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REVIEW OF PROBABLE SURVIVAL TIMES FOR IMMERSION IN THE NORTH SEA

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SUMMARY

There is a need to define a realistic estimate of probable survival times for people immersed in the North Sea. The requirement underlying this work is to provide reliable data on which to base judgements on the time available to effect a successful rescue and recovery of people immersed in the waters of the UKCS. Estimates are required of times for which there is a good prospect of survival for persons entering the water, before individuals begin to succumb to the various threats to life posed by the prevailing conditions. Maximum survival times for which at least one person out of a group may survive are more relevant to decision making with regard to continuation or cessation of search and rescue activities. Such maximum likely survival times are not within the remit of this paper.

Survival in the sea is dependant upon a wide range of variable factors and predictions cannot be based upon a rigorous scientific analysis. This study has been based upon identifying the primary threats to life, reviewing relevant data and applying appropriate factors to derive realistic times when it can be expected that relatively thin, reasonably fit and uninjured survivors will begin to succumb to the prevailing conditions.

The dominant threat to an immersed person is drowning. However much of the past effort has focused upon death from hypothermia. While the study of human thermal physiology is amenable to scientific analysis, survival times based upon cooling of the vital organs alone is irrelevant if the victim is unable to breathe due to inhalation of water. Nevertheless the effects of cold are debilitating and increase the probability of drowning. Due to this contributory effect, data on the early stages of hypothermia are an important input factor in the overall estimation of survival times in cold water.

Assessments have been made of the typical environmental conditions for summer and winter in the North Sea and estimates of survival have been derived for various clothing assemblies appropriate to these conditions. As survival estimates for a working population are required it has been necessary wherever possible to estimate times appropriate to people who are likely to be disadvantaged ie have a greater susceptibility to cold. In this manner the survival of the bulk of the population should have some factor of safety if rescue times are appropriate to this disadvantaged person.

A wide range of probable survival times have been predicted depending on the environmental conditions, the individual and the survival equipment available. This study has focused on the initial three hours of immersion; any survivors who are immersed for longer than this are likely to be so separated that locating them will be difficult and hence the individual will be placed at increased risk. Therefore even in favourable conditions where it is predicted that a person is capable of survival for a prolonged period, the search and recovery procedures should be designed to locate and rescue immersed persons within approximately 3 hours.

Within a group of survivors a proportion of them are likely to succumb to cold shock upon initial immersion in the water. Others within the group may be injured prior to immersion and hence be incapable of self-help once in the water. The estimated survival time ranges presented in this paper therefore assume death within minutes for these most vulnerable individuals. The upper bounds of the survival time ranges are for a thin, reasonably fit and uninjured individual. The estimate for survival in winter for such people, wearing a typical UKCS immersion suit and lifejacket combination, is within half an hour. It is considered that survival time estimates which are significantly longer than this period probably include an unjustified degree of optimism.

It is clear that in typical winter conditions in the North Sea the provision of leak proof immersion suits with inherent thermal insulation together with sufficient buoyancy to keep the mouth clear of the water should significantly increase the probability of survival.

CONTENTS

Page

TABLES

FIGURES

1. INTRODUCTION

1.1 OBJECTIVE

To provide industry with realistic survival times for offshore personnel immersed in the North Sea in a variety of circumstances, as an input to necessary performance criteria for rescue capabilities.

1.2 BACKGROUND

The Prevention of Fire and Explosion and Emergency Response Regulations (PFEER) (HSC, 1995) require offshore operators to design their rescue facilities in such a manner that they will provide a good prospect of rescue and recovery. Unbiased information is required by the industry on likely survival times for immersed personnel awaiting rescue. A review is required which encompasses current data relevant to life threatening factors for people immersed in the North Sea in a variety of typical circumstances.

It is readily apparent that in-water survival times depend upon a number of inter-related factors, such as the ability to breathe, the response to cold water immersion, determination to survive, reduction of heat loss, prevailing weather conditions etc. Much of the literature relating to prediction of survival times focuses exclusively on the effects of cold water immersion on human physiology. Survival times have often been calculated as the time taken to reach some critical deep body core temperature, taking account of the level of insulation provided by the clothing or immersion suit worn by the victim. Such an approach tends to ignore the many other factors which have a bearing on survival, notably protection from drowning.

Other studies have considered the effectiveness of survival equipment in providing buoyancy in the water, such as that provided by lifejackets and immersion suits. However this work tends to comment on the effectiveness or otherwise of the equipment in preventing inhalation of water, rather than presenting the results in terms of survival times.

Few, if any, studies appear to consider all factors which might impinge upon the safety and survival of the individual in the water in a manner that would predict probable survival times. In order to try to take account of all the potential variables in addressing the objective, this study draws upon data from a range of sources.

1.3 METHOD

A search of the open literature and HSE reports was conducted to identify and obtain relevant documents from past research and from relevant incidents. Where appropriate the Medline and NASA computerised research reference databases were accessed using various combinations of keywords encompassing in-water survival, buoyancy, thermal insulation, clothing, temperature, drowning, and hypothermia.

Data have been collated on: the thermal and physiological factors of survival in cold water; the contribution and effectiveness of survival equipment such as immersion suits and lifejackets; and the potential effects of other factors which may impinge on the individual's likelihood of survival in typical North Sea conditions. The data include reports of actual incidents, field trials, laboratory experiments and thermal modelling. All data have been assessed for their relevance and analysed in order to identify the primary threats to survival for the immersed individual, together with other factors prejudicial to survival, in typical North Sea conditions. Survival time estimates referenced in this report are times for which there is a good prospect of survival for persons entering the water, before individuals begin to succumb to the prevailing conditions. It is not the objective of this paper to consider maximum likely survival times, which are more relevant to decision-making on the continuation or cessation of search and recovery activities.

In preparing the report, it is recognised that the primary interest of many readers will be in the presentation of predicted survival times. However these times are strongly influenced by a range of factors whose effects cannot be quantified. In order to establish clearly what these factors are, and to outline the uncertainties surrounding them, background information has been included so that the data and results which follow can be read with appropriate caution. Thus Section 2 discusses the physiological response to cold water immersion. Section 3 sets out the primary threats to survival in cold water, as derived from the literature search. Section 4 discusses the many factors which may affect survival for the individual, and which may have a critical bearing on estimates of survival times.

Section 5 presents the predictions of survival times as identified in the literature and discusses the inherent limitations of such predictions. It is clear that there is a wide range of variables and imponderables associated with survival, few of which are adequately reflected in many previous predictions of survival times. Due to these imponderables, it has not been possible to subject the existing data to a rigorous scientific analysis. In presenting an alternative strategy in Section 6, we have made certain practical assumptions, drawn from various aspects of the data, and then applied defined rules to derive probable survival time ranges for various conditions. The results of this analysis are presented in Section 7. This pragmatic and reasoned approach produces defensible survival times which may be used to assess the validity of estimates from other sources. The primary conclusions are identified in Section 8.

2. PHYSIOLOGICAL RESPONSE TO COLD WATER IMMERSION

Predictions of survival times vary with the physiological response of the individual to immersion in cold water. In order to enable the reader to appreciate later references in the text to physiological phenomena, this section provides a brief explanation of the human reaction to immersion in cold water and subsequent gradual cooling.

In calm conditions requiring no physical movement from the individual immersed in cold water, there are broadly five stages in the body's physiological reaction:

i) **Initial immersion**, resulting in 'cold shock' responses to cold water (Keatinge, 1961a, 1965). Cold shock is defined as a sudden drop in skin temperature which causes a reflex reaction inducing hyperventilation and abnormal cardiac output. After an initial involuntary gasp on entering the water, breath-hold times will decrease significantly and most individuals will hyperventilate. In addition both heart-rate and cardiac output increase significantly, imposing severe demands on the cardiovascular system with the potential for cardiac arrest in susceptible individuals.

ii) **Shut down of peripheral perfusion** reducing the cold venous return to the core and reducing the heat lost from the limbs and extremities. In this way the temperature of the less vital areas of the body is sacrificed in order to preserve the temperature of the vital organs (Burton, 1955; Keatinge 1969). The unperfused outer layers of tissue act as a thermal insulating barrier for the core.

   Perfusion shut-down is achieved by active vasoconstriction which can be maintained above a critical minimum temperature. Once the temperature of peripheral tissues falls below this critical temperature, the blood vessels may relax and some reperfusion occur, allowing further heat loss through limbs etc. (Keatinge, 1972).

iii) **Onset of shivering** where spontaneous synchronised contractions of muscles burn up energy reserves to generate heat (Burton, 1955). The heat generated in this way is initiated by a slight fall in core temperature and helps to delay further lowering of this temperature while energy stores are available to sustain shivering.

iv) **Cessation of shivering** when metabolic fatigue sets in primarily due to a lack of energy. Anaerobic metabolic heat production begins when 50% of aerobic energy reserves have been used up. Lactic acid levels then increase until fatigue sets in. Metabolic fatigue is defined as the point at which aerobic and anaerobic energy sources are exhausted. At this point the core temperature will fall at a greater rate due to the absence of internal heat generation (Shender, 1995).

v) **Post-immersion collapse** (Golden, 1981, 1991) where the loss of hydrostatic pressure assistance to circulation when the survivor is removed from the water. This may lead to collapse of arterial blood pressure and, as a consequence, reduction in cardiac output and hypoxia in the vital organs of the brain and heart. Post immersion collapse has been responsible for a significant number of fatalities following cold water immersion.

Stages ii) to iv) describe the physiological reactions to prolonged cooling. The response times and temperatures for these three stages vary considerably between individuals. They depend upon a number of factors such as percentage body fat, physical fitness, previous acclimatisation to cold etc, and to a considerable extent on the effectiveness of any external thermal insulation worn by the individual and his determination to survive. These factors are discussed in Section 4.

It is often mistakenly assumed that the individual immersed in the sea is primarily at risk from death directly by hypothermia. Clinically, hypothermia is defined as a core body temperature below 35°C. Based on rectal core temperature (Tr), hypothermia may be sub-divided as mild (35-32°C), moderate (32-28°C) and severe (less than 28°C) (MacLean, 1977; Ferguson, 1983; Harnett, 1983; Sterba, 1993). The progressive stages of hypothermia are presented in Figure 1 (Edmonds, 1992), where it can be seen that the individual is likely to become disorientated and confused at a core temperature of 34°C. Thus the mildly hypothermic person will begin to be incapacitated at this stage. The consequence of this in the water environment is likely to be drowning due to an inability to protect the mouth from spray and breaking waves (Bullard, 1970; Allan, 1983a; Cotter, 1995). For these reasons death solely attributable to hypothermia is unlikely to be the outcome of immersion in the North Sea.

