STUDIES ON SATURATION DIVING IN POLAND AND PRACTICAL APPLICATION OF THEIR FINDINGS. PART 2A. DEVELOPING A POLISH SYSTEM OF SATURATION DIVING IN THE 1980S AND 1990S

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ABSTRACT

This is another from the series of papers discussing studies on saturation diving technology and its use in Poland. This part explains the specificities of the Polish context and achievements against the backdrop of economic and historical circumstances. It describes how the central base for saturation diving came into being in the times of economic collapse in the country. At that time, the shipbuilding industry was the driving force behind research on saturation diving as a cornerstone for building a framework for diving systems to be exported to other countries to secure the extraction of assets from the sea shelf. The paper introduces the readers to the efforts of animators and protagonists of that period of underwater research in Poland whose achievements are continued until to-date. The second part of the paper shows how the Polish system of saturation diving was created. The article also considers the technical and organisational aspects of the first saturation diving experiences and the history of the Polish method of decompression for saturation diving. To accomplish this difficult task, it was crucial to ensure a solid industrial and academic base working for the defence sector and assisted by relevant state agencies. A multiannual CPBR programme was also set up with measures 9.2 and 9.5 dealing with medicine and technology which resulted in the development of a diving system with its organization, medical support and reliable technology. Outcomes of this programme are still being implemented today. Despite progress made in medicine, technology, and organisation issues involved in saturation diving are still pertinent because independently of their complexity and high cost this type of diving is the most efficient and allows for very deep diving operations up to 400-500 m.
Keywords: medical and technical aspects of decompression, validation of decompression tables, saturation diving, diving system, organization of diving operations.

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INTRODUCTION

In 2022 we celebrated the centenary of naval education in Poland, which trained and still trains the staff for the Polish Navy and conducts research and development works for this branch of Armed Forces. In the mainstream celebrations of this anniversary, few experts and historians of the Polish Navy took up the subject of the importance of the Naval Academy for Polish technology and hyperbaric medicine securing research and development in underwater activities both for the purposes of defence capabilities and for the national economy. Few know that the first therapeutic oxygen hyperbaric treatments took place as early as 1983 in the chambers of the then Department of Diving Equipment and Underwater Work Technology of the Naval Academy. Equally few are aware that the first hyperbaric oxygen treatment chamber in our country, adapted for the purposes of the Institute of Maritime and Tropical Medicine, was equipped with an oxygen installation based on KP-18 aerial inhalers and with an original external oxygen exhaust device by the founder of the Department, Commander Medard Przylipiak.

The research described in this article, provided the foundations and potential for nearly 30 years of fruitful scientific and technical cooperation with the Polish offshore industry, as well as secured diving operations for the defence of our country. The Naval Academy, as the heir and continuator of the tradition of naval education, has been conducting training and research activities for nearly half a century. It carried out the largest programme of works for the Polish shipbuilding industry producing hyperbaric technology in terms of scope, funds and the number of research, technical and diving personnel. This is not the only record in the 100-year history of the Academy. For more than a quarter of a century, it has been developing underwater work technologies, modernising diving techniques and training diving specialists for the Polish offshore industry. It also takes an active part in making decisions concerning the development of the industry for the extraction of oil and gas from beneath the bottom of the Baltic Sea.

DOMESTIC CIRCUMSTANCES RELATED TO THE DEVELOPMENT AND APPLICATION OF DIVING SYSTEMS FOR SATURATION DIVING IN THE 1980S

The late 1970s and 1980s were an era of research and widespread deployment of saturation diving in fifteen offshore countries around the world for various underwater mining industries extracting mainly energy resources, especially offshore oil and gas. The deposits exploited at that time are located at different depths and distances from the shore. The distance from the shore and the depth of extraction are the main factors that stimulate technical solutions related to the extraction and transport of raw materials [1]. The fundamental research and technical problems of underwater work, which were solved on offshore extraction platforms, concerned transportation systems, the installation of heads for the controlled extraction of oil and gas and pipelines to transport the extracted raw material to the recipient. The associated assembly operations required and still require extensive underwater work, which implies the need for long-term work by divers. Associated with the construction of underwater structures is the need to service them under water. Until the commencement of the exploitation, after the heads and pipelines have been installed, such servicing generally includes maintenance, repairs and inspections. The depths of exploitation of raw material deposits during this period began to exceed the depths accepted for offshore work, i.e. 200m. [2].

