National Research Council Canada | Conseil national de recherches Canada
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HUMAN PERFORMANCE IN IMMERSION SUITS

Prepared for:
The Honourable Robert Wells, Q.C.
Offshore Helicopter Safety Inquiry

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Introduction

The National Research Council of Canada’s Institute for Ocean Technology (NRC-IOT) is committed to the development of technologies that preserve human life at sea. Of particular importance are those technologies that allow survival in harsh environments, in the event of accident or system failure. The Institute’s Marine Safety Research Program is wholly dedicated to the characterization of safety equipment performance in extreme conditions, for use by private and public sector clients to increase the safety of those who work or travel at sea. One of the driving goals of the program is to address the knowledge gap that currently exists between the performance of Life Saving Appliances in the calm water conditions they are often tested in, and in the real world situations in which they are often used. The following is a summary of research on human performance in survival suits, both at NRC-IOT and elsewhere, and its implications for safety regulation in the offshore industry

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1.0 Review of Existing Work

A large number of individuals work or travel over the cold ocean waters off the east coast of Canada every day. Immersion in cold water represents a significant risk to those both at leisure and at work in the country. If an unprotected human is suddenly immersed in cold water, a series of physiological responses termed the “Cold Shock Response” (CSR) occurs and is responsible for the majority of drowning deaths in cold water within the first few minutes of immersion [8]. Upon sudden immersion in cold water, a person can experience a large involuntary gasp [4] and hyperventilation [11]. These sudden changes in respiratory responses increase the likelihood of aspirating water upon immersion in cold water, leading to death by drowning as opposed to hypothermia, which is defined as a drop in deep body temperature of 2°C or more. Even in unprotected individuals, hypothermia does not usually occur before 30 minutes of immersion [11]. Additionally, an increase in cardiac output is caused by immersion in cold water [11]. While this increased cardiac output is of little danger to healthy individuals, it can be lethal to people with pre-existing cardiac conditions such as hypertension or heart disease [17].

The best approach to protecting people from cold water is to keep them out of it. In an emergency situation, however, there is always a chance that people will be immersed in water. In these situations, immersion suits can greatly increase the chance of a person being able to avoid the CSR and prolong their survival times. Current Transport Canada (TC) regulations require immersion suits to be carried on board all class 9 ships and higher in sufficient quantity so that every person has one. Offshore oil installations follow a similar policy.

Immersion suits are usually a one piece suit system that provides thermal protection and buoyancy to the wearer [2]. Immersion suit systems can be loosely placed into two separate categories: marine abandonment suits, and helicopter transportation suits. The most appreciable difference between the two styles of suits is highlighted in the scope for the standard of each one. Both styles of suits are meant to reduce thermal shock, delay the onset of hypothermia, provide acceptable flotation and minimize the risk of drowning [1-2]. The largest difference between the two suits is with respect to buoyancy, with the marine abandonment suit not having a maximum buoyancy requirement and the helicopter transportation suit requiring a specified minimum and maximum levels of buoyancy.

The Canadian General Standards Board (CGSB) requires both helicopter and marine abandonment suits systems to have their thermal protective properties tested. The thermal protective properties can be tested using either human participants or thermal manikins. For human participant tests, deep body temperature is measured using a rectal thermistor; the skin temperature of the index finger and large toe are also measured. The participant is immersed in calm, circulating water with a temperature between 0-2°C for up to 6 hours. The test is terminated if the participant's deep body temperature drops 2°C lower than baseline conditions (hypothermia), if the finger or toe skin temperature drops below 5°C, or if the attending physician determines that the participant should not continue [1]. When testing with a thermal manikin, the suit system has to have a mean level of thermal insulation of at least 0.75 Clo [1-2]. Where, 1 clo = 0.18°C/m^2/W, which is equal to the amount of clothing insulation required to keep a person comfortable in 21°C air moving at 0.1m·s^{-1}, and less than 50% relative humidity [8].

Previous work by Hayward highlights how important immersion suits are to a person's ability to survive a sudden immersion in cold water. Ten males and ten females dressed in light clothing performed immersions in 0°C water. Within 30 minutes of immersion, the participant's deep body temperature dropped by 2.0°C, and they experienced a 49% increase in heart rate after only 2 minutes in the water [10]. In a subsequent study Hayward examined the effects of immersion in 1.0°C water on thirty males who were wearing dry, insulated survival suits. The mean decline in deep body temperature was significantly less, 0.8°C over six hours, when wearing survival suits compared to just light clothing [10]. As well, there was no significant increase in heart rate for the males wearing the survival suits compared to the volunteers wearing only light clothing[10-11].

