HOME OFFICE (FIRE DEPARTMENT)
SCOTTISH HOME AND HEALTH DEPARTMENT

TECHNICAL BULLETINS
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PROBLEMS ASSOCIATED WITH FIRE SERVICE OPERATIONS IN PRESSURISED ATMOSPHERES

1. In 1966 Technical Bulletin No 7 was issued describing the effects of working in pressurised atmospheres when wearing breathing apparatus. Since that date new information has come to light as a result of a series of trials and it has been decided that changes should be made to the recommended maximum pressure at which oxygen breathing apparatus may be worn, and in other factors. Accordingly Technical Bulletin No 7/1966 is cancelled and replaced by this revised Bulletin.

2. One of the recommendations in Technical Bulletin No 7/1966 was that Proto breathing apparatus could be worn at pressures up to 18 psi gauge. This figure was based on practical experience with these sets as at that time no research work had been carried out on men breathing oxygen when performing hard work in air under pressure, although a great deal was known of the effects of breathing oxygen under water. A series of trials was therefore undertaken by the Royal Naval Physiological Laboratory with the co-operation of about 40 volunteers from Portsmouth fire brigade wearing Proto breathing apparatus. These trials were conducted under strict medical supervision and entailed the men carrying out a prescribed pattern of work for a set period at pressures ranging from 9 psi to 21 psi gauge.

3. The results of these tests indicated that the pressure of 18 psi gauge recommended in Technical Bulletin No 7/1966 was too near the limit of safety bearing in mind the extreme variability in the sensitivity to oxygen of different individuals. This could have been corrected by reducing the maximum pressure for oxygen sets by say 2 psi to 16 psi gauge; but the tests also revealed that despite the normal clearance procedure being followed when the sets were donned the concentration of oxygen was generally very much lower than expected, in some cases as low as 70%, the balance being nitrogen. This factor is important because the presence of nitrogen reduces the amount of oxygen to which the body is subjected and so increases the tolerance of the wearer to the effects of pressure; for example, breathing a mixture of 85% oxygen and 15% nitrogen at 18 psi gauge is equivalent to breathing pure oxygen at only 13 psi gauge. Therefore although a pressure of 16 psi gauge might be acceptable for Proto breathing apparatus in view of the lower oxygen concentration in the breathing mixture, it would be too high in the case of other sets such as the "Minox" in which the oxygen concentration would be very much higher.

4. Accordingly it has been decided that the pressure limit for the use of oxygen breathing apparatus should be adjusted to allow a wearer to breathe pure oxygen with an adequate safety margin and be reduced to 12 psi gauge pressure.

5. In addition to this question of the pressure limit for the use of oxygen sets other developments have occurred since Technical Bulletin No 7/1966 was issued. Revised tables providing longer decompression times than the tables in "The Work in Compressed Air Special Regulations 1958" are being tried out experimentally on the recommendations of a sub-committee of the Medical Research Council. In addition more is known about the effects of oxygen poisoning and the question of mixture breathing apparatus for use at pressures above that recommended for oxygen breathing apparatus has been explored.

6. In this Bulletin, Part 1, under the heading of "General Considerations", includes the revised text of Technical Bulletin No 7/1966. Part II is a new section headed "Provision of Special Equipment".

PART 1 GENERAL CONSIDERATIONS

Introduction

7. It is sometimes necessary to work under artificially pressurised conditions, e.g. when building a tunnel under a river pressure may have to be increased to prevent the ingress of water. Regulations made under the Factories Act entitled "The Work in Compressed Air Special Regulations 1958" (Statutory Instrument No 61) lay down requirements and precautions to be taken when work is undertaken in such conditions. There has to be an air lock at the entry to the workings to prevent the escape of compressed air. The Regulations state that there shall be a lock attendant and that pressure gauges shall be provided to indicate the pressure in the workings and the pressure in the air lock. The lock attendant controls the pressure in the air lock to compress men gradually before entering the workings and to decompress them on leaving. Decompression must be carried out in accordance with tables included in the Regulations.

