Control of Substances Hazardous to Health (Regulations)
CSE	Concept safety evaluation
CSS	Co-ordinator surface search
DC	Direct current
DEn	Department of Energy
DHSV	Down hole safety valve
DoT	Department of Transport
DOTI	Department of Trade and Industry
DPCV	Differential pressure control valve
DSF	Deck support frame
EADU	Exploration, Appraisal and Development Unit (of DEn)
ECV	Emergency control valve
EEC	Emergency Evacuation Controller
EPS	Emergency power supply
ERQ	East Replacement Quarters
ESD	Emergency shutdown
ESV	Emergency shutdown valve
FCV	Flow control valve
F&G	Fire and gas (panel, system)
FILO	Flight information and logistics officer
FRC	Fast rescue craft
FSA	Formal safety assessment
GA	General alarm
GCM	Gas Conservation Module
GMT	Greenwich Mean Time

GOV	Gas operated valve
GTC	Gas to Claymore (valve)
HAZOP	Hazard and operability (study)
HF	High frequency
HFT	Hydrate formation temperature
HMV	Hydraulic master valve
HP	High pressure
HSC	Health and Safety Commission
HSE	Health and Safety Executive
HSWA	Health and Safety at Work etc, Act 1974
HVAC	Heating, ventilation and air conditioning
IMO	International Maritime Organisation
IP	Institute of Petroleum
IR	Infra-red
IUOOC	Inter-Union Offshore Oil Committee
JB	John Brown (generators)
JCP	Joint control panel
JT	Joule Thomson (effect, flash drum, valve)
LCV	Level control valve
LEL	Lower explosive limit
LIC	Level indicator controller
LP	Low pressure
LPG	Liquefied petroleum gas
LQW	Living Quarters West
LSA	Low specific activity
MCP	Manifold compression platform
MERSAR	Merchant Ship Search and Rescue (Manual)
MHAU	Major Hazards Assessment Unit (of HSE)
MOB	Man overboard
MOL	Main oil line
MOV	Motor operated valve
MRCC	Maritime Rescue Co-ordination Centre
MWA	Mineral Workings (Offshore Installations) Act 1971
MWP	Maximum working pressure
NCS	Norwegian continental shelf
NEL	National Engineering Laboratory
NPD	Norwegian Petroleum Directorate
NRV	Non-return valve (also called check valve)
OESD	Overall emergency shutdown
OIAC	Offshore Industry Advisory Committee
OIM	Offshore Installation Manager
OPG	Offshore Projects Group
OSC	On-Scene Commander
PA	Personal address
PCV	Pressure control valve
PED	Petroleum Engineering Division (of DEn)
PESD	Platform emergency shutdown

PM	Preventive maintenance
POB	Persons on board
PPA	Petroleum (Production) Act 1934
PSPA	Petroleum and Submarine Pipe-lines Act 1975
PSV	Pressure safety valve
PTW	Permit to work
QA	Quality assurance
QMS	Quality management system
QRA	Quantitative risk assessment
RCC	Rescue co-ordination centre
RGIT	Robert Gordon Institute of Technology
RIV	Rapid intervention vessel
RNLI	Royal National Lifeboat Institution
ROV	Remotely operated vehicle
RTJ	Ring type joint
SBV	Standby vessel
SMS	Safety management system
SOLAS	Safety of Life at Sea
SPEEM	Submersible Pump Electrical Equipment Module
SRV	Safety relief valve
SSIV	Subsea isolation valve
TEMPSC	Totally enclosed motor propelled survival craft
TRA	Total risk analysis
TSR	Temporary safe refuge
TUC	Trades Union Congress
UHF	Ultra high frequency
UKCS	United Kingdom continental shelf
UKOOA	United Kingdom Offshore Operators Association Ltd
UPS	Uninterrupted power supply
UV	Ultra-violet
VDU	Visual display unit
VHF	Very high frequency

Units

BPD	barrels per day
MCF	thousands of cubic feet
MMSCF	millions of standard cubic feet
MMSCFD	millions of standard cubic feet per day
SCF	standard cubic feet
bara	bars absolute
barg	bars gauge
bbl/d	barrels per day
cfm	cubic feet per minute
psia	pounds per square inch absolute
psig	pounds per square inch gauge
scfm	standard cubic feet per minute
v/v	volume/volume
w/w	weight/weight

Statutory Instruments

Construction and Survey Regulations - Offshore Installations (Construction and Survey) Regulations 1974 (SI 1974 No 289)

Emergency Pipe-line Valve Regulations - Offshore Installations (Emergency Pipe-line Valve) Regulations 1989 (SI 1989 No 1029)

Emergency Procedures Regulations - Offshore Installations (Emergency Procedures) Regulations 1976 (SI 1976 No 1542)

Fire-fighting Equipment Regulations - Offshore Installations (Fire-fighting Equipment) Regulations 1978 (SI 1978 No 611)

Included Apparatus or Works Order - Offshore Installations (Included Apparatus or Works) Order 1989 (SI 1989 No 978)

Inspectors and Casualties Regulations - Offshore Installations (Inspectors and Casualties) Regulations 1973 (SI 1973 No 1842)

Life-saving Appliances Regulations - Offshore Installations (Life-saving Appliances) Regulations 1977 (SI 1977 No 486)

Operational Safety, Health and Welfare Regulations - Offshore Installations (Operational Safety, Health and Welfare) Regulations 1976 (SI 1976 No 1019)

Public Inquiries Regulations - Offshore Installations (Public Inquiries) Regulations 1974 (SI 1974 No 338)

Well Control Regulations - Offshore Installations (Well Control) Regulations 1980 (SI 1980 No 1759)

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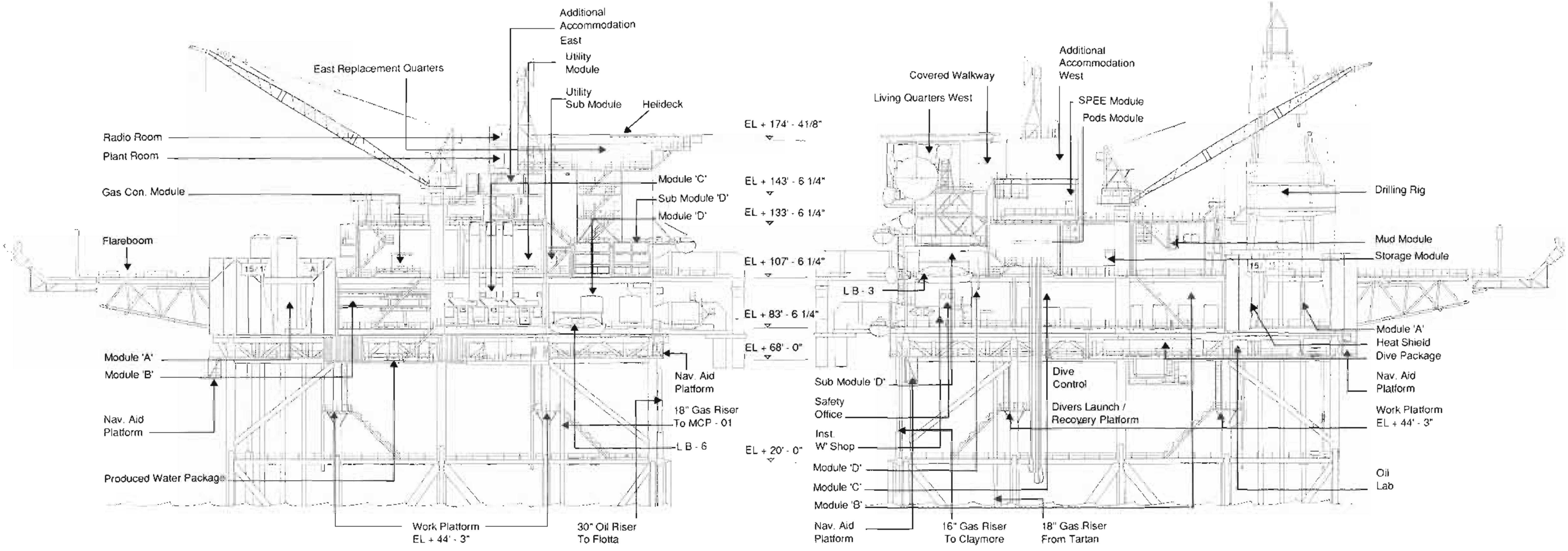


PIPER 'A' PLATFORM EAST ELEVATION

(a)

PIPER 'A' PLATFORM WEST ELEVATION

(b)

Fig. J.1 The Piper Alpha platform: (a) east elevation; and (b) west elevation.