With physiological limitations eliminating diver operations at very deep depths, research was launched to determine the limit of what a diver could do with helium-hydrogen mixtures. In parallel, rapid development of diverless technology and diving support systems began to take off. In the Polish offshore area, oil and gas production depths are in the 45-110m zone with an average depth of 78m. This dictated the scope of research into underwater physiology and diving technology and the design and construction requirements for the construction of diving systems to support underwater work. The shallow saturation diving zone (30-100m depth) is the zone where the use of robots and vehicles in the mining industry is more expensive and therefore less cost-effective than the use of divers using saturation diving technology [3].

PIONEERING EXPERIMENTS IN SATURATION DIVING CARRIED OUT BY UNDERWATER WORKS COMPANIES AND THE NAVY

Poland already had some experience in conducting underwater works using air-supply systems for the underwater services industry at shallow and medium depths. At the time in question, demand for underwater works was generated by export orders from the Szczecin Shipyard and a fledgling Polish offshore oil production company Petrobaltic. The company operated under a tripartite international agreement (GDR, Poland, USSR).

Back in the 1970s, the Szczecin Shipyard specialised in the production of specialist vessels, including offshore support vessels and the internationally renowned oceanographic research vessels. The main customer for these ships was the USSR, which was also interested in ships equipped with diving systems with a diving range of up to 200m. As at that time East-West relations were marked by tension and confrontation, barriers to technology transfer and information exchange were high. In the late 1970s, the shipyard's construction centre began its preparations to the building of such specialist vessels used for marine research conducted with the participation of divers. In matters of diving and diving technology, the Shipyard turned to the Navy as the only institution that carried out research into diving and, especially, into long-time diving technology, which was of interest to the commissioning party.

In 1964, a scientific and research department was established at the Naval Sea Rescue Headquarters to solve diving problems in the Polish Armed Forces. Scientific and research work on new diving equipment and underwater work technology from the late 1960s was carried out by Navy officers and engineers: M. Przylipiak, J. Humer and L. Kramer, and a physician J. Torbus. The first step for this team was to prepare the research base, which in the first period was based on two large-scale chambers built at the Gdansk Shipyard. The chambers

"*Dzwoniec*" (built in 1968) and "*Kobuz*" with a water pool (built in 1969) laid the foundations for the testing ground in which the first Polish semi-closed-circuit APW-3 apparatus was tested in the years 1971-1973. [4].

Upon the initiative of CDR Medard Przylipiak and with his great commitment, the construction of a stationary pressure chamber complex with technical facilities for securing projects was initiated with a view to assist in:

- research into diving technology and equipment for defence purposes,
- research into methods of decompression and therapeutic recompression for the purpose of rescuing submarine crews;
- securing research and development work in the field of underwater physiology,
- increasing the possibility of treating specific diving diseases with recompression procedures,
- research and implementation of components and systems of life support solutions for diving complexes built in the Szczecin Shipyard,
- carrying out expert opinions and studies for administrative and judicial purposes.

The newly built hyperbaric unit consisted of three interconnected chambers (three compartments), forming a functional whole. The "*Kobuz*" chamber compartment was, and still is, intended for the examination of divers and equipment. The "*Dzwoniec*" chamber, after reconstruction, served as a living compartment and was also adapted for medical research and technical decompression processes. These chambers were connected by a transfer chamber, which also served as a sanitary compartment (built in 1973). The versatility of the design of the chambers to this day allows them to be adapted for any research of divers and diving equipment and techniques.

The large diameter of the manholes of the *Kobuz* and transfer chambers allows for the insertion of large research and safety equipment, and the introduction of any transport chamber for the transfer of the injured diver during evacuation in the course of a rescue operation for medical recompression procedures. Thus, in 1975, the only pressure chamber complex in Poland was created for scientific research and experimental diving, including saturation diving to a depth of 120m. The centre was the 'brainchild' of CDR Medard Przylipiak and had many 'godfathers' from the Navy and industry. The construction and equipment of the chamber complex was based mainly on domestic technology and imports from the then Warsaw Pact countries. Putting the project into practice was very difficult due to the collapsing socialist economy and the embargo from Western countries. In the late 1970s and into the 1980s, the economy relied on strategic self-sufficiency, which made decision-making difficult, and resulted in a lack of support from industry. Industrial plants avoided cooperation, especially with the military due to the stringent requirements and unprofitability of the venture.

Having a hyperbaric centre laid the foundation for the establishment of the Department of Diving Equipment and Technology of Underwater Works (Polish abbr. ZSNiTPP) within the organisational framework of the Naval College in 1976. This allowed greater opportunities for obtaining research work, and bypassed many organisational and administrative obstacles. In order to strengthen the potential of the Centre, resources and full-time jobs were allocated to it from the structures of the Marine Rescue Headquarters of the Navy, the Marine Rescue Equipment Department, the Polish Army Diving Centre and the Technical Department of the Naval Academy. The involvement of government agencies of the Ministry of Defence and the support of industry, particularly the Szczecin Shipyard, was helpful in the establishment of this centre [5].

