COMPRESSED AIR WORK - FRENCH TABLES 1992 OPERATIONAL RESULTS

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ABSTRACT:

After publication by the French Ministry of Labour in 1992 a new set of compressed air decompression tables became legal in France in replacement of tables enforced since 1974 which proved not to be safe enough in the range of pressure 1.8 to 2.4 bars. The new set of procedures include decompression tables on air, on pure oxygen and for both breathing media, emergency tables for use in case of unexpected extension of exposure time for 30 minutes after the maximum allowed working time. Data collected from 25 tunnelling operations requiring compressed air work between May 1992 and December 1995, are analyzed. Exposures to pressures below 1,2 bar (0,12 MPa) are not considered in this study although the tables impose stops for exposures longer than 5 h 30 min at pressures between 0.9 and 1.05 bar. No cases of decompression problems have been recorded in that range of low pressure. Most of the time the compressed air work operations are not associated with working in shifts, since all tunnels involved in the study are bored with TBMs. Total number of exposures collected is 3400, number (27 cases) and description decompression problems reported are discussed. A tentative evaluation of the tables is given as well as recommendations for users. A comparison with other recent national procedures is presented.

INTRODUCTION

The French regulation applicable to diving and compressed air work includes the decompression tables to be used [17]. The validation of 1974 air diving tables has been carried out by Imbert et al. [4]. The validity of the 1974 compressed air tables has been questioned after a series of decompression sickness cases reported in the Métro project at Lyon [1] and in a sewage project close to Paris. In 1992 a complete new set of compressed air tables has been introduced [8] and is being used since that date.

The evaluation of the results obtained in the field has been started retrospectively in 1995 using the collection of operation data. The first set of results is presented hereafter.

For simplification purposes, all pressure measurements are presented in bar which is strictly equal to 10^5 Pa, or 0.1 kPa, or 1 000 hPa. All pressures are gauge pressures.

THE TABLES

The compressed air decompression tables contain 2 sets of schedules: Standard air tables and Oxygen decompression tables [17]. Each set has a series of "Tables de rattrapage" giving an extra exposure time to deal with the risk of accidental extension of exposure duration for 30 minutes.

The total duration of a single exposure, inclusive of decompression time is restricted to 6 hours maximum (except below 0.75 b for which 8 hours under pressure per day is permitted). A procedure to calculate decompression after one repetitive exposure is included, with two restrictions: no repetitive exposure is permitted when pressure exceeds 2.1 b, and total time under pressure should remain shorter than 6 hours for each period of 24 hours.

Tables 1 and 2 show an example of each of the schedules, and figures 3 and 4 the general performances of the tables. These tables have been calculated by J.P. Imbert, at COMEX, on the same theoretical basis than the air diving tables [4] with an extra safety coefficient of 25 % on ascent limiting factors to take into account the previous experience of compressed air work conditions and the type of work performed under pressure.

Comparison of these tables with other schedules is not the purpose of this paper, Kindwall has carried out several comparisons [6] and the example of Nishi [12] may be used to compare tables. However, one would note that No-D limits are longer than those given in Black-Pool tables [18], decanting [3] is not given as a possible technique of decompression for compressed air workers; for significant exposures the French tables require longer and deeper stops. For oxygen decompression, French tables are also longer than the new German oxygen tables [19]. Validation of various compressed air work tables are available in [15, 11, 5, 14].