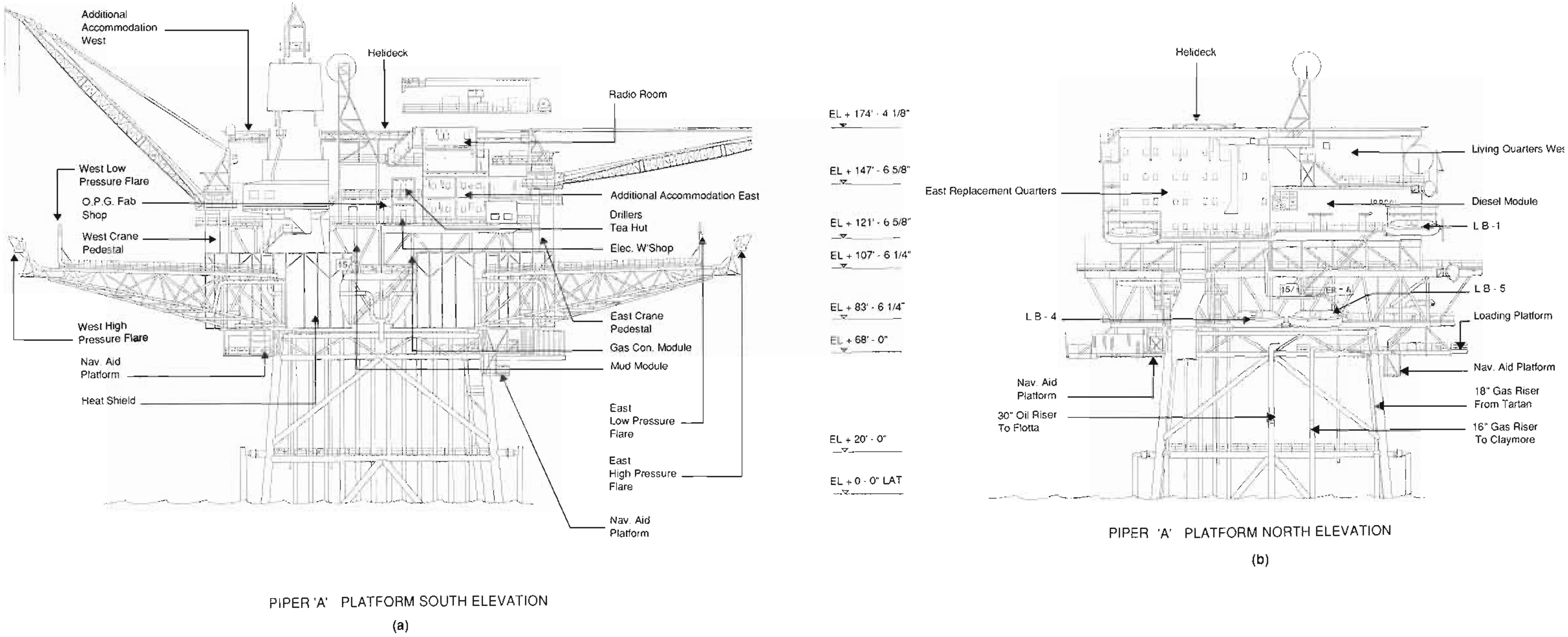
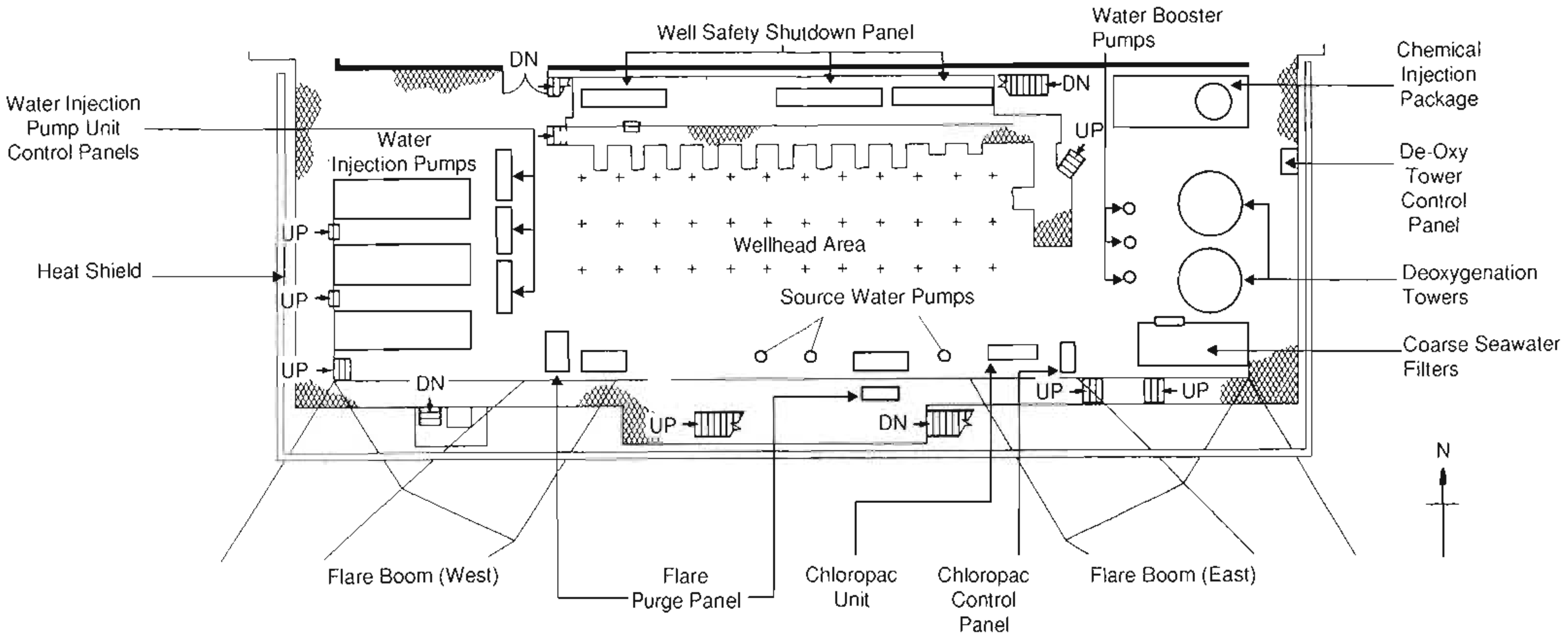
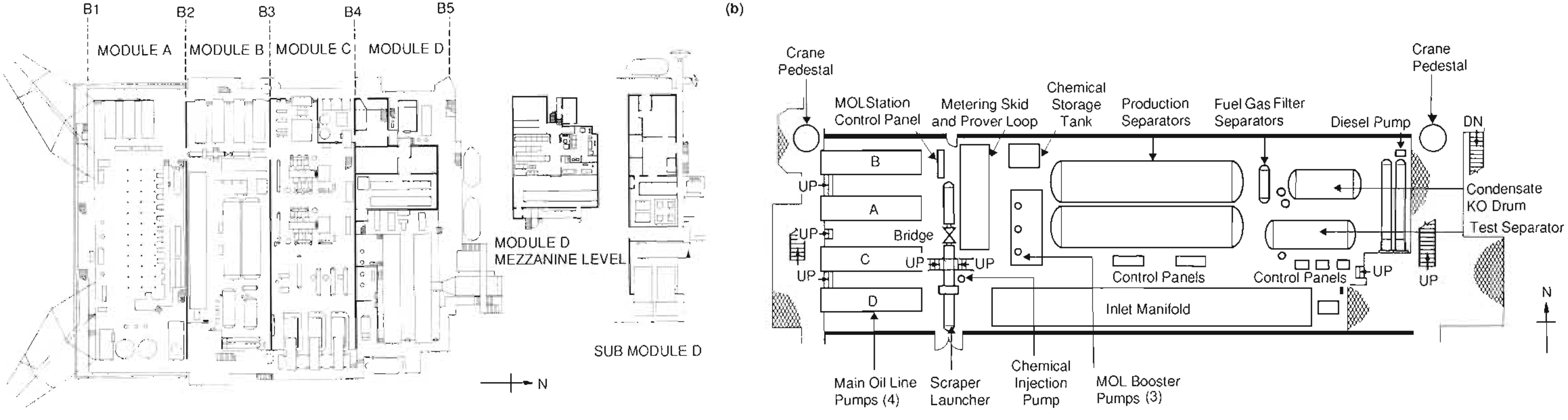