3. PRIMARY THREATS TO SURVIVAL IN COLD WATER

The previous section has discussed how hypothermia may contribute to death by drowning. However hypothermia is not the sole threat to life. Typical North Sea conditions pose other significant threats to the continued survival of immersed personnel. These must be appreciated so that any survival predictions take realistic account of the full range of threats to life. This section therefore sets out these primary threats, as identified from the literature.

It is apparent from laboratory trials and real-life incidents involving the general population, offshore and military personnel that the primary threats to immersed individuals are associated with the sudden shock of immersion in cold water causing an involuntary gasp and the possible inhalation of sea water; gradual cooling of the body core as the immersion time increases; and the psychological state and determination of the survivor. The outcome to those who succumb to these threats is invariably drowning. Drowning, by definition, is death from acute asphyxia while submerged, whether or not liquid has entered the lungs (Bradley, 1976). The above factors are discussed in more detail below.

3.1 COLD SHOCK

Drowning due to the effects of cold shock can be the greatest threat to survival in cold water (Tipton, 1989a). It is reported that in as many as 50% of the annual UK water deaths, cold shock may be implicated (Tipton, 1995b). Cold shock is possible in a water temperature of 25°C, but becomes of dominant concern at temperatures less than 10°C (Tipton, 1994). After an initial involuntary gasp on entering the water, breath-hold time will probably decrease to less than 10 seconds, and breathing rate is likely to increase ten-fold. This will greatly increase the risk of inhaling water. The most likely outcome of persons succumbing to cold shock at sea is therefore drowning within minutes of immersion. In addition people with a pre-existing cardiovascular weakness may succumb to cardiac arrest due to the stresses caused by the high cardiac demand induced by cold shock (Keatinge, 1969). In the case of the offshore population the medical screening prior to employment may reduce the likelihood of cardiac arrest during cold shock.

3.2 INHALATION OF SEAWATER

Constant immersion in turbulent water inhibits breathing ability. There is a high probability that water will be ingested when gasping for breath in turbulent sea conditions where the survivor is continually exposed to breaking waves and spray. The most likely outcome for persons immersed in turbulent water is that they will eventually be unable to maintain an airway clear of water, will experience breathing difficulties and drown within minutes of the onset of their difficulties (Nunneley, 1985).

3.3 DECLINE IN CORE TEMPERATURE

If the individual does not succumb to drowning induced by cold shock, the body's core temperature will gradually cool. The rate of cooling will depend primarily on water temperature, available insulation, immersion time and levels of physical activity required. As the vital organs lose temperature their performance is adversely affected and will eventually cease functioning (severe hypothermia). However, prior to this the deeply chilled person will be debilitated by the cold, will lose motor function and will be physically and psychologically unable to make the necessary effort to maintain an airway (Bullard, 1970; Allan, 1983a; Cotter, 1995). He is most likely to drown due to inhalation of water either before or as he loses consciousness (Keatinge, 1969).

3.4 LOSS OF WILL TO SURVIVE

The psychological stress associated with immersion at sea is considerable (Higginbottam, 1992). The drive to fight surface turbulence to maintain breathing and remain conscious can be significantly eroded by many factors such as cold, seasickness, the absence or ineffectiveness of rescue attempts, and the continual physical effort required to maintain an airway in turbulent seas. As conditions deteriorate, the energy and will-power required to survive are more likely to become exhausted. The most likely outcome for persons who lose the will to survive is drowning due to inhalation of water shortly after they "give up".

3.5 SUMMARY OF THREATS

It is apparent that a range of conditions may affect the immersed person, all of which are likely to result in an inability to breathe due to aspiration of water, and consequent death by drowning. Gradual cooling of the body core may be only one of the factors which influence survival, and even where it is a prime consideration, death will result from drowning rather than from severe hypothermia. Estimated survival times based solely on thermal factors are therefore unrealistic.

The person who succumbs to cold shock may drown within minutes of initial immersion. If the individual survives this initial shock, other factors will come into play, namely the ability to maintain an airway clear of the water; the ability to maintain a core temperature above the level at which hypothermia may begin to cause incapacity; and their will to survive. As an individual gradually succumbs to one or a combination of these conditions, drowning may occur over a range of times from minutes to hours after immersion.

The time taken to succumb to any combination of these primary threats for a given set of environmental conditions is strongly influenced by a range of contributory factors. These include the effectiveness of survival equipment in providing protection against the primary threats identified above, and physical and psychological variables peculiar to the individual. These factors are discussed in some detail in the following section.

4. FACTORS AFFECTING SURVIVAL

A wide range of contributory factors have been identified which will affect the individual's ability to survive; they have both direct and indirect effects on the primary threats to life identified in the preceding sections. These factors have been categorised as equipment variables, which encompass the means of providing buoyancy (lifejackets and immersion suits) and thermal insulation (immersion suits); and individual variables such as physiology, cold adaptation and in-water competence. The importance of these and other variables in contributing to survival is reviewed, and summarised at the end of this section.

4.1 EQUIPMENT VARIABLES

4.1.1 Buoyancy

In order to survive, the individual must be able to maintain an airway and hence be able to breathe. To achieve this, the survival equipment worn by the survivor must be effective in providing buoyancy distributed in such a way as to ensure that the person's mouth is continually maintained above the water (Herrman, 1988).

The two items of equipment which in practice provide buoyancy are lifejackets and immersion suits. These have, to a large extent, been developed separately. The specifications of lifejackets have been defined over the years and are aimed at keeping the airways clear of water, assuming that the lifejacket is the sole means of providing buoyancy. The specifications of immersion suits have been primarily aimed at providing thermal insulation and protection from the adverse effects of cold water immersion. However, in practice the two items interact and affect each other's performance in their primary roles. Because of this there will be a considerable range of performance in terms of probable survival times, dependent upon the efficiency or otherwise of the lifejacket/ suit combination worn by the individual.

Survival assessments should always consider lifejackets and immersion suits in combination as a system (Robertson, 1989). Unfortunately experience gained from incidents and from experimental trials indicates that this ideal situation is not always the case (RGIT, 1988; Higginbottam, 1992; CAA, 1995).

When wearing an immersion suit, the relatively even distribution of buoyancy within it will tend to float the wearer in a horizontal attitude at the surface, even when wearing a lifejacket. This brings the legs up and can bring the level of the mouth and nose nearer to the water's surface compared to a survivor wearing a lifejacket without a suit. This in turn may increase the hazard of drowning unless the lifejacket has considerable buoyancy which raises the head clear of the water (RGIT, 1988).

Substantial leakage of water into an immersion suit will soak any clothing worn underneath and will increase the in-water inertia of the wearer. This will also lead to an overall loss of buoyancy and hence a greater risk of inhaling water, requiring the wearer to make swimming efforts to remain above the surface (Higginbottam, 1992).

The inherent buoyancy of an insulated (closed-cell neoprene) suit will provide support when immersed, in addition to any lifejacket worn. While this additional buoyancy may be a disadvantage during an underwater escape, it has considerable benefit once the survivor is floating clear on the surface. The suit's inherent buoyancy together with an efficient lifejacket which provides a high level of buoyancy round the back of the neck, significantly reduces the probability of inhaling water (Rislaa, 1990). In the event of leakage with an insulated suit, it's overall buoyancy will be compromised less than that of a membrane type with a similar level of leakage.

Lifejackets are a key component in any personal survival equipment system. In-water trials have demonstrated the importance of adequate buoyancy of lifejackets to enable survivors to maintain their ability to breathe in turbulent sea conditions. Even with 15kg of buoyancy some test subjects have been submerged by near-cresting waves of 1.2m (Girton, 1984).

Lifejackets have been found to be deficient in keeping the airways clear in turbulent waters, in particular twin lobe designs and those without crotch straps to prevent the jacket riding up (RGIT, 1988; Higginbottam, 1992; CAA, 1995). It is possible for waist straps to loosen with movement, the lifejacket to ride up, and for an unconscious survivor to slip down low in the water with the jacket riding above him. Even a conscious survivor may be at risk of drowning if the lifejacket harness works loose, especially in circumstances where the person is wearing a membrane suit which floods (Higginbottam, 1992). Trials have demonstrated that it takes very little time for harness straps to work loose. A five minute swim was sufficient for 20mm to be lost in mouth clearance above calm water, due solely to the lifejacket straps working loose (Higginbottam, 1992). In these circumstances unless the suit retains significant buoyancy the survivor is vulnerable to being swamped by waves, and will be forced to expend energy clinging to the lifejacket in an attempt to stay above the water (Higginbottam, 1992; CAA, 1995).

Inadequate support with some lifejackets may allow the head to fall sideways within the jacket and permit waves to wash over a survivor's face if he is relaxed or unconscious (Girton, 1984; RGIT, 1988). Insufficient support may also prevent the survivor obtaining a clear view of the waves, and hence being unable to control his breathing in relation to them. Wearing an insulated hood may assist in providing some buoyancy to the head (Shender, 1995), as well as providing thermal and physical protection.

Experimental trials have demonstrated the unsatisfactory performance of some lifejacket/suit combinations in protecting the mouth from wave splash and submersion. In 1.2m steep waves in a wave-tank a lifejacket/suit combination which is in common useage in the North Sea failed to prevent a marine anthropomorphic mannikin's mouth from being submerged for over 30% of the 5-minute test duration (RGIT, 1988). The probability of a survivor inadvertently inhaling water in these circumstances is high. It should also be recognised that this represents the 'best' scenario for this particular equipment combination, since the test evaluated only the initial stages of the immersion. During more prolonged immersions, the probability of the lifejacket harness working loose will increase, resulting in a loss of support and increased vulnerability to waves washing over the mouth.

4.1.2 Thermal Insulation

Immersion suits which are currently available to provide thermal protection can be broadly divided into two types, namely membrane and insulated. Membrane suits are discussed first.

A membrane suit is manufactured from waterproof fabric, commonly a tri-laminate material composed of a synthetic rubber membrane bonded to two layers of durable, abrasion resistant nylon facing fabric. An alternative fabric which may be used combines a breathable, waterproof membrane bonded to nylon facing fabrics. The suits are a one-piece design with a waterproof zip sealing the entry and with wrist and face or neck seals, commonly made of thin synthetic latex. The aim of these suits is to keep any clothing worn under them dry to provide thermal insulation. It is the air trapped within the clothing under the suit which provides the thermal protection from the effects of cold water immersion. The levels of clothing worn under membrane-type immersion suits varies considerably in the offshore population. Long transfer flights in warm helicopter cabins, for example, encourages wearing relatively light clothing which will provide minimal thermal protection in the event of ditching.