OPERATIONAL SAFETY ENVIRONMENT

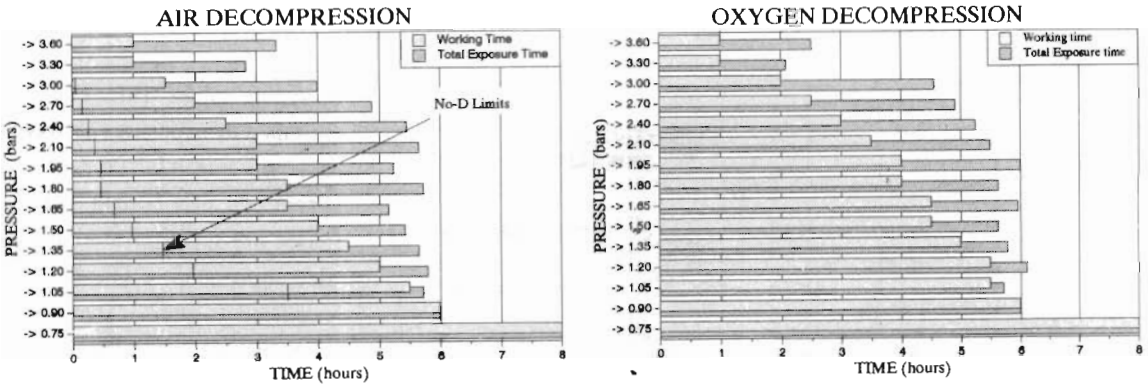
Efficiency of decompression tables are not independent from the general safety organisation of compressed air works. In particular the personnel training has a significant part in the decompression quality. Only fit personnel may be exposed to the tables. Any evaluation of decompression tables in compressed air work should describe the general safety environment associated with the published results.

TABLE AIR/MENTION D/STANDARD						PRESSURE 2,1 bars
WORK TIME	DECOMP. TO 1st STOP	AIR 0,9 bar	AIR 0,6 bar	AIR 0,3 bar	DECOM P. TIME	INTERVENTION DURATION
0 to 0h 25	7 min				7 min	0h 32
0h 30	6 min			3 min	9 min	0h 39
0h 45	6 min			15 min	21 min	1h 06
1h 00	5 min		3 min	25 min	33 min	1h 33
1h 30	5 min		15 min	45 min	65 min	2h 35
2h 00	4 min	3 min	25 min	60 min	92 min	3h 32
2h 30	4 min	3 min	40 min	80 min	127 min	4h 37
3h 00	4 min	5 min	50 min	100 min	159 min	5h 39

TABLE AIR/MENTION D/OXY						PRESSURE 2,1 bars
WORK TIME	DECOMP. TO 1st STOP	AIR 1,2 b	OXY 0,9 b	OXYGEN 0,6 bar	DECOMP. TIME	INTERVENTION DURATION
0h 25 - 0h 45	6 min			10	16 min	1h 01
1h 00	4 min		5	10	19 min	1h 19
1h 30	4 min		10	15 5 5	39 min	2h 09
2h 00	4 min		15	10 5 20	54 min	2h 54
2h 30	4 min		20	5 5 25 5 15	79 min	3h 49
3h 00	4 min		25	5 25 5 25 5 5	99 min	4h 39
3h 30	3 min	3	25 5 5	20 5 25 5 25	121 min	5h 31

CAUTION : During oxygen stops, every 25 min, observe an oxygen break for 5 minutes as indicated in small font. This time is included in total decompression time

Table 1 & 2 : Sample of French tables - Air & Oxygen for 2.1 b



DATABASE

A data collection form is compulsory by law for each intervention. These forms have been collected from 7 job sites using compressed air in France between 1992 and december 1995. A database run under EXCEL^{R} has been used to display the data and evaluate the results.

Medical records of personnel who have suffered from DCI, have been extracted from the medical database (Dr BARRE & Dr BAUD for most of the workers) for further discussion of the cases. This has been done in accordance with recommendation from EUBS Workshop [16]. In this study only persons exposed to a decompression risk have been considered, therefore only exposures to more than 1,2 bar have been included (no cases of DCI has been reported after exposure to less than 1,2 bar using the french tables and exposure conditions which go with it).

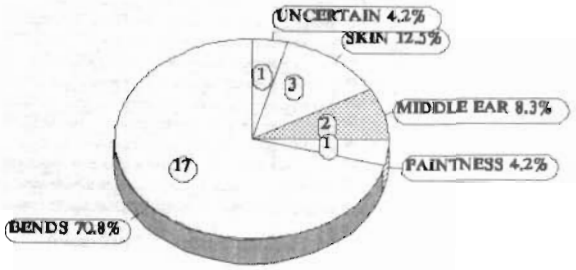
RESULTS

A total of 26 job-sites used compressed air work at pressure higher than 1.2 b, the various types of machines and the number of occurrences of DCI are displayed in table n° 3, only 6 of them have returned the information and are included in the survey (last entry is march 96). The number of exposures in table 3 are those obtained from the survey, the actual number is much higher however all known DCI cases are reported.