Fig. J.2 The Piper Alpha platform: (a) south elevation; and (b) north elevation.



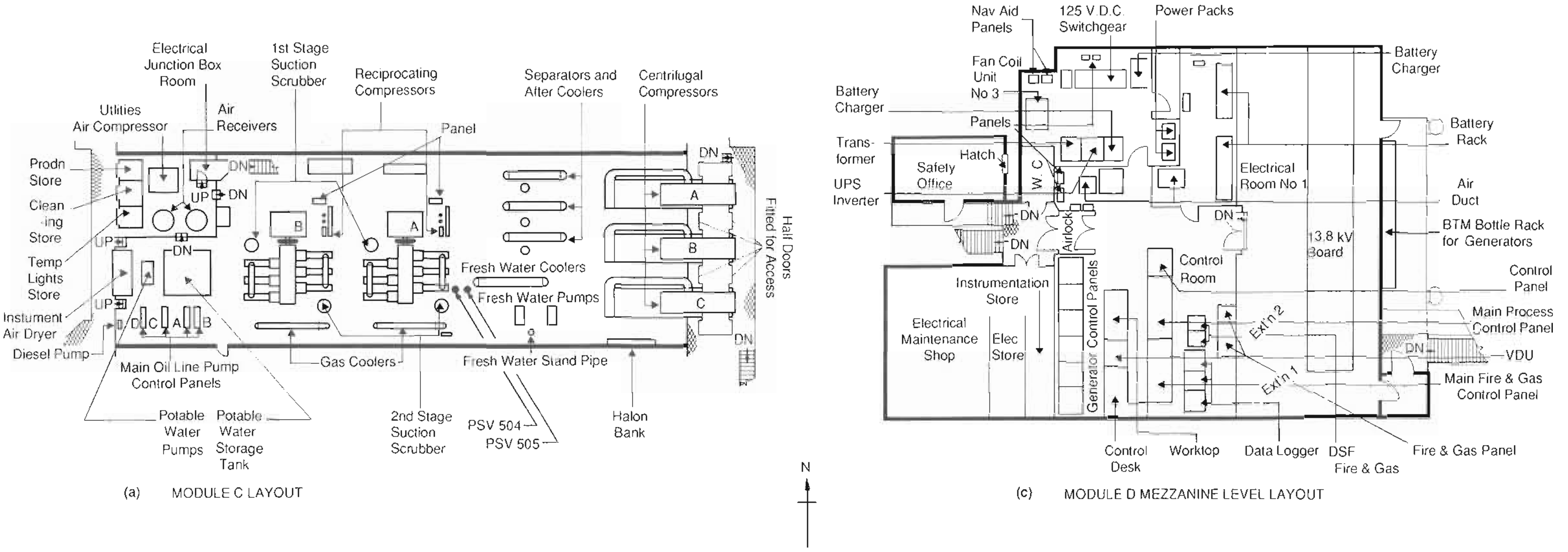
MODULE A LAYOUT
(b)



PRODUCTION DECK LAYOUT
(a)

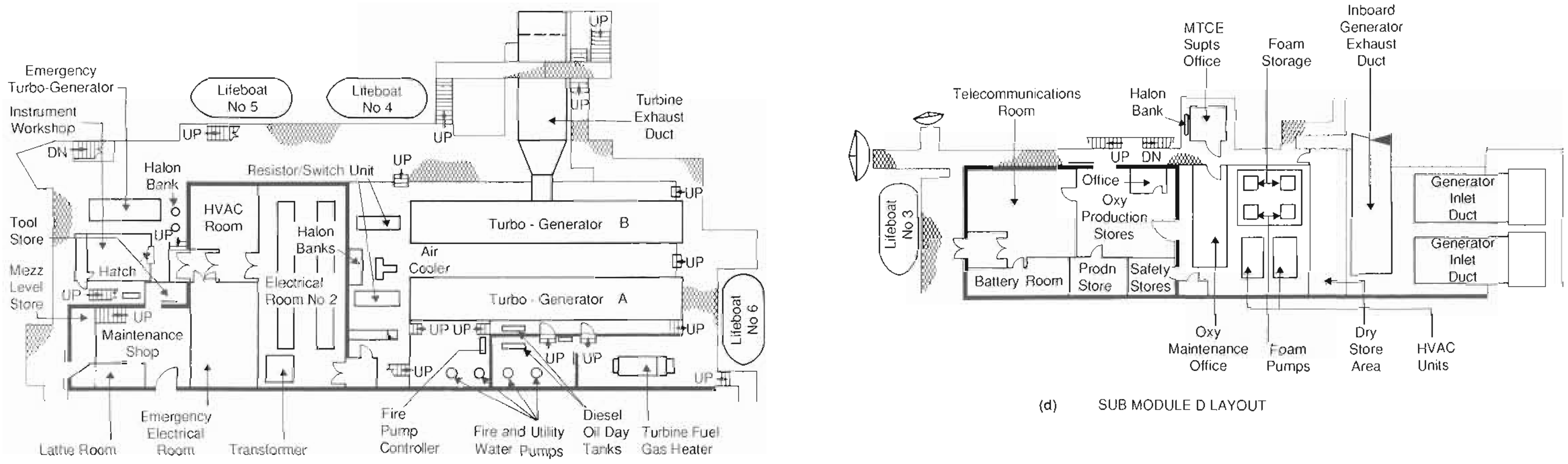
MODULE B LAYOUT
(c)

Fig. J.3 Layout of the production deck and production deck modules — 1: (a) production deck; (b) A Module; and (c) B Module.