In 1976, the Szczecin Shipyard launched a programme to prepare the staff for the construction of diving systems (as diving complexes were called at the time) with which offshore and ocean-going vessels were to be equipped. The first step to undertake the production of diving systems was the training of shipyard personnel in two groups: designers and constructors, and technical personnel taking part in the production and future maintenance during approval tests. The training was organised and conducted by CDR Przylipiak together with the physicians from the Department of Underwater Medicine at the Faculty of Maritime Medicine of the Military Medical Academy (Polish abbr. ZMP KMM WAM) and the author of this article, the sole representative of the Naval Sea Rescue Service.

The construction of a series of complexes for saturation diving according to the requirements of the Soviet shipowner, the Academy of Sciences of the USSR, for two vessels, "Vityaz" and "Sadko 2", began in the Szczecin Shipyard in 1978. For carrying out the production and research, the shipyard activated the entire scientific and technical potential available in the country. Cooperation initiated by CDR Przylipiak with the shipyard launched Polish research on the life and health safety of saturation divers in three thematic blocks: technology, organisation, and medicine. The shipowner's contract with the manufacturer, the Szczecin Shipyard, envisaged performing a simulated saturation dive for a saturation plateau of 100m H2O in the complexes commissioned for exploitation as part of the approval tests. The production of the shipyard's own diving complexes forced out the development of a national base in the centres that could take up the subject of saturation diving in the basic aspects of human safety, divers' work and rest hygiene and the reliability of the safety systems.

The Szczecin Shipyard started an intensive, long-term cooperation initially with the Naval Sea Rescue Headquarters and then with the leading Department of Diving Equipment and Underwater Work Technology of the Naval Academy (AMW) and the Department of Underwater Medicine of the Chair of Maritime Medicine of the Military Medical Academy (ZMP KMM WAM).

The first fruit of this cooperation was the implementation of many interesting original scientific programmes, including the launching of the production of components and complexes for saturation diving in the three leading fields of medicine, technology and organisation. CDR Przylipiak, the head of ZSNiTPP together with the then head of ZMP KMM WAM Prof. Tadeusz Doboszyński and the chief constructor of the Szczecin Shipyard, M. Kukliński conducted and were responsible for research and development in this field. On the practical side, the main implementers were the Szczecin Shipyard and the Naval Academy (known as WSMW until 1987). While establishing and building up the scientific and research base between 1977 and 1981 the following tasks were accomplished:

1) construction of a research centre, which at the

same time served as a training ground for Navy divers in the 1970s;
2) training the Warski Shipyard in Szczecin specialist staff in the construction of deep-sea diving systems, (1977-1980);
3) supplying the centre at the Department of Diving Equipment and Underwater Work Technology of the Navy with equipment needed to conduct deep-sea and saturation diving research (1983-1987);
4) in-house training of scientific staff and a team of specialist constructors, as well as designers and operators of diving systems. (1977- 1988);
5) training medical staff to deal with health and safety issues involved in saturation diving. (1978-1988);
6) engagement in designing life support systems and hyperbaric chambers of the GWK diving system for Russian ships of the 'Vityazh' type (for 2 complexes1978 -1981) and the GWK-200 and LSH -200 (for 4 systems in the Warski Shipyard in Szczecin).

The developments at international and domestic stage in 1981 made the Soviet shipowner acutely interested in receiving vessels from Poland quickly. The accelerated tests of the diving complex lasted just over 3 days and took place on the 'Vityaz' ship with a simulated saturation plateau of 5m and excursions to a depth of 45m. The medical programme was secured by Prof. T. Doboszyński, and the technical side by specialists from the shipyard with the participation of the team from the ZSNiTPP and the Department of Ocean Engineering at the Gdansk University of Technology. The test divers were members of the PTTK [Polish Tourist Society] diving clubs (the diving team included the later Vice Minister of Health, Dr Krzysztof Kuszewski).

In the Navy, the board of the Rescue Service put in place a diving system for deep-sea diving on PIAST-type rescue ships in the early 1970s (1972-1982). The main consultant for the construction and implementation of the diving node on these ships in the Polnocna Shipyard in Gdańsk was CDR M. Przylipiak. This enabled using his experience and that of the diving teams from the Navy's rescue ships for the construction of diving systems in the Szczecin Shipyard. The co-author of the paper, Stanislaw Skrzynski, was responsible for implementing the diving technology on behalf of the rescue ship unit [4,6].

