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**HOME OFFICE (FIRE DEPARTMENT)
SCOTTISH HOME AND HEALTH DEPARTMENT**

TECHNICAL BULLETINS

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Working in Pressurised Atmospheres

1. It is sometimes necessary to work under artificially pressurised conditions, for example 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 in the air lock to indicate the pressure in the workings and the pressure in the lock. The pressure in the air lock can be regulated by the attendant to compress men gradually before entering and to de-compress them on leaving the workings. De-compression is carried out in accordance with tables included in the Regulations.

2. This paper has been prepared to draw attention to the special circumstances which arise from breathing under pressurised conditions and the additional problems which have to be taken into account in the case of firemen wearing breathing apparatus.

Pressure Scales

3. As is well known the pressure of the atmosphere on the earth's surface is about 15 p.s.i. 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 p.s.i. absolute is equal to 15 p.s.i. gauge pressure. In other words absolute pressure is always 15 p.s.i. 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 in subsequent paragraphs are gauge pressures as this is the scale used throughout The Work in Compressed Air Special Regulations 1958.

The Effects of Increased Pressure

4. It is generally known that if a certain volume of gas at atmospheric pressure (zero gauge) is compressed by doubling the pressure to 15 p.s.i. gauge then the volume is reduced to a half; if the pressure is increased by 3 times, i.e. 30 p.s.i. the volume is reduced to one-third and so on.

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5. If a man enters an atmosphere of say 15 p.s.i. gauge 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.

6. Another effect of entering an atmosphere of 15 p.s.i. gauge is that the gases dissolved in the body will become pressurised to double the amount of gas 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

7. 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 increases in nitrogen in the body. When a man returns to atmosphere this extra gas has to be dispelled by being breathed out through the lungs. This occurs very quickly in the case of a man who has not been exposed to pressures above 18 p.s.i. gauge (see paragraph 8), but at higher pressures a man needs to be de-compressed 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, particularly in the joints, causing severe pains known as "bends" among divers and these pains can only be dispelled by increasing the pressure so that the gases are once more dissolved in the body.

8. The Regulations state that at pressures up to 18 p.s.i. gauge there is no limit to the permissible working period and no special de-compression measures are necessary. For pressures above 18 p.s.i. gauge however minimum times to de-compress are given in the de-compression 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 de-compress increases rapidly as the pressure increases up to 30 p.s.i. gauge for working periods up to one hour.

| <i>Pressure p.s.i. gauge</i> | <i>Working period</i> | <i>Min. time to decompress</i> |
|----------------------------------|-----------------------|------------------------------------|
| 18-20 | $\frac{1}{2}$ -1 hour | 4 minutes |
| 20-22 | " | 6 " |
| 22-24 | " | 8 " |
| 24-26 | " | 10 " |
| 26-28 | " | 13 " |
| 28-30 | " | 16 " |

Problems arising from the use of Breathing Apparatus

9. When a man enters the 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.

Compressed Air Breathing Apparatus

10. As regards effects on the body and the de-compression 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 p.s.i. gauge (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 p.s.i. gauge (3 atmospheres) the duration would be reduced to one-third and so on. This obviously imposes severe limitations on the use of compressed air sets, particularly at high pressures, as even if an ample supply of cylinders is made available the men will have to withdraw to the air lock for the cylinders to be changed. This could be satisfactory so long as the men are working near the air lock, but if they are working any distance from the lock, the only practical method of maintaining an adequate supply of air would seem to be by compressed air line equipment or by the provision of two-way adaptors on sets to enable cylinders to be replaced at the scene of operations.

Oxygen Breathing Apparatus

11. The duration of oxygen sets is also 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 as a rough guide it may be assumed that in an atmosphere of 15 p.s.i. gauge (2 atmospheres) the duration of a 1 hour oxygen set will be reduced by about 15 minutes.

12. Provided the set is cleared of nitrogen in the usual way before it is donned pure oxygen will be breathed and 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 no question of de-compression arises on return to atmosphere. In fact pressures up to 15 p.s.i. gauge (2 atmospheres) are used a great deal in medicine over many hours with very beneficial effects. At higher pressures however 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.

13. Normally oxygen in the body is 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 CO_2 . 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 CO_2 which as a result accumulates in the tissue. This accumulation is dangerous and causes so-called oxygen poisoning which is really a gradual accumulation of CO_2 in the body. Symptoms of oxygen poisoning are similar to drunkenness and lead ultimately to unconsciousness.

14. It is quite safe to wear oxygen breathing apparatus at pressures up to 18 p.s.i. gauge i.e., a little above 2 atmospheres absolute, without any limit on the working period. 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.

Conclusions

15. Where compressed air sets are to be used in pressurised atmospheres it is important to allow for the reduced duration of the sets by the provision of an ample reserve of cylinders. Air-line equipment would be eminently suitable for this purpose, but it is

not in general use in fire brigades. In the case of oxygen sets the reduction in duration is comparatively small and a normal reserve of sets or cylinders and absorbent should meet requirements.

16. At pressures up to 18 p.s.i. gauge both compressed air and oxygen breathing apparatus can be worn without any limits on working time and without the need to take any special precautions on returning to atmospheric conditions.

17. Between 18 and 30 p.s.i. gauge compressed air sets may be worn provided wearers are de-compressed afterwards in accordance with the rules laid down in The Work in Compressed Air Special Regulations 1958. It will be seen from the de-compression tables in these Regulations that at pressures above 30 p.s.i. gauge the time spent in de-compressing becomes rather long in relation to the working time, but pressures above 30 p.s.i. gauge are unlikely to be encountered by firemen, except under very exceptional circumstances.

18. Oxygen sets should not be used at pressures above 18 p.s.i. gauge because of the possibility that oxygen poisoning may develop.

Precautionary Measures

19. Where brigades may have to attend incidents in pressurised workings it is desirable that the following measures should be given consideration:—

- (i) Being subjected to pressure affects individuals differently and firemen likely to attend incidents should be given the opportunity of visiting the workings, and experiencing the effects of being compressed and de-compressed.
- (ii) As it is not possible to take delivery hose through an air lock one or more fixed pipes should be provided with instantaneous couplings at each end to which standard delivery hose can be connected. A valve must be incorporated to seal off the pressure in the workings when the pipe is not in use.
- (iii) If the use of compressed air line equipment is contemplated, it may be convenient to install pipes through the air lock in the same way as suggested for delivery hose. This will avoid the need to carry the air supply cylinders into the pressurised atmosphere.

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