(a) MODULE C LAYOUT

(c) MODULE D MEZZANINE LEVEL LAYOUT



(d) SUB MODULE D LAYOUT

Fig. J.4 Layout of the production deck and production deck modules — 2: (a) C Module; (b) D Module;

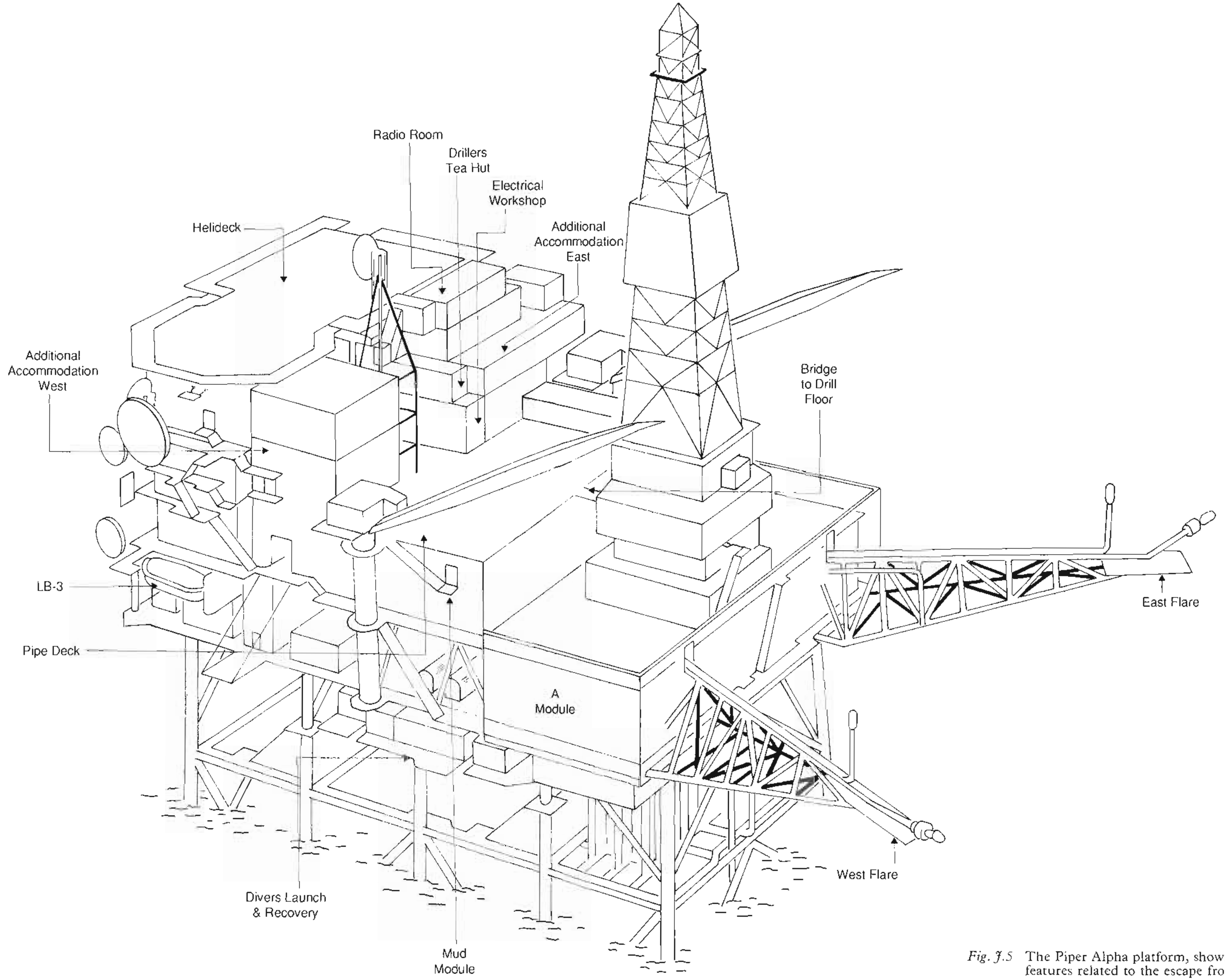


Fig. J.5 The Piper Alpha platform, showing pipe deck and other features related to the escape from the platform.