As effective as immersion suits are, a knowledge gap currently exists between the calm testing conditions used to determine a human's thermal responses in immersion suits, and a real world scenario where a person could experience high winds and waves. Hayes et al. attempted to address this knowledge gap, reporting that "Other factors which are of importance [for survival] but are extremely difficult to quantify, are the sea conditions of waves and splash, and the effectiveness of the survival aids in fair and adverse conditions" [9]. The authors examined the effect of wave motion on study volunteers who were wearing a variety of clothing ensembles across a range of water temperatures. The clothing ensembles varied from semi-nude in 30.0°C water, to flight suits with a Clo value of 0.84 in 7.0°C water. The authors found that the rate of cooling was higher in waves in 8 out of the 10 cases tested, but the results were not statistically significant [9]. They suggest that the detrimental effects of waves are more pronounced when wearing little clothing, however they state that the importance of proper neck/face seals for suits is important in any appreciable level of wave motion. Hayes et al. concluded that their study demonstrated a trend for waves to increase cooling in some cases, but a more definitive experiment would be required.

Later work by Steinman et al. examined the effects of rough seas on the thermal protective properties of a variety of suits, including wet suits, coveralls, and dry immersion suits [16]. Calm water tests were performed in the ocean near a set of docks with a mean water temperature of 10.7°C, no wave action, and wind speeds between 2.5-5.0$m \cdot s^{-1}$. A 44-foot motor lifeboat and a 17-foot rigid hull inflatable boat generated rough sea conditions. The boats were able to produce 1-2m swells, 0.5m chop, with occasional 1.5m breaks in the 11.1°C water, with wind speeds ranging from 5-10$m \cdot s^{-1}$. The authors found that the rate of decline in deep body temperature was significant greater for some clothing ensembles in the rough weather conditions compared to calm [16]. Oddly, one of the two immersion suits had a significantly greater rate of cooling in calm conditions compared to rough seas. There were no significant differences in the rate of deep body cooling between calm and rough seas for the second immersion suit tested. The authors conclude that immersion in rough seas may result in significantly lower survival times than those estimated from calm water [16].

The results from Steinman et al.'s work suggest that rough sea conditions may only significantly affect wet suit style garments, and that dry immersion suits may not be adversely affected. A limitation of the study is the lack of control over the environmental conditions. Due to the random nature of the wave action created by both boats, combined with the already random effects of the weather, it would have been extremely difficult to ensure that each of the every 8 volunteers experienced the same conditions as the other. It is possible that the lack of significant difference in cooling rates between calm and rough seas in the two styles of immersion suits could be attributed to variations in the conditions experienced by the volunteers. This is a common limitation of testing outside laboratory conditions, as the environmental conditions are strongly influenced by the weather that introduces a degree of randomization in what the volunteers experience.

A later study conducted by Tipton in a laboratory setting allowed for more control of the conditions experienced by the volunteers [18]. Ten healthy males volunteered to perform 2, 4-hour immersions in 4°C water using two different styles of helicopter passenger immersion suits. One suit did not provide any inherent insulation, while the other was an inflatable suit that used small CO_2 cylinders for inflation. The subjects wore swimming trunks, short-sleeved cotton vests, woollen socks, polyester/cotton long-sleeved shirt and long pants, and a polyester/cotton pullover. During the 4-hour immersions the environmental conditions consisted of 15cm waves generated by a wave maker, wind with an average speed of $3.1 m \cdot s^{-1}$, and a 9 litres of water sprayed every 15 minutes on the volunteers. The mean immersion time for the volunteers wearing the first immersion suit was 71.5 minutes. The immersions were ended for a variety of reasons including low deep body temperature, volunteer request, and low skin temperature. The mean immersion time for the second immersion suit was 189.5 minutes, with 4 of the participants completing the full 4 hour immersion, while the other 6 requested to end the test early. Tipton concluded that there exists a possibility for calculations to overestimate survival time if they are based on laboratory conditions that do not recreate the stresses placed upon a suit in adverse conditions during a real emergency. [18]. Tipton suggests that this limitation could be reduced if laboratory tests could be made more realistic, which would result in minimizing the discrepancy between laboratory based assessment of protection provided by a suit, and the actual level of protection provided in real world scenarios [18].