As membrane-type suits have virtually no inherent thermal insulation properties, the watertight integrity of the suit must be maintained to make use of the dry insulation provided by the clothing under the suit. This clothing can become damp or even wet prior to the immersion due to heat stress and sweating (Light, 1987b; Tipton 1991; Tipton, 1993). Once in the water the clothing can become wet due to leakage, either due to a poor design or fit or to failure to secure the zip completely. Membrane suits which utilise latex neck and wrist seals are often prone to damage particularly by tearing the seal while attempting to don the garment.

Wearing a thermal liner under a membrane suit (eg closed-cell neoprene or hydrophobic material) will provide improved thermal insulation over standard clothing. Some of this additional insulation will be retained in the event of leakage (Reeps, 1984). A closed cell neoprene thermal liner will also have the advantage of providing additional buoyancy.

An insulated suit is usually composed of closed-cell neoprene material, faced with nylon fabric. The garment may be manufactured to different thicknesses, depending on the level of insulation required. A suit of 8mm neoprene is generally considered appropriate for North Sea use. The design is generally similar to membrane suits, although the seals are more commonly made of foam neoprene, rather than latex.

The aim of these suits is to provide a significant amount of thermal insulation over and above that provided by the clothing worn under them. Thus the cold water immersion survival times for this type of suit are less sensitive to the levels of clothing or leakage when compared to membrane suits. Heat stress within these suits prior to immersion can be significant. The foam neoprene seals utilised on these types of suit are generally less susceptible to damage by snagging while being donned but leakage under these seals is quite common. However, the dampened clothing is not likely to completely destroy the thermal insulation of the suit.

4.1.3 Leakage

Leakage into immersion suits is still a common occurrence (Pasche, 1984; Allan, 1985; Light, 1987a; Rislaa, 1990; Tipton, 1991; Tipton, 1993; CAA, 1995; Cotter, 1995; Higginbottam, undated). Leakage is more likely in turbulent water, when the combined effects of water surge and movement by the individual will lead to water being forced under seals or into channels formed between the seal and the sinews of the neck and wrist. In one laboratory trial where subjects were required to swim for 20 minutes, an **average** of 560 ml water leakage was noted in suits which were fully zipped-up (Higginbottam, 1992). In another trial where subjects simulated an underwater helicopter escape, followed by a 20 minute swim, an **average** of 1 litre of water was observed inside fully zipped-up suits (Tipton, 1991).

After prolonged immersion in cold water, diuresis will also occur (Knight, 1985), leading to internal wetting of the suit. This is significant in isolation and has to be further combined with any leakages of seawater to calculate the residual insulation of an immersion suit.

The significance of leakage is that it will reduce the thermal insulation provided by the suit and clothing. Wetting the clothing worn under a drysuit by one litre of water has been demonstrated to reduce insulation values by greater than 40% (Hall, 1956; Allan, 1984; Allan, 1985; Light, 1987a; Herrman, 1988). Saturation of the clothing will result in a further reduction in insulation values. Wearing a hydrophobic type undergarment will probably confer some advantage over standard clothing, since the insulation provided by the hydrophobic material will still retain approximately 30% of its thermal insulation when saturated (Reeps, 1984). In the same circumstances an insulated suit will lose some of its' insulation properties, but to a lesser extent than a membrane suit, and it will also retain a significant amount of buoyancy (Pasche, 1984).

Failure to seal the suit correctly, notably by having the waterproof zip partially undone, will significantly compromise the suit's effectiveness (CAA, 1995). Unless this can be corrected immediately, any unzipped immersion suit will quickly fill with water, leading to a loss of buoyancy and insulation. It is worthy of comment that in one incident four persons drowned out of a total of eight who were recovered. The four who died all had suits which were unzipped and flooded (Naesheim, 1981). In an earlier incident five of six persons who died had flooded suits (Jessop, 1993). In laboratory trials, an **average** of 17 litres of leakage was recorded following a 20 minute swim test, during which the suit zip was left open by 100mm (Higginbottam, 1992).

4.1.4 Hydrostatic Forces

Thermal insulation will also be lost due to hydrostatic compressive forces on the clothing covering parts of the body which are submerged. Therefore a person who is floating at an angle of 45° will experience greater loss of overall insulation than someone who is floating in a near horizontal position (Light, 1987a). In practice a person wearing an immersion suit will tend to float in a horizontal attitude, with the bulk of the body above the water due to the distribution of buoyancy in the suit. However heat loss will still be experienced, especially from the back.

4.1.5 Accessories

Heat loss through the unprotected head and neck regions can be considerable. Early work suggests that the non-evaporative heat loss from the head may amount to half the total resting heat production in a man (Froese, 1957). It is essential that these areas are protected by an insulated hood. Hoods of this type also provide some impact protection, particularly during recovery from the water. Hoods are now generally integrated into most survival suits and should no longer be considered as accessories.

Wearing thermally insulated gloves in cold water will have a significant comfort and psychological benefit to the immersed person (Higginbottam, 1992). However, if the survivor is not wearing gloves at the time of initial immersion in cold water, he will rapidly reach a state where he will be unable to pull on his gloves due to cold paralysis and loss of grip strength in his hands (Sterba, 1993). The loss of manual dexterity caused by the gloves is not likely to be more than that caused by cold hands. The benefits of gloves in maintaining the core temperature are less clear. The effects of cold induced vasodilation in the hands should be mitigated, possibly making some contribution to maintaining core temperature.

Some spray hoods have been demonstrated to be of limited value in maintaining an airway in turbulent sea conditions (Raeburn, 1988; RGIT, 1988; CAA, 1995). Not only are they difficult to deploy and subject to flooding, but they also deprive the survivor of sight and sound which are essential senses in being able to fight the elements and keep in contact with other survivors. The benefit of a spray hood in terms of extending survival times is thus difficult to predict. However if internal flooding, deployment and psychological difficulties can be overcome, spray hoods must become beneficial in heavy weather.

4.2 INDIVIDUAL VARIABLES OF THE SURVIVOR

Individual variability has a significant impact on predicting the likelihood of survival. This section discusses the various physiological and psychological factors which will influence survival for the individual, but which are often difficult to quantify in terms of their influence on survival time predictions.

4.2.1 Body Fat

Differences in body morphology will have an influence on the immersed individual's ability to minimise heat loss and sustain shivering. It is known that fatter individuals with thicker layers of subcutaneous fat cool more slowly than those with less fat. (Carlson, 1958; Keatinge, 1960; Nunneley, 1985). The insulation provided by fat remains fairly constant, regardless of whether the individual is exercising or not, eg shivering or swimming. It has been estimated that each additional percentage of body fat equates approximately to a 0.1°C rise in deep body temperature during cold water immersion (McArdle, 1984).

One study (Light, 1986) has identified anthropometrical data for the UK offshore population compared to their onshore contemporaries. It is concluded that the offshore population is generally fatter than onshore workers, a fact which could stand them in good stead during cold water immersion. On the other hand fat does not equate well with fitness, and it was reported that few of the subjects in this study took regular dynamic exercise. This may counteract the assumed benefits of additional fat if the subject is immersed in turbulent water.

4.2.2 Effect of Physical Movement

It is suggested that 70 to 90% of total body insulation of individuals at rest in cold water is provided by resting muscle with low blood flow (Rennie, 1984). Thus differences in body mass may be significant, but only if the individual is resting. However physical movement is required in most practical conditions when immersed in the North Sea. Swimming actions are required to ensure that an optimum position is maintained with respect to wind and wave and preserve the ability to breathe. Physical movement requires the blood supply to the limbs to be re-activated, thus raising the surface temperature of the limbs and losing heat by convection to the surrounding water (Bullard, 1970; Strong, 1985). The blood will be cooled and provide a cold venous return to the core and the insulating value of the previously inert muscle will be diminished. In addition physical activity will aggravate any tendency for the immersion suit to leak.

The significance of movement in contributing to heat loss should not be underestimated. One study (Keatinge, 1972) indicates that the effect of in-water exercise is dependent on water temperature. In water above 25°C exercise will help maintain core temperature, whereas below 15°C exercise will accelerate the fall in core temperature. Laboratory trials with subjects wearing immersion suits in 15cm waves, a 6 knot wind and water spray reduced core cooling times to a rectal temperature of 36°C by approximately 30% compared to times for the same subjects in calm conditions (Tipton, 1991; Tipton, 1995c).

A further indication of the effect of movement is seen by comparing the results of trials using resting subjects seated in still water within test tanks to those conducted in the open sea. In 7°C still water in a tank wearing a membrane suit with cotton underwear, resting subjects cooled to a core temperature of 36°C in 80 minutes. The same subjects were immersed in calm sea water at 10.5°C, while wearing additional clothing (long underwear, flying clothing, woollen socks) under the same membrane suit. In these less stressful conditions the subjects reached a rectal temperature of 36°C in only 45 minutes (White, G, 1979). Thus despite immersion in warmer water and the provision of improved insulation, when faced with more realistic sea conditions, the subjects' cooling rates almost doubled. It should be noted that even these more realistic conditions were still relatively favourable, both in terms of sea state and water temperature.

4.2.3 Fitness

The fit individual is more likely to be able to sustain shivering and the physical effort required to maintain an airway in rough water for longer, and hence be able to delay the onset and consequences of fatigue. Conversely an unfit individual is liable to cool more rapidly due to the early onset of fatigue and subsequent cessation of shivering. The unfit individual is also likely to suffer a greater psychological deficit as fatigue sets in.

Fitness may have some bearing on survival in terms of surviving cold shock. There is some evidence that the individual with high levels of fitness has a reduced response to cold shock (Keatinge, 1965; Tipton, 1989b).

4.2.4 Cold Adaptation

It is known that persons with previous exposure to cold have the ability to adapt to this environment and be less affected by heat loss than would otherwise be the case (Golden, 1980). Therefore if an individual has recent previous experience of cold exposure, for example from swimming or diving, this may be beneficial. Likewise in a few individuals sudden immersion in cold water may elicit a 'diving response' which may depress the cardiovascular response and provide some protection from hypoxia and hypothermia (Gooden, 1992). However the number of individuals likely to benefit from such responses is probably very low.