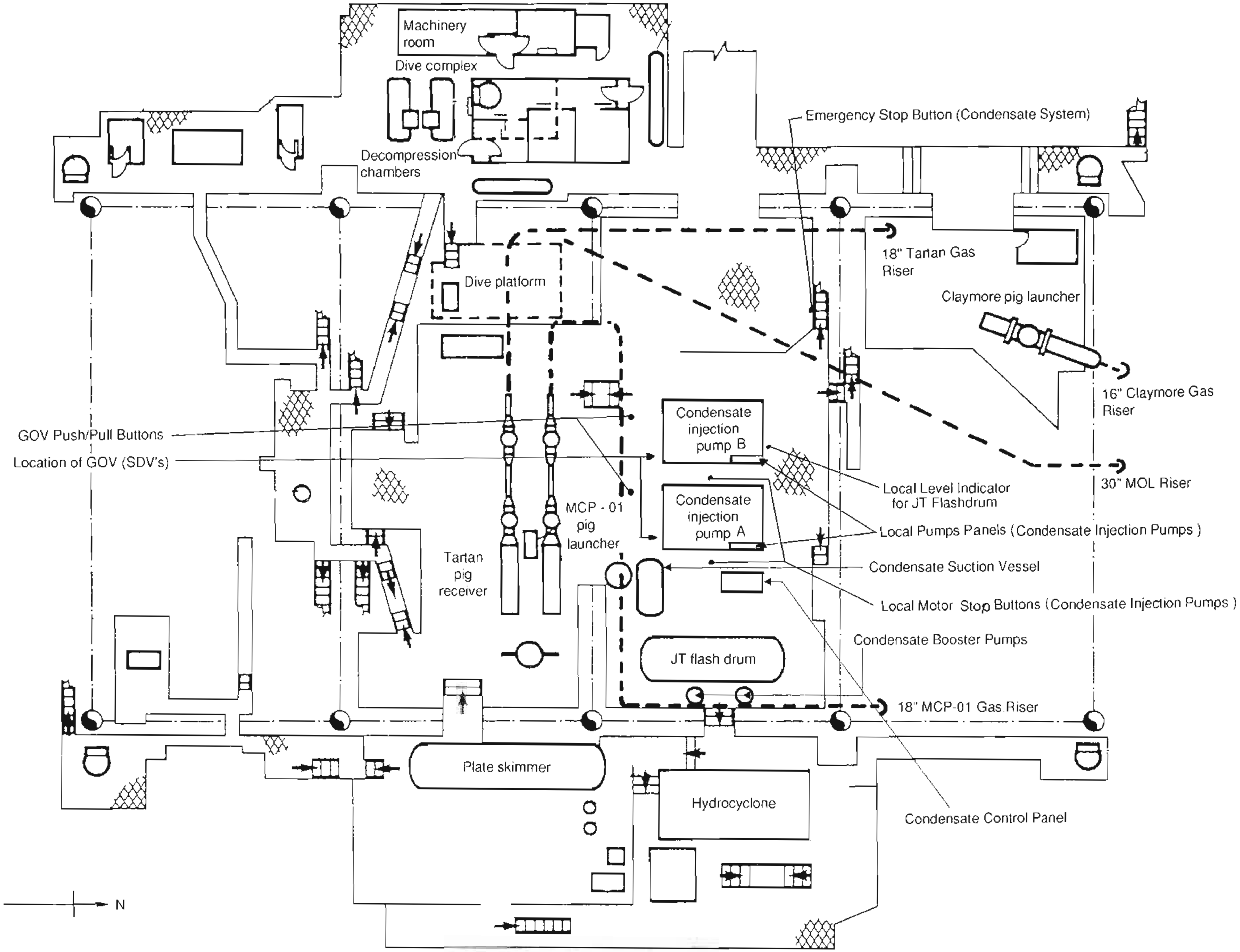
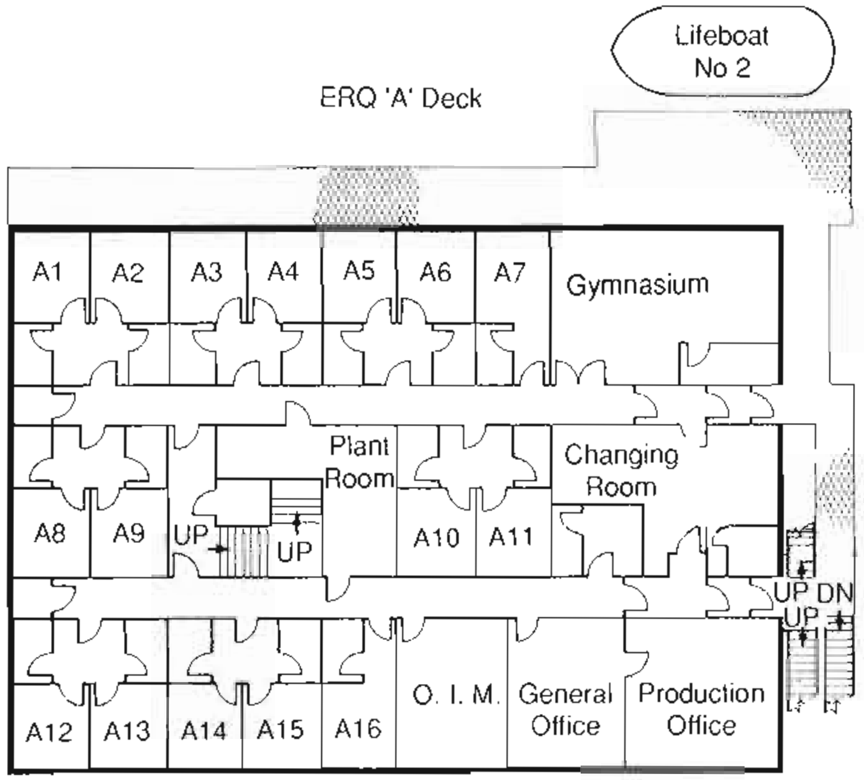
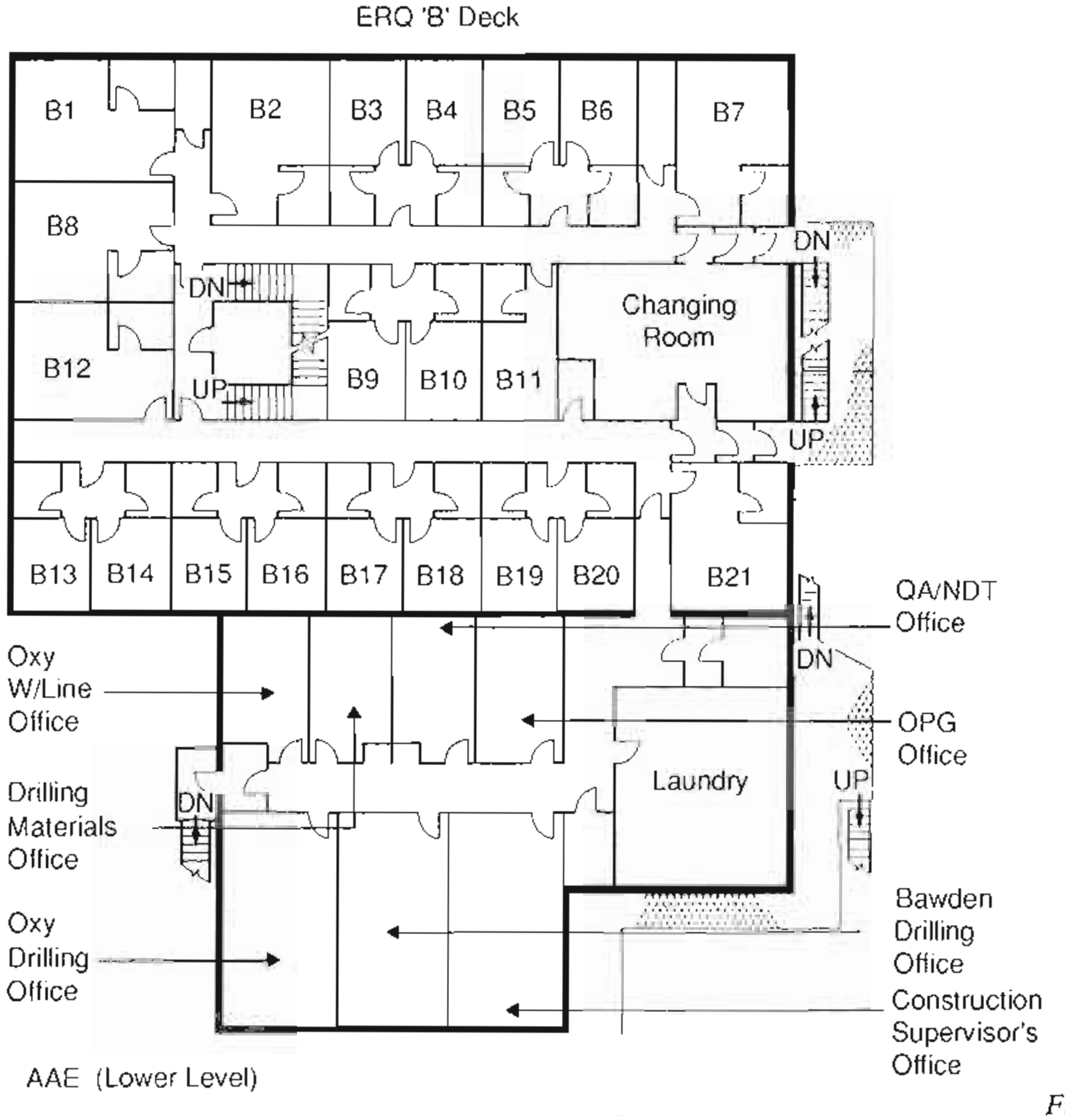


Fig. J.6 The 68ft level, or deck support frame.