TMB TYPE	SITES number	Trained Persons	Pressure range bar	Sites using Oxygen dec.	Exposure nb P > 1.2 b	DCI cases
Manual digging	3	34	0.7 to 1.0	non applicable	unknown	0
Earth pressure	3	126	0.9 to 2.4	none	837	16
Hydroshield	11	229	1.6 to 2.4	2	1423	2
Mechanical	7	67	0.5 to 2.7	1	95	2
Earth pressure Tunnel doors	2	43	1.2 to 2.1	none	447	4
Total	26	499		3	2802	24

Table n° 3 : Job sites and activities

Among the 24 DCI cases at least 4 are clearly triggered by exercise after exposure, even 48 hours after , 20 involved manipulation of heavy tools or repetitive muscular exercise during exposure. Figure 2 shows the type of symptoms, 17 cases are multiple articular mild pain (bends) which responded to oxygen recompression even several days after onset of symptoms (max 6 days).



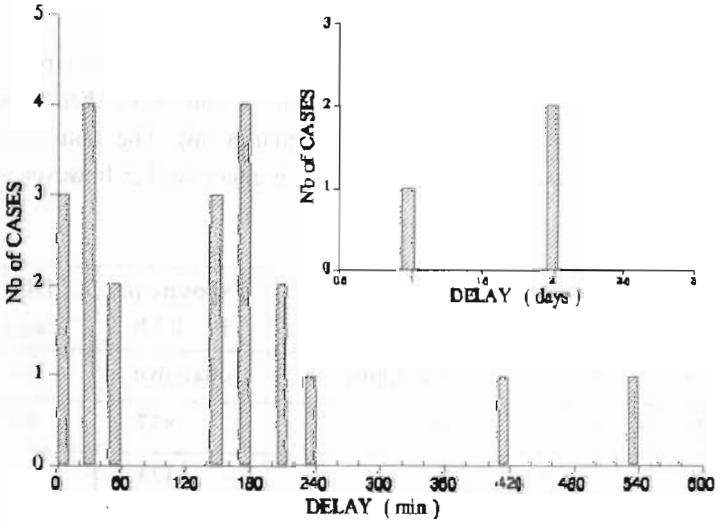
Oxygen tables [9]. The total number of exposures to oxygen decompression is 106.

From the DCI data, only 2 cases are reported after oxygen decompression. These cases occurred after the same exposure (2.7 b / 1h 30), both are skin symptoms. The temperature in the airlock was close to 0°C, and both workers complained from cold during decompression. Cold is an obvious aggravating factor.

DISCUSSION

General

It must be underlined that in that range of pressure above 1.2 b not a single project has been organized with compressed air work by shift. All compressed air-work are in relation with TBMs which need occasional interventions to solve technical problems like tools inspection and maintenance/replacement, cutting head modifications, boulder removal, clay jetting, ground inspections [14].



Reporting symptoms by victims is extremely difficult to control or evaluate [6]. However this population has been educated to do so, they know the possible long term consequences of non reporting, there is no significant penalty moneywise from becoming unfit in relation with DCI. It can be assumed that reporting is normal and not considered negatively among the group members. Any pain in relation with an hyperbaric exposure is considered and treated as a bend. Some over reporting may be present since at least 2 cases of mild pain have not responded to recompression with oxygen... In addition, only 7 sites have returned the information for the survey, and it is known that those which have not, are free from DCI cases. Therefore DCI rates from the survey are over estimated and are not shown as per cent of total exposure number which would be meaningless.

Type of work inducing DCI

The detailed evaluation carried out in one site which had to face 16 of the cases, shows that not only heavy work is an important parameter but also the type of exercise : repetitive action with static effort, although with moderate hart-rate response recorded with Holter [13] is clearly associated with the bends. This is also correlated with the fact that heavy cutters changes induces more bends (Earth pressure TBMs). A short series of bubble detection has been carried out after such exposures which showed no significant bubble grade but no bends in the surveyed decompressions (n = 6).