STUDIES ON SATURATION DIVING WITH AIR SUPPLY 1979–1983

In the years 1979-1983, under the direction of CDR M.Sc., Eng. Medard Przylipiak and CDR Prof. Tadeusz Doboszynski of the Military Medical Academy, surface-supplied saturation diving was carried out at the ZSNiTPP of the Naval Academy in Gdynia as a scientific project. The research at the national level was initiated by the Szczecin Shipyard. The hyperbaric chamber complex, suitable for short-term dives up to 60 m, had to be upgraded for long-term saturation diving. The facilities, equipment and measuring and control devices available from the domestic industry at that time did not meet the requirements for saturation diving not only for breathing mixtures, but even for air. The chamber installations needed to be upgraded or even designed from scratch which was difficult as the engineering and scientific staff had no experience in this field. The classification regulations of the Western countries (DNV Lloyd or GL) contained only indicative guidelines, while foreign exchange shortages did not allow for the imports of necessary equipment and components of installations.

At this time, a life support system consisting of a displacement pump, CO2 filter cooler, CO filter and a biological filter was designed and built from scratch. The system was equipped with an automatic temperature control in the chamber and chamber ventilation control settings. In the installation of the chambers, available domestic components and equipment were used, as well as originally designed structures manufactured by Polish companies, such as: life support system drive, measurement and sanitary installation. The main designer of the life support systems and the functional whole was CDR M. Przylipiak, [7] while the elements and systems were designed and manufactured by members of the newly established Department of Underwater Work Technology, Szczecin Shipyard, Department of Electronics and Automation of the Naval Shipyard, RADMOR and other domestic companies cooperating with and manufacturing for the Navy [7,8].

In addition to analogue pressure gauges meeting the accuracy requirements of the regulations for saturation diving at the time, the chambers were also equipped with custom-made digital resonator pressure gauges with very high accuracy. Measurements of the humidity in the chamber, temperature controllers and prototypes of sensors measuring oxygen partial pressure were developed from scratch. A difficult research challenge was the measurement of pressure and gas parameters, validated by the in-house measurement laboratory. The methodology for measuring oxygen and carbon dioxide provided for duplication of measurements with chromatographic measurements by adapting instruments produced by the former GDR Infralit and Permolit. A partial pressure sensor for oxygen and carbon dioxide was designed together with humidity and temperature meters, as well as highly accurate pressure measurements, which were tested in parallel during saturated exposures. Measurements of carbon dioxide and harmful admixtures were adopted from the chemical industry, validated with a very accurate instrument operated by medical doctors. Before the dives, the measurements of harmful admixtures in the chambers were checked as a result of the paints and materials used and a certificate of these measurements from the Sanitary and Epidemiological Inspection was the pass for the divers to work in the chamber [6].

The electrical and lighting installations inside the chamber were made in accordance with the electrical anti-shock requirements for hyperbaric conditions. A diver's communication station with speech corrector, taking into account the influence of helium on speech distortion, was developed and installed. Sanitary facilities, a toilet and a washbasin and shower with cold and hot water were installed in the transfer chamber. A chamber heating system was designed and installed. For the 'Kobuz' chamber, water pool cooling systems were installed to simulate water temperatures at depth. Numerous components of the chamber installations, such as valves, regulators, pipe fittings, electric and gas penetrators (passages in the chamber shell), seals for manholes and hatches, fan drives for carbon dioxide absorbers caused research and technical difficulties, as they were largely made in-house. Each fabricated component was subject to suitability tests under pressure. These components were decisive for the tightness and reliable operation of the entire installation and chamber equipment. Extremely important was the problem of sealing, i.e. reliably maintaining the set pressure and its control, which is the basis of the operation of any hyperbaric chamber. This required the testing of the seals of manholes, portholes, fittings and, in particular, penetrators. For example, to detect leaks in the case of helium or its mixtures, a detector for this gas was developed and manufactured. The entire gas installation relied on available valves for the chemical industry used for ammonia, which were sealed using the metal-on-metal method, while their stems were sealed traditionally with a rope.

The equipment so installed was subjected to testing procedures for suitability for saturation diving during both simulated and human exposure.

Fig. 1 The pool of '*Kobuz*' chamber (late 1970s).

The first air dives validated the quality of the design solutions against the medical team's requirements for decompression and diver's work health and safety. In addition, they trained the scientific and technical service personnel and the test divers for the tasks at hand. Test divers coming from amateur diving clubs were subjected to medical and psychological examinations before and after the saturation exposure according to the medical examination programme developed by ZMP KMM WAM.