4.2.5 In-water Competence

The ability to maintain an airway with minimal effort will delay the onset of fatigue and enhance the prospect of survival. A key factor in this will be the ability to time one's swimming and breathing efforts in relation to the wave action and thus avoid the inhalation of water. This will require concentration and confidence on the part of the individual, which will be greatly influenced by his swimming technique in a seaway and his psychological state (Rislaa, 1990; CAA, 1995).

4.2.6 Psychological State

Past experience indicates that the individual's psychological state will play a crucial role in survival (Keatinge, 1969; Raeburn 1988; Rislaa, 1990; CAA, 1995). An individual who is unfit, wet, cold and seasick, whose survival equipment is ineffective, who is demoralised by lack of rescue attempts, and who is unfamiliar with the water environment is less likely to be determined to make the necessary efforts to maintain an airway. A fit, well insulated, dry and buoyant individual will clearly be better placed to demonstrate the **determination** necessary to survive.

4.2.7 Seasickness and Dehydration

Some immersed individuals may be susceptible to sea sickness and vomiting. This will be debilitating in itself due to fatigue and heat loss, as well as psychologically (Keatinge, 1969). During a long immersion, seasickness will also aggravate any tendency for dehydration.

Dehydration may arise from a range of circumstances. Wearing a survival suit in a heated airport departure lounge or helicopter cabin may lead to excessive sweating (Light, 1987b). Immersion in cold water will inevitably lead to diuresis and possible dehydration (Knight, 1985).

4.2.8 Gender

Gender is probably not a dominant issue in the context of North Sea survival in the UKCS. Various different and subtle mechanisms may be at work which confuse the differences in probable survival between the sexes. On balance it would appear that while exercising, females and males produce similar levels of heat (Hayward, 1975; McArdle, 1984). For a given body fat to weight ratio, core temperature cooling rates are likely to be comparable for as long as exercise and metabolic heat production are sustained. However at rest women display a lower thermoregulatory sensitivity, as witnessed by a smaller increase in metabolism, than for a man with similar subcutaneous fat thicknesses. This results in the deep core temperature of the resting female falling by a greater amount that a comparable male (Tipton, 1994); by implication the resting female may be more vulnerable to cooling than a male counterpart. For practical purposes there is little difference in the response to cold between the sexes when immersed in moving water. The additional subcutaneous fat normally associated with females would be expected to be beneficial in these conditions.

4.2.9 Age

The aging process tends to reduce the protective vasoconstriction response to cold and also the shivering response (Tipton, 1994). On exposure to cold, older people in the age range approximately 50 to 70 are less likely to be able to delay a fall in body core temperature. It is possible therefore that the survival of the immersed older offshore worker may be slightly compromised when compared to younger workers: however this is unlikely to be a significant factor when compared to the range of other variables which may affect the immersed individual.

4.2.10 Injury

The range of scenarios for injured survivors is great, but it may be assumed that the unconscious, injured person will be unable to fend for himself and is likely to drown. The conscious but injured survivor may be unable to deploy equipment effectively, or may be unable to undertake the actions required to maintain an airway. He may also be susceptible to shock from the injury itself, which may further reduce the probability of survival. It is thus impossible to make specific allowances in survival times for injury, other than to be aware that these times will be reduced.

4.2.11 Post-Immersion Collapse

It is too simplistic to assume that a survival time is defined as the time to rescue from the water. Experience has demonstrated that after prolonged periods of immersion, death due to post-immersion collapse may still occur within 24 hours of being recovered from the water (Golden, 1981; Golden, 1991; Oakley, 1995). In a study of RNLI/HMCG data (Oakley, 1995) post immersion collapse accounted for 25% of the people who died. In an incident reported by McCance, of the 40 men rescued alive after a 60 minute immersion in -1°C water, 9 died within 24 hours of recovery (McCance, 1956).

Post-immersion collapse contributed to a great number of deaths during both World Wars (Golden, 1991) and more recently during the Fastnet race in 1979, when three of the 15 fatalities among the competitors occurred during the rescue (Golden, 1991). The duration of the immersion and the sea temperature appear to be key factors, but it is difficult to judge what adjustment is required to predicted survival times to allow for post-immersion collapse. The overall effect is to make some predicted times optimistic, since they fail to take into account the reduced chances of survival after rescue from the water.

4.3 ENVIRONMENTAL VARIABLES

Environmental variables primarily encompass prevailing weather conditions at the time of immersion. This includes sea state, wave steepness, surface sea and air temperatures, wind speed and direction.

4.3.1 Sea Surface Temperatures

Probable maximum and minimum sea surface temperatures for the North Sea are in the ranges 18 to 22°C (summer) and 0 to 2°C (winter) (White, P, 1989). However these are extremes, and it appears unrealistic to assume that such temperatures will generally be encountered. It would be preferable to have used a reasonably pessimistic temperature on which to base predictions of survival times. However we have failed to identify such data. In its absence we have chosen to use mean temperature data for assessing this environmental factor. Inevitably the use of mean data introduce some element of optimism to the predictions. In summer (taken as the month of August) the mean temperature range is 16°C in the southern sector, to 13°C north of Shetland. In winter the range is 5°C in the south to 8°C in the north (Lee, 1981).

It is interesting to note that water depth and the influence of adjacent land and sea masses affect the mean sea temperature. As might be expected, the southern North Sea is warmer than the northern sector in summer. However in winter the shallow, more enclosed southern sector is colder than in the north due to cooling by cold continental air streams, while in the north the water temperature continues to be influenced by the warm North Atlantic Drift.

4.3.2 Sea State

Data on mean significant wave heights are available for summer and winter (Draper, 1989). However a man in the water, wearing a buoyant suit and lifejacket, may well be able to survive big seas if the wave length is long. With buoyancy aids, the man in the water will rise and fall with the swell, provided the wave is not breaking. The key factor to survival is the wave-front steepness and whether or not the wave is breaking and spume is being blown off the crest and into his face. These circumstances are likely to arise in high wind strengths, if the wind speed has increased quickly or if wind is acting against tide, creating short steep seas and breaking waves. Probability data on this form of sea has been impossible to locate. Due to the primary survival problems being associated with short seas and the absence of specific data on this type of sea, the Beaufort wind scale has been used as an indicator of surface conditions which are likely to pose a threat to the individuals' ability to breathe. It is assumed that breaking waves and spume are likely to be experienced with winds in the range Force 5 and upwards. The description of Beaufort Force 5 is a fresh breeze, (17-21 knots) with small waves and many white horses.

Wind speed and air temperature data for the location 54°-56'N, 4°-6'E, have been reported (White, P, 1989). This position lies towards the southern sector of the North Sea. The data are presented as a joint frequency distribution of the number of observations over the period 1855 to 1985, against specific air temperature ranges and Beaufort wind speeds.

Using these data, this study has allocated air temperatures greater than 10°C and up to 10°C to represent summer and winter seasons respectively. The number of observations in these temperature ranges have been related to Beaufort wind force ranges 0-2, 3-4 and 5 and above. The number of observations in each range is expressed as a percentage of the total for summer and winter respectively as set out in Table 1.

It is apparent that conditions of Beaufort wind force 5 or greater are likely to be experienced for almost half of the winter period (45%) and are not uncommon in summer (32%). Calm conditions, defined as Beaufort wind forces 0 to 2 occur for approximately one quarter of the summer period (23%) but are relatively infrequent in winter (15%). It should also be noted that these observations refer to an area in the southern sector. It is probable that winds of Beaufort Force 5 and above will occur more frequently in the northern sector.

4.3.3 Air Temperature

The mean air temperature for the North Sea in summer is 15-17°C, and in winter is 5-6°C (Hopkins, 1995). Air temperature will have a limited effect on the man in the water, since most of his body will be immersed. However if the individual is floating high with his head out of the water, and particularly if his head is unprotected, this may lead to excessive heat loss in winter conditions. This effect will be aggravated by any wind chill.

4.3.4 Additional Hazards

It is possible that the immersed person may also be exposed to hazards such as a surface fire or the aspiration of oil contaminated water. These will clearly prejudice the individuals' survival. It is not however possible to apply specific factors to the prediction of survival for these hazards.

4.4 SUMMARY OF FACTORS AFFECTING SURVIVAL

Overall there is a considerable range of factors affecting the survival of the immersed individual. These fall broadly into three categories; equipment performance, individual or personal variables, and environmental conditions.

Survival is critically dependent on the effectiveness of equipment in providing adequate buoyancy, and thermal insulation. Unfortunately laboratory and sea trials have demonstrated that various combinations of immersion suit and lifejacket fail to maintain the survivor's mouth clear of the water at all times. Lifejacket harnesses tend to work loose, allowing the survivor's head to sink lower within the jacket. This increases the risk of inhalation of water and subsequent drowning, especially in turbulent water conditions or where the survivor is incapacitated. Immersion suits tend to leak, leading to reduced buoyancy and substantially reduced insulation values. Clothing worn under membrane suits may be inadequate to provide the level of insulation required for extended immersion periods, even when the clothing remains dry. The high probability of liquids being present within the suit will lead to a reduction in expected survival times. In this respect the person wearing an insulated suit is less likely to be disadvantaged.

The key individual variables are body fat, fitness, cold adaptation, psychological state and most importantly, whether the individual has to make swimming movements to protect his airway. In-water movement will contribute significantly to body cooling; on the other hand failure to maintain one's position in relation to the waves will lead to inhalation of water and possible drowning. The fit, well motivated survivor who can demonstrate a high level of in-water competence will cope better with difficult conditions. A survivor who is demotivated and weakened by ineffective survival equipment, dehydration, seasickness, injury, and shock is clearly less likely to survive.

The range of environmental factors encompass primarily water surface temperature and sea state. The water temperature will probably range from 5 to 16°C, depending on time of year and location. The colder the water temperature, the higher is the risk of initial cold shock or of subsequent incapacitation due to decline in core temperature. Critical surface conditions are dictated by the local wind speed, which may give rise to short, steep breaking seas and wind-blown spume in winds of around Beaufort Force 5 and above. As sea conditions deteriorate, the greater is the risk of the survivor being unable to continually maintain an airway clear of the water, resulting in drowning.

This study does not attempt to quantify each of these variables individually. However those which are quantifiable in broad terms have been incorporated into the 'rules' set out in Section 6 which have been used to predict likely survival times.

5. EXPERIMENTAL DATA AND THEORETICAL PREDICTIONS REPORTED IN THE LITERATURE

The literature survey undertaken for this review has identified a number of references pertinent to predicting survival for the immersed individual. The data relate to theoretical modelling, trials and incidents.