The immersion conditions used in Tipton's study [18] can be considered relatively mild compared to those found in the ocean. Remarkably, both helicopter immersion suits suffered large amounts of water leakage. The first suit had 1.32 litres of water leak into it after only 71.5 minutes of immersion, and the second had 2.2 litres [18]. A later study by Tipton and Balmi investigated how deleterious the effects of water leakage into suits can be [20]. Twelve male volunteers performed immersion in 10°C agitated water wearing an uninsulated immersion suit with a woollen insulating garment ("woolly bear") underneath. The volunteers performed 2 immersions dry, and 4 additional immersions with 200, 500, and 1000ml of water added to the suit. When 500ml of water was sprayed over the torso, it produced a rate in drop of deep body temperature between the 200 and 1000ml leak. Interestingly, when 500ml of water was applied over the limbs, it resulted in a change in deep body temperature equivalent to the no leakage conditions. The 500ml applied to the torso resulted in a 30% reduction in clothing insulation [20].

Tipton's previous work [18, 20], demonstrated that testing in calm water underestimates the performance of suits in rough sea states. The leakage of water into the suits in the previous studies resulted in a decrease in suit insulation, which may possibly explain the degradation in performance compared to calm conditions. Ducharme and Brooks investigated the effects of varying wave heights on heat flow in humans at NRC-IOT's facilities [7]. Six healthy males performed 9, 1 hour immersions in waves ranging from 0 to 70cm in height in steps of 10cm, with another immersion performed, vertically, in calm water up to the neck. The water temperature was 16.0°C, and the air temperature was 16.6°C. The volunteers wore uninsulated dry immersion suits with one-piece undergarments. Water leaked into the suits on only 2 of the 54 runs, with the leakage being estimated as only a few grams [7]. Deep body temperature was not affected by wave heights, but this is not unexpected given the duration of the immersion and temperature of the water and air. Mean heat flow was affected by wave height; with the larger waves (30cm and higher) producing a significantly greater amount of heat flow compared to calm water. Ducharme and Brooks concluded that the total thermal resistance of dry immersion suits is decreased by waves, compared to calm water, and that further studies are necessary to determine the practical limit of this reduction [7].

A large body of work has been completed to date that has examined the effects of rough sea states on human thermal responses. Earlier work has shown the importance of immersion suits [10-11] but these were limited to calm water pools. Later studies [9, 16] began to investigate the effects of rough sea states on volunteers, but the variability of the environmental conditions possibly resulted in a lack of conclusive results being produced. Later work [7, 18, 20] conducted in laboratory conditions clearly showed that wind and waves would result in degradation in immersion suit performance compared to calm conditions. In his paper "Immersion fatalities: Hazardous responses and dangerous discrepancies" Tipton discusses the potential for laboratory tests to over-estimate the performance of immersion suits [19]. Volunteers performed two separate immersions wearing the same clothing ensembles; with the only difference being one immersion was performed in 15cm waves, with periodic surface spraying, and $3.1 m \cdot s^{-1}$ of wind. These mild weather conditions resulted in a 30% reduction in predicted survival time when compared to the calm water immersions [19]. Tipton stated that tests defined in a standard must give an accurate indication of the level of protection offered by equipment during an emergency.

> "To do this, tests must either recreate the tasks which may have to be undertaken and the environmental conditions which may exist during an accident, or provide a reliable and valid way of predicting performance in such situations. If they do not, then there is a danger that 'approved' suits will be inappropriate, or not as appropriate as they might be".
>
> Tipton [19]

The result of not considering the environmental conditions where protective equipment is used, and the resulting human responses, will lead to a different level of performance compared to calm conditions. An excellent diagrammatic representation of the results of considering or ignoring these factors was created by Tipton, and is presented in Figure 1.