8. When being pressurised it is necessary from time to time to hold the nose and "blow" with the mouth closed in order to clear the ears. A man with a cold, ear-ache or sore throat, or who is suffering from bronchial or catarrhal trouble, should not be pressurised. In the event of a man feeling pain or discomfort while being pressurised he should warn the lock attendant who will stop compression and, if the pain does not go, will reduce pressure slowly and let the man out of the lock.

Pressure Scales

9. As is well known the pressure of the atmosphere on the earth's surface is about 15 psi. Zero on this scale, which is known as the "absolute" scale, would be found only in a perfect vacuum. Pressure gauges, on the other hand, are scaled to read zero at atmospheric pressure so that 2 atmospheres or 30 psi absolute is equal to 15 psi gauge pressure. In other words absolute pressure is always 15 psi more than the equivalent gauge pressure. When talking of pressures it is therefore important to specify whether the figures referred to are "absolute" or "gauge" readings. In this paper all pressures mentioned subsequently are gauge pressures as this is the scale used throughout "The Work in Compressed Air Special Regulations 1958".

The Effects of Increased Pressure

10. It is generally known that if a certain volume of gas at atmospheric pressure (zero gauge) is compressed by doubling the pressure to 15 psi then the volume is reduced to a

half; if the pressure is increased by 3 times, ie 30 psi, the volume is reduced to one-third and so on.

11. If a man enters an atmosphere of say 15 psi he will inhale the same volume of air at each breath as under atmospheric conditions, but this will, in fact, contain twice the amount of air as compared with air at atmospheric pressure.

12. Another effect of entering an atmosphere of 15 psi is that the gases dissolved in the body will increase and will eventually be double the amount of gases dissolved at atmospheric pressure. This change occurs without any discomfort to the man provided the increase in pressure is not too sudden and presents no problem until he returns to atmospheric conditions when the pressurised gases in the body expand and seek to escape.

Releasing Pressurised Gases in the Body

13. When a man returns to atmospheric conditions from a pressurised atmosphere the extra gases dissolved in the body have to be released. The problem when breathing air under pressure arises from the increase in nitrogen in the body. When a man returns to atmosphere this extra gas has to be expelled by being breathed out through the lungs. This occurs quickly in the case of a man who has not been exposed to pressure above 18 psi (see paragraph 14), but at higher pressures a man needs to be decompressed at a controlled rate as, if the pressure is reduced too quickly and the nitrogen tries to get free faster than is possible through the lungs, bubbles of nitrogen will form in the body causing symptoms such as pain, particularly in the joints (when it is referred to as the "bends"). These symptoms could be more severe after prolonged exposure ie 3 hours or more to high pressure, and are known as "decompression sickness". The cure is to increase the pressure so that the gases are once more dissolved in the body and to decompress at the appropriate rate.

14. The Regulations state that at pressures up to 18 psi there is no limit to the permissible working period and no special decompression measures are necessary. For pressures above 18 psi however minimum times to decompress are given in the decompression tables according to the pressure to which the man has been subjected and the length of time he has been at work. The following extract from these tables shows how the time to decompress increases as the pressure increases up to 30 psi, for working periods up to one hour.

PRESSURE psi	WORKING PERIOD	MIN TIME TO DECOMPRESS
18–20	½–1 hour	4 minutes
20–22	,,	6 ,,
22–24	,,	8 ,,
24–26	,,	10 ,,
26–28	,,	13 ,,
28–30	,,	16 ,,

15. As stated in paragraph 7 the decompression tables referred to above are included in the Regulations, but a special panel of the Medical Research Council known as the "Decompression Sickness Panel" has been studying the effects of decompression and has produced an alternative set of tables. These tables are known as the "Blackpool Decompression Tables" and a number of contractors have received special dispensation to use them on an experimental basis. The Blackpool tables start controlled decompression at 14 instead of 18 psi pressure and their general effect is to reduce decompression times between 18

and 30 psi pressure and to increase them at higher pressures. The following table gives the Blackpool figures up to 30 psi and the difference will be noted between these figures and those in paragraph 14.