Safety measures

Only 2 sites have experienced several cases of DCI and both have taken action to stop the occurrences. These actions are based on observations made on the occasion of the hits : selection of the schedules, rest and oxygen after return to atmospheric pressure, precautions on fitness. All these actions resulted in the elimination of DCI on both sites. However most of these decisions have been implemented at the same time and it is not possible to decide if one of them is efficient by itself. The results of these actions are not included in the data because the survey was closed too early, updated data will be shown at the meeting.

Air decompression

In the operating rules of the tables it is prescribed that in case of heavy workload or stressful conditions, the next time available in the table should be used to add a safety factor. The appreciation "when to do it" is difficult, it has been done systematically on the 2 sites with multi occurrences. It appeared that this has not been sufficient to eliminate all hits and that it is more efficient to decrease exposure time by 30 minutes and keep the same decompression profile.

Oxygen

The use of oxygen decompression has not been decided after DCI occurrences. Safety measures necessary for oxygen decompression have been the limiting factor.

It must also be remembered that upon arriving back at atmospheric pressure the compressed air workers undergo the "last decompression stop" at 1 bar. They are trained to observe a normal life for 12 hours, avoiding any physical exercise which is DCI provocative (despite of the information, at least 4 cases have been triggered by exercise). To keep personnel quite during the first hour after exposure it has been organized sessions of oxygen breathing (closed circuit 100% O_2 sets) for 45 minutes after shower ... Results: only 1 more DCI case.

Acclimatization

The study of the number of exposures and eventually the delay between exposures before each DCI case show no relationship supporting either acclimatization nor nitrogen accumulation effect. However the number of cases is too small for statistical testing.

Fitness

On one site, several cases (4/6) happened on mondays ... All concerned personnel had travelled back from home either by car or by train during the night before exposure. Restriction have been imposed on personnel who had not slept normally the night before the intervention. Planning was given the day before each intervention, in order that personnel could declare himself unfit.

GREATBELT experience

The French tables (1992) have been selected by MT GROUP for compressed air work carried out in the 4 hydroshield TBMs used to built the Greatbelt tunnels in Denmark. Results published in the press show

about 10 000 exposures between 1 to 2.4 b and an occurrence of 6 bends and 1 so called type 2 hit. All cleared after on site recompression oxygen tables. This is an outstanding good result. The operational safety environment including appropriate training and organisation is claimed to be one of the factors leading to that low rate of DCI, in addition to the tables by themselves. No oxygen decompression has been use on those sites.

VALIDATION ?

Are those results comparable with other published data ? The general agreement is that a rate between 2 and 0.5 % of incidence is common practice even if not acceptable in terms of safety [6, 10, 11, 14]. Most of the times, many of the exposures considered in the statistics include works at low pressures or for short exposures, gross under reporting of cases improving the overall results. Comparisons and conclusions must be very careful. In addition the French tables are not intended to be valid as such in all circumstances, because it may become an undue penalty for most of the operations or unsafe for specific task. The principle is adaptation for extreme exposures. Results presented here include already several exposures with special adaptation to the situation resulting in an efficient reduction of DCI cases ...

RECOMMENDATIONS

At this stage of evaluation, French tables modification should not be necessary, however emphasis should be given on the need to use extra safety factors in some circumstances, like reducing exposure time for the same decompression schedule when heavy work or steady efforts are necessary during the performance.

Fitness to work, is an important point, not only on the occasion of annual checks, but in the every day situation, personnel may be unfit when tired, whether in relation with previous work or personal reasons. Every worker should be trained to that concept and declare himself unfit when he believes so. No money penalty should be the consequence of this decision.

Use of oxygen : Oxygen tables, although their evaluation is of limited value due to the small number of exposures, should be recommended at pressure above 1.8 bar every time it is compatible with the organisation of the work. Oxygen rest after exiting the lock, has been accepted by the personnel with no problem, only one DCI case have been reported when this is used.

Continuation of follow up of the results is needed and will be carried out in the future, results will be revisited when number of documented exposures will be more than 10 000.