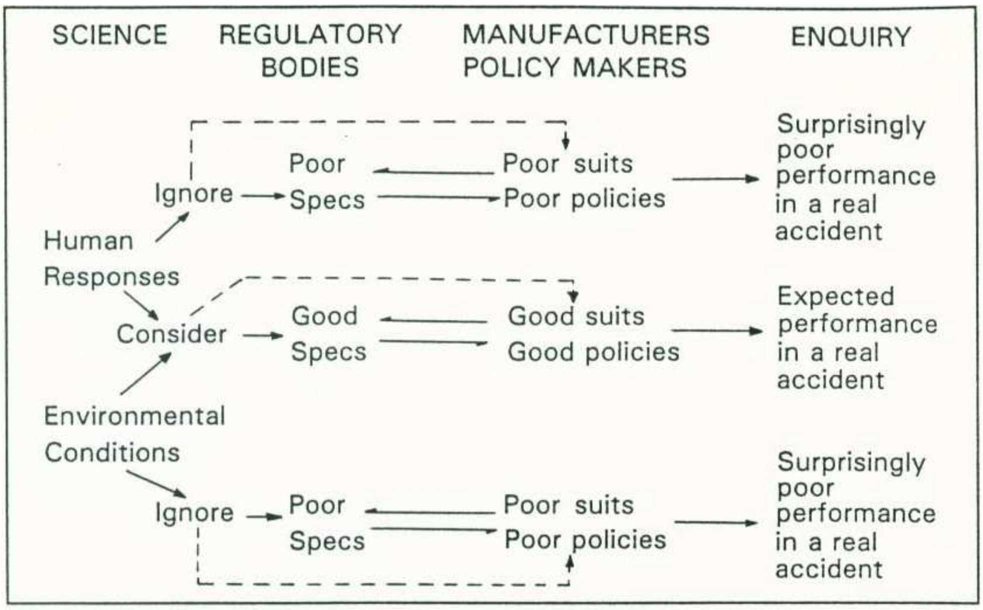

Figure 1: Relationships between the groups involved in survival in the sea. Note: "Specs" = specifications, regulations, standards, and guidelines. (Reprinted with permission from [19]).

It is extremely important for future studies to recreate as realistically as possible the conditions where protective equipment will be used, and to measure the human responses during these tests. Unfortunately, this can be challenging to do as not many facilities in the world are capable of recreating consistently the environments where the equipment will be used in. While testing in the open ocean can provide valuable insight into the performance of the equipment and humans, these trials can be extremely expensive and difficult to conduct. Randomized environmental conditions due to weather can result in not all study volunteers experiencing the same sea states as the others. Additionally there is a very narrow range of weather conditions with sea states more turbulent than calm water, but still safe enough to test in.

2.0 Summary of NRC-IOT Led Work

Assessing the performance of protective equipment in realistic conditions can be challenging. Testing in the ocean will allow for a measure of performance of the equipment, but these trials can be very expensive and difficult to complete. Varying weather conditions can also result in some test volunteers not experiencing the same sea states as others do, which does not give an “apples to apples” comparison. As well, there is a very narrow range of weather conditions where the sea state is turbulent enough not to be considered “calm, circulating water”, but still safe enough to work in.

The advantage of laboratory-based tests is the ability to ensure that each test volunteer experiences the same conditions as the rest. However, there are few laboratories in the world capable of generating both wind and waves of a level close to that seen in real world scenarios.

In 2007, the NRC-IOT multi year project “Human Thermal Regulation in Wind and Waves” was proposed to examine the effects of varying weather conditions on human thermal responses. While previous studies have examined the effect of simulated and actual rough sea states on immersed humans, NRC-IOT sought to add to this body of work by using its Offshore Engineering Basin (OEB) to address earlier shortcomings of these studies. The OEB is one of the few facilities in the world capable of generating programmable waves up to 1 meter in height, as well as being able to produce wind speeds up to $10 m \cdot s^{-1}$. By conducting experiments in the OEB, the project’s research team was able to ensure that each participant experienced the same test conditions as the others did; conditions that were significantly worse than the calm, circulating water used for current immersion suit certification.

Three separate experiments were conducted over the course of three years that examined the effects of varying weather conditions on human thermal responses. The first experiment was conducted in 2008, and investigated the effects of 4 separate immersion conditions on 12 human volunteers during 1-hour immersions. The four immersions were in calm water (no wind or waves), wind only (no waves), waves only (no wind), and wind + waves (wind and waves). The wave spectrum used in the experiment was created from data collected in February 2008 from a wave buoy located on the south west margin of the Grand Banks. The 20 minute, irregular Joint North Sea

Wave Analysis Project (JONSWAP) wave spectrum had a maximum height of 0.67m, with a wind speed of $4.24 m \cdot s^{-1}$, which was matched to the sea state associated with the given wave height. Water temperature ranged from 10.8-11.1°C, and air temperature was between 17.6-18.5°C.

Compared to the calm immersion, all immersion conditions produced a significantly greater increase in heat flow. The wind + waves condition caused a 36.8% increase in mean skin heat flow compared to the calm immersion, with no significant change in water or air temperature [14].

Building upon the results collected from the first phase of the project, the second experiment examined the effects of varying wind speeds and wave heights on human thermal responses during 3-hour immersions. The findings of the first phase of the project showed that immersions in environments consisting of both wind and waves will cause a significantly greater increase in heat flow compared to immersions in calm water, wind only, and waves only. The main objective of the second experiment of the project was to investigate if the human thermal responses changed proportionally to increasing wind speeds and wave heights.