5.1 MODELLING

The underlying assumption to many studies which are designed to predict survival times following immersion in cold water is that the primary threat to life is severe hypothermia. Hence a significant amount of effort has been devoted to modelling both cooling rates and times required to reach a severely hypothermic condition. In terms of practical survival these times are only likely to be relevant to a breathing, yet comatosed individual in still water. Modelling thermal physiology to core temperatures in the region of 30°C is particularly open ended in that it is not possible to verify the predictions by human experimentation in any ethically acceptable manner. Ethical considerations prevent cooling the subject to core temperatures below 35°C. Therefore thermal modelling of severe hypothermia has to extrapolate from trials data where subjects' core temperatures cannot be allowed to fall below 35°C.

Incapacitation of an individual at a rectal temperature of 34°C is reasonably well accepted as an indicator for predicting immersed survival times (Allan, 1983a; Allan, 1983b; Nunneley, 1985; Cotter, 1995). However extrapolating cooling rates in a linear manner to 34°C is too simplistic, given that thermogenesis will delay the fall in core temperature until the point at which energy stores are exhausted (Nunneley, 1985; Shender, 1995; Tipton, 1995). This time to metabolic fatigue relies on complex physiological responses which are as yet not fully understood by researchers in the field (Tipton, 1995). Mathematical modelling techniques attempt to simulate the human thermoregulatory response and fall in core temperature based on a number of variables including subcutaneous fat, weight, and the ability to sustain shivering. There is some concern that the models are underpinned by complex mathematical equations, for which there is inadequate supporting scientific experimental evidence or reliable incident data (Flook, 1991; Shender, 1995).

Models also do not generally take account of physical movement and assume the subject is completely at rest. These assumptions are unrealistic for typical North Sea conditions. Mathematical models are therefore limited due to their inability to simulate practical circumstances in a sea way.

5.2 TRIALS

Many trials have been undertaken using instrumented human subjects, seeking cooling rates for various levels of thermal insulation in different water temperatures. While some of these trials represent a sincere attempt to identify survival times, the majority are probably invalid due to the unrealistic test conditions. Inevitably most testing has been undertaken in calm water, normally in a test-tank with the subject at rest. Invariably the subjects have been specifically screened and selected for medical fitness to take part in the trials for which they volunteer, thus skewing the results by eliminating both the infirm and psychologically unprepared. There are a few notable exceptions to the calm water testing where an attempt has been made to simulate more realistic conditions (Girton, 1984; Tipton, 1995c). It is significant that each of these trials predict significantly shorter survival times compared to equivalent still-water trials. However even in these more realistic experiments it was clearly impossible to conduct them in truly stressful conditions without risking the lives of the subjects. Thus the most severe trials tend to relate to little more than what would be considered as calm conditions at sea.

Loss of insulation due to leakage has been studied extensively. However there are very limited experimental data on which to base predictions of loss of insulation due to increased convection from turbulent water (ie moderate to rough sea conditions), or exercise induced vasodilation. Nor are there any reliable experimental data on the times taken to reach a state of physical and psychological exhaustion when immersed in rough seas. Indeed apart from a limited number of trials to investigate the effectiveness of lifejacket/immersion suit combinations in preventing the inhalation of water, the only data available on experience in rough water conditions come from incident reports.

5.3 INCIDENTS

There have been many immersion incidents at sea, some in truly severe weather conditions, however limited data are available on both survival times and fatality rates. Inevitably much of the data are imprecise as record keeping of all the relevant parameters is low on the list of priorities during a rescue. The data tend to relate to the time a survivor was immersed prior to rescue or the time the body was recovered in the case of fatalities (Oakley, 1995). These times can be related to estimates of sea conditions and temperatures to provide some guide as to the likely times when the most vulnerable individuals begin to succumb.

In the case of the Cormorant Alpha helicopter crash in the North Sea in March 1992, six individuals survived the initial impact, were seen alive in the water, but subsequently were found to be dead when recovered from the sea (Jessop, 1993). One person was believed to have died within 30 minutes of immersion, when attempts to recover him from the water failed at that time. In two other cases the presumed time of death is given in the time range 10 to 70 minutes after immersion, based on witness reports and the time of recovery of the bodies. In the remaining three cases, one was alive after 55 minutes but believed to be dead after 80 minutes in the water, while there are few facts upon which to base estimates of survival time for the other two persons, who are presumed dead within 55 to 70 minutes. Hence one out of six persons is presumed to have succumbed within half an hour and there is a possibility that two others died within the same period.

It is relevant to note that of the five persons who failed to reach the surface alive, at least two were overcome while attempting to escape from the helicopter, while one was found on the seabed, and appeared to have been successful in exiting the helicopter. Four of the five had successfully released their seat belts. It is possible that their efforts to escape and reach the surface were hindered by the 'cold shock' of sudden immersion in the sea and consequent loss of breath-holding capability.

Of further interest is the fact that of the six persons who survived the initial impact but subsequently died, five are reported to have flooded suits. It is likely that this will have prejudiced their prospects of survival. In at least one case the weight of water inside the suit is reporting as making it impossible for the crew of the rescue craft to recover the body which had to be recovered some time later.

In an earlier accident, the sinking of the Ocean Ranger off Newfoundland in February 1982, none of the crew survived the accident (NTSB, 1983). It appears that the last known communication with the vessel was made at 0130 hours, at which time the crew went to lifeboat stations. The standby vessel arrived on the scene at 0150 hours and observed persons on board a lifeboat which had been damaged. In attempting to evacuate survivors from the lifeboat, the boat capsized and some of those on board fell into the sea. Some of them clung to the lifeboat for a minute or two but then let go and began to drift away. They failed to grab hold of either lifelines or a liferaft thrown to them by the crew of the standby vessel. It is apparent that in the cold winter sea conditions, the survivors who were not equipped with immersion suits succumbed within minutes to cold shock and hypothermia.

5.4 PRESENTATION OF DATA

Data from incidents, modelling predictions and trials relating to cooling are presented in Tables 2 to 4. The times in minutes to reach a core temperature are referenced within these tables.

Considerable variation exists between the data sets and within them. However there is a clear trend observable in that modelling techniques tend to predict the longest survival times for a given set of conditions. Incident data, where available, indicates the shortest times.

The differences between the data sets is understandable in that mathematical modelling generally assumes that the subject is at rest in still water, with no allowance being made for other factors such as the effects of wave action or physical movement. Some of the trials referenced do expose the subject to wave action, but the degree of water movement which it is practical to simulate is relatively low compared to typical sea conditions. Survival times from the very limited amount of incident data therefore are unique in representing the full range of threats to the individual, and not merely gradual cooling. These are clearly the most relevant data; however the paucity of reliable data from this source forces us to consider the use of experimental and modelling data to supplement the incident data.

Very little of relevance to the objectives of this study can be said regarding the wide range of variance for the data within each set. For example the mathematical modelling studies used different criteria for the onset, contribution and duration of shivering. Much of this is difficult to define by ethically acceptable experimentation. Likewise the wide range of experimental differences represented in Tables 2 to 4 have a significant effect on the results obtained.

We have therefore been highly selective in using data from the literature. The mathematical model cooling predictions are based upon the Wissler model as modified by Hayes and Cohen (1987) and the experimental data deemed to be most relevant are those from Tipton (1995c) and Steinman (1985) relating to enhanced cooling rates due to movement.

The approach used to predict survival times relevant to practical conditions likely to arise in the North Sea is described in Section 6.

6. APPROACH ADOPTED TO DEFINE LIKELY SURVIVAL TIMES

Section 5 identified the inherent limitations of the data obtained from mathematical modelling, trials and incidents. We have therefore adopted a pragmatic approach which aims to take account of the primary threats to life and contributory factors identified in Sections 3 and 4 respectively.

In doing so we have focused on immersion times of less than three hours. The complete immersion system - suit, lifejacket and clothing worn under the suit - should be able to keep the wearer alive long enough for the rescue services to find and recover him. Although some systems may possess the capability to keep the wearer alive for extended periods of time provided that conditions are generally favourable, in practice if a group of men in the sea are not rescued within about three hours, they are likely to be so scattered and separated that locating them will be extremely difficult (Robertson, 1989). There is thus an additional threat to the individual as the time to rescue is extended.

6.1 METHOD

Despite the weaknesses and limitations of the mathematical modelling technique, in the absence of reliable experimental and incident data, modelling remains the best available option to use **as a starting point** for assessing survival times.

The method adopted by this study has therefore been to use the most accepted mathematical model of the resting 2nd percentile thin offshore worker to predict the time to reach a rectal temperature of 34°C. At this point it is assumed that the immersed person will be incapable of self help and hence at a particularly high risk of drowning.

Having identified the times taken to reach a core temperature of 34°C for the resting subject in still water conditions, wherever possible these times have then been modified to take account of the additional factors identified in Section 4 and listed in Section 6.5 below. These are primarily associated with the influence of turbulent sea and suit leakage on the individual, and serve to reduce the original estimates of survival time.

6.2 THE 'STANDARD MAN'

It is assumed that the person to be modelled i.e. the study 'standard man' is thin, falling within the thinnest two percent of the offshore population. Hence he does not benefit from any of the advantages conferred by additional body fat insulation. It is assumed that he is of average fitness, is uninjured, and is not in a distressed psychological state or prone to panic. He is not suffering from extreme seasickness or dehydration. In terms of equipment he is wearing a lifejacket in all conditions.

Thus the 'standard man' may be deemed to be somewhat disadvantaged in comparison to his fatter colleagues, but otherwise is relatively well placed. Those who benefit from having greater amounts of body fat than the 'standard man', may be better placed to survive for longer than the time ranges presented in the results of this study. A few individuals may gain further advantage by being extremely water confident, having equipment with effective buoyancy characteristics and being of above average fitness. However others may be at a considerable disadvantage compared to the 'standard man' due to injury, poor motivation, lack of fitness, lack of essential equipment such as a truly effective lifejacket and so on. These are the most vulnerable individuals who are unlikely to be able to achieve the upper bounds of the predicted survival time ranges.

As already noted, it is assumed that the 'standard man' is wearing a lifejacket in all conditions. Any person who enters the water without either an immersion suit or a lifejacket i.e. wearing only working clothes, will have no means of additional buoyancy and hence the prospects of survival are likely to be poor for that individual. The risk of drowning will further increase in cold water and as surface conditions deteriorate.

