The Diving Medical Advisory Committee

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Thermal Stress in Relation to Diving

A Workshop held at The Institute of Naval Medicine, Gosport, Hampshire

19-20 March 1981, Chaired by Dr DH Elliott (Co-Chairman, DMAC) and Surg. Cdr F St. C Golden, Royal Navy

DMAC 08 – March 1981

The Diving Medical Advisory Committee is grateful to the Norwegian Petroleum Directorate and the Association of Offshore Diving Contractors for financial support which enabled such an international group of experts to be brought together.

The Committee is also grateful to the Medical Officer in Charge for the extensive help provided by so many members of the Institute of Naval Medicine.

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Attendees

Dr J Adolfson	*Swedish Defense Institute*
Dr W Crosbie	*Health and Safety Executive (EMAS), London*
Dr R Cox	*Philips Petroleum, London*
Dr R Dyson	*MRC Clinical Research Centre, Northwick Park*
Surg. Capt. Eidsvick	*Royal Norwegian Navy*
Dr H Ellis	*Aberdeen University*
Dr D Elliott	*Shell UK, London*
Dr T Fallowfield	*Comex Services, Aberdeen*
Cdr R Goad USN	*Institute Of Naval Medicine, Gosport*
Surg. Cdr S Golden RN	*Institute Of Naval Medicine, Gosport*
Dr P Hayes	*Ante (Physiological Laboratory), Gosport*
Prof. GR Hervey	*Leeds University*
Mr V Humphrey	*Oceaneering International*
Mr J Imbert	*Comex Services, Marseille*
Prof. WR Keatinge	*The London Hospital*
Dr L Kuehn	*D.C.I.E.M., Toronto, Canada*
Lt. P Layton USN	*Naval Medical Research Institutes USA*
Lt. Cdr Manalaysay USN	*Naval Medical Research Institute, USA*
Dr N McIver	*North Sea Medical Centre, Great Yarmouth*
Dr B Minsaas	*Norwegian Petroleum Directorate, Stavanger, Norway*
Dr T Nome	*Philips Petroleum, Stavanger, Norway*
Prof. N Norman	*Aberdeen University*
Dr A Pasche	*Norwegian Underwater Institute, Bergen, Norway*
Surg. Cdr R Pearson RN	*Institute Of Naval Medicine, Gosport*
Sir John Rawlins	*Diving Unlimited Inc., UK*
Surg. Cdr T. Shields RN	*Institute Of Naval Medicine, Gosport*
Dr A Thornton	*Admiralty Experimental Diving Unit, Portsmouth*
Dr S Tønjum	*Norwegian Underwater Institute, Bergen, Norway*
Dr P Webb	*Webb Associations Yellowsprings, USA*

Introduction

This workshop was set up to consider the best approach to the principal thermal problems confronting the naval and commercial diver. It was held on 19 and 20 March 1981, at the Institute of Naval Medicine, Alverstoke, Hampshire, UK. The programme was divided into distinct sessions with a certain amount of interrelation between each.

Each session was introduced by a speaker who had been tasked to give a general review lasting about 30 minutes to be followed by about 2½ hours of free discussion. In his welcoming address, Surgeon Rear Admiral RJW Lambert, the Medical Officer in Charge of the Institute of Naval Medicine, thanked the Norwegian Petroleum Directorate and the Association of Offshore Diving Contractors for their financial support which made it possible to invite some distinguished speakers and help with some of the general administrative expenses associated with the meeting. He went on to say that he considered the meeting to be timely: technological progress may well have extended man's potential to endure in a hostile environment, but it does not necessarily follow that man's capability to perform work efficiently will also be increased. Before the advent of saturation diving, cold was considered to be little more than a discomfort the diver had to endure; it did not constitute the threat of residual injury or even death that dysbarism did. In the deep diving associated with the offshore oil industry, cold is at best a factor which impairs diver performance, and at worst a threat to life itself. Although he considered all four sessions to be very pertinent, he expressed a hope that some guidelines on management of survivors from the lost bell situation might be agreed before the end of the meeting.

The Chairman, Dr Elliott, described the background for the workshop, relating that the Diving Medical Advisory Committee (DMAC) is an Anglo-Norwegian group concerned with diving medical problems in the North Sea. As such, thermal problems have always been a priority and, for some time now, a practical workshop for thermal physiologists with diving physiologists, physicians and engineers has been needed. Dr Elliott stressed the practical goals of the meeting, namely to define current and future thermal requirements of men in the water and attempt to answer the questions posed for each session.

The Co-Chairman, Surgeon Commander Golden, then remarked that recent diving engineering triumphs leading to more sophisticated equipment, new breathing gas combinations and longer times spent at pressure have been accompanied by a number of accidents which have no obvious cause. In some cases cold has been blamed, perhaps because no other factors could be identified. He pointed out the analogy between this state of affairs and the term "pilot error" which is often used to explain aviation accidents. In some cases "pilot error" may really mean that the task required was beyond the physiological and/or psychological capabilities of the man in the particular system. Similarly, with diving accidents, we need to ask whether too much is being expected or demanded of the diver. Is equipment, particularly safety or emergency equipment, capable of being operated by an individual who is hypothermic or even suffering from just extensive local cooling? Is there evidence that cold stress in diving causes physiological changes that can lead to human errors; or is the primary problem a psychological one, with discomfort from cold affecting the psychosomatic performance of the diver, resulting in errors of omission or commission?

Session 1 "What is the Influence of Cold upon the Mental and Physical Performance of the Diver?"

Reviewer: *Dr H Ellis*
Rapporteur: *Cdr R Goad, USN*

Dr Hayden Ellis' review took the form of attempting to answer or, at least, produce information on a number of questions posed in relation to cold stress and psychophysiological performance. Dr Ellis explained that he is a psychologist with a particular interest in cold, currently working with Professor N. Norman at Aberdeen looking at the relationship of cold to sensory judgement.

Does mild hypothermia affect cognitive efficiency?

At core temperatures below 33 degrees centigrade there is undoubtedly a gross decrease in cognitive abilities, but above this level there does not appear to be a significant decrease in mental efficiency, judgement or thought processes. However, Dr Ellis pointed out that, while there has been no real systematic pursuit of this area of mild hypothermia, available data is not necessarily either reliable or consistent. An alternative pattern is beginning to emerge from the literature suggesting that, in certain areas, performance is adversely affected. Dr Ellis did not discuss manual dexterity in detail, as it was to be discussed in another session, and, though he had found no evidence of cold adversely affecting the special sense receptors such as vision and audition, he did find evidence that certain indicators of cognitive performance are adversely affected. These include time estimation, vigilance, tracking, verbal memory and some aspects of problem solving, namely arithmetic abilities and syllogisms. He pointed out that certain other cognitive performance indicators, including reaction time, digit span, weight estimation and other aspects of problem solving such as verbal reasoning and symbol substitution, seem not to be affected by cold. The general trend seems to be that as tasks become more complex they become increasingly vulnerable to cold stress, an exception to this being digit span and perhaps weight estimation. By the same token, it seems that people cannot sustain performance in the cold for very long without decrement; in other words, when information is presented in a fairly continuous stream (i.e. sustained as opposed to discrete mental processes), there is more likely to be evidence of cold stress causing an effect.

Why does mild hypothermia affect cognition?

Dr Ellis approached this question first from a psychophysiological viewpoint which hinges on the theoretical concept of arousal that supposedly underlies all stress effects on performance. With increasing stress there is a funnelling of attention with loss of peripheral input, so that performance deteriorates.

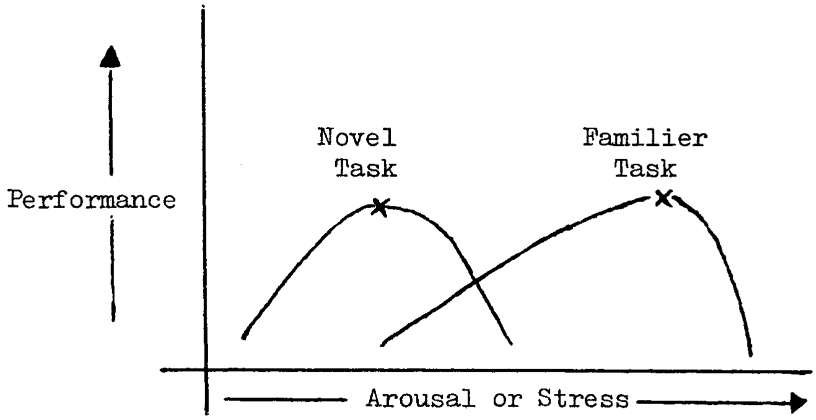

Figure 1: Arousal Curve *– X marks the point of peak performance –*
arousal levels below or above this point are associated with decline in performance.

The Arousal Curve demonstrates that optimum performance levels with familiar tasks are less likely to be affected by moderate degrees of stress than are novel tasks. One difficulty is that some researchers argue that cold stress produces a lessening of arousal while others say it produces a heightening of arousal.