PRESSURE psi	WORKING PERIOD	MIN TIME TO DECOMPRESS
14–16	½–1 hour	2 minutes
16–18	,,	2 ,,
18–20	,,	2 ,,
20–22	,,	2 ,,
22–24	,,	5 ,,
24–26	,,	5 ,,
26–28	,,	10 ,,
28–30	,,	15 ,,

The Effects of Wearing Breathing Apparatus

16. When a man enters a pressurised atmosphere wearing breathing apparatus, whether it be a compressed air or oxygen set, his body is subjected to the same pressure both inside and out as if he were not wearing a set. The internal pressure builds up automatically to balance the external pressure; in the case of a compressed air set at the exhaling valve and the diaphragm controlling the demand valve, and in the case of an oxygen set in the breathing bag. Different problems do however arise according to whether air or oxygen is breathed and these are considered separately in the following paragraphs.

17. *Compressed Air Breathing Apparatus.* As regards effects on the body and the decompression measures to be taken on leaving the pressurised atmosphere, the same conditions apply as if no set were worn. An operational problem arises, however, from the fact that a man in a pressure of say 15 psi (2 atmospheres) inhales twice the amount of air he would inhale at atmospheric pressure and consequently the nominal duration of the set is halved. At 30 psi (3 atmospheres) the duration would be reduced to one-third and so on, and it should be noted that the safety margin indicated by the warning whistle would be reduced in the same ratio as the working duration of the set. These reductions in duration obviously impose severe limitations on the use of compressed air sets, particularly at high pressures, unless special provision is made to maintain the supply of air cylinders or air from another source (eg airline equipment).

18. *Oxygen Breathing Apparatus.* When oxygen at a high concentration is breathed in atmospheric or pressurised conditions the nitrogen dissolved in the body will gradually be replaced by oxygen, the nitrogen being breathed out into the set and to some extent expelled through the relief valve. This transfer takes place without any ill-effects and as oxygen can readily be used up in the body in a very short space of time there is no need for a controlled decompression on return to atmosphere. If however oxygen is breathed above a certain pressure danger can arise from a phenomenon known as oxygen poisoning and to understand this it is necessary to give a simplified account of the functions of oxygen in the body.

19. Normally oxygen in the body is held partly in solution but chiefly in the red blood cells in chemical combination. This chemical, known as haemoglobin, carries oxygen to the tissues, gives it up and in its place takes in carbon dioxide. Under normal atmospheric conditions over 99% of the oxygen needed by the body is carried in haemoglobin. When the atmospheric pressure is greatly increased no more oxygen can be carried by the haemoglobin, but the amount of oxygen dissolved in the liquid part of the blood is increased. At high pressures enough oxygen is carried in solution for the needs of the body tissues and

consequently no oxygen is given up by the haemoglobin. The effect of this is that the haemoglobin cannot pick up carbon dioxide which as a result accumulates in the tissue. This accumulation is dangerous. Too much oxygen in the body can by itself cause disturbances of the normal processes of metabolism and interfere with energy production. This hindrance is made worse by increased amounts of carbon dioxide, and the combination of the 2 is responsible for so-called oxygen poisoning. Oxygen poisoning therefore occurs more readily when a man is working hard because his body produces more carbon dioxide. The symptoms in many ways are similar to those of drunkenness and lead ultimately to unconsciousness.

20. The duration of Proto sets is reduced in pressurised atmospheres but, because these sets have a re-circulating system, the effect is less marked than in the case of compressed air sets. It is not possible to state precise reductions in relation to the ambient pressure, but from experience gained during the RNPL trials it may be assumed that in an atmosphere of 12 psi the working duration of a one hour Proto set will be reduced by about 12 minutes and the safety margin indicated by the warning whistle will be reduced in the same ratio. With Minox sets, however, the duration is only slightly affected by pressure because of the method of operation of the flow control valve.

21. It is safe to wear oxygen breathing apparatus at pressures up to 12 psi for the working duration of a nominal one hour set, ie about 45 minutes. Above that pressure it is however impossible to state safe working limits because toxic symptoms may occur sooner or later depending on the individual and the physical effort involved. It is for this reason among others that the use of mixture breathing apparatus has been investigated.