A series of five- and four-day saturated air exposures at depths of 9m, 12m, 14m, 16m, and 18m were carried out in the chambers of the ZSNiTPP. These studies did not draw on the experience of the pioneer times for two reasons. Firstly, it was believed that medical research had been started from scratch to establish the basics of decompression and for other technical considerations. The second reason was that the saturation dives involved a different method of working in the water depths (i.e. surface habitat - chamber and diving bell). These saturated exposures were mainly concerned with decompression assessment without the elements of in-water work, but only with inflicting effort loads on the divers.[9]

An extended oxygen window was used in the air tables. For example, in decompression table 1 for a saturation plateau of 18m, a 15-minute return from 18m to 12m was used, and then at stops from 12m every 1.5m decompression was done with oxygen exposures. Fractionated decompression with oxygen was used. To secure oxygen decompression with oxygen exhalation outside the chamber, KP 18 aircraft inhalers from MiG 21 aircraft were used.

Tab. 1

Decompression table for saturation dives with air from saturation plateau of 18m [9].

Stop depth [m]	Return time [min]	Time at stops and the gas mixture [min]	Total decompression time [min]
18.0	15	Air	15
12.0		Air 90 oxygen 10	115
	5		120
10.5		Air 165 oxygen 20	305
	5		310
9.0		Air 355	665
	5		670
7.5		Air 75 oxygen 30	775
	5		780
6.0		Air 115	945
	5		950
4.5		Air 115 oxygen 50	1115
	5		1120
3.0		Air 165	1285
	5		1290
1.5		Air 105 oxygen 60	1455
	5		1460

The fact that the data from A. Debski's experiments were ignored was not accidental as they were seen as unprofessional and dilettantish because they 'skipped', as it was termed at that time, some stages of the research methodology. The only thing that linked the air exposures to the pioneering days of saturation diving was the similar decompression tables of saturation air dives used in the aforementioned air exposures with those used in the Geonur II bathyscaphe documentation. This may have been due to the use of the same literature or the collaboration between CIOP [Central Institute for Labour Protection] and ZMP KMM WAM.

Advances in saturation diving under the National Research and Development Plan (Polish abbr. CPBR) 1985-1990

For the development of underwater techniques and research, the law of 23 December 1985 on centrally distributed funds for the development of science and technology was used. A single, centrally integrated fund was established from subsidies allocated from the budget and (predominantly) corporate subsidies. This fund was divided into a part earmarked for the research and development stage and another one for the implementation stage (for subsidising investment projects related to government procurement). In a difficult economic situation, a reserve pool of convertible currency (the so-called foreign exchange - money from Western countries) was ring-fenced at the central level for imports from the West needed to accomplish certain tasks included in the national programmes intended to promote the development of science and technology. The Act also modified the classification of employees of research centres by introducing a new category of the so-called research-technical employees, whose main task was to cooperate with the scientific staff in adapting the results of research to socio-economic needs. The law opened up the opportunity to conduct long-term projects covering the cycle from research through development up to implementation.

Back in 1985, the Szczecin Shipyard as the main contractor supported by the ZSN and TPP AMW (with the participation of IMMiT and ZMP KMM WAM) competed for launching these programmes. As a result of the call for applications and after the final agreements were signed, Szczecin Shipyard became the coordinator and implementer of the CPBR-9.5 programme.

The Naval Academy was entrusted with research work related to saturation diving for measure CPBR-9.5 objective 31 "Technical, medical and legal problems of long-term human presence under water up to a depth of 120 m". The second programme carried out by the Academy was CPBR 9.2 objective 17.07 "Preparation for operational saturation dives." These projects were carried out in collaboration with the ZMP KMM WAM. Their titles were very general summaries of issues intended to be solved at the national level. The Polish system of saturation diving was focused on the Szczecin Shipyard producing GWK-200 (Glubokowodny wodolaznyj Kompleks [deep-sea diving complex] - 200m) diving complexes for offshore support vessels [6].

Measure CPBR 9.2 Objective 31 entitled "Technical, medical and legal problems of long-term human presence under water up to a depth of 120 m" was awarded to the Institute of Maritime and Tropical Medicine (Polish abbr. IMMiT) in Redlowo. The research part concerning decompression of saturation dives with air and nitrox was entrusted to ZSNiTPP AMW and ZMP KMM WAM due to the lack of scientific and research base and substantive staff at the Institute of Maritime and Tropical Medicine.

Results of the aforementioned research were sent to the Szczecin Shipyard, which in its research and implementation programme was tasked with;

- preparing for the production that would secure the construction and equipment of hyperbaric complexes,
- preparing tools for underwater work and carrying out commissioning tests at the client's site.

These tasks were carried out in cooperation with the Szczecin University of Technology and domestic industry working for the shipbuilding industry. The medical side of the preparation and medical supervision of the test divers was entrusted to the Department of Physiology of the Pomeranian Academy of Szczecin, headed by Prof. J Paradowski [4].