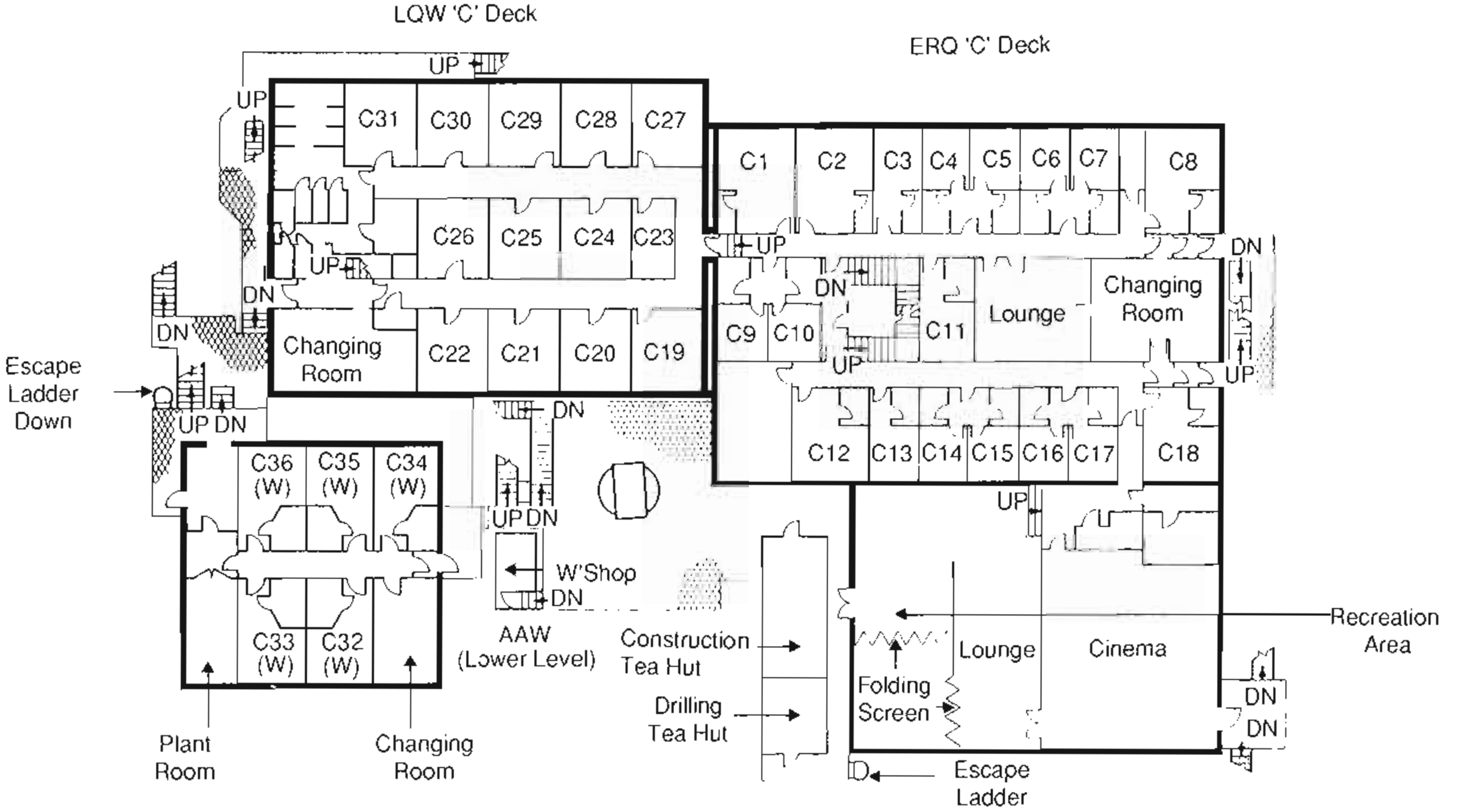
ACCOMMODATION LEVEL 1 (BOTTOM) LAYOUT

(a)



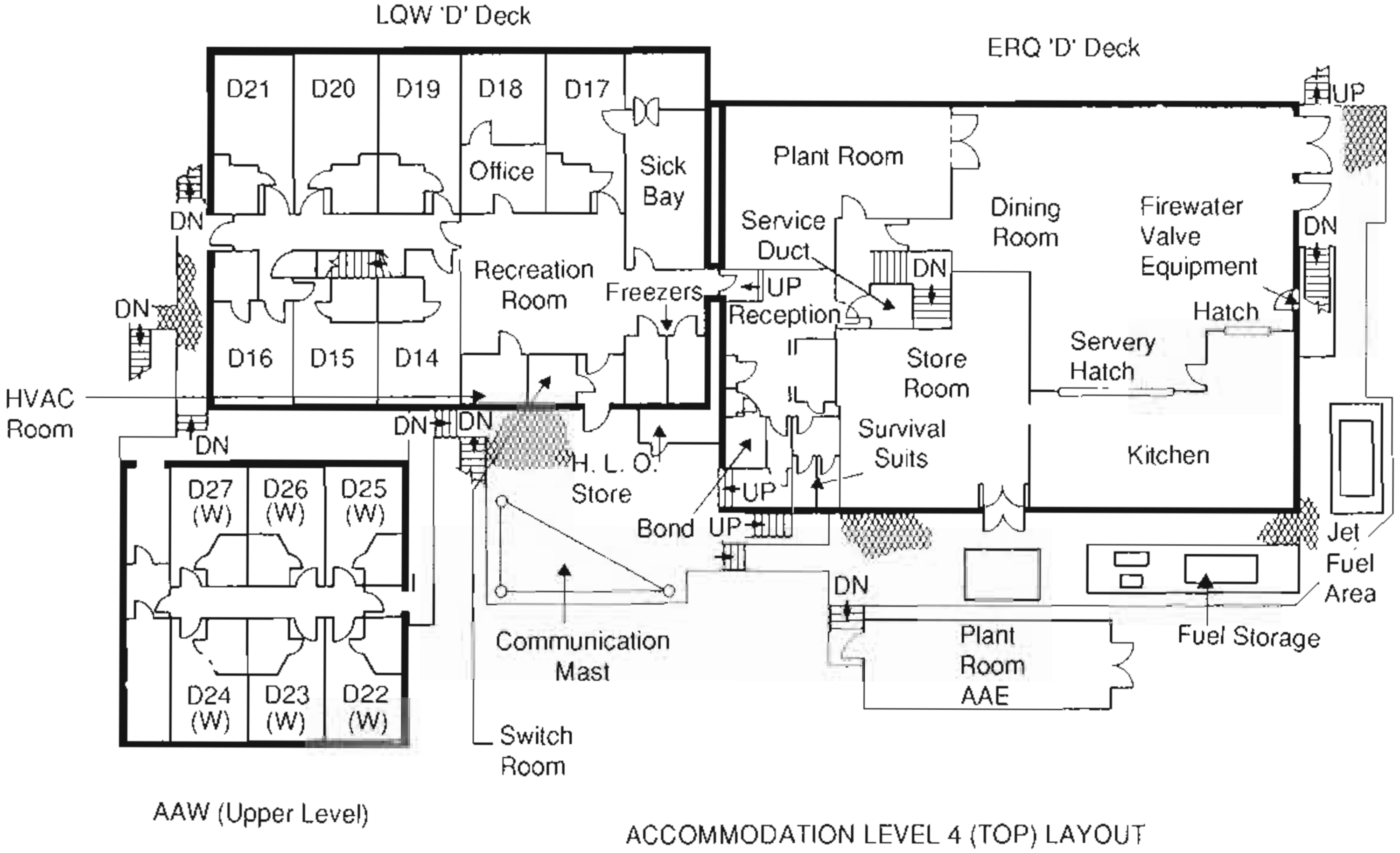
ACCOMMODATION LEVEL 2 LAYOUT

(b)



ACCOMMODATION LEVEL 3 LAYOUT

(c)



ACCOMMODATION LEVEL 4 (TOP) LAYOUT

(d)

N

Fig. J.7 Layout of the accommodation modules: (a) level 1 (ERQ A deck); (b) level 2 (ERQ B deck and AAE lower level); (c) level 3 (ERQ and LQW C deck, AAE upper level and AAW lower level); and (d) level 4 (ERQ and LQW D deck and AAW upper level)