Dr Ellis felt that if cold does affect arousal, it probably heightens it but in the process it would tend to narrow attention. However, this theory has not yet been systematically tested. Severe hypothermia slows down cognition and produces a very low state of performance. Immediate reaction to cold stress may increase arousals but this will probably be reversed if the stress is maintained or is severe. In other words the peak point will be surpassed and performance will decline. Dr Ellis stated that many psychologists only approach Question 2 from a cognitive, as opposed to a psychophysiological viewpoint, believing that the decreased performance is explained solely by the distracting influences of cold. To support their argument they point out that most cold effects are seen early rather than being necessarily associated with decreased core temperatures. Dr Ellis tended to think this was too simplistic a view and offered an alternative hypothetical mechanism: that, as the body surface cool, the reticular activating system is aroused via sensory skin receptors. This in turn leads to cortical arousal and interference with certain types of mental processes.

How can cold effects on cognition be modified?

In discussing the place for tranquilisers, oxygen, alcohol, analgesics, hypnosis and relaxation techniques, Dr Ellis pointed out that, as most cold work is done by highly trained and motivated people, it may be irrelevant whether cold acts as an arousal or a distractor stimulus. Divers in the bell situation may be so highly trained that they function better under a cold stress which might prove deleterious to others.

Are there any differences between wet and dry cold environments?

Dr Ellis saw little difference other than the facts that: Wet cold includes a higher rate of body cooling. There is an 'in water' effect in addition to the cold effect; underwater work in tanks, open ocean, water with poor visibility, each have their own unique set of stressors. Any difference between the two environments therefore, is probably an interaction or multiplication effect of all these various stresses. Dr Ellis summarised his review by re-emphasising the following points:

i) Certain tasks are prone to cold stress effects, in particular continuous and/or complex tasks. We should ask what diving tasks have these characteristics and try to relate this information to accidents caused by so-called 'human error'.

ii) Any effects due to mild cold stress (i.e. core temperature not decreased by more than 1 or 2°C) can occur very early in the work period and we need to find out whether this is dependent on the rate of skin cooling or whether there is some threshold value below which one can find a fall in cognitive performance.

iii) The answer to whether arousal or distraction is the cause of cognitive performance changes should help us better to predict real-life situations.

iv) A drop in core temperature down to 35 or 36°C appears to be relatively insignificant in terms of cognitive abilities but we still need to determine what core temperature is associated with decreased efficiency. Even though cold stress to this degree is not encountered as a matter of course, it could be in an emergency situation such as a lost diving bell.

v) It would help to know whether it is practical to try and reduce shivering.

vi) Cold may be modified by drugs and other methods. Is there any point in pursuing these avenues for the working diver?

Discussion

The Chairman, Surg. Cdr Golden, thanked Dr Ellis for his very interesting review and suggested that in the subsequent discussion attention should be paid not only to the lowest core temperature levels at which a diver in a lost bell can take actions to ensure his survivals but also to superficial, low-level cold stress and its effects on the working diver in normal circumstances.

Low-level cold stress

For this consideration we should ask how comparable the studies described by Dr Ellis are to the situations that a working diver encounters. Does a diver habituate to cold to any degree? Can he tolerate lower skin temperatures or lower core temperatures than the subjects in the experiments described by Dr Ellis?

In response to this, the results of a recent study at NUI were presented by Dr Tønjum which indicated that skin temperatures did not have a great deal of influence on determining when a diver stopped working and also that there was no evidence of performance changes with slight cooling other than that the time taken to complete a specific task was increased.

The Chairman said it was still not clear when "marginal" cold becomes hypothermia and asked for comments on the relationship between marginal and severe cold stress and how best to quantify cold stress other than by manual dexterity tasks.

The ensuing discussion pointed out that a core temperature of 33°C is a severe cold stress, despite any statements to the contrary, and that rapid cooling must be distinguished from slow cooling. Rapid cooling leads to pain, distraction and shivering, all of which are clear warnings to the organism and which shouldn't be suppressed with drugs or hypnosis. Long slow cooling over 4 to 6 hours is quite different. One calorimetry experiment described by Dr Paul Webb, produced a very large heat loss (greater than 200 kilocalories net) despite the absence of a significant drop in core temperature, very little in the way of subjective discomfort and no evidence of shivering. Does this type of cooling lead to performance decrement? The suspicion was that it does, but so far evidence is minimal though one experiment was described in which there appeared to be a decrement in higher cognitive abilities when highly trained military divers were cooled in a similar longs slow fashion. Habituation

It was pointed out that habituation has a considerable modifying effect on physical response and most likely on psychological performance as well. In relation to rapid as opposed to slow cooling, it was noted that rapid cooling to 34°C commonly produces complete retrograde amnesia, but this is much less common with slow cooling to the same core temperature. Other than anecdotal stories, no one at the workshop had evidence of habituation to cold stress causing an improvement in performance in divers, although it is well documented that fish filleters and the like are able to perform quite complex manual dexterity tasks with their hands immersed in iced water. Performance testing

On the question of measuring performance it was suggested that the Wilkinson test, or a modification thereof, was a good indicator of cognitive processes. This test consists of a randomised sequence of lights to which the subject responds, the test score being based on the number of correct responses, the number of errors and the time taken to respond. The disadvantage for cold studies is that weeks of familiarisation are needed, in addition to a large investment of time, to allow the test to be used in the actual conditions of interest. In fact, some of the discordant results in the literature may well be due to incomplete training of subjects and/or insufficient time spent on the tasks in the particular environment.

The discussion then continued for some time on whether there are good ways to measure performance changes in situations of large net heat loss without subjective complaints or significant drops in core temperature. Are there generally recognised testing methods for environmental stress situations? Is the learning curve identifiable? Does variability decrease after some definite time? Some of the thermal physiologists at the meeting are currently using a combination of tests such as a modification of Wilkinson test plus visual hand-eye co-ordination TV games such as target shooting or "night driver" and a type of numerical checking audio test to look at 'reserve cognition function', a term relating to the ability to do more than one task simultaneously. It was generally agreed that this was probably the best combination currently available since the most important consideration was to look at continuous tasks where effort must be sustained and the subject is not able to simply overcome short-term distracting effects. It was cautioned again that, while these tests may be the best currently available, they are difficult to apply properly as they need long training periods and highly motivated subjects. Also, the applicability of such tests to realistic diving situations with the effects of immersions pressure and so on, remained unresolved. Nevertheless, it was agreed that we need to know whether in fact marginal cold does produce performance changes before we can try to relate marginal cold to loss of consciousness and underwater accidents.

Marginal cold

The Chairman then directed discussion back to the problem of trying to define marginal cold, how to be aware when it's present, whether it is related to a fall in deep body temperature or merely related to peripheral stimuli, whether the rate of temperature change is important, et cetera.

There was also a brief discussion as to whether a catecholamine response might affect performance rather than the cold per se. It was pointed out that little or no adrenaline is released into the circulation during iced water showers and this may be a protective mechanism against ventricular fibrillation. There is, however, a noradrenaline response to shivering and pressure apparently affects this response. It was generally agreed that habituation can occur to the physical responses to cold water on the skin. It occurs fairly rapidly, and is also fairly short-lived (1 to 2 weeks) if habituation is not maintained.

The other marginal cold problem is a loss of heat from body stores without inducing a subjective or metabolic response. This could conceivably be a problem in North Sea repetitive diving. It may be true that a diver will terminate his dive when he gets cold enough and it is not known whether any accidents are caused by marginal colds but there is a danger that many individuals are not aware of their performance under a cold stress. In this regard, it was suggested that a lot of anecdotal evidence should now be available since extremely cold water and under-ice diving has been going on for some time and perhaps such evidence should be properly documented and analysed. It was pointed out that such a task would probably only be of value in identifying a starting point for a proper research programme. Analysis of anecdotal dives, if type of suit, water temperature and subject body type were known, might indicate whether these types of exposure do involve a cold stress. If so, the next step would be to try to relate similar exposures to a statistical analysis of accidents.

Monitoring

There was a brief discussion of monitoring and several participants expressed doubt that temperature monitoring at any site or combination of sites, and the setting of arbitrary limits based on such monitoring, would be of any value, since there is such a wide subjective variability between comfort/discomfort and performance at any specific core temperature.

Response to cold

It is still not known what the differences are between the man who responds to and complains of the cold, and another man who cools and is unaware that he is cooling. Presumably this latter type of diver is a potential hypothermic casualty, though on available evidence, this is not a certainty. The workshop agreed that personality profiles of diving trainees are not indicative of future performance, in the cold or otherwise. Though it was mentioned that modern divers might now go through a whole career without ever being exposed to cold, all appeared to agree that this does not mean we need not try to identify the non-responder to cold who may be a potential hypothermic casualty. As equipment is not infallible and occasionally divers may work for 4 to 6 hours in cold water with intermittent failure or inadequate functioning of hot water supply or respiratory heating, it is important that if there are potential hypothermic casualties, they should be identified.