Ensuring the technical safeguarding of the emergency procedures used in diving technology and the use of the national scientific potential that the Navy had at the time were crucial. Emergency procedures for anticipated emergency conditions and hazards, which must be included in organisational, technical and medical safeguards are an indispensable component of any diving technology. These safeguards for saturation diving had to be created from scratch. The security system had to take into account all maritime and state institutions with technology for underwater work. In parallel with solving the problems concerning the launch of the technical and personnel base, formal documentation had to be drafted concerning technical issues related to the division of duties, procedures and regulations for them, which should have been defined at the research stage, modified at the development stage and double-checked during implementation. Implementation was the most difficult stage; it took place at in the course of commissioning tests at the manufacturer's site, i.e. at the Szczecin Shipyard. The shipyard at that time was also building its technical base and testing grounds based on the formal documents indicated by the ordering party (the DNV classification regulations and MRS – Morskoj Rejstr Sudow [Maritime Register of Ships]). In order to carry out research, approval and commissioning tests, a hall was designed and equipped with all the equipment and gas storage facilities for the above-mentioned tasks (this hall was colloquially known as the 'Valley' because of its location).

Responsible for the implementation of the CPBR programmes were Eng. Marian Kukliński, and the chief designer of the Szczecin Shipyard and founder of ZSN and TPP AMW, CDR Medard Przylipiak, who for years had set up research and engineering teams and developed the research base in Gdynia and Szczecin. At the Naval Academy, the research problems covered by the CPBR were undertaken thanks to the support of the Deputy Commandant for Scientific Affairs, CDR Ph.D., Eng. Stefan Czarnecki, and the Dean of the Faculty of Mechanical and Electrical Engineering, Prof. Władysław Wojnowski.

After the untimely death of Eng. M. Przylipiak in 1986, the topics and tasks of the CPBR at the Naval Academy were carried out under the organisational leadership of CDR Lt. M.Sc., Eng. Marian Pleszewski, and from 1990 of M.Sc., Eng. Stanislaw Skrzynski. CDR Pleszewski was responsible for the entire CPBR project and directly managed the technical and production-related organisational topics. The 'Wodniczka' programme dealt with the modernisation of the base for saturation diving, and the 'Alga' project with the production of life support and saturation diving control systems for the Szczecin Shipyard. At the same time, from 1985, the medical side of the project was carried out under the leadership of Prof. Doboszynski and Dr Łokucijewski of the ZMP KMM WAM. On the other hand, CDR Stanislaw Skrzynski was responsible for the execution of CPBR 9.2 objective 17.07 titled: "Preparation for operational saturation dives". In addition, he carried out selected technical problems concerning the individual equipment of divers in the chamber and bell, and was responsible for the execution of the legal, technical and operating procedures within the framework of CPBR-9.5 objective 31. As part of the execution of CPBR 9.2 objective 17. 07, a comprehensive programme was developed and carried out at ZSN and TPP AMW with the participation of shipyard technical and construction teams, test divers, doctors from ZMP KMM WAM, and the Medical Academy in Szczecin, inspectors from classification societies DNV and MRS, and representatives of the ordering Russian shipowner.

Specialised training and preparation was given to the specialist staff engaged in medical examinations, technical examinations and tests, diver trials and seconded specialists from companies and institutions which provided training to tester divers and the commissioning test programme. This was one of the most difficult components in the implementation of this measure in which many different, sometimes conflicting requirements had to be reconciled and animosities of those involved had to be overcome. This involved the production and commissioning of 4 GWK-200 and LSH-200 (Land Hyperbaric System for IMMT) diving complexes designed in 1985 in cooperation with CDR Przylipiak and built by the Szczecin Shipyard under a turnkey contract for the Soviet shipowner. The commissioning tests conducted at the shipyard and at shipowner's site relied on the original Polish saturation diving technology and Polish diving and technical teams. During the shipyard's commissioning trials, a commissioned saturation dive was performed at a depth of 100m on the GWK-200-I complex and at a depth of 40m on the GWK-200-II complex.

We owe the positive outcome of the trials to research into the development of a safe method of diver saturation in the 30-120 m depth zone. During these years, the country's economic situation and the volatility of the contracting party's requirements caused perturbations and even the suspension of programmes for a year, which had a negative impact on the execution and staff rotation. The above necessitated constant adjustments to the research, technical and financial efforts of both the shipyard and the Naval Academy. Contrary to the circumstances, this did not fundamentally affect the positive results of the work in CPBR-9.5 objective 31, CPBR-9.2 objective 17.07 and CPBR-9.7 in both technical and medical issues. The country's own technology for long-term human presence at depths of up to 120 m was created and, most importantly, our country had research and engineering staff specialised in this field. Noteworthy, the consistency of CPBR-9.5 objective 31 and CPBR-9.2 17.07 enabled the validation of the research results achieved at the Naval Academy DGKN-120 experimental complex and at the GKW-200 operational complex on its stationary industrial test bed at the Szczecin Shipyard. The next stage was to be approval tests at the Soviet shipowner. As a result of the political and economic turbulence, it was not possible for the Polish teams to carry out operational dives in sea conditions on the GWK-200 industrial complexes manufactured by the Szczecin Shipyard and already installed on the shipowner's vessels.