Table J.1 - Process quantities flowsheet on 6 July 1988

Stream Name		100	110	120	150	170	190	200	210	211	220	230	240	300	301	320	330	350	360	400	420	600	700	710	720	730
Phase		Vapour	Vapour	Vapour	Vapour	Vapour	Vapour	2-Phase	2-Phase	Vapour	Vapour	Vapour	Vapour	Liquid	Liquid	2-Phase	Liquid	Liquid	Liquid	Liquid	Liquid	Vapour	Vapour	Vapour	Vapour	Vapour
Temperature (^{O}F)		150.0	64.2	64.2	105	105	92.5	52.5	55.6	55.6	55.6	198	198	64.2	105	103.7	55.6	60.2	60.2	150.0	149	105	64.2	105	55.6	198
Pressure (psia)		154.7	150.0	150.0	675	675	1465	635	635	635	635	1735	1735	150	675	635	635	1,100	904.7	154.7	904.7	675	150	675	635	1,735
Vapour Mole Fraction		1.000	1.000	1.000	1.000	1.000	0.987	0.864	0.835	1.000	1.000	1.000	1.000	0.000	0.000	0.023	0.000	0.000	0.000	0.000	0.000	1.000	1.000	1.000	1.000	1.000
Av MOL Weight (lb/lb mol)		26.5	25.6	25.6	25.1	25.1	25.1	25.1	25.8	22.6	22.6	22.6	22.6	45.4	47.6	47.6	42.0	42.0	42.0	78.7	76.4	25.1	25.6	25.1	22.6	22.6
Density (T-P)(lb/ft^3)		0.650	0.721	0.721	3.42	3.42	-	-	-	3.19	3.19	6.61	6.61	46.3	29.9	-	30.1	30.4	30.1	50.9	50.1	3.42	0.721	3.42	3.19	6.61
Liquid S.G (STP)		-	-	-	-	-	-	-	-	-	-	-	-	0.674	0.528	-	0.495	0.495	0.495	0.839	0.819	-	-	-	-	-
Total Flow (lb/h)		301,380	278,690	270,260	258,430	186,870	186,870	186,870	198,700	145,320	132,720	132,720	132,670	22,677	11,833	11,833	53,387	53,387	53,387	1,494,400	1,547,800	26,146	8,431	45,411	12,598	46
Total Flow (lbmol/h)		11,390	10,890	10,560	10,312	7,456	7,456	7,456	7,705	6,435	5,877	5,877	5,875	499.9	248.8	248.8	1,270	1,270	1,270	18,991	20,261	1,043	329.4	1,812	557.9	2
Liquid Flow (bbl/d)		-	-	-	-	-	-	-	-	-	-	-	-	2,306	1,537	-	7,394	7,394	7,394	122,090	129,490	-	-	-	-	-
Vapour Flow (MMSCF/D)		103.7	99.2	96.2	93.9	67.9	-	-	-	58.6	53.5	53.5	53.5	-	-	-	-	-	-	-	-	9.5	3.0	16.5	5.1	0.0
Component Flows (lb mol/h)	Mol Weight																									
Water	18.02	259.7	22.4	21.8	20.0	14.5	14.5	14.5	16.2	2.9	2.7	2.7	2.7	237.3	1.8	1.8	13.3	13.3	13.3	11,593.0	11,606.0	2.0	0.7	3.5	0.3	0.0
H_2S	34.08	0.37	0.37	0.36	0.35	0.25	0.25	0.25	0.26	0.21	0.19	0.19	0.19	0.00	0.01	0.01	0.05	0.05	0.05	0.05	0.11	0.04	0.01	0.06	0.02	0.00
CO_2	44.01	42.9	42.7	41.4	40.9	29.6	29.6	29.6	30.1	26.9	24.6	24.6	24.6	0.2	0.5	0.5	3.2	3.2	3.2	3.0	6.1	4.1	1.3	7.2	2.3	0.0
Nitrogen	28.01	401.9	401.8	389.6	388.6	281.0	281.0	281.0	282.0	276.2	252.3	252.3	252.2	0.1	1.1	1.1	5.8	5.8	5.8	3.2	9.0	39.3	12.2	68.3	23.9	0.1
Methane	16.04	6,578.7	6,569.2	6,370.5	6,329.5	4,576.9	4,576.9	4,576.9	4,617.9	4,368.5	3,989.8	3,989.8	3,988.4	9.5	41.0	41.0	249.4	249.4	249.4	179.4	428.8	640.4	198.7	1,112.2	378.7	1.4
Ethane	30.07	1,763.1	1,748.4	1,695.5	1,660.3	1,200.6	1,200.6	1,200.6	1,235.8	1,003.1	916.1	916.1	915.8	14.6	35.2	35.2	232.7	232.7	232.7	199.8	432.6	168.0	52.9	291.7	87.0	0.3
Propane	44.09	1,425.8	1,384.1	1,342.3	1,277.6	923.8	923.8	923.8	988.5	598.9	547.0	547.0	546.8	41.7	64.7	64.7	389.6	389.6	389.6	449.0	838.6	129.2	41.9	224.5	51.9	0.2
i-Butane	58.12	113.1	105.3	102.1	93.2	67.4	67.4	67.4	76.3	32.3	29.5	29.5	29.4	7.9	8.8	8.8	44.0	44.0	44.0	73.4	117.4	9.4	3.2	16.4	2.8	0.0
n-Butane	58.12	401.2	362.1	351.2	313.4	226.6	226.6	226.6	264.4	93.9	85.7	85.7	85.7	39.0	37.8	37.8	170.5	170.5	170.5	351.2	521.8	31.7	11.0	55.1	8.1	0.0
i-Pentane	72.15	128.6	100.9	97.9	79.5	57.5	57.5	57.5	75.9	15.5	14.2	14.2	14.2	27.7	18.4	18.4	60.4	60.4	60.4	237.2	297.5	8.0	3.1	14.0	1.3	0.0
n-Pentane	72.15	146.3	106.9	103.7	81.1	58.6	58.6	58.6	81.2	13.7	12.5	12.5	12.5	39.4	22.6	22.6	67.5	67.5	67.5	338.1	405.6	8.2	3.2	14.2	1.2	0.0
125-175	85.00	88.7	43.3	42.0	26.7	19.3	19.3	19.3	34.6	2.8	2.5	2.5	2.5	45.4	15.3	15.3	31.8	31.8	31.8	479.6	511.3	2.7	1.3	4.7	0.2	0.0
175-365	119.75	38.6	2.2	2.1	0.5	0.3	0.3	0.3	2.0	0.0	0.0	0.0	0.0	36.5	1.7	1.7	2.0	2.0	2.0	1,886.2	1,888.2	0.0	0.1	0.1	0.0	0.0
365-475	167.24	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	933.6	933.6	0.0	0.0	0.0	0.0	0.0
475-662	227.82	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1,083.0	1,083.0	0.0	0.0	0.0	0.0	0.0
662-707	294.20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	189.6	189.6	0.0	0.0	0.0	0.0	0.0
707+	468.79	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	991.4	991.4	0.0	0.0	0.0	0.0	0.0

Note:
This flowsheet is for Phase 1 operation on 6 July 1988
and is the final revised version produced by Occidental.
The accompanying flow diagram is Fig. J.8.

KEY TO PIPER ALPHA PHASE 1 OPERATION PROCESS FLOW SCHEMATIC.

NOTES:

(1) Compiled from information available in the technical library.

(2) Only selected PSV's (Pressure Safety Valves) are shown.

(3) Process conditions taken from PSK-A1-1229-Rev. 1.

(4) Valves are designated as follows :-

Wellhead Safety Valves - DHSV (Down Hole Safety Valve)
- Master Valve
Hydraulic Oil to open - Fail close

ESV (Emergency Shutdown Valves)
Hydraulic Oil to open/close - Fail close with back-up Hydraulic Accumulator under Nitrogen Pressure.

ESV (Emergency Shutdown Valves)
Motor Operated Valve with Pneumatic Nitrogen back-up fail close mode.

PCV or dPCV (Pressure or Differential Pressure Control Valve)
Fail open but with local back-up Instrument Air Accumulator.

PCV or LCV (Pressure or Level Control Valve)
Fail open **(closed) - no local back-up Instr. Air Supply. (See note (7)).**

GOV's — Gas Operated Valves (Instrument Air Powered)
Suction and Discharge Valves FC: Vent Valves FO: (See note (7))

MOV's — Motor Operated Valves

Non-return Valves

HCV (Hand Control Valve) / Manual Throttle Valve

PSV — Pressure Safety Valve (Relief Valve)

Indicates valve normally closed.

(5) METH. INJ. — Methanol Injection

(6) The main oil line passes from Module B to the 68 ft level (not through Module C.).

(7) FO — Fail Open.
FC — Fail Close.
BPD — Barrels Per Day.
MMSCFD — Million Standard Cubic Feet Per Day.

Fig. J.8 Simplified flow diagram for phase 1 operation on 6 July, including emergency shutdown features. The flowsheet quantities are given in Table J.1.