Summary

General consensus seemed to be reached on the following points:

1. There are 3 possible different types of cooling problems of concern:
   - i) Very cold skin exposure (with normal core temperature)
   - ii) Large net heat loss (with near normal core temperature)
   - iii) Slowly and insidiously developing drift down in core temperature without associated subjective symptoms.
2. Equipment monitoring, and gas and water temperature monitoring are more important for the deep lock-out diver than monitoring of skin or deep body temperatures. The question of what to monitor for the surface diver is unresolved.
3. In general, cooling problems in surface-oriented divers occur rapidly and will not present a big problem since appropriate subjective responses will warn the diver of the danger of continued exposure although there are exceptions, particularly in specialised military applications.
4. Acute and fatal responses to very cold skin stimuli are a potential problem but probably very rare.
5. The main problem to be addressed in future research relative to diver performance, is the slowly cooling diver, either due to a slow drift down in core temperature or a net heat loss with a near normal core temperature. As yet, it is not certain whether this situation really causes accidents but anecdotal evidence is mounting to justify continued investigation.
6. The search must continue for methods of psychomotor testing applicable to the practical diving situation and acceptable to the diving world.
7. There is a need to know more about the catecholamine response to cold and whether such a response alters with habituation.

Session 2 What are the Particular Problems of Deep Oxy-Helium Diving?

Reviewer: *Sir John Rawlins*
Rapporteur: *Dr Philip Hayes*

The Session was opened by Sir John Rawlins who reiterated the principle of applying the laws of thermodynamics to the deep diver and removing the cold stress by supportive engineering. Problems arose when there was a breakdown in the support. Various emergency situations could then occur.

Heating systems for suits and respiratory gas

The effectiveness of current hot water suits and gas heating systems appeared adequate at lesser depths, but their efficiency could be questioned for the deep dives. System control could be improved by moving the temperature sensor from the surface boiler to the diver where inspired gas temperature and water temperature in the suit should be the controlling factors.

Free-flooding hot water suits offer a reasonably effective protection system with good heat transfer at the skin surface. They are also cheap, relative to closed-circuit tube suits, though closed suits are often a necessity due to circumstances (e.g. lockout submersible). Closed-circuit systems also require effective insulation in the dry mode. Alternatively, water can be used as the transfer agent in the wet suit mode. The main problem with electric suits appeared to be the attainment of a 'balance' between the sensitivity of safety cut-out devices and the requirement of operation. The diver was given great electrical safety reassurances, but the actual heating often cut out, due to the presence of minor faults in the suit.

Improvements in the closed-circuit systems would involve a cheaper method of manufacture and better skin/heat coupling. Open systems require better monitoring at the diver end of the heating system.

Monitoring and restoration of heat loss post-dive

The next question introduced was how to restore and monitor thermal stress post-dive. What psychological, physiological or biochemical tests could be employed to indicate the severity or recovery from hypothermia?

At present there appears to be no easily applied test that could be used to indicate a dangerous thermal situation. Likewise, measurement of urine temperature, thyroxine levels or even lactic dehydrogenase, do not give tell-tale signs of a diver being unfit to repeat a cold dive. How reliable are simple indices such as shivering or numbness in indicating a situation where the diver should not return to the water? The assistance of the group assembled was sought in indicating the possible guidelines that could be given to a diving supervisor to help in his assessment of cold status. This interpretation would depend upon the dive scenario where the depth/duration of the dive would indicate a particular combination of equipment providing lesser or greater protection in the event of an engineering failure.

Discussion

The Chairman, Dr Elliott, thanked Sir John for his concise review and went on to state that the objectives of the subsequent discussion were to establish whether a consensus of opinion existed on the effectiveness of current hardware to keep the diver warm in the normal running mode and then to review the emergency situations. Methods of monitoring the machines would be treated later in the session, as would means of restoring and monitoring body heat content prior to subsequent dives.

Currently available equipment

Representatives of commercial concerns were called upon to state their views with regard to current equipment and to consider if some consensus of opinion existed about the use of closed, open and electric-suit heating.

Dr Imbert stated that open-circuit suits function well at the normal working depths but are prone to lack of control at increased depths. Divers become too hot or cold. Electrical suits were not practical and further development work by Comex has ceased. To describe accurately the temperatures and flows required by the diver at depth, a more complete understanding of the overall system is required and Comex have initiated a 'mathematical modelling' approach. As monitoring of the working diver is not feasible, then extrapolation from an experimental model can be used to assess the correct requirements for any depth.

Dr Fallowfield added that he had seen three cases of divers with scalds from hot-water suits who were unaware that they were being scalded at the time of injury.

Mr Humphrey said that in order to prevent a 'slug' of cold or hot water from arriving at the diver, Oceaneering had installed a reservoir and, in keeping with a Department of Energy ruling, had added 'high' and 'low' alarm facilities. This solution has been effective.

In reply to a question from Professor Keatinge, Mr Humphrey said that the alarm limits are set to 5°? either side of a top-side boiler output temperature of 140 P (60°C) in order to provide the diver with water at 95°2 (35°C). The difference between top-side and diver temperature is a consequence of umbilical heat loss.

Dr Tønjum added that the present top-side heating systems are probably depth-limited in their effectiveness. Beyond a certain critical depth they may well become inadequate due to heat loss during transmission.

Operators appear to be relatively happy about using open-circuit suits to depths of 300 m (about 1000 ft). Problems may arise if the contractor does not have a system capable of providing a sufficient flow rate of water at the required top side temperature. Where power sources are limited a new solution is required.

Gas heating

The Chairman then turned the attention of the meeting to that of gas heating and the exchangers employed. Problems were not encountered down to 268 m (870 ft) with the 'Rat-Hat' system, where the heater was close to the demand valve and formed an integral part of the helmet. Experience at NUI and AMTE(PB) had shown a high water temperature is necessary to drive the in-line exchangers to provide inspired gas at a sufficiently high temperature. These high temperatures could scald the skin. Minimum inspiratory gas temperature limits were available from the USN and AMTE(PL) (vide infra) but little attention had been focused on maximum temperatures.

Experiments at 1 bar confirmed that, at high temperatures, air needed to be humidified (75% RH) to prevent damage to the respiratory tract. Discomfort was likely to occur at inspired temperatures in excess of 45°C. When moving to the hyperbaric helium environment, the need to humidify the gas was also recognised. Although pressure was unlikely to affect upper temperature limits to any great degree, the increased heat transfer properties of the helium mix required maximum temperatures to be reduced to 40°C or less to avoid any discomfort.

Gas temperatures are also an important aspect of emergency procedures when hot water heating is lost at depth. For depths in excess of 180m the limiting factor is likely to be respiratory cooling, whereas it is pain in the extremities that limits cold duration at lesser depths. It was thought that 15 minutes could be the recommended maximum time a diver should stay in the water when heating is lost.

Monitoring the equipment

Mr Humphrey reviewed the question from the operator's stand point. Their opinion favoured limited monitoring. The temperature of hot water topside and at the bell are, from experience, sufficient to provide enough information to keep the diver warm, especially if high/low alarm facilities are used. In general, he considered that there is no problem.

Dr Tønjum wished to know what happens if the water becomes too hot and, if only the temperature at the bell is monitored, how does one know what is going on at the diver? How can one control the breathing gas temperature properly if one does not know what it is?

Mr Humphrey replied that the diver will tell you if he is too cold or too hot.

Dr Tønjum then asked what happens when the hot water to the suit is OK, but the gas still feels too cold?

The Chairman asked Dr Tønjum if he was implying that the two heating requirements of the skin and respiration should be controlled independently.

Dr Tønjum said they should be, for both shallow and deep dives.

Information from NUI and AMTE(PL) was then presented by Dr Hayes which demonstrated the inadequacy of using minimal surface temperature information to assess breathing gas temperature. During normal diving operations, the effectiveness of the gas heating relies on the diver assessing his own condition. Some additional means of heating and control was required to satisfy the new minimum temperatures required for cold gas breathing at depth. (Fig. 2).

In the subsequent discussion, Professor Keatinge stated that he questioned the validity of the diver being able to make a correct assessment of his own temperature status. Diver 'thermal confusion' has been reported to be a common operational occurrence. After a time in the waters the diver is not sure what the hot water supply is doing.

Dr Kuehn added that one of the conclusions arrived at during the earlier UMS Workshop was that the supportive technology was not sufficient and the data presented previously adds further weight to this view.

It was noted that, in spite of a number of proven and anecdotal accounts of divers becoming chilled or scalded, there was as yet no provision for water temperature monitoring at the diver. Commercial diving representatives accepted that diving in excess of 300m would require more sophisticated apparatus to achieve the standards for inspired gas temperatures (Fig. 2). These levels are unobtainable from current hardware at the greater depths.

DEPTH	USN		AMTE	DEPTH
(ft)	°F	°C	(FL)	(M)
400	42.8	6.0	6.0	121
700	62.6	17.0	17.6	213
1000	71.4	21.9	26.2	305
1500	74.7	23.7	32.1	457

Figure 2: Minimum Inspired Breathing Gas Temperatures
from Piantadosi (NEDU Report 10 -80) and Hayes et al (Int. Diving Symp. 1981, ADC)

Dr Kuehn then presented data obtained from dives at Panama City where the comfortable skin temperature in hot-water suits was shown to be about 34°C. He concurred with the earlier comments about the importance of gas heating, and showed how easily hypothermia without realising it could develop as a consequence of inadequate gas heating.