One of the substantive issues of CPBR- 9.5 - 31 was the legal aspect of conducting saturation diving in the country. The diving regulations in force at the time did not provided for the use of this modern diving technology therefore all experimental saturation diving exposures were carried out as scientific experiments with the participation of humans. This required the approval of the relevant commissions allowing experimental research with humans. Due to the fact that the DGKN-120 complex was made and operated at the Naval Academy, the above approval was obtained from the commission of the Ministry of Defence working under the Head of the Department of Health Services. In accordance with the provisions of the Declaration of Helsinki, the commencement of trials with humans required the approval of a designated special commission, the Commission for the Conduct of Research with Human Participation. By virtue of a regulation of the Minister of Health and Social Welfare of 1986, the commissions were established at the Medical Academy in Wrocław.

Within the framework of CPBR-9.5 - 31, draft regulations were developed, with which, after their validation under real diving conditions (in the GKW-200 complexes), national diving regulations were planned to be supplemented. Unfortunately, to date, the legal regime of saturated diving has not been fully formalised. In 2021, the PRS Interim Classification Rules were published, addressing issues of design and supervision of diving systems, including for saturation diving. On the other hand, the normative document on diver decompression still lacks saturation diving tables and treatment tables, despite the fact that operational saturation diving has been an everyday occurrence on the Polish shelf since 1995. The currently binding Regulation of the Minister of Health of 17 September 2007, as amended, on the health conditions for carrying out underwater work, resulting from Article 11, paragraph 6 pp. 4 of the Act of 17 October 2003, as amended, on the performance of underwater work deals only with decompression and compression concerning divers performing long-term underwater work.

SELECTED RESEARCH, ORGANISATIONAL AND TECHNICAL PROBLEMS OF CONDUCTED STUDIES

The distinctive medical, technical and organisational features characterising the research side of saturation diving included:

- the type of breathing mixtures used and their quality requirements;
- the microclimate parameters of the chamber atmosphere ensuring the comfort of the divers;
- the development of overall measurement framework with regard to their accuracy, reliability and dependability for the selected equipment and measuring tracks, taking into account compression, plateau stay and decompression,
- how various phases of the dive, i.e. compression, plateau stay and decompression are performed,
- technical and organisational support for emergency operations,
- methodology for preparing and training test divers,
- training of divers and technical personnel of the research team,
- training the medical team involved in the tests.

Fundamental to achieving the stated objective, in addition to medical issues, was the development of requirements and the establishment of an experimental technical base, the quality of which would allow experimental saturation exposures to be carried out safely for divers.

The facilities, equipment and measuring and control devices available at that time in the domestic industry did not meet the requirements for saturation diving. Difficulties in obtaining suitable facilities, equipment and instruments were compounded by high requirements for accuracy, "oxygen purity" and "hygienic and biological purity" criteria. These requirements fundamentally tightened the design, execution and testing criteria for individual technical systems.

Habitability - the suitability of the hyperbaric chamber assembly for saturation diving is determined by the quality of the systems for regeneration and maintenance of the assumed parameters of the atmosphere. [10] They include systems whose operation must guarantee the maintenance of many parameters of the hyperbaric atmosphere, with a strictly defined level of measurement error. This applies primarily to parameters such as total pressure (p_k)), partial pressure of oxygen (pO2), pressure of carbon dioxide (pCO_2), temperature (T_k), relative humidity (ϕ_k), homogeneity of the breathing mixture throughout the vital volume of the chambers, and the amount of impurities resulting from metabolism and materials used.

Four groups of disturbances and hazards need to be eliminated during the stay in the chamber and diving bell:

1. disturbances and hazards resulting from safeguarding life, health, securing physiological needs and the divers' stay in the chamber or bell,
2. disturbances and hazards resulting from the time of day and the divers' tasks ,
3. disturbances and hazards resulting from improper operation and handling by divers and technical staff,
4. disturbances and hazards resulting from technical failures, lack of basic power supply and disruption of logistical supplies due to external factors.