For the second experiment conducted in March 2009, 12 participants performed 3 hour immersions in three separate conditions: calm water, Weather 1, and Weather 2. The calm water condition consisted of no waves or wind, with a water temperature of 11.4°C, and an air temperature of 17.2°C. The Weather 1 condition had a 20 minute, irregular JONSWAP spectrum with a maximum wave height of 0.34m, wind speed of $3.5 m \cdot s^{-1}$, water temperature of 10.9°C, and air temperature of 17.4°C. The Weather 2 condition have a 20 minute, irregular JONSWAP spectrum with a maximum wave height of 0.67m, wind speed of $4.6 m \cdot s^{-1}$, a water temperature of 10.9°C, and air temperature of 17.3°C.

Similar to the previous experiment, the two immersion conditions consisting of wind and waves resulted in a significantly greater increase in mean skin heat flow compared to the calm conditions [15]. There were no significant differences in the change in deep body temperature between the three immersion conditions. The lack of differences in deep body temperature was possibility the result of the high level of protection provided by the immersion suits used, and the relatively warm water and air temperatures in each environmental condition. Due to these factors, the study volunteers own thermoregulatory responses were sufficient to cope with the added thermal stress placed on them by the environmental conditions.

A third experiment was conducted in March 2010 that examined the effect of water leakage on the thermal responses of 12 volunteers performing 3 hour immersions in varying weather conditions. The objective of the third experiment was to determine if the effects that varying weather conditions have on the thermal responses of humans are increased due to the presence of 500ml of water in the suit. The weather conditions used in the third experiment were the same as in the second, with water and air temperatures being only slightly cooler in the former as compared to the later. At this time, the data collected from the third experiment has not been fully analyzed, but volunteers were observed to have blue lips, intense shaking, and near hypothermic level drops in deep body temperature during the tests.

In related investigations, NRC-IOT has also conducted studies that have investigated the ability to use thermal manikins to determine immersion suit thermal protection under non-uniform cooling conditions [13], and the correlation of human thermal responses to manikins [12, 14]. NRC-IOT has participated in a series of international, round robin style tests tasked to determine if thermal manikins are viable to be used for international immersion suit approval testing. The results of the NRC-IOT study show that under non-uniform cooling conditions (different water and air temperatures), that further research would need to be conducted before thermal manikins could be used with confidence for suit evaluation [13].

Before, and during, the round robin testing NRC-IOT has undertaken studies to correlate human thermal responses to those of manikins. In a pilot study, two separate thermal manikins were tested alongside two human volunteers dressed in immersion suits in calm water. While there was some slight variation in heat loss between the manikins and the humans, though this was attributed to the fit of the suits on the humans and manikins. The results from this pilot study suggest that heat lost from manikins in the conditions tested was a good representation of heat loss from humans [12]. A similar study by NRC-IOT correlated the responses between a thermal manikin and 12 humans across four separate weather conditions [14]. Heat flow from the human volunteers increased significantly from calm conditions when they were immersed in conditions consisting of wind and/or waves. There were extremely similar responses measured between the increase in heat flow in humans and manikins when moving from the calm conditions to the weather conditions [14]. When examining the comparing the increase in heat flow between calm and the wind + waves condition, there was only a 1.6% difference measured between the human's and manikin's responses. The results obtained from the thermal manikin during these tests also provided more support that testing in calm conditions will result in an overestimation of performance, as the thermal insulation of the suit (as measured by the manikin) dropped 20% by adding wind and waves without changing the temperature [14].

The results collected so far from the NRC-IOT lead work has established that wind and waves will significantly increase the cooling capacity of an environment, without a significant change in temperature. Testing the thermal protective properties of immersions suits and people in calm water pools will not provide accurate assessments of their performance in real world scenarios.

3.0 Existing Knowledge Gaps in Immersion Suit Performance

3.1 Performance vs. prescriptive based regulations

As shown by Tipton [19], it is possible for a knowledge gap to exist in how a suit performs under standardized test conditions, and in real world scenarios. Current prescriptive based regulations require suits to be tested in conditions not representative of where they may actually be used. Performance based regulations require more realistic testing, and would help to address the knowledge gap that exists. In this section we will differentiate between specification-based regulations and goal-based regulations and will attempt to explain how a goal-based regulatory regime may be useful in circumstances that require innovation, which is the case with immersion suit systems in cold regions, as well as to draw attention to some of the arguments and cautions raised concerning the use of a goal-based regulatory regime.