22. *Masks with Air-Cushion Seals.* With air-cushion seals the pressure in the cushion must be the same as the ambient pressure. Therefore when masks of this type are to be used under pressurised conditions the sealing plug to the cushion should be removed and replaced when the maximum pressure is reached.

PART II PROVISION OF SPECIAL EQUIPMENT

General

23. Underground workings vary in type and complexity. The tunnels and passageways for the underground railway at Oxford Circus are like a rabbit warren whereas the tunnel under Southampton Water built for the Central Electricity Generating Board to carry power cables runs straight for its whole length of nearly 2 miles.

24. However it is common to all tunnels under construction that the "going" under foot is somewhat hazardous and conditions are generally damp and sometimes misty. The cross-section of tunnels is circular and as a tunnel is built and lined, beams are usually laid across at a convenient height to serve as sleepers for rails to carry the "muck" trucks, usually referred to as "skips". Between the rails planks are laid to provide a footway eg for the men pushing the trucks, but these are laid in a casual fashion and there are often gaps between them. There is generally no other continuous footway and it is necessary to proceed carefully even in good visibility. In smoke progress would inevitably be hazardous and slow.

25. The supply services fed into a tunnel under construction, whether pressurised or not, are electricity, water (about 1″ bore pipe) and an air main (also about 1″ bore) if pneumatic boring equipment is used. Equipment may however be electrically operated in which case no air main will be installed. The water main is for the purpose of supplying water to the working face, and arrangements may be made with the contractor for the provision of

take-off points at intervals along its length to which standard hose reel tubing can be attached for fire-fighting purposes. Pneumatic equipment operates at 80/100 psi pressure and the air main may also have take-off points along its length.

26. For obvious reasons construction companies only pressurise workings when absolutely necessary.

27. When a tunnel is to be pressurised an air lock is installed at the beginning of the section. This consists usually of a steel chamber which is sealed into the tunnel with concrete which may be several feet thick depending on the pressure it is intended to withstand. The electricity, water and air lines are embedded in the concrete and there would be no difficulty in making provision for additional supply lines, with suitable couplings at each end for delivery hose and air lines for breathing apparatus and a conduit with wiring and connections at each end for breathing apparatus communications equipment, provided the necessary arrangements were made with the contractor before the air lock was installed. The water supply line for delivery hose may be extended along the tunnel and be provided with instantaneous outlets at intervals.

28. Often vertical shafts have to be sunk to the level at which a tunnel is to be driven and it may be necessary for a shaft to be pressurised in which case an air lock is installed at the head of the shaft. These locks may take only one or two at a time and access to the foot of the shaft is by means of ladders and staging. As work progresses the shaft air lock is usually replaced by an air lock in the tunnel. Provision may be made with the contractor for fire brigade supply lines through these locks in the same way as for locks in tunnels (see paragraph 27).

29. Before a decision can be reached on the supplies to be installed through an air lock it is necessary for the brigade to decide what would be the most suitable equipment to use in the event of an incident in that particular section of the workings. The choice of equipment should be based on the highest pressure the contractor thinks he may have to use. This maximum may never be reached as the pressure is kept as low as practicable, but it may have to be increased as tunnelling progresses.

Types of Breathing Apparatus

30. Oxygen sets would be the obvious choice as their duration is only moderately affected by the increased pressure and they allow wearers complete freedom of movement. However if the pressure is above that recommended for the use of oxygen sets then provision must be made for the use of compressed air or special breathing apparatus. (See paragraph 37.)

31. With pressures over 12 psi even the ultra lightweight cylinders are unlikely to provide an adequate working duration for a compressed air set and it will be necessary to augment the supply of air carried in the cylinders. This can be done either by making available sufficient spare cylinders or by using air line equipment. Each of these methods has its own particular problems and these are discussed in the following paragraphs.

Spare Cylinders

32. Taking in sufficient spare cylinders creates a serious transporting problem under very difficult conditions. One possibility would be to make use of an empty skip to carry the cylinders, but there would always be the likelihood of encountering another skip, perhaps fully loaded, or some other obstruction on the line which would prevent further progress. In the tunnel under Southampton Water there were 2 overhead trolley tracks running the full length. These would provide a ready means for transporting equipment, but tracks of

this type in tunnels are exceptional and would probably only be installed where cables or pipes had to be laid after the tunnel was completed. In some large tunnels battery driven locomotives are used to move the skips and these would simplify the problems of transport.