In the first group, the disturbing elements are mainly activities that maintain normal life processes, such as receiving food or throwing out waste, hygiene and disinfection materials, materials and medicines and medical and technical examination equipment, changing clothes and underwear and diving gear components. Each opening of the hatch introduces pressure changes, additional contamination of the atmosphere e.g. with nitrogen, biological contaminants, contaminants due to material specificity etc. It is important how harmful admixtures emitted by humans and present in many materials will affect the measurement sensors, filter beds and, most importantly, the wellbeing of the divers. A group of liquid medicines and personal care products can also interfere with or pose a fire risk when inappropriately selected and administered.

The second group includes changes caused by the divers' physical activity, depending on the time of day and the daily programme of tasks (e.g. sleeping time means less carbon dioxide release and oxygen consumption, doing physical work is the opposite, having a bath means an increase in humidity, etc.). For each time of day, the prescribed atmospheric parameters must be maintained and, importantly, the atmosphere must be homogeneous (so that no so-called oxygen pockets form or heavy carbon dioxide accumulates in the lower zones during sleep). When working in water, fouling can be caused by dirty water or fouling due to the type of underwater work [11].

In the third group of disturbances and hazards are those resulting from the improper operation and handling by divers and technical staff. Although they were all trained and subject to round-the-clock medical and maintenance supervision by the project managers, there were instances of lack of discipline, irritation and incorrect decisions, despite the rule of double-checking the correct action. Being in the chamber for long periods of time and in a military mode of work for the technical staff resulted in fatigue, a desire to improve the comfort and handling, inattention and misinterpretation of measurements. The stress of the unknown, exacerbated by the environment and the nervousness of the supervisors, faded with experience. This stress was reinforced by supervisors and team members. In general, those without diving practice and those best "informed" warned of the danger [5].

This stress was also shared by the management of the experiment, particularly with the threat of failure, with the health or lives of the divers at stake. The divers' time in the chamber was associated with the revealing of their character traits and their ability to cooperate with their team mates. This is why the selection of test divers, who were examined by a psychologist at all stages of the experiment, was so important.

"There were two very stressful situations throughout the series of experiments. The first one, while the divers were leaving the chamber after decompression from a saturation plateau of 80m, three divers lost consciousness and fell over. Fortunately, they quickly regained consciousness. The cause was difficult to determine, but after a long and detailed analysis of the course of the last hours of decompression, the mystery cleared up. The large hatch to the transfer chamber at a pressure of 1.2.m H_2O was becoming leaky, resulting in a loss of breathing mixture. It was therefore necessary to top up the breathing mixture to maintain the required pressure in the chamber. The shift-watch manager, to save expensive mixtures in the final decompression phase, added residual 7% oxygen heliox bottom mixtures to the chamber atmosphere instead of using 20% oxygen heliox. This caused temporary hypoxia. The fortunate thing about this situation was that the hypoxic mixture was added to the atmosphere of the transition chamber, not the living chamber. The second highly stressful case was the last saturated exposure in the programme using nitrox with a saturation plateau of 45m. The impact of the relatively high nitrogen partial pressure put the test divers in a good mood. The impact of nitrogen narcosis was at a different level for each diver, and increased with exposure time. This phenomenon did not facilitate communication with the divers in the chamber, and caused them to be insubordinate. These are just two cases out of a dozen showing that such situations were difficult to avoid." - recalls the author from his experience.

Difficulties arising from external factors were technical failures, and disruptions to logistical supplies. Electricity supply interruptions also occurred, although the relevant services were informed. When such difficulties occurred, we tested the operation in real emergency situations and the resilience of the system to external threats, as well as the performance of our base to ensure that the relevant parameters for life support and comfort of the divers under pressure were maintained. In these cases, the systems and devices supplying the chamber together with their equipment forming the internal and external emergency life support systems and maintaining atmospheric parameters, were tested.

The least disruptive to the maintenance of the chamber's atmospheric parameters is the stay on the plateau, as the parameters are maintained at a constant pressure and the main disruptions are the time of day and the maintenance of the divers' psycho-physical condition and task performance. During the dynamic phases, i.e. compression and decompression, the parameters have to be maintained at varying pressures, which requires close supervision by the operators so as not to exceed the set parameters, in particular the partial pressures of oxygen at the lower and upper limits and of carbon dioxide at the upper limit.

For this reason, during research and experimental saturation dives, reliability of measurement is vital. This was achieved using three different methods of measuring these gases, based on chromatographic, electrochemical and paramagnetic measurements. Thanks to the cooperation with specialists from the Central Mine Rescue Station in Bytom, the research used the latest measurement methods of the time for exposures where high measurement accuracy was required, increasing with depth. The Central Station's specialists carried out measurements to verify the results of the ZSNiTPP laboratory's decompression tests using trimix. The measurement base in the country was not advanced enough for measurements in a helium environment and this problem was one of the research tasks.

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