Monitoring the diver's post-dive thermal status

The next topic for discussion was the possible means of monitoring thermal status post-dive. Professor Keatinge introduced the topic, describing the work performed in the North Sea (BMJ No. 6210, Vol. 280, 1978, p 291). As a background to the study he showed several slides depicting the physiological response to sudden cooling. Moderately sinister arrhythmias could occur during the first few minutes of an ice-cold shower. This in itself could be seen as a justification for monitoring in the sudden cooling situations and requires the provision of a defibrillator in the laboratory. Other subjects were immersed in water at a temperature which was the lowest at which they could stabilise their body temperature. Maintenance of body temperature under these conditions is less well correlated with fat thickness and the large variation in cooling is primarily dependent upon the differing vasoconstrictor responsiveness of the limbs of these subjects.

In one particular case, a cold-habituated thin man in water at 29°C demonstrated very little shivering, felt moderately comfortable, but his rectal temperature fell to a dangerously low level of 34.7°C in only a short time. This water temperature of 29°C is not likely to register as a particularly uncomfortable experience and could well be the sort of temperature that hot-water suit systems provide for the diver.

In measurements of urine temperatures from divers following return to the bell, there appeared to be great variations in the derived core temperature. Intense shivering was reported in subjects where the heating had failed, but lower temperatures were recorded from divers whose hot water had been running in the normal satisfactory mode.

In the subsequent discussion, Dr Tønjum asked how reliable is urine temperatures in assessing core temperature? Professor Keatinge replied that the measurements were made using a funnel system and, as long as 50-100 ml are collected and due care and attention is taken, then the system measures core temperature to within + 0.2°C.

The Chairman, Dr Elliott, asked whether the technique could be used to provide its own control by taking measurements before the lockout and/or using the bellman? Professor Keatinge replied that bellmen had also, it appeared, become cold on occasions.

Cdr Goad then asked if cooling of a bellman was often a problem when more hot water is on bypass to the diver and less to the bell. Mr Humphrey replied that this had been a problem. Technology is needed to improve bell-heating systems to safeguard the bellman during diversion to him at the expense of the bellman.

Dr Kuehn stated that, although perhaps not always feasible, the advantage of rectal temperature is of a continuous recording; the urine temperatures can only be obtained at best before and after a dive or lock-out.

Professor Keatinge rejected most monitoring techniques for use on the operational diver as they could not be trusted absolutely. The breakdown of such equipment would be forever jeopardising the course of the dive, rather than adding to the safety of the man. Dr Webb and Dr Kuehn expressed hopes that in the future an insulated head transducer may provide a scalp temperature that would approximate to a core temperature.

Restoration of thermal stores between excursions

The next question for discussion was one of restoration of heat to divers now back in the bell, perhaps with a repeat excursion imminent. How does the man know if he is unfit to dive again - what is to be monitored and how should the diver rewarm?

Professor Keatinge stated that unfortunately the Zero Gradient Aural Thermometer (ZGAT) was unsuitable for on-the-spot measurements in hyperbaric environments: urine temperature may be the only simple method.

Cdr Golden stated that an alternative may be to use pulse rate as an indicator of the loss of vasoconstrictor tone. It was better than a core temperature measurement because the pulse rate would respond to a rewarmed periphery and give a better indication of restoration of overall body heat stores.

Dr Tønjum suggested that the diver would need to be at rest.

Cdr Golden agreed, but added that he considered that heart rate may be a better indicator than, say, a core temperature of 37°C when the periphery may in reality still be very cold.

Dr Kuehn proposed that an additional criterion for assessing heat state may be the position of the testicles which drop when heat stores are returned.

Sir John Rawlins stated that in Sealab III two divers had been asked if they could perform a repeat dive after an initial 7-hour cold exposure. Experience has subsequently shown that they were both extremely cold, but both agreed at the time to dive again. Undoubted confusion of the senses exists during extreme cooling and the two divers found further exposure to 4°C water to be a pleasant experience compared to that of residing in the cold gas.

Cdr Goad said that conditions have now improved as bells are both now heated and insulated, and the divers are depth warm even during long duration transfers. In the ensuring discussion Dr Webb thought that 15 to 20 mins usually existed between the pulse rate rise and the onset of sweating during a continual rewarm. Cdr Goad remarked that sweating was a good indicator for one diver to recognise in the other when rewarming from the acute cold state. However, Surg. Cdr Golden felt that fast rewarm was not to be recommended for the lost bell situation.

Cdr Goad then asked whether every diver should rewarm between dives to the sweating point?

Dr Fallowfield said that operational shift systems tended to remove such a requirement because, following a long excursions divers showered and then slept. It is the next day before the next dive occurs.

Dr Elliott considered that, in the event of heating equipment failure or inadequacy, any decision to abort the dive must be a local decision. However, it would seem sensible to recommend the use of a hot shower and a urine temperature before a repeat dive.

Dr Kuehn added that in studies where the response to a hot shower had been monitored in a cold diver the application of the hot water to the back of the head caused a cessation of shivering. Rewarming to subjective comfort was not a good indicator of return to normal body temperature: core temperature could still be low after 15 to 30 mins of showering.

Dr Hayes pointed out that measuring core temperature straight after a dive is unreliable because the rectal temperature may not fall to its lowest level for another half an hour or so.

Mr Humphrey said that, as a matter of policy within his diving company, the lockout is aborted if hot water heating fails.

Cdr Golden summarised by saying that it would appear that the problem still remains that we can offer no really reliable and simple index for the supervisor to use to assess the cold or rewarmed status of the diver in the bell.

Diving deeper than 300 m

Dr Elliott asked if the session could be concluded by an individual examination of problems and possibilities for diving in excess of 300 m, perhaps down to 500 m.

Dr Hayes: A problem still exists even if temperature monitoring of the water supply at the man becomes a reality. No simple method is available that would also monitor the correct flow rate.

Closed-circuit systems mounted at the bell offer an advantage with a shorter umbilical that has no top-side to bell hot-water hose. Water can be circulated at a much higher temperature and this improves the condition of the breathing gas because the gas exchanger now runs much hotter. Unfortunately the higher inspired limits, presented earlier, would cause drying of the respiratory tract and there is a need to humidify the gas, An electrical gas heating system under development will, hopefully, provide a means for both heating and humidifying adequately. An additional advantage of electrical gas heating with high current density heaters is the rapid response of the system to variations in depth and frequency of breathing.

Dr Thornton: One aspect of the human engineering not yet fully discussed or exploited is the use of passive systems as an addition to the active systems. Passive heat exchangers could be used to great advantage to control respiratory heat loss. Better passive insulation could reduce the demands on the active systems. This was particularly relevant to the self-contained power situation (e.g. for lockout submersibles).

Respiratory, not body surface, losses are directly related to the pressure. Existing systems are plainly not suitable to counteract the high respiratory loss at, say, 450 m and probably not even at 300 m. Is the gas being heated at the right place anyway? Following heating of the gas by the exchanger, the gas is then subsequently cooled during passage across the demand valve. Moving the source of heat to a preferred position, such as after expansion through the demand valve, would not decrease the power requirement but would enable greater control of the inspired gas temperature.

St. Cdr Manalaysay: The USN is experimenting with expanded aluminium as a passive heat exchanger of very low gas resistance.

Surg. Cdr Golden: Prom a physiological viewpoint, it is important to undertake further research on the responses to breathing hyperbaric cold gas.

Professor Norman: Short term studies need to be extended because the saturation environment results in any exposure to a minor detrimental condition becoming a major factor with time.

Dr Kuehn: Such examples may be weight loss and irritability, where only a small thermal stress can be exaggerated with duration to produce a notable effect. Living in the chamber requires good control of both temperature and humidity to prevent any subtle changes in body temperature or heat balance. Sir John Rawlins: Any heating of the gas must be properly controlled, as over-compensation is likely to produce drying in the helium environment. The whole question of high heat transfer across respiratory membranes needs exhaustive study.

Summary

1 This meeting must lead to useful information that can be passed on to the diver. To sponsor improvements in the heating systems, the physiologist must provide data to the manufacturer so that both flows and temperatures can be adjusted for optimum performance. Instead of boiler output temperatures the preferred reading would be water temperature at the man and this should be used to control the system.

2 The discussion on the restoration and monitoring of the thermal status post-dive was most interesting, but little additional information can, at this stage, be passed on to the diving supervisor. There appears to be a consensus of opinion that when an emergency has occurred, then the diver must be rewarmed to the point of sweating if it is essential that he lockout again. We as a group are still looking for the correct physiological/psychological tests that one diver could perform on another (within the bell) to provide the answer to a 'go' or 'no go' dive situation.

3 Clearly there is a requirement for guidelines to be provided for the diving supervisor. Sufficient information would appear to be available for the construction of a set of recommendations that would enable the supervisor to react correctly according to the circumstances. This meeting has brought us that much closer to providing that information which, with judgement, would allow or restrict a further dive.