33. It would therefore be reasonable to consider providing sufficient reserves of air in spare cylinders only if the means of transporting them were known to be reliable. However, where an adequate supply of spare cylinders could be made available the breathing apparatus should be provided with two-way adaptors to enable cylinders to be replaced during operations. Alternatively special arrangements could be made for a man to carry a spare cylinder already connected to his set.

Airline Equipment

34. When air line equipment is used the transporting of supply cylinders should not present serious difficulties if provision had been made for a special air line through the air lock for fire service use, which would permit the supply cylinders to remain outside the lock. In such a case firemen could enter the pressurised section breathing air from the cylinder on their breathing apparatus and carrying a reel of air line hose, which they could then plug into the special air line inside the pressurised section and connect to their sets, keeping in reserve the air remaining in the cylinders they are carrying. Penetration of the tunnel could then proceed up to the length of hose on a reel which is at most 300 ft. A transporting problem arises, however, if deeper penetration were necessary as a spare reel would have to be brought in to extend the line. Transporting a reel this distance would present difficulties, bearing in mind the condition of the timber staging and obstructions in tunnels under construction, and the heavy drain on the air in the BA cylinders of sets worn by the men undertaking the work. If however reliable transport facilities were available it might be a practicable proposition, and it might even be possible to transport both supply cylinders and air lines into the tunnel to a point convenient for operations.

35. An alternative would be to make use of the air main where one is installed for pneumatic tools. In such cases the air is supplied by large compressors, usually on the surface, and the use of this main would have the advantage of providing a continuous supply of air for an indefinite period and would dispense with the need to arrange for a supply of air from cylinders. The air from the main would have to be dried and freedom from oil mist ensured to make it suitable for breathing. This type of air installation may be found to have a high water content, in which case it will be necessary to allow time to drain the system to expel any accumulation of water before coupling up. In order to dry the air sufficiently to allow comfortable breathing a special filter unit should be incorporated in the feed from the main to the air line hose reel. The filter units can be obtained from the suppliers of air line equipment.

36. Whenever air line equipment is used the limiting factor will be the duration of the sets worn by the men, which they will use on entering until the air line is connected up and subsequently on withdrawal after the air line is disconnected. Bearing in mind the limited duration of these sets under pressure and the difficulties involved, it is not considered likely that it will be practicable to penetrate a toxic atmosphere in excess of 300 ft ie one hose reel length.

Special Breathing Apparatus

37. At pressures above 12 psi, when oxygen breathing apparatus should not be worn, there are likely to be circumstances where the limitations on the duration of compressed air sets and the restrictions imposed by air line equipment would seriously hamper operations. Consideration has therefore been given to special breathing apparatus which would provide

a working duration of at least 45 minutes irrespective of the pressure in which it is used, and which would be self-contained and consequently allow complete freedom of movement to the wearer.

38. In order to avoid oxygen poisoning it is necessary for the oxygen breathed to be diluted with an inert gas, usually nitrogen, and the amount of dilution will depend on the pressure in which the set is to be used. A liquid air set would provide this gas mixture. These sets have the advantage of providing cool air for long periods, but it is not considered that the provision of these sets could be justified to meet a remote contingency, particularly in view of the high cost of the apparatus and the difficulty of keeping a supply of liquid air constantly available. However, a practical alternative is to convert Proto 1 hour sets to "mixture" breathing apparatus as used by the Royal Navy and to use a 60% oxygen 40% nitrogen mixture. This is a standard Navy mixture which permits a man to work hard with no ill effects for periods up to 1 hour in pressures up to 35 psi, irrespective of the degree of work undertaken by the wearer.