BIBLIOGRAPHY

1. BAUD J.P., DELAFOSSE B., MARTIN A. and VINCENT S. (1988), Tunneliers et pathologie hyperbare. Revue de médecine du travail, XV, 11-16
2. CABARROU P., SUSBIELLE G. (1973),Tables de décompression après travail à l'air comprimé. Revue de médecine du travail, II, n°3, 217-229
3. CATTON M.J., (1992), The technique of decanting in compressed air work, In : Engineering and health in compressed air work, Proceedings of International conference Oxford, JARDINE F.M. and McCALLUM Ed., E & FN SPON publishers, page 389 - 407
4. IMBERT J.P. and BONTOUX M., (1989), A method for introducing new decompression procedures, In : Validation of decompression tables, 37th UHMS Workshop, Bethesda, SCHREINER AND HAMILTON Editors, 97 - 105.
5. JARDINE FM, McCALLUM R.I. Eds. (1994) Engineering and health in Compressed Air Work : Proceedings of International Conference, Oxford, Sept. 1992, London : E & FN Spon Publishers.

6. KINDWALL E.P., (1992), Optimum schedules for caisson decompression, In : Engineering and health in compressed air work, Proceedings of International conference Oxford, JARDINE F.M. and McCALLUM Ed., E & FN SPON publishers, page 156-171.

7. LE PECHON J. Cl. (1990). Sécurité pour les travaux hyperbares, In : Franchissements souterrains pour l'Europe, LEGRAND Ed, A.A. BALKEMA, Rotterdam, 1 - 10

8. LE PECHON J. Cl. and PASQUIER J.L.(1992) French regulations 1992 for hyperbaric works. In : Engineering and health in compressed air work, Proceedings of International conference Oxford, JARDINE F.M. and McCALLUM Ed. page 483-492

9. LE PECHON J. Cl. (1992), Oxygen decompression in tunnelling. In : Engineering and health in compressed air work, Proceedings of International conference Oxford, JARDINE F.M. and McCALLUM Ed., E and FN SPON publishers. page 529-538

10. MANNCHE K.H., DREYER K.H., PEUSCH- DREYER D., (1992), Observations of decompression sickness and effects of working conditions in two caissons in Bremen. In : Engineering and health in compressed air work, Proceedings of International conference Oxford, JARDINE F.M. and McCALLUM Ed., E and FN SPON publishers, page 408-412

11. NASHIMOTO I., (1991), Epidemiology of bends (2) : the actual situation in Japan. In : What is bends? 43rd UHMS Workshop, Shimizu Japan. page 25 - 37

12. NISHI R.Y. and KOCH G.H., (1972), Decompression procedures for caisson work - a review of various techniques., DCIEM Report n° 905, Defense research board, CANADA 24 pp.

13. NORMAND J.C., et all, (1990), Enregistrement holter en milieu hyperbare au niveau du front de taille du chantier du métro de Lyon. Arch. Mal. Prof. n°5, 313 - 317

14. RUEGGER M., BUHLMANN A.A. and VOLLM E., (1992), Decompression in tunnel construction using the hydroshield process. In : Engineering and health in compressed air work, Proceedings of International conference Oxford, JARDINE F.M. and McCALLUM Ed., E and FN SPON publishers, page 319 - 327

15. SCHREINER H.R. and HAMILTON R.W., (1989), Validation of decompression tables. 37th UHMS Workshop, 74(VAL)161-88. Bethesda MD UHMS.

16. STERK W. and HAMILTON R.W., (1991), Operational Dive and decompression data: collection and analysis. EUBS Workshop, EUBS Publ.(DATA)17-8-90, 183 p.

REGLEMENTATION

17 - Travaux en milieu hyperbare, mesures particulières de prévention. J. O. Rep. Franç. Brochure n° 1636, Juin 1992

18 - CIRIA (1982), Medical code of practice for work in compressed Air, Report 44, 3rd Ed. London, p 52

19 - Novellierung der Druckluffverordnung (DLV), Aufenthalts - und Ausschleusungszeiten fur Arbeiten in Druckluft, Bek. des BMA vom 26 Oktober 1994, IIIb2-34572.2-