It is assumed in the results that a proportion of individuals who are suddenly immersed in cold water will succumb to the effects of cold shock and will drown within a very few minutes of immersion. The results of this study take account of this, in that the predicted survival times are presented in ranges within which individuals may succumb. These ranges run from the time of initial immersion to the upper bounds of when it becomes unreasonable to expect the 'standard man' to survive in the prevailing conditions. For example a time range presented as "within half an hour" assumes that some individuals may drown as a consequence of cold shock within the first few minutes, but that the 'standard man' who survives this initial cold shock may have a good prospect of survival for up to half an hour.

Post-immersion collapse is also a well recognised phenomenon, described earlier in this report. However it has not been possible to devise a mathematical factor to account for this in the results. It should therefore be borne in mind that some of those survivors who are recovered alive from the sea may succumb soon afterwards.

6.3 THERMOREGULATORY MODEL PREDICTIONS

There are several mathematical models in existence which can be used to predict cooling times for differing insulation levels and water temperatures (Wissler, 1964; Montgomery, 1974; Nishi, 1977; Richardson, 1985; Werner, 1994;). It should be noted that these models were generally not originally designed for this specific purpose, but rather were developed to assist with predicting the insulation required to protect against the effects of cold immersion for specific periods. The experimental data used to validate these models are necessarily limited in terms of subject numbers and rates of cooling (Nunneley, 1985) and are liable to individual subject variations and differing experimental conditions.

Of the models available the Wissler model (Wissler, 1964; Nunneley, 1985; Wissler, 1985) appears to be broadly accepted for predicting times to a rectal temperature of 34°C in calm, resting conditions. It has been adopted by the five nation Air Standardisation Consultative Committee as being the most relevant model for estimating insulation requirements against rescue times for aircrew flying over cold water (Allan, 1983b). It is known that estimates of cooling rates beyond the onset of metabolic fatigue are unreliable. Thermal fatigue is sensitive to a variety of environmental and physiological parameters, which are not reported in sufficient detail in experimental studies to enable workers to make reliable use of the data (Shender, 1995). However the time taken to reach a rectal temperature of 34°C, rather than to a lower temperature, requires less extrapolation from experimental data, and thus provides some degree of confidence in the model's predictions.

In using modelling techniques to predict survival times, it is prudent to use 'reasonable pessimism' in assessing the risks of cold water immersion, and to provide protection for the most susceptible individuals (Allan, 1983a; Nunneley, 1985). The Wissler model represents a generalised human male thermoregulatory response. The variability in individual responses underscores the inherent limitations of modelling and reinforces the need to adopt a conservative approach to predicting survival times.

To this end the Wissler model can be programmed to predict the cooling of the nth percentile thin man. It has in the past been found to be rather pessimistic, and therefore different workers have introduced modifications to the model to better reflect human physiology. For the purposes of this study, the Wissler model incorporating the modifications introduced by Hayes and Cohen (Hayes, 1987) has been adopted as the starting point for calculating survival times. The modified Wissler predictions for cooling to a rectal temperature of 34°C in the resting man with different levels of insulation and water temperatures are presented in Figure 2.

The cooling predictions in Figure 2 form the basis of the sequence of stages required to estimate the probable survival times in this study. An early study using the Wissler model adopted the 10th percentile thin man derived from a study of 2000 RAF airmen to predict immersion protection requirements (Boulton, 1973). Hayes and Cohen used the 10th percentile thin man from an anthropomophic study of a population of USAF airmen (Hayes, 1987). A further study (Light, 1986) provided anthropomorphic data on a population of 419 UK offshore workers. Comparison of these populations indicates that the UK offshore worker appears to be significantly fatter than either of the airforce populations. The initial survival times used in this review based upon the 10th percentile USAF population most closely represents the 2nd percentile thin offshore worker. This degree of conservatism is considered essential in order to take account of some of the many unquantifiable factors threatening survival which were identified earlier (ie. fitness, psychological state, in-water competence, gender, age, flotation angle, lifejacket/suit compatibility, and individual buoyancy characteristics).

The Wissler model assumes calm resting conditions wearing pre-defined levels of insulation. It does not model physical effort and hence makes no allowance for changes in perfusion and heat loss due to turbulent sea conditions. It also assumes a starting core temperature of 37°C, which may be optimistic if the individual has cooled prior to immersion, but in turn may be somewhat pessimistic if the individual has been exercising before immersion (Shender, 1995).

Taking account of these limitations of mathematical modelling techniques, the following pragmatic assumptions and factors for varying conditions have been applied in order to derive probable survival times.

6.4 ASSUMED PRIMARY THREATS

The primary threat to survival is deemed to be drowning rather than purely hypothermia (ie defined as death directly attributable to cold-induced failure of the vital organs). This applies to all conditions, including summer and winter sea temperatures, calm and turbulent water and all suit/clothing combinations. However, severe chilling to a core temperature of 34°C will influence all conditions, except those where the immediate threat of drowning is predominantly due to turbulent seas or cold shock. The assumptions underlying the survival predictions are:

- Cold shock is likely to be a significant threat to survival in water temperatures of 10°C or less. This threat is likely to remain even when membrane suits are worn unless extra clothing is worn under them. Cold shock with an insulated suit is unlikely to be a significant threat.

- In calm water (defined here as associated with Beaufort wind force 0-2) with no significant wave action and assuming the individual survives the initial cold shock, reduced consciousness at a core temperature of around 34°C is a probability. In this case the head can often fall to one side within the lifejacket and immerse the mouth and nose. Hence time to a core temperature of 34°C drives the survival time predictions for calm conditions.

- In moderate surface conditions (defined here as associated with Beaufort wind force 3-4) a combination of the effects of occasional wave action and cold induced unconsciousness is likely to apply. The Wissler model predictions of survival based on time to a rectal temperature of 34°C have been reduced to account for the additional effects of wave action, together with enhanced heat loss due to exercise induced vasodilation and the increase in the heat transfer from the limbs together with the probable increased suit leakage resulting in a loss of buoyancy and the earlier onset of fatigue.

- In turbulent seas (defined here as associated Beaufort wind Force 5 and over) it is assumed that the individual is likely to be subject to steep breaking waves. In these conditions continued maintenance of the optimum buoyancy distribution is essential. The assumption here is that suits will leak and lifejackets will work loose. This will make it difficult to sustain and protect an airway, eventually leading to aspiration of water and drowning. The time to a core temperature of 34°C becomes less relevant in these conditions.

- In turbulent seas it is assumed that individuals wearing an effective single-lobe lifejacket and an insulated immersion suit will be less at risk than an individual wearing a twin-lobe lifejacket and a membrane suit which has a significant amount of leakage. These latter individuals will be continuously exposed to wave action and potential submersion of the airway, posing a cumulative risk of drowning which is related to immersion time.

- It is assumed that a completely flooded membrane suit is reduced in thermal protection effectiveness to the insulation value provided by saturated working clothes.

6.5 'RULES' TO ACCOUNT FOR TURBULENT WATER AND SUIT LEAKAGE

Based on the limited data available, the following pragmatic 'rules' have been applied in sequence to the predicted survival times for calm water conditions to derive times for turbulent water and suit leakage. The factors applied are cumulative. Results have been rounded to the nearest quarter of an hour.

All suit/clothing types

- In calm conditions the Wissler model survival time predictions for the 2nd percentile thin man to reach a core temperature of 34°C will determine survival times (Figure 2).

- Reduction of 50% in predicted survival time for the physical effort required in sea conditions associated with winds of Beaufort Force 3 and above (see 4.2.2). This applies to all suit types and sea temperatures, and is to account for the effects of vasodilation, fatigue and possible inhalation of water.

The factor of 50% reduction in predicted survival time for physical effort has been derived primarily from the experimental data referenced in Section 4 (White, G, 1979), which indicate that the time taken to reach a pre-defined core temperature may reduce by 50% in turbulent water conditions. This is supported by earlier work which identifies that exercise in water below 25°C accelerates the fall in body core temperature (Carlson, 1958; Keatinge, 1961b; Beckman, 1963).

Suit Leakage (all suit types)

- In clam conditions the Wissler model survival time predictions for the 2nd percentile thin man to reach a core temperature of 34°C, with 1 litre of leakage within the suit and consequent loss of insulation, will determine survival times (Figure 2).

Data indicate that 1 litre leakage in a membrane suit is predictable in many circumstances and that a loss of insulation of over 40% can be expected to result from this level of leakage. The corresponding reduction in predicted survival times have been derived by obtaining times for survival with this reduced level of insulation (Figure 2).

Increased In-Water Inertia (membrane suits only)

- Reduction of an additional 10% in predicted survival time, in moderate water conditions and above (defined as Beaufort wind force 3 and above) with 1 litre of leakage, to account for increased inertia in the water due to loss of buoyancy.

This factor reflects the fact that the persons in-water inertia will increase as his buoyancy decreases with the additional water within the suit. As sea conditions deteriorate, the immersed person will move out of phase with the waves, and his airway will be submerged for longer periods of time as the wave height increases. The risk of inhalation of water will increase, and the person will become fatigued by the physical swimming efforts required to try to maintain his airway above the water. The risk of drowning is consequently increased.

6.6 WORKED EXAMPLES

The following are presented as worked examples to demonstrate the methodology adopted by the study:

Example 1

A group of uninjured survivors are immersed in moderate seas associated with Beaufort wind Force 3, with a sea temperature of 5^0 C. The survivors are wearing membrane suits with lifejackets. It is assumed that one man in the group represents the 'standard man' and that no water leaks into his suit.

The first threat to the group is posed by the inhalation of water immediately after the sudden shock of immersion, due to the inability to control breathing. This is a significant risk to survival in 5^0C water even though they have some thermal protection from their membrane suits. It is impossible to quantify the risk other than to say that there is a significant risk of drowning at the time of initial immersion. For the purposes of this example, the further optimistic assumption is made that all survive the initial immersion.

From Figure 2, the 'standard man' adopted by this study is assumed to cool to a core temperature of 34^0C in 2 hours for calm water conditions with no movement. However in sea conditions associated with Beaufort wind Force 3, physical movement will reduce the time to 34^0C by 50% i.e. to one hour.

Example 2

The same conditions as in Example 1 apply for the standard man. However in this case the membrane suit leaks, reducing the insulation value of clothing worn under the suit. A leakage of 1 litre is probable. From Figure 2, the predicted time to cool to a core temperature of 34^0C in calm conditions with this level of reduced insulation is about 80 minutes. In the sea conditions associated with Beaufort wind Force 3, a reduction of 50% in the survival time is predicted to take account of physical movement, reducing the time to 40 minutes. In addition the leakage into the suit will increase the in-water inertia of the immersed person, exposing him to an increased risk of submersion of the airway as waves break over his face and requiring greater swimming efforts to try to protect the airway. An additional 10% reduction in predicted survival time is applied to account for increased risk of inhalation of water, reducing the predicted time to 36 minutes (rounded down to half an hour).