39. The conversion of Proto sets entails the provision of a 2 hour Proto cylinder, a special reducing valve giving a rate of flow of 6 litres per minute and the fitting of an automatic relief valve. A 2 hour Protosorb charge must be used and the set should be fitted with Mark V breathing tubes because they provide a lower breathing resistance than Mark IV tubes. The warning period indicated by the low cylinder pressure warning whistle will not be affected because the larger cylinder capacity compensates for the effects of pressure. The cylinders can be charged commercially, and will be painted grey and black with the percentages of oxygen and nitrogen stencilled on them.

40. Firemen likely to wear mixture breathing apparatus should receive special instruction in their maintenance and use. Mixture sets behave differently from standard Proto sets in that, with a constant flow of 6 litres per minute the relief valve is venting continuously and the set is under slightly higher internal pressure. Good maintenance is essential and it is important that the flow never drops below 5·7 litres per minute. If the flow drops below this figure or the reducing valve should fall, the bag will continue to remain full for some time and the wearer might be unaware of the fact that he is steadily reducing the oxygen content. This could be dangerous because lack of oxygen causes a man to behave as if drunk and eventually lose consciousness. Men working in pairs should bear this in mind when watching their companions.

41. With proper maintenance a reducing valve is unlikely to become defective, but even so it is essential that firemen withdraw promptly at the limit of their working duration or if they have any reason to suspect the functioning of the reducing valve.

42. The duration tables for 1 hour Proto sets are applicable to these mixture breathing apparatus as the working durations of both sets are approximately the same. White tallies should be provided for mixture sets, marked at each end and in the centre with a $\frac{1}{4}$ inch wide grey band to distinguish mixture sets from 1 hour Proto sets.

43. It is essential that entrapped procedure is not practised with mixture breathing apparatus sets. The reason for this is that, because of the high nitrogen content, the breathing bag will not show signs of deflating before the wearer is breathing an excessive amount of nitrogen, which can have serious consequences.

Time of Withdrawal

44. Attention has been drawn to the fact that the operation of low cylinder pressure warning

devices on some sets is affected by pressure and will give a reduced warning period. But whatever apparatus is used, it is important to start withdrawal in sufficient time to allow for possible delay in entering the air lock which may be in use at the time of the wearer's return and in view of the need to allow this extra safety margin it would in any case not be practicable to rely on low cylinder pressure warning whistles.

Summary

45. The choice of breathing equipment to use in pressurised workings depends on the pressure, the ease of access to the workings and also on the arrangements it is possible to make with the contractor before an air lock is installed. The conditions may be split into 2 groups, i. where pressures are low enough to permit the breathing of pure oxygen and ii. where pressures are too high for pure oxygen to be breathed.

i. *Lower Pressures.* It is always most convenient to use self-contained breathing apparatus and at pressures up to 12 psi, oxygen sets are to be preferred because they provide the longer duration which is not materially affected by the pressure (see paragraph 20). Compressed air sets may be used if their duration is considered to be sufficient in the prevailing circumstances (see paragraph 17).

ii. *Higher Pressures.* At higher pressures where pure oxygen should not be breathed there are 3 possible alternatives:

a. *Where Penetration is not deep and transporting facilities are known to be reliable*—self-contained compressed air breathing apparatus with a supply of sufficient spare cylinders to last the required working duration (see paragraph 32).

(*NB* Sets used for this purpose would require a special adaptor to allow a full cylinder to be fitted while the one to be replaced was still in use).

b. *Where the depth of penetration is too deep for* a.—Air line equipment used in conjunction with self-contained breathing apparatus. The cylinder on the set should be used until the air line reel is connected up and then the cylinder shut off and kept in reserve.

Where reliable transport facilities exist within the workings large capacity air supply cylinders and air lines could be taken into the pressurised section to a point convenient operations (see paragraphs 34 to 36).

c. *Special breathing apparatus*—Sets of this type may be provided in a brigade by converting standard Proto 1 hour breathing apparatus. These sets have the advantage of being self-contained and of being safe to use in pressures up to 35 psi for the working duration of the apparatus, ie at least 45 minutes (see paragraph 37).

46. In all cases ample time should be allowed for withdrawal, bearing in mind that there may be a delay at the airlock. Reliance should not be placed on low cylinder pressure warning whistles (see paragraph 44).

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