Session 3 Have We Solved the Problems of the Isolated Divers in a Lost Bell or Hyperbaric Lifeboat?

Reviewer: *Mr Vic Humphrey*

Rapporteur: *Surg. Cdr R Pearson RN*

In introducing this session, Mr V Humphrey explained that he was representing the views of a diving contractor and he believed those views were representative of a diving industry as a whole. He felt that two questions were particularly relevant to this session of the workshop.

i) Have all the problems of isolated divers in the lost bell or hyperbaric lifeboat situation been solved?

ii) Are the tests so far carried out by the Norwegian Underwater Institute (NUI) on passive thermal protection systems for use in the lost bell situation adequate to ensure 24-hour survival?

In addressing the first questions Mr Humphrey was quite satisfied with progress so far, but felt that more trials were needed to establish a complete answer to the various hazards of divers in the lost bell situation. Many of the problems of divers in this situation are common to divers exposed to the use of hyperbaric lifeboats. These problems were dominated by hypothermia but also extend into the areas of resuscitation, life-support systems and nutrition.

With regard to the NUI trials of passive thermal protection systems, Mr Humphrey referred to the 24-hours survival capability required by legislation either in existence or about to be introduced. Although NUI reported that current passive thermal protection systems seemed capable of this requirement, industry would like firm assurance. He offered full co-operation in any trial designed to investigate the performance of passive thermal protection systems in the worst possible realistic conditions. He defined his own concept of the important features of such a trial:

i) It should be carried out in a submerged bell.

ii) At least two divers should be in the bell and they should be wearing representative hot water diving suits which should be wet at the start of the trial.

iii) The bell should be at the normally required temperature at the start of the trial.

iv) The bell should contain all the equipment normally carried on an operational dive.

v) The ambient water temperature should be 4 to 5°C.

Mr Humphrey then went on to discuss four accidents that had involved lost bells. He felt they would provide a useful background for subsequent discussion although he pointed out that all these accidents were the result of surface-related problems and, in this sense, the question of subsequent hypothermia was an outcome of some other system failure. The accidents were:

i) "Seaway Falcon". Although full details were not available, it is known that the bell was lost for 2 hours with failure of all surface supported systems. The two divers survived but were said to be very cold on recovery.

ii) "Star Canopus". Two divers died following a severed umbilical to the bell. Hypothermia was the cause of death. Passive thermal protection was not available.

iii) "Wild Drake". Two divers died from hypothermia in a bell following a severed umbilical. Again, passive thermal protection was not available.

iv) "Stenna Seaspread". Two divers were recovered from a lost bell after 10 hours. A rescue vessel was able to place a second bell within 20 metres of the lost bell. The divers had to be rewarmed by being hosed with hot water and were then able to carry out a "through water transfer to the rescue bell. Both divers had insulating bags but did not have respiratory heat exchangers and had been shivering uncontrollably before rescue.

Mr Humphrey went on to list several clear problems raised by these four accidents and he hoped the workshop would consider them carefully.

They were:

i) Should the required survival time capability be extended from 24 to 36 hours?

ii) Should special attention be paid to the problem raised by the "Wild Drake" accident which involved a top-mating bell?

On recovery, the divers were lying on the hatch making it very difficult to open. This problem would not occur with side-mating bells.

iii) What actions should be taken by rescue divers approaching a lost bell?

An order of priorities should be established.

iv) If it was necessary to attempt a through water transfer of the trapped divers to a rescue bell, what actions were necessary to assess their ability to survive the transfer and to prepare them? Would a change to dry suits be possible and/or advisable?

v) What thermal criteria were available to help decide whether trapped divers ought to remain in their bell and await recovery of the bell to the surface?

vi) How capable would divers in survival packages be in assisting with their rescue?

vii) If a lost bell is recovered, should time be taken to hose it with hot water before mating it to the deck chambers?

viii) What advice could be given concerning the partial pressure of oxygen to be aimed at in the lost bell?

ix) Were any drugs available which could help the divers in a lost bell?

Turning to the hyperbaric lifeboat, Mr Humphrey said that, in addition to hypothermia, there were other practical problems to be considered. Although outside the scope of the workshop, he felt they ought to be mentioned. One particularly difficult question was concerned with the chamber atmosphere. It had been suggested that switch from oxygen helium to air might be necessary in a lost power situation where the scrubbers were out of action. If depth permitted, air flushing could be a practical solution. Another question lay in the possible need for tables giving accelerated decompression, taking account of the inevitably higher risk of decompression sickness. Mr Humphrey said that his personal view was that decompression was not a problem once the lifeboat had been recovered and the whole situation stabilised. In conclusion, Mr Humphrey said that the pressing need of industry was a set of practical guidelines and he hoped the workshop would make a great contribution to this need.

Discussion

Lost Bell Emergency

The Chairman suggested that the ‘lost bell’ situation resolved itself into three main problems:

i) Passive thermal protection systems for the diver.

ii) Active bell-mounted emergency heating systems

iii) Management of rescued hypothermic divers

As a prelude to discussion, Dr Thornton gave the results of trials on bell cooling which showed that an oxygen helium filled bell at 31 bar in sea water with a temperature of 6.5°C would cool to ambient water temperature within 4 hours (Figs. 3 and 4). Equally important was the fact that the internal gas temperature took only 30 mins to fall below the minimum recommended level for 31 bar. The bell used was typical insulated bell and although Figure 3 would seem to indicate an initial increased rate of fall in temperature if the scrubber motors were running, this was later shown to make no difference. Figure 4 also shows that only 30 mins were required to return bell temperature to normal once heating was restored. It was therefore clear that the bell itself had no effective heat storage in these conditions.

In general discussion of the performance required for passive thermal protection systems, it was agreed that the initial target should be survival for 24 hours. Although longer periods had been suggested, it was recognised that none of the commercially available systems had ever been tested beyond 12 hours. Dr Tønjum, of the Norwegian Underwater Institute discussed the results of the "Polar Bear II" experiment. He said that the test proved very stressful. He queried the ethics of asking subjects to carry out a 24-hour test, even though a projection of the 10-hour test in "Polar Bear II" suggested that the thermal protection systems tested would indeed last 24 hours. The heat loss for the divers was 80 watts in 2 hours and inspired gas temperature was maintained at 37°C. The scrubbers used for inspired gas heating needed absorbent replenishment at 6 hours (Diving Unlimited) and10 hours (Kinergetics). The absorbent efficiency was predictably low at cold temperatures and it took 10 to 15 mins to get the soda-lime absorbent activated. This implied that scrubbers should be used immediately in a lost-bell situation. Resistance was satisfactory for both scrubbers.

A question was raised concerning the possible value of letting the bell CO_2 level rise. Opinion was unanimous that any benefit in terms of the heat transfer properties of the bell gas would be trivial and physiologically it would be definitely contraindicated.

A reference was made to the actual values of protection required for internally insulating materials. Dr Kuehn drew attention to the figures given by Schmidt at the Undersea Medical Society workshop held in August 1980. These suggested that materials were available to allow a 24-hour thermal protection capability. A minimum thermal insulating valve for materials would be 16 Clo in 1 bar or 1 to 2 Clo at depth, both figures assuming 100 per cent respiratory heat reclamation.

Figure 3.