Example 3

The 'standard man' is immersed in water at a temperature of 13°C, wearing an insulated suit. Sea conditions are those associated with winds of Beaufort Force 3. From Figure 2, the predicted time to reach a core temperature of 34°C is greater than 12 hours for calm conditions. A reduction of 50% to take account of the effects of movement will give a predicted survival time of at least 6 hours. This is shown as greater than 3 hours in the results, because of the need to locate such survivors within about 3 hours, before the risk of them becoming scattered over a wide area is considered to be too great.

7. RESULTS

Using the "reasonably pessimistic" rules together with the data in Sections 3 and 4 and the pragmatic factors identified in Section 6, **the broad estimates of likely survival times for the 2nd percentile thin offshore individual are given in Table 5.** It is important to recognise that these times give an indication of the time period within which individuals in a group of survivors will begin to succumb to the prevailing conditions. The time estimates are presented in ranges to indicate the upper boundaries where the probability of survival becomes increasingly less likely.

The predicted time ranges are for the 'Standard Man' i.e. a reasonably fit individual, within the 2nd percentile grouping, who is not significantly incapacitated by injury, sea sickness etc. The fatter, highly motivated, fit individual who is water-competent and wearing an effective lifejacket which gives adequate mouth clearance above the waves is likely to exceed these time ranges. The survivor who is incapacitated, weak, wearing ineffective survival aids and close to panic might only achieve survival times in the lower bounds of the time ranges.

As already noted, a number of individuals will succumb within the first few minutes of immersion due to the cold shock response and consequent increased risk of drowning. These individuals are reflected within the time ranges presented. A further number of individuals may not survive the immersion experience due to the effects of post rescue collapse; it has not been possible to account for this increased risk in the time predictions because it does not affect the time ranges per se, although it does impinge upon the prospects of survival.

The time ranges presented cover the period from time of initial immersion up to 3 hours afterwards. Immersed persons may be able to survive for longer than this under favourable conditions. However survivors who are immersed in the sea for extended periods of time will inevitably become scattered, due to the influence of wind and tide and individual swimming efforts. This will increase the difficulties for the rescuers in locating them and will increase the risk faced by those in the water as the time to recovery is extended. Hence any rescue system should be designed to ensure that survivors are recovered from the sea before it is likely that they become widely separated.

Inevitably predictions based upon the approach described will be contentious to the scientific community. However, it is considered justified in the absence of hard data and the need to provide practical estimates. This is especially so in the light of the considerable range of possible values and outcomes for each of the parameters to be evaluated.

8. MITIGATION

The five stages of physiological response to cold water immersion described in Section 2 can be condensed down to three primary phases of threat to a person immersed in the water:

i. drowning due to cold shock on initial immersion and inability to control breathing.

ii. drowning due to inhalation of water at a later stage of the immersion, having survived the initial cold shock, with gradual cooling contributing to a deterioration in the person's ability to maintain a clear airway.

iii. post-immersion collapse after recovery from the water.

It may be possible to reduce the risks presented during each of these three phases, by the adoption of effective measures to inform and train those who may be at risk, and those who may be responsible for the recovery of persons immersed in the sea, and by the provision of fully effective survival equipment.

Cold Shock

This is the threat which is least amenable to mitigation for any set of circumstances. The primary aim is to reduce the sudden fall in skin temperature. The only practical approach to this problem appears to be prior training to ensure that the individual is aware of the need to clad himself with as much thermal insulation as is practical in the time available to him prior to immersion, and to ensure that his suit is fully zipped up.

Subsequent Drowning

The dominant factor in circumstances where the individual survives the initial immersion is to provide high levels of strategically placed buoyancy. Immersion suits, particularly those with inherent thermal insulation material, can provide significant amounts of buoyancy which will raise the body to a horizontal floating position. Without a suitable lifejacket the person wearing a buoyant immersion suit is equally stable face-up or face-down. If in the latter position, a significant amount of effort is required to turn over to a face up position. Providing a high buoyancy, single lobe lifejacket with a large collar not only aids with self-righting but keeps the head high out of the water. The collar lifts the head, while the high buoyancy reserve is required to lift the individual against the inertia forces as a wave passes through. Without a considerable buoyancy reserve there is a tendency for the wave to break over the survivor rather than him being lifted over it. The single lobe of the buoyancy compartment also acts as a wave-breaking device when the person is floating face into the waves, which is the stable position with large volume lifejackets. On the other hand, twin lobe lifejackets tend to channel the water directly into the survivors face, making it unnecessarily difficult to maintain breathing (RGIT, 1988).

Post Immersion Collapse

The person who has been immersed for a prolonged period and is recovered from the water loses the hydrostatic assistance to circulation, leading to a collapse of blood pressure and consequent reduced cardiac output. Hypoxia in the vital organs and brain may follow. A rescue which involves a vertical lift from the water may compound the seriousness of the situation.

The provision of rescue equipment which enables a survivor to be lifted from the water in a horizontal position will probably be beneficial. In addition training for rescue crews should include awareness of the threat posed by post-immersion collapse, and practice in the recovery techniques available which are least likely to lead to a deterioration in the survivors condition. Those responsible for immediate after-care and first aid should likewise be made aware of the causes and potential consequences of post-immersion collapse and receive training in how to handle such patients.

9. CONCLUSIONS

From a comprehensive review of the literature encompassing thermal physiology, incident data and survival equipment trials, it can be concluded that:

1. For a group of **uninjured** survivors immersed in the North Sea in typical winter conditions and wearing twin-lobe lifejackets and membrane immersion suits, the first individuals will probably begin to succumb within a time range defined by the first few minutes of immersion to half an hour later. Survival estimates which are significantly above this time range for similar conditions probably include an unjustified degree of optimism.
2. The provision of readily sealed insulated suits to UKCS offshore workers is likely to significantly extend probable survival times in winter, provided these suits do not hinder escape to the sea.
3. A key factor in an individual's ability to survive is the provision of effective buoyancy, preferably by means of a lifejacket which supports the person's head above the waves and assists in maintaining a clear airway. Although an immersion suit, particularly an insulated one, will provide some buoyancy, it will not be effective in providing adequate support to the head. Therefore failure to wear an effective lifejacket will compromise the prospects of survival. The probable prospects of survival for an individual who enters the water with neither a lifejacket nor an immersion suit are likely to be very significantly reduced.
4. Data pertinent to predicting survival times can be found in a range of studies, but no single study appears to take account of all the potential factors affecting survival. Experimental trials are limited in scope and cannot adequately reflect the conditions which are likely to be met in the North Sea. Thermal modelling studies focus solely on physiological constraints, have limited validation and are unlikely to take into account other factors which may have a greater bearing on survival, such as the provision of effective buoyancy. Given these difficulties, it is unrealistic to assume that any predictions of survival times can be regarded as being precise and accurate. At best they provide an indication of the likely timescale within which the first individuals will begin to succumb to the prevailing conditions.
5. Individuals in the water will become scattered as immersion time increases, making location difficult and increasing the risk to the individual. Therefore even in favourable conditions where it is predicted that the individual is capable of survival for a prolonged period, the search and recovery procedures should be designed to locate and rescue immersed persons within approximately 3 hours.

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	BEAUFORT WIND FORCE		
	0-2	**3-4**	**5-12**
% of Summer * observations	23%	45%	32%
% of Winter * observations	15%	40%	45%

* Summer defined as period when air temperature is greater than 10°C

** Winter defined as period when air temperature is 10°C or less

Table 1
Wind Force Distribution (Derived from White, P, 1989)

WORKING CLOTHING	**WATER TEMPERATURE**				
Data Source	-2 to 0°C	1 to 3°C	4 to 7°C	8 to 10°C	11 to 15°C
Incident		To unconsciousness <5 mins (10)			
Trials			Tr35 **50mins** (2)		Tr36 **35mins** (18) Tr34.5 **65mins** (16) Tr34.5 **45mins** (16)
Theory	Tr34 **24mins** (1)	Tr34 **25mins** (1) Tr34 **90mins** (13)	Tr34 **30mins** (4) Tr34 **20mins** (11) Tr26 **85mins** (7)	Tr34 **90mins** (11) Tr34 **40mins** (1)	Tr34 **60mins** (11) Tr26 **128mins** (7) Tr25 **216mins** (16) Tr25 **250mins** (16)

Notes: Trn = Rectal Temperature of n°C
(x) = Reference Number of Literature Source
Numbers in Bold = Times to Reach Core Temperatures (min)
e.g. Tr34 **24 mins** (15) = Time taken to reach rectal temperature of 34°C is 24 minutes (from Ref 15)

Table 2
Data Collated from Literature on Time to Reach Identified Core Temperature - Wearing Working Clothing

MEMBRANE SUIT		WATER TEMPERATURE				
	Data Source	-2 to 0oC	1 to 3°C	4 to 7°C	8 to 10°C	11 to 15°C
No Leakage Into Suit	Incident					
	Trials	Tr36 **120mins** (15) Tr35.5 **80mins** (14) Tr35 **170mins** (14)		Tr35 **78mins** (17) Tr35 **70mins** (18) Tr35 **60mins** (18)		Tr36 **45mins** (18)
	Theory		Tr34 **140mins** (9) Tr34 **90mins** (5)	Tr35.2 **260mins** (15) Tr34.8 **260mins** (15) Tr34 **330mins** (15) Tr34 **180mins** (1) Tr34 **106mins** (6) Tr34 **96mins** (3) Tr26 **189mins** (7)	Tr34 **135mins** (9)	Tr35 **150mins** (12) Tr34 **450mins** (11) Tr34 **180mins** (1) Tr34 **180mins** (1) Tr26 **331mins** (7)
With Leakage Into Suit	Incident			Presumed dead <30 mins (8)		
	Trials				Tr35 **40mins** (17)	
	Theory			Tr 35 **66mins** (9) Tr 34 **66mins** (6) Tr 34 **41mins** (6)		Tr35 **60mins** (12) Tr34 **120mins** (3)

Notes: Trn = Rectal Temperature of n°C
(x) = Reference Number of Literature Source
Numbers in Bold = Times to Reach Core Temperatures (min)
e.g. Tr34 **24 mins** (15) = Time taken to reach rectal temperature of 34°C is 24 minutes (from Ref 15)