Specification-based regulations are prevalent in the shipping industry. On matters relating to marine operations the offshore petroleum industry adopted many of these regulations and the regulatory approach in which they were developed. In many jurisdictions both the shipping and offshore petroleum industries are governed by prescriptive specification-based conventions and regulations in matters of EER. In general this is applicable to emergency response's escape, evacuation and rescue (EER) and more specifically to helicopter emergency operations with regards to ditching and subsequent EER. The EER technology developed to ensure compliance with marine regulations has been widely adopted by the offshore industry.

The inherited regulatory apparatus and corresponding EER technology may not be adequate in terms of its coverage of and utility for cold east coast of Canada EER. In these circumstances, compliance with regulations and off-the-shelf solutions is inadequate. The current trend by the shipping and offshore petroleum industries towards activities in northern ice-covered regions will require them to deal with a host of issues that will involve innovative solutions that are unlikely to be fully addressed under existing regulations and existing technical solutions. In these circumstances, developments in northern cold regions may be most effectively advanced under a goal-based regulatory approach. The goal-based approach is described below, along with practical definitions of the roles of both regulators and operators under such a regime. To highlight the differences in the approaches the contrasting features of the specification-based approach are presented as well.

In a goal-based regulatory environment, a regulatory body establishes performance goals. The regulator presents clear statements of the goals and corresponding expectations of what is required and sufficient to be addressed in order to achieve adequate safety. In broad terms, performance goals will generally reflect society's values and norms, and should specifically reflect any requirements of the law. Embodied in regulations, these effectively become matters of public policy whose application is mediated in some way by a regulatory agency. In practical terms, a performance goal is the objective or purpose of a piece of equipment, procedure, system, or other element of a particular installation, ship or for this specific purpose, an immersion suit system as it relates to helicopter operation.

The operator has the responsibility to meet or exceed the performance goals, and establish the means by which to achieve and maintain them. The operator must present clear arguments and evidence to give confidence that the regulatory goals are met. The operator must further ensure that there are clear, auditable connections between the goals and expectations, and the arguments and evidence. In many instances in the attempt to demonstrate capability, knowledge gaps are identified which require innovative solutions. The general expectation from the added responsibility is that goal-based regulations promote a culture of safety rather than one of compliance.

A performance standard is the operator's specification of a solution to achieving a given goal. It constitutes the basis of the operator's argument that safety goals can and will be met. It is a verifiable statement of the performance required of the equipment, procedure, or system. Performance standards should be cast in terms of reliability, functionality, availability, survivability, independence. They should contribute to the overall goal of reducing the risk of harm. Each standard should provide a basis for monitoring and maintaining the basic performance of the equipment, procedure, or system throughout its life cycle, and should account for the specific circumstances particular to the installation, ship, immersion suit system, etc. and its operation. In the context of East Coast of Canada EER, for example, the performance standards must reflect factors such as cold temperatures (air and water), fog, high wind and waves and possibly sea ice cover.

For a goal-based regulatory approach to work, performance standards must be supported by evidence and be open to objective evaluation. Goal-based regulations can incorporate existing specification standards, as they provide a window into what has been accepted under a specification-based regime and may still be acceptable to the regulator under a goal-based system. In general, where engineering design and operation matters are covered by codes of practice, classification society rules, industry guidelines, or other accepted norms, the goal-setting approach gives the operators some flexibility in choosing a way forward, including a facility to adopt evolving best industry practice without the delays experienced in jurisdictions where specification regulations are embodied explicitly in legislation.

An operator may choose to claim that compliance with an international standard or code of practice constitutes meeting best practice and therefore the goal. This may be a reasonable approach, but it is generally insufficient to claim that compliance in one jurisdiction equates to compliance in another: evidence must be presented that addresses specific goals.

In the absence of acceptable norms, the operator has an additional responsibility to propose a new performance standard and demonstrate its efficacy in achieving the performance goals. This can be a challenging requirement involving added uncertainty for the operator in terms of meeting the obligations of the law, but can also stimulate innovation. In the goal-based regulations regime innovations must find their way into practice if the advantages are to be realized. By this measure, a framework in which regulations are set out as high-level goals, rather than detailed specification standards, should facilitate the relatively rapid adoption of evolving best practice and improved technology.

With this in mind the high-level goal for helicopter emergency operations related to ditching can be stated as follows:

> "In circumstances that necessitate a ditched helicopter escape, personnel must be fitted with abandonment suit systems that permit escape from the ditched helicopter safely, clearance from the helicopter and survival until rescued, and have a reasonable expectation of successfully escaping harm in the environmental conditions that can be expected to prevail in the area of helicopter operation. The survivor fitted with the suit system must maintain a 2° C threshold on deep body temperature for as long as it takes the SAR to perform the rescue."