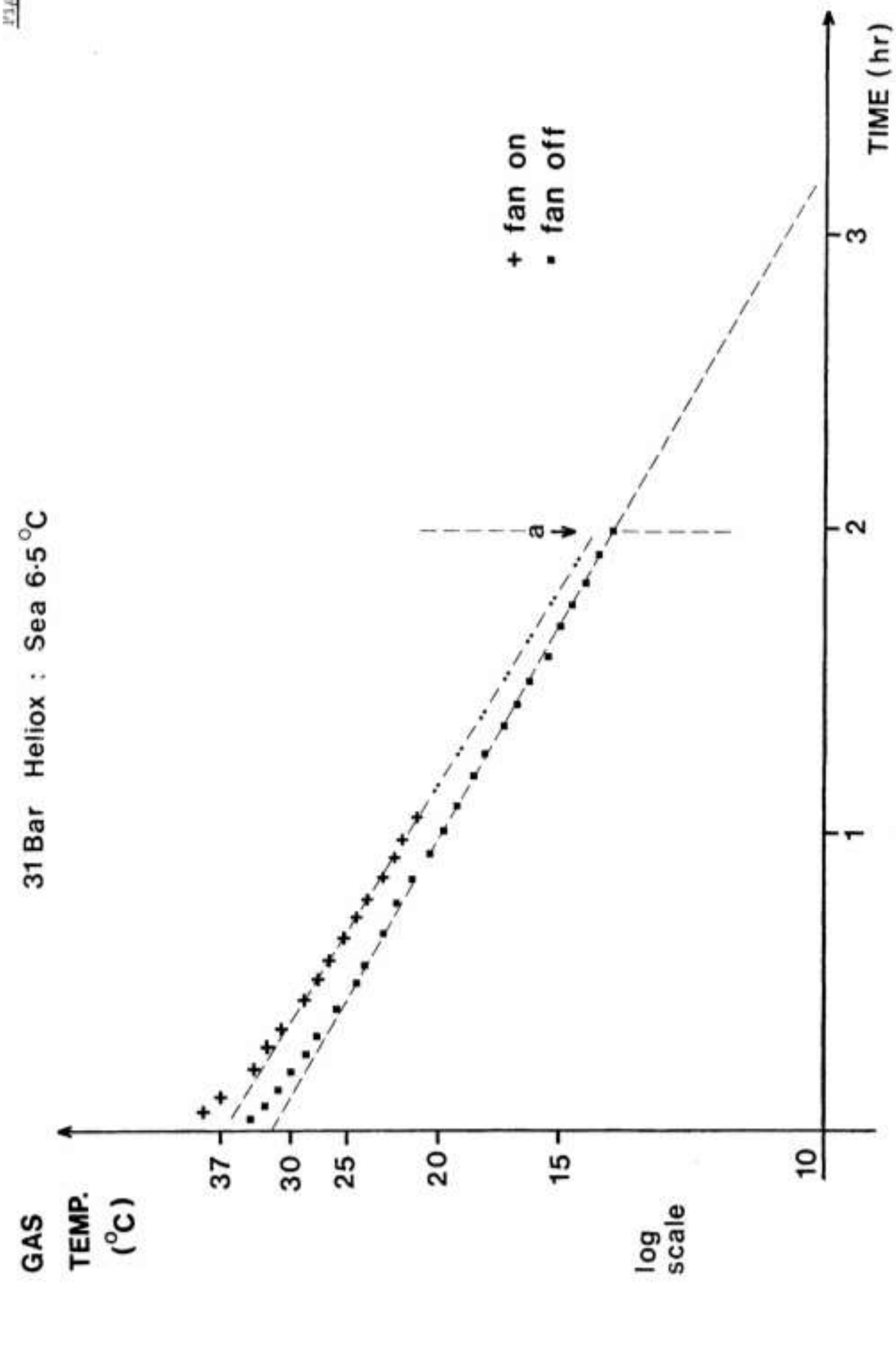

Fig. 3. - Bell cooling trial - with and without scrubbers running.

Figure 4.

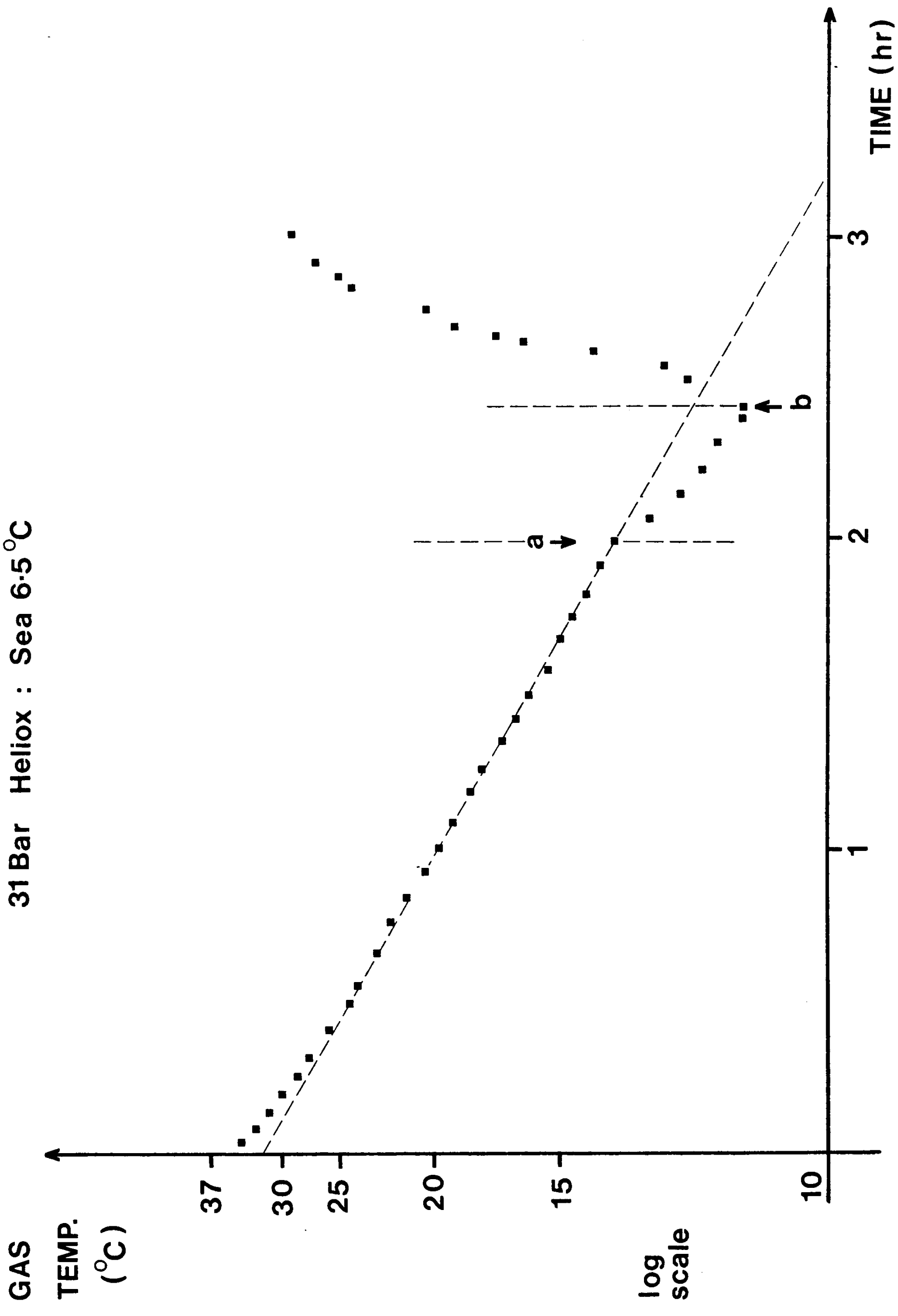

Fig. 4. - Bell cooling trial followed by restoration of bell heating

Some discussion of these figures ensued and their implication in terms of material thicknesses required. Both Dr Thornton and Dr Hayes suggested that a figure of 4 Clo might be more realistic for materials subjected to pressure, whereas Dr Webb supported a value of l to 2 Clo. Surg. Cdr Golden referred to new types of insulating materials such as "Flectalon" which was composed of aluminium strands in mesh form and provided radiant as well as conductive and convective insulation. Its great advantage was that it withstood compression.

Although no firm conclusions were reached, it was generally agreed that there might be some benefit in looking at the possibility of using a dense inert or other gas with a low thermal capacity to inflate a gas-tight passive thermal protection garment. The main problem envisaged was that of ensuring gas-tight integrity of the garment and the avoidance of contamination of the bell atmosphere.

Dr Elliott suggested that further research was probably needed and accepted the NUI comment that the systems tested in the "Polar Bear II", by extrapolation of the 10-hour point, could have ensured survival for a 24-hour period. Dr Kuehn disagreed and said that systems should be tested for 24 hours in a space equivalent to the bell volume.

Dr Hayes said that he was planning a trial of passive thermal protection systems in the realistic setting of the bell of the Seaforth Clansman. The bell would be in the water with the divers at a pressure of 250 m. He asked whether it was ethical to expect men to spend 24 hours in such conditions and whether extrapolation of results for a shorter trial (of the order of 8 hours) was satisfactory. There was general agreement that the only truly convincing trial would be one lasting 24 hours but it may be asking too much of subjects.

Other Problems Of Survival In A Lost Bell

1 The Chairman asked for opinions on nutrition of divers in the lost bell situation and whether there were any drugs that could be of value. He also asked for views on what position the divers should assume.

2 There was general agreement that some form of carbohydrates should be provided. Two thousand calories would be a realistic amount for each diver. Such a value would be equivalent to approximately 1 lb (2.2 Kg) of carbohydrates per diver. Professor Hervey stated that there was no drug known that would boost metabolic heat production in these circumstances. Dr Fallowfield drew attention to a need for anti-motion sickness drugs if the bell was unstable due to currents.

3 It was also agreed that there was not really any option for the divers but to adopt the sitting position. Surg. Cdr Golden pointed out that some form of supportive collar would be required to prevent the diver from choking when losing consciousness through hypothermia.

Management of the Hypothermic Diver after Rescue

The Chairman asked what were the major considerations in the management of the hypothermic divers either on rescue at depth or on recovery to the surface hyperbaric system. In particular, is immediate rewarming practical or even advisable?

In the ensuing discussion, this topic proved to be the most controversial of the entire workshop and it was clear that some fundamental issues remain to be researched and resolved.

In general, it was agreed that the minimum of handling of the hypothermic divers is necessary before rewarming is attempted. From this, it follows that no rewarming should be attempted at depth if the bell can be recovered with a pressure seal intact. If a seal and thus lifting is impossible there is merit in using hot water hoses to spray the bell interior as had been done in the most recent North Sea lost bell incident.