Table 3
Data Collated from Literature on Time to Reach Identified Core Temperature - Wearing Membrane Suit

INSULATED SUIT		WATER TEMPERATURE				
	Classification	-2 to 0°C	1 to 3°C	4 to 7°C	8 to 10°C	11 to 15°C
No Leakage	Incident					Tr37 **90mins** (16)
	Trials	Tr35.7 **360mins** (14) Tr35.7 **270mins** (14) Tr34.9 **300mins** (14)		Tr36.5 **45mins** (17) Tr35.8 **360mins** (15) Tr35 **240mins** (17)		Tr36.3 **90mins** (16) Tr36 **90mins** (16)
	Theory			Tr34 **660mins** (11) Tr34 **330mins** (4) Tr30 **285mins** (17) Tr26 **642mins** (7)	Tr34>**900mins** (12)	Tr35 **200mins** (12) Tr34 >**900mins** (11) Tr30 >**900mins** (16) Tr26 **1384mins** (7) Tr25 **1200mins** (16)
With Leakage	Incident					
	Trials					
	Theory					Tr35 **120mins** (12)

Notes: Trn = Rectal Temperature of n°C
(x) = Reference Number of Literature Source
Numbers in Bold = Times to Reach Core Temperatures (min)
e.g. Tr34 **24 mins** (Ref 15) = Time taken to reach rectal temperature of 34°C is 24 minutes (from Ref 15)

Table 4
Data Collated from Literature on Time to Reach Identifed Core Temperature
- Wearing Insulated Suit

CLOTHING ASSEMBLY (WORN WITH LIFEJACKET)	BEAUFORT WIND FORCE [1]	TIMESCALE WITHIN WHICH THE 'STANDARD MAN' IS LIKELY TO SUCCUMB TO DROWNING	
		WINTER (WATER TEMP 5°C)	SUMMER (WATER TEMP 13°C)
WORKING CLOTHES (NO IMMERSION SUIT)	0-2	within $^3/_4$ hour	within 1$^1/_4$ hours
	3-4	within $^1/_2$ an hour	within $^1/_2$ hours
	5 and above	within significantly less than $^1/_2$ an hour	within significantly less than $^1/_2$ hours
DRY MEMBRANE SUIT WORN OVER WORKING CLOTHES - NO LEAKAGE INTO SUIT	0-2	within 2 hours	> 3 hours
	3-4	within 1 hour	within 2$^3/_4$ hours
	5 and above	within significantly less than 1 hour	within significantly less than 2$^3/_4$ hours
MEMBRANE SUIT WORN OVER WORKING CLOTHES WITH 1 LITRE LEAKAGE INSIDE SUIT	0-2	within 1$^1/_4$ hours	within 2$^1/_2$ hours
	3-4	within $^1/_2$ an hour	within 1 hour
	5 and above	within significantly less than $^1/_2$ an hour	within significantly less than 1 hour
DRY INSULATED SUIT WORN OVER WORKING CLOTHES - NO LEAKAGE INTO SUIT	0-2	> 3 hours*	> 3 hours *
	3-4	> 3 hours	> 3 hours*
	5 and above	⩾ 3 hours	> 3 hours
INSULATED SUIT WORN OVER WORKING CLOTHES 1 LITRE LEAKAGE INSIDE SUIT	0-2	> 3 hours	> 3 hours*
	3-4	within 2$^3/_4$ hours	> 3 hours*
	5 and above	within significantly less than 2$^3/_4$ hours May well exceed 1 hour	> 3 hours*

* Any times estimated in excess of 3 hours are shown as > 3 hours (See Section 6 and Section 9, conclusion 4)

[1] See Section 4.3.2 for reasons for using wind force

[+] Rounded to nearest $^1/_4$ hour

Table 5
Timescale Within Which the 'Standard Man' is Likely to Succumb to Drowning

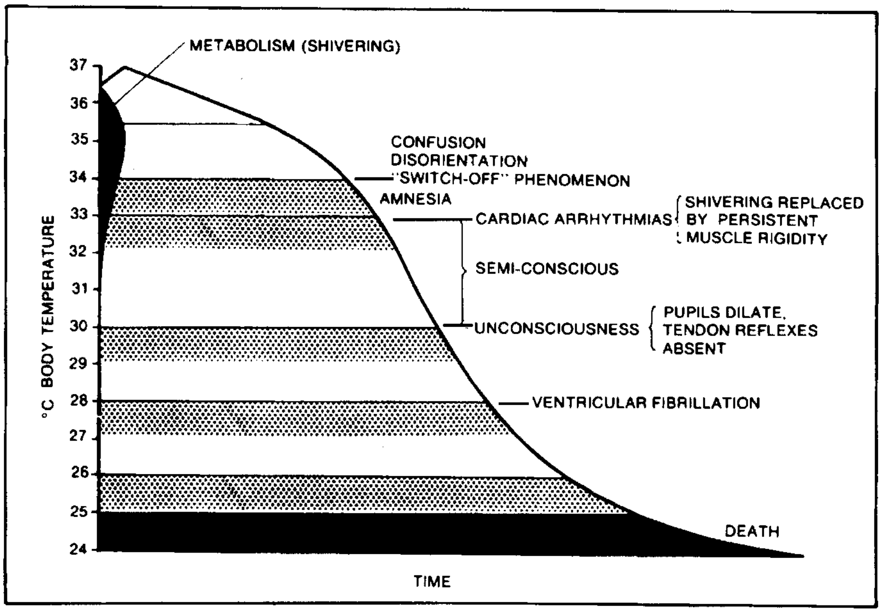

Figure 1
Clinical Features of Acute Hypothermia (Edmonds, 1992)

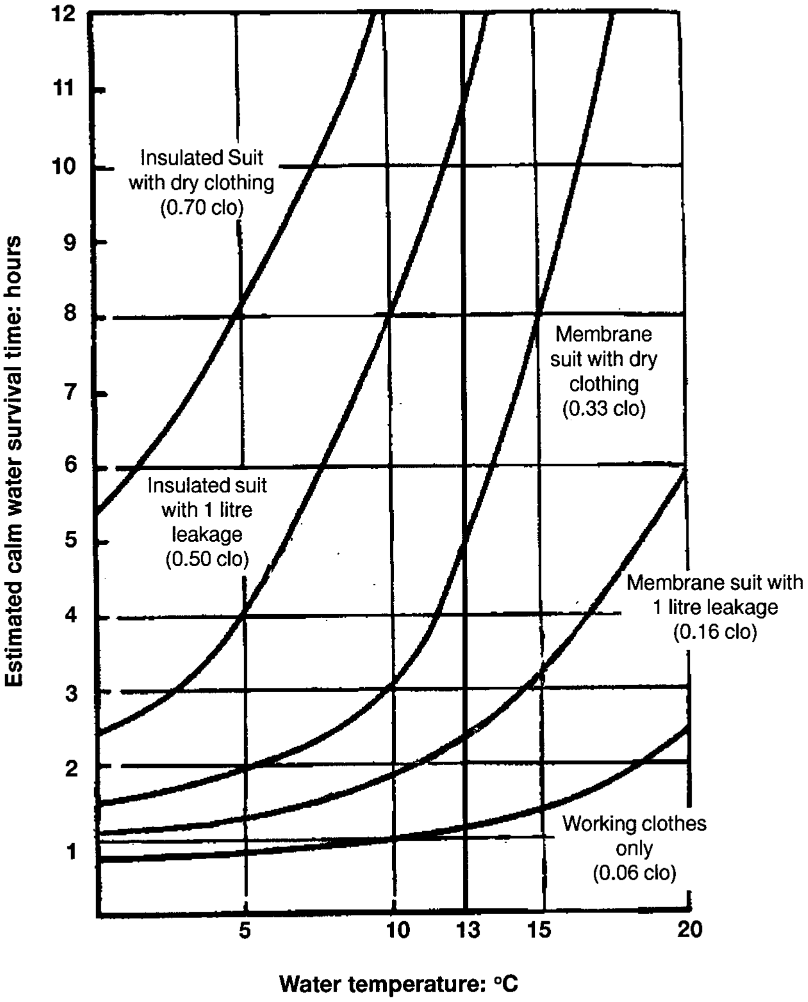

Figure 2
Predicted Survival Time Against Sea Temperature for Different Levels of Immersed Clothing Insulation - As Derived from Wissler Model, Modified by Hayes, 1987

GLOSSARY

Anthropometric	Conforms with the measurement of the human body
Asphyxia	Suffocation; cessation of breathing
Body Morphology	The form of the human body
Cardiac Arrest	Cessation of the heart's activities
Cardiovascular System	The heart and blood circulatory system
Cold Shock	The response of the body to sudden immersion in cold water, affecting the heart and respiration. There is an immediate inspiratory gasp, followed by uncontrollable hyperventilation, increased heart rate, constriction of the blood vessels at the surface of the body, and consequent increase in blood pressure. The immersed person may be unable to control their breathing and drown, or may experience heart failure due to the increased work demand on the heart
Comatose	In a state of coma
Diuresis	Increased secretion of urine
Diving Response	A fall in heart rate during breath-holding, associated with facial immersion in water
Drowning	Death from acute asphyxia while submerged under water, whether or not liquid has entered the lungs
Hydrophobic	Water repellant
Hyperventilation	Rapid, deep breathing
Hyopthermia	Below normal body temperature (may be clinically defined as a deep body temperature of 35^0C)
Percentile	A value of the parameter of interest associated with the sample population divided into 100 equal groups
Marine Anthropomorphic Manikin	A physical model conforming to the (size) and density of the human body components
Metabolism	Process by which nutritional energy sources are utilised to maintain cellular function
Motor Function	Muscular activity

Thermal Modelling	Use of mathematical techniques to simulate the body's metabolic response associated with any given set of body and environmental temperature conditions
Thermogenesis	The metabolic production of heat
Thermoregulation	The control of heat production by the body
Subcutaneous	Beneath the skin
Vasoconstriction	Narrowing of the blood vessels
Vasodilation	Widening of the blood vessels
Ventilation	Exchange of gas through the lungs
Vital Organs	The organs of the body essential to maintain life and metabolism e.g. the brain, heart, liver etc
Post Immersion Collapse	Collapse due to the effects of prolonged immersion in cold water. The physiological reponses include vasodilation, a rapid fall in blood pressure due to gravity-induced pooling of the venous blood in the lower limbs; consequent increase in heart rate to compensate for the fall in blood pressure; inadequate cardiac filling; and reduced blood and oxygen supply to the brain.