When innovations with demonstrated benefits in terms of reducing the risk of harm are available at costs that are not grossly disproportionate to the benefits, the operator should adopt them; otherwise, the regulator should insist they do. Such provisions (e.g. that best available technology be used) can be incorporated in both specification-based and goal-based regulations to help ensure the adoption of effective innovations.

The regulator accepts the operator's proposed performance standards or not, and holds the operator to the stated standards. Rather than using inspections as the key mechanism to ensure operators are in compliance with regulations, as is generally the case under a specification type regulatory framework, regulators in a goal-based framework rely more heavily on audits of the operators' safety plans. The relatively heavier use of auditing than inspecting has given rise to some criticism of goal-based regulations as entailing self-regulation by industry, and too much focus on the management of safety rather than the matter of safety. Subsequently, this has led to some opposition to change from specification-based regulations to goal-based regulations, although the latter seem to be ascendant. In practice, the regulator is the ultimate authority under both types of regulatory system, although the activities and skill sets required by regulators are likely to be quite different under the different regimes.

There are other arguments against the move away from specification-based regulations, including that they capture a wealth of historical knowledge and experience, are relatively easy to use by designers and operators, and are relatively easy to check by regulators and their designated inspectors. Indeed, existing specification regulations do incorporate valuable experience, including that from accidents, although the context is sometimes lost once the specification type regulation is constituted. Routine application of regulations without clear understanding of their context then provides some unspecified level of safety that is still accepted by the regulator. This is the situation even when the value of the specification standards derives from experience with installations that differ significantly from a given specific situation at issue.

It is sometimes argued that specification regulations are fair in the sense that they apply equally to all operators so that no commercial advantage can be sought through variance from the specified rules. There is also the view that as safety is often considered to be a cost, it will therefore generally be eroded over time unless specific regulations are applied and enforced. Goal-based regulations have also been criticized as relying too heavily on risk management, particularly on quantitative risk assessment and its attendant uncertainties.

The advantages and disadvantages of both prescriptive and performance based standards are summarized in Tables 1 and 2 below.

Table 1: Prescriptive based standards advantages and disadvantages

ADVANTAGES	DISADVANTAGES
Easy to create and implement	Compliance may not provide best solution
Provides certainty for operators and regulators as to compliance	Reduces the flexibility available to operator to provide best solution
	Does not account for improvements in technology
	Reduces innovative solutions
	Operators tend to become passive in their approach to safety

Table 2: Performance based standards advantages and disadvantages

ADVANTAGES	DISADVANTAGES
Puts responsibility for solutions on operators	Requires that the regulators, inspectors, and operators be highly qualified
Provides flexibility in developing solutions	Management system must be adaptive and closely monitored in order to change the

	system if required.
Fosters innovative solutions	Regulators and Operators must work together harmoniously to provide the best solutions available
Allows for continuous upgrading of system	
Allows adaptation of new technologies	

3.2 Current Regulations, Standards and Guidelines

In this sub-section we will identify standards that deal specifically with immersion suit or helicopter passenger transportation suit systems.

CAN/CGSB-65.16-2005 Marine Abandonment Suit System and

CAN/CGSB-65.17-99. Helicopter Passenger Transportation Suit system.

These two standards aim to provide the evacuee(s) with a system that offers protection against the cooling effects of immersion in cold water, and provides adequate floatation.

The Canadian General Standards Board standards for immersion suits are among some of the most rigorous in the world. The leakage test for suits require that both jump and one hour swim tests be conducted. Once the tests are completed, the values used to calculate the water ingress for both the jump and swim tests are to be one standard deviation above the mean for the results from eleven subjects. The values from the one hour swim test are then multiplied by 3 and added to the jump tests to give the total water ingress for the suit. By using one standard deviation above the mean as the calculated value, this helps to create a safety factor by over reporting the average water leakage for eleven subjects.

Prior to the start of the thermal protective tests, the amount of water to be added is the value calculated from the water leakage tests. By using the value of one standard deviation above the mean, the thermal protective tests are more challenging for the suit due to the increase in water leakage.

The CGSB test conditions for using humans to evaluate the thermal protective properties of immersion suits is for them to be immersed in calm, circulating 2°C water.

If the suit prevents a drop in deep body temperature of 2°C in six hour, and keeps the finger, toe, and buttock temperature from dropping below 10°C, then it passes the test. Thermal manikin tests are conducted in turbulent water with a wave height of 40cm, with there being at least a 3°C difference between the water temperature, and the target temperature for the manikin.