Surg. Cdr Golden pointed out that rewarming would cause vasodilation of the skin and could be accompanied by hypovolaemic shock and collapse. Ventricular fibrillation was also a complication which became increasingly possible with a deep body temperature below 30°C. Therefore, with severe hypothermia, the manipulation necessary to start rewarming might provoke fibrillation whereas active surface rewarming could give hypovolasmic shock. The need emerged for some means to monitor very early the divers thermal and cardiac status. Although no such systems currently exists, it was agreed that an ECG reading might be possible using a radio pill and telemetry. Pulse rate would greatly assist the plan of action during and after recovery. It would also facilitate a controlled rewarming. It was envisaged that the radio pills could form part of a survival package in bells and Mr Humphrey said that it was his personal opinion that operators would assist and co-operate in the development of such a procedure.

There followed some discussion on the value of using inspired gas heating to effect rewarming after recovery. Although not validated at normal atmospheric pressure, the greater potential for heat transfer in a hyperbaric environment gives attraction to this concept. Dr Hayes said that his work in this area showed it would be a difficult concept to evaluate effectively but he felt it had no fundamental disadvantage and might be of help. Therefore, it should be attempted if at all possible.

From the discussion relating to the initial action to be taken on location of the bells it was concluded that any efforts to rewarm the divers should be left until the bell is mated to the deck chamber. A survival package in the bell should include some means to assess the cardiac status of divers. Information from an ECG transmitted by telemetry would allow pre-planning and control of rewarming.

Treatment within the deck chamber

To some extent, the dangers inherent in moving hypothermic divers from the bell continued to dominate the discussion of appropriate therapy within the deck chamber. It was agreed that where possible, rewarming should take place in the bell and the risk of moving divers would be minimised. It was pointed out that hypothermia per se does not kill people but it is the secondary cardio-respiratory destabilisation which has lethal potential.

Therefore, the ideal course of action would be assessment and stabilisation of the divers in the bell before any attempt at moving them. There was no agreement, however, on the actual degree of risk in transferring divers to the deck chamber if this were necessary. In particular, the risk of precipitating ventricular fibrillation, it was said by some, could be small and, by others, as high as 50 per cent.

Summary

This session had raised a number of issues for some of which answers were not available. Nevertheless current knowledge needed to be incorporated into emergency operating procedures.

Although active bell heating systems would remove many of the problems considered under the heading of passive thermal protection, there was a clear need for consideration of the following:

i) Passive thermal protection systems with a reliable performance are needed for 24 hours. Future development may even allow a target of 48 hour protection.

ii) Provision of emergency food supplies in bells.

iii) Remote monitoring of the cardiac status of divers in an emergency situation to allow informed decisions on moving and rewarming hypothermic divers.

iv) Clear guidelines on the immediate and post-rescue procedures for rewarming of divers on recovery of a lost bell.

In addition to these essentially medical or physiological problems, there was a parallel need to develop engineering solutions to the thermal protection of divers in a lost bell.

Session 4 What are the Problems of Surface-Orientated Diving?

Reviewer: *Surg. Cdr R Pearson, RN*
Rapporteur: *Surg. Cdr TG Shields, RN*

Surgeon Commander Pearson opened by stating that he had a special interest in what he would like to term "Non-bell-supported, Non-saturation Diving", as the majority of military diving fell into this category. He felt that such divers were largely neglected in the flourishing interest of the challenging, and occasionally dramatic, problems of the saturation diver. He saw his task as Reviewer of this session as that of identifying the problems and questions that required addressing, in the belief that the purpose of a workshop was to provide answers where possible and to indicate what research and development was necessary if answers were not available.

Some surface-orientated diving uses closed-circuit breathing apparatus, whereas other types of diving use surface-supplied open-circuit sets. Surface-orientated divers may have to carry out in-water stops which may be as much as 90 mins duration. For most of the deeper dives, oxy-helium or a mixture of oxygen, helium and nitrogen ("trimix") is used. Because of the limited surface support available, the thermal protection of the diver currently depends on passive systems. Additionally, some degree of cooling may occur in adverse climatic conditions while the diver waits his turn to dive or while another diver is deployed. The relatively prolonged and shallow mission of the attack swimmer or diver engaged in military tasks, or the police diver engaged in searches, are other sources of thermal stress in surface orientated diving.

All too often cold is incriminated as one of the important causative factors in decompression sickness even if it is a difficult factor to quantify. Some attempts have been made to identify minimal deep body temperatures (or rates of fall of deep body temperature) and minimal acceptable skin temperatures. Should we regard these criteria as the lower limit of what is acceptable or the upper limit of what is dangerous and therefore temperatures which should be rarely observed? How were these criteria selected: through experimental research or by arbitrary decisions? If by the latter, which must be suspected, are they accurate?

Another area which requires clarification is that of acceptable inspiratory gas temperatures for the surface orientated divers. Surg. Cdr Pearson said that he had experience of investigating a case of bronchorrhoea with bronchospasm in a diver who did 40 mins at 30 ft in a wet-suit in water at 0.5°C in the Antarctic. The diver was shivering uncontrollably for the last 5 mins of the dive and on surfacing was in poor condition. Yet it was denied by diving experts that he suffered unduly from the cold. If one can encounter problems like that with air divers, what about the deeper oxyhelium or trimix surface-orientated divers?

The next question concerns the hands. A working diver is almost always as effective as the strength and dexterity of his hands; but to maintain these functions in cold water seems to imply maintaining peripheral skin temperature above 15°C. Such temperatures can often be achieved only by the addition of so much insulation that dexterity is sacrificed. Should we be looking for new insulating materials or active hand heating techniques?

Surg. Cdr Pearson went on to highlight other areas of concern in relation to thermal problems of surface orientated diving such as inert gas suit inflations diver monitoring, habituation etc. He concluded by saying that he hoped that from his brief review it would be obvious that thermal problems in diving were not limited to saturation divers.

Discussion

The Chairman, Surg. Cdr Golden thanked Surg. Cdr Pearson for his review which raised many issues for discussion. First, in response to questions raised on diver monitoring, he asked Lieutenant Layton to describe his views on heat-flow discs.

Heat-flow discs

Dr Layton explained that the heat-flow discs used at NMRI were one inch diameter discs of insulating material with thermocouples on both sides to measure any temperature drop across the disc. Thus they measure actual heat flow rather than a skin temperature. They were sensitive devices which in general worked well, but it is questionable whether it is valid to extrapolate from information obtained from a few point sources to the thermal status of the whole body. NMRI are evaluating this at present and feel that the discs have a definite use in the experimental situation to obtain comparison between two different exposures rather than to give an accurate absolute value of thermal status. Because of this, and the fact that they are relatively fragile (each has five connecting leads), the feeling is that for the foreseeable future they will remain useful only as laboratory tools.

Dr Kuehn endorsed the remarks on fragility, pointing out that in operational use they have approximately a l-in-12 failure rate and cost about £100 each. He was concerned also about calibration, as the manufacturer from whom most of these discs are obtained had failed to produce reliable calibration data. Anyone using these discs should ensure that they are calibrated independently and he suggested that to ensure comparability of results they be calibrated against a common standard either at EMRI or DCIEM.

Need for thermal monitoring

Surg. Cdr Golden summarised by saying that thermal monitoring appeared to be required only when protective equipment such as thermal underwear or divers' suits were being developed or evaluated but not for routine use in the field as a diver's ability to work is entirely subjective and does not depend on skin temperature. Dr Kuehn suggested that, if some indication of incipient cooling were required in the operational situation, consideration might be given to the use of DCIEM radio pills. These can now be considered to be disposable, being about $7 each. They are accurate to plus or minus 0.2 to 0.3°C with little variation in output and, therefore, are good crude indicators of the hypothermic individual.

Active heating

Cdr Golden then moved to the second question and asked for comments on whether active heating of such divers was desirable.

Dr Thornton displayed calculated typical heat losses in different dive situations (see Fig 5). The suggested maximal acceptable heat loss is taken as 0.23 kilowatt/hour.

Depth (metres)	Time (hours)	1) Current clothing	2) Improved equipment
10	6	1.2	0
30	1	0.3	0.1
30	1	0.5	0.2
300	1	1.0	0.4

Figure 5: Calculated Heat Losses at Different Depths
Wearing Current Clothing Assemblies Compared to Improved Assemblies

In any of these situations with equipment in current use in the RN, the diver is outside the accepted limit. By using 'improved equipment' (i.e. improving suit protection by a factor of 2 and utilising a 50% efficient respiratory heat exchanger) the majority of these missions fall within the accepted limit. This reduction in loss is important even when active diver heating is being considered as it cuts down the power requirements. To consider a particular case, a dive to 80 m for I hr all that is required over and above improved equipment to reduce losses to zero is some 0.2 kW/hr for a I hour dive. An ordinary caracid-lead battery can produce about 0.7 kW/hr, so battery capacity and weight is not a problem, especially if silver-zinc or similar batteries are used.

The real problem with any of the active systems lies not in the capacity of the heat store but in the difficulty in distributing heat around the diver. In closed-circuit hot water systems, the problems of control and of powering the pump result in a complicated bulky piece of equipment. The alternative, an electrically heated suit, gives simpler control and is inherently much more efficient as the electrical energy is converted directly to heat. Much engineering effort is still required before it would be practicable.