NOTES:

- (1) Only main pipework is shown. Vents, drains and minimum flow returns not shown for clarity
- (2) General arrangement - not to scale
- (3) All equipment and piping shown was located on 68ft level with the exception of condensate injection pump pressure safety valves (PSV-504/505)
- (4) By-pass, to route condensate from centrifugal compressor scrubbers or C202 to main oil line - not in use, valves closed

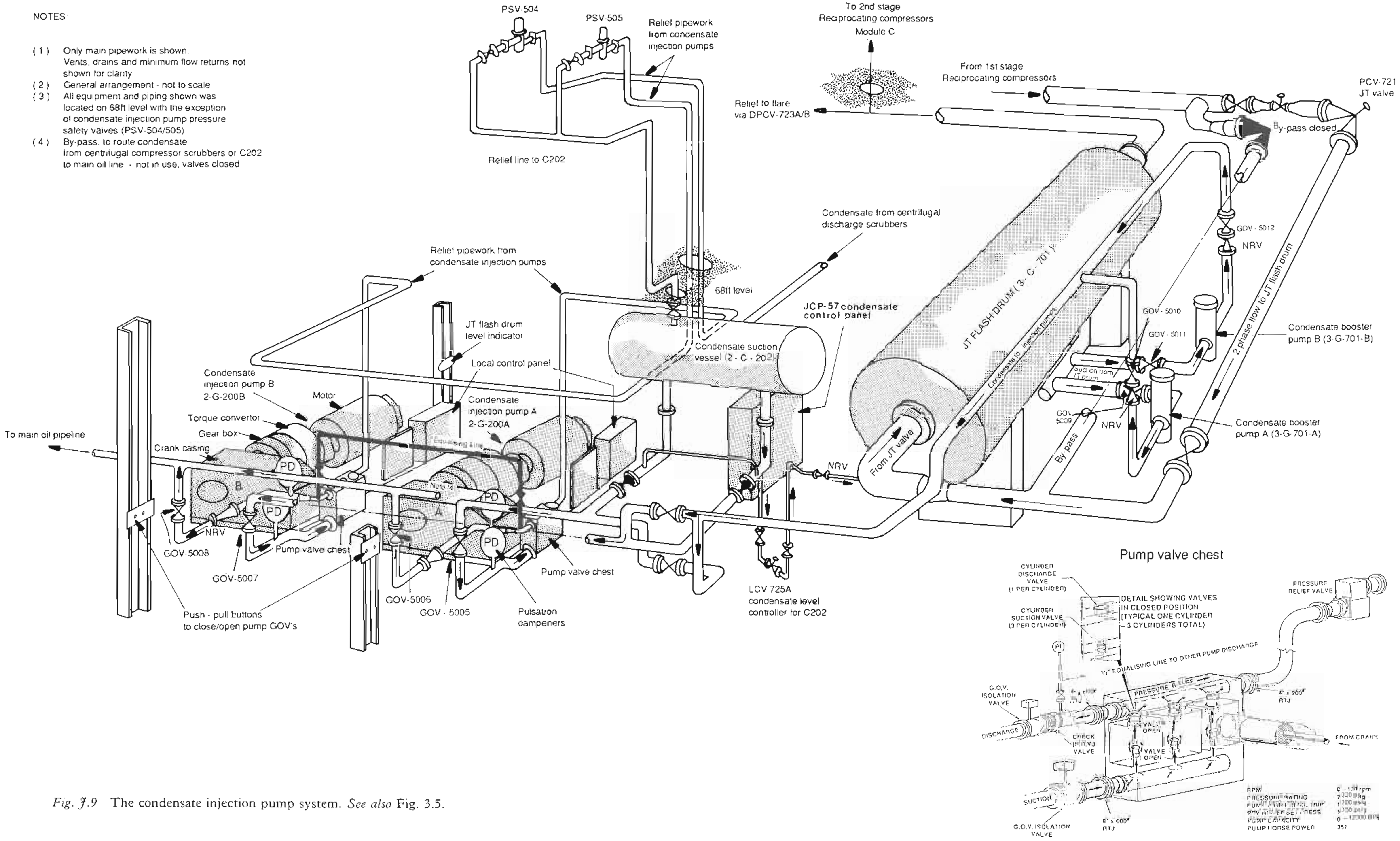


Fig. J.9 The condensate injection pump system. *See also* Fig. 3.5.

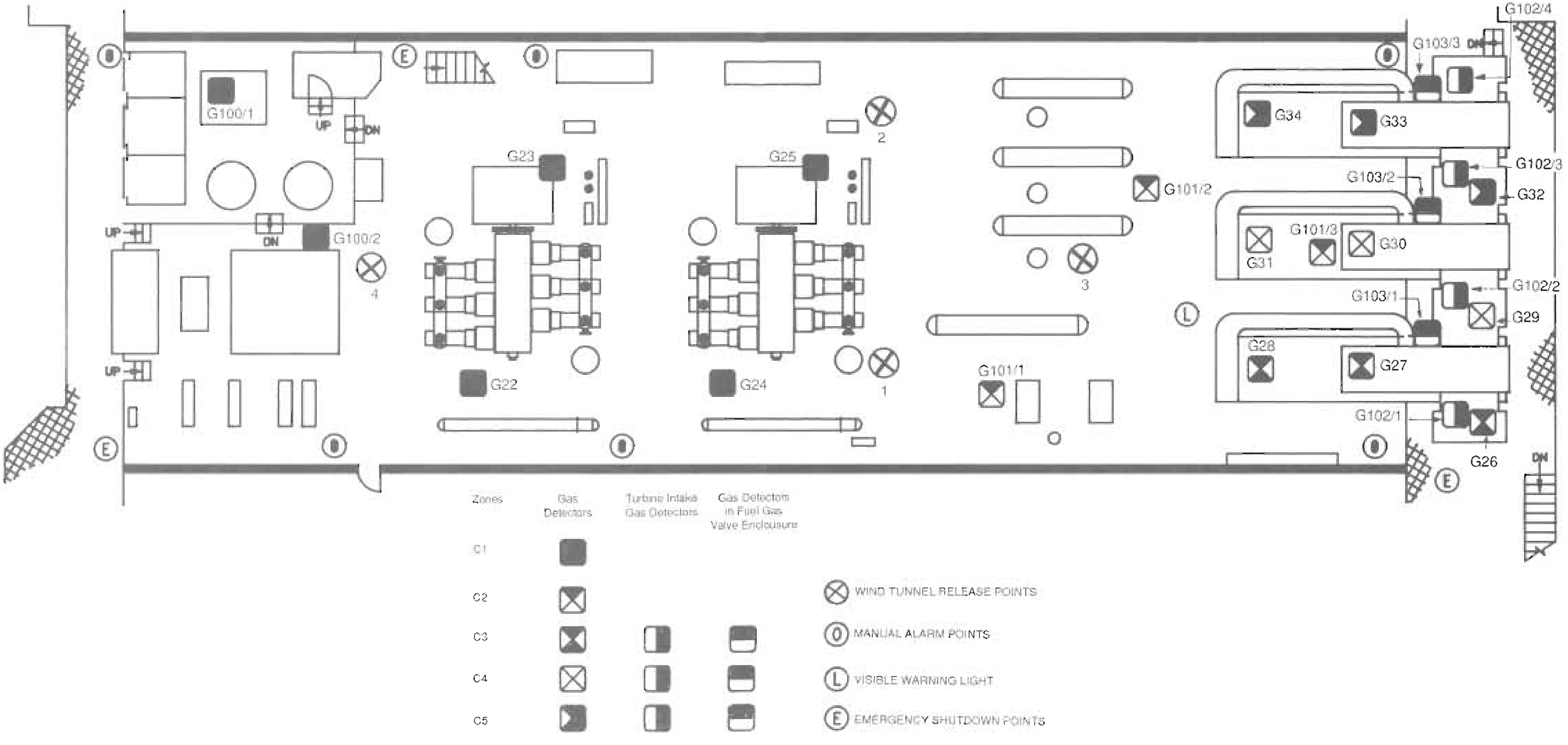


Fig. J.10 The gas detection system in C Module. Further details of the location of the detectors are given in Table F.4. Also shown are the four leak release points, positions 1-4, used in the BMT wind tunnel tests.

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