Dr Thornton summarised his views by stating that he saw little requirement for active heating in this type of diving provided that the heat loss can be reduced to acceptable levels by the use of passive protection. He thought that there was a very large potential for research into improved suit materials and the development of respiratory heat exchangers.

Sir John Rawlins pointed out that the above comments refer only to dry suits, but that many surface orientated divers use wet suits. The major cause of heat loss in these suits is by cold-water flushing, which can be eliminated by better design using dry suit principles. On the question of insulation, wet suits are now on the market using polypropylene fibres which retain their insulation even when wet.

By far the greatest number of surface orientated dives are done to less than 80 or 90 feet and countless numbers of such dives of I to 2 hours duration have been done successfully without active heating. Usually, the only effect is to feel slightly chilled on surfacing. Heating would make such dives more pleasant, but it is not essential. In the depth range of 150 to 250 feet however, Sir John said that the option of heating should be available, and he felt that the problems of providing this were not as great as had been stated. In most naval diving situations, the divers are tethered and it is very easy to provide a 'liquid conditioned' suit, powering the device electrically on the surface. It is cheap and easy to produce.

In Sealab III an ex-aircraft Bendix fuel pump and a standard immersion heater provided the heat required for a 600 foot dive. In the self-contained diver, many options had been investigated from the simple to the very complicated such as the US Marines plutonium238 radioisotope powered device. Few of these options have been looked at further although some working models were produced. For example the helicopter fuel JP4 (which is available in most naval ships) can be burned catalytically in oxygen fluoride with a good return of heat and a Stirling-style engine used to pump the heat around. The engine has actually been built (at the National Institute of Health as part of the artificial-heart programme) and is very small and efficient. All this was reported to the RN and USN in 1970, but has not been followed up. It should probably now be looked at further.

Surg. Cdr Golden asked Dr Thornton whether it was possible in his data table to separate the benefits of 'improved clothing' from those of decreased respiratory heat loss.

Dr Thornton, using 80 m diving for I hr as an example, said that at depth the respiratory heat loss would be around 200 watts, which was not acceptable. A significant improvement could be obtained by using a respiratory heat exchanger. A study on respiratory heat exchangers has been carried out in AMEE (EDU) to determine the limitations on increased dead spaces on pressure drop across the exchanger and just what can be achieved with a simple non-toxic device. He showed a plot of efficiency (i.e. percentage saving in energy which would otherwise have been lost) against the surface area of materials from results obtained at atmospheric pressure. This showed that it is possible to achieve an efficiency of 80 to 90% for a pressure drop through the device of around 3 millibrars. Hyperbaric evaluation is currently under way. If this data is used to predict what might happen with gas at 8 to I0 bars within the limits of a 5 millibar pressure drop and a I00 ml dead space, it should be possible to produce a heat exchanger with an efficiency of 50% (i.e. a saving of I00 watts).

Dr Kuehn presented data on dives using the Kinergetics passive heat exchanger fitted to a Rat-hat helmet (70% efficient) and a Yokohama dry suit (i.e. dry overgarment over 2 layers of woolly bear undergarment) to depths of 140 ft for 30 mins in open water at 4°C. The Clo value of 3.7 on the surface drops to roughly I Clo on the bottom because of hydrostatic compression. It rises very slowly during the decompression in the water to about 1.5 Clo on return to the surface. Because of the very short nature of these dives, there was minimal rectal temperature change, but the contribution of the heat exchanger could be assessed from the marked differences in mean skin temperature recorded between the use of air and heliox as the breathing gas. These results endorsed Dr Thornton's opinion that the problems of passive protection have not yet been solved.

Dr Webb stated that he had heard some very impressive reports from EDU US Navy on the properties of 'Thinsulate' (a woven polypropylene mat) as an undergarment for use with dry suits. It does not crush readily and is therefore little affected by hydrostatic compression with retention of its insulation to a large extent even when wetted. Surg. Cdr Pearson said that his research into the use of Thinsulate confirmed this.

Surg. Cdr Golden summarised at this stage by saying that the meeting was agreed that the major effort should be on passive protection (i.e. improved suit insulation and respiratory heat exchangers) but at the same time to continue to pursue the engineering development of active diver heating devices. He then asked Dr Adolfson to comment on the problem of heating divers' hands.

Heating the divers' hands

Dr Adolfson stated that it is essential to keep the hands warms otherwise the diver is useless. The problem is that there is no actively heated glove system available at present which gives adequate thermal protection without causing an unacceptable decrement in manual dexterity. A series of experiments is planned later this year to look at the passive protective effect of inner gloves made of modern insulating materials combined with thin rubber outer gloves.

Sir John Rawlins said that he had done a lot of work on this for Sealab III and that there were 3 options. The first was to use extremely well made inner gloves, tailored to the individual hand by the glove manufacturer, inside zipped overmitts which could be peeled off as necessary. The second was to use electrically-heated gloves with a knitted stainless-steel element, which gave a very good application of heat to the back of-the hand. He then found that equally good results could be obtained if the glove fingers were removed and the heat applied only to the backs of the hands. The same principle could be applied to a closed circuit hot water suit. If heating could be applied to the back of the hands, the fingers required passive protection only.

Catalytic burning of hydrogen

Dr Thornton asked if there were any physiological objections to the use of very small percentages of hydrogen in breathing gas, for catalytic burning in a respiratory gas warmer. Such a device has been available for about 10 years and works perfectly on the surface, but has received little further attention.

Cdr Goad (USN) said that he had some experience of the device which he considered to be superb. The products of the reaction were heat and water only thereby giving a continuous supply of warm moist non-toxic gas. There was no physiological objection to the use of hydrogen and it has, of course, been used as a breathing gas. The device can readily be adapted for use in a bell. The only possible objection to the use of hydrogen lies in its explosive properties and with the percentage used this would not apply once mixed. The consensus of the meeting was that the technical problems of gas mixing using hydrogen had been overcome.

Use of thermistors

Dr Dyson replied to Surg. Cdr Pearson's questions on thermal monitoring techniques. She said that, because of problems encountered with heat-flow discs, her laboratory had decided to use thermistors in the form of a 6" x 4" pad fitted with 12 thermistors. On the question of radio pills, she felt that for accurate use in research there were definite calibration problems but individual pills could be used once their history is known. Passive (i.e. externally activated) pills exist, but are very rare and only a research tool.

Oxygen toxicity

Surg. Cdr Shields replied to a question that there was no evidence to suggest that oxygen convulsions were more likely to occur in cold divers.

Cold during decompression

Surg. Cdr Golden then invited comments on the effects of cold during the in-water stops on decompression.

Dr Kuehn said that studies have shown that divers who are warm on the bottom and cold during decompression suffer more decompression sickness than those who are cold or warm throughout the dive. It might therefore be necessary to modify current diving tables to cater for the diver with active heating. Dr McIver endorsed this and mentioned a diving firm who had previously carried out a large number of uneventful decompressions in divers without any active heating but who suddenly experienced a significant incidence of decompression sickness when their divers were provided with hot-water suits. He also pointed out that it is not unusual for a diver to be hot on the bottom with active suit heating and cold for several hours during decompression in a damp helium-filled bell. Should the tables be modified to cater for impaired gas elimination during such decompression?

Surg. Cdr Shields stated that, although specific experimentation had not been done, it was now the practice in AMTE(PL) when testing decompression schedules for surface-orientated diving to bias the odds against the schedule by testing it on divers who were warm and working on the bottom, and cold and relatively immobile during decompression.

Hyperthermia

Dr Elliott then asked the meeting to conclude by considering briefly any possible problems of hyperthermia. Mr Imbert quoted the case of a diver who had become overheated while dressing in a hot water suit and who, as a result, was not fit to dive. The consensus was that such problems would be recognised by the diver himself and were not a cause for concern. More important was the use of surface decompression techniques in the tropics, where the temperature inside the deck decompression chamber can become very high. It was concluded that this was a training as well as a technical problem. It should be solved by an awareness of the potential problem by all those working in the tropics as well as by adequate shade and cold water sprinklers.

Dr Webb drew attention to the problem of the overheated bell diver and pointed out that the heat induced peripheral vasodilatation might result in sudden syncope when hydrostatic squeeze is removed on locking in to the bell. Dr McIver quoted such a case where a diver had become too hot while working in a Norwegian fjord and who had passed out on being recovered to the bell.

Mr Humphrey reminded the meeting of the two fatalities due to hyperthermia in the North Sea. In this case the chamber had been overheated initially and additional circumstances resulted in them being repressurized with complete loss of control of temperature. Several participants pointed out that hyperthermia, once established, is a much more serious condition than hypothermia.

Conclusion

The principal points raised at this 2-day meeting are given in the pages of this report.

One additional comment remains : that, besides the need for further research and development in this field, it became very apparent that there is a need for a greater flow of information from the laboratory to the operational diving teams.

The editors hope that this document will contribute to this flow and that further workshops will follow.