ISO15027 – International Standard under the general title of "Immersion Suits" meeting the requirements of persons carrying activities on or near water and consisting of the following:

Part 1: ISO15027-1:2002 ~ Constant wear suits, requirements including safety

Part 2: ISO15027-2:2002 ~ Abandonment suits, requirements including safety

Part 3: ISO15027-3:2002 ~ Test methods

The ISO standards (ISO15027-2:2002 and ISO15027-3:2002) are often used by others to define the testing criteria for immersion suits. The leakage measurement tests require that water leakage only be measured after a jump from 4.5m, and a 20min swim. The average amount of water that leaked into the suit during this test (jump and 20min swim) is then recorded.

The thermal protective tests for the ISO standards are very similar to those defined in the CGSB. However, the amount of water to be added to the suit prior to the start of the tests is the value recorded during the water ingress tests. This value could possibly be significantly less than that recorded in the CGSB if the same suit was used, resulting in a less challenging thermal test.

European Aviation Safety Agency

ETSO - European Technical Standard Orders

ETSO-2C502 ~ Helicopter Crew and Passenger Immersion Suits for Operations to or From Helidecks located in a Hostile Sea Area

Specifies the minimum standard of design and performance of helicopter and integrated immersion suit. This standard refers back often to ISO 15027-3:2002 to define the testing standards, and acceptable pass criteria.

Civil Aviation Authority United Kingdom

Specification No.19 ~ Helicopter Crew Members Immersion Suits

This standard addresses the minimum standard of design and performance. In contrast to the previous three standards, the UK standard requires that no more than 200g of water leak into a suit when performing tests similar to those outlined in the ISO and CGSB standards. There is no proposed test in the UK standard to check the thermal protective properties of a suit. Instead, it is stated that if any suit allows less than 200g of water into it, and the person is wearing the recommended clothing under the suit, then it should provide 3 hours of protection from hypothermia in 5°C water.

The Norwegian Oil Industry Association (OLF)

This standard is similar to that of the European Aviation Safety Agency in that it often refers back to ISO 15027-3:2002 for suit requirements. It differs from the European standard by requiring stronger testing conditions. The OLF requires that leakage tests be performed as outlined in 15027-3:2002, but that no more than 200g of water enter the suit. The thermal protection tests are also conducted according to 15027-3:2002, but are made more strenuous by adding 5 $m \cdot s^{-1}$ of wind and pouring water over the front of the body every 10 minutes. For determining suit floatation and stability, the OLF standards require that the suits give the test subjects a stable position lying on their back, and placed crosswise in relation to waves. The OLF requires that the tests be conducted under controlled conditions with a minimum of 80cm waves.

3.3 Example of use of prescriptive and performance based approaches

In this sub-section we will use as illustration the CAN/CGSB 65.17-99, Floating Characteristics, paragraph 6.2.3, and Stability and Floatation Characteristics, paragraph 8.1.3.7, as the prescriptive approach and subsequently we will present an approach that we believe is more in tune with goal based regulatory approach.

> **6.2.3** ***Floating Characteristics*** -When tested as described in par. 8.1.3.7, the suit system shall provide a stable floating position, with a face plane angle between 30 and 80° to the horizontal, in which the subject is face-up with the mouth and nose at

least 120 mm above the surface of the water. This shall be achieved for at least eight out of the eleven subjects.

8.1.3.7 ***Stability*** **and** ***Floating Characteristics*** -Each subject, while wearing a suit system, shall enter the water gently, activate the inflatable buoyancy element and adopt a face-up position with the legs together and the arms at the sides. After a period of 5 min it shall be established that the subject is stable in that position by depressing each shoulder in turn to ensure that the subject returns to the face-up position and does not invert.

With the subject in a relaxed position, measure the freeboard to the mouth and nose, perpendicularly from the surface of the water.

Measure the angle, relative to the surface of the water, of the plane formed by the most forward part of the forehead and chin of the subject floating in the attitude of static balance in which respiration is least likely to be impeded. For each subject determine the stable position and the face plane angle.

In the above paragraphs of the CGSB standard an understanding of suit system floating stability is sought. In the approach used the regulatory body ignored both the human response as well as the environmental conditions, both pre-requisites for assessing the performance of the suit system in a real accident world scenario. A “pass/fail” approach doesn’t address anthropometric characteristics of the human volunteers, only attempts to looks at the suit system static stability, even though the magnitude of the disturbing force and the point of application aren’t quantified, and doesn’t consider the effects of the environment, wind and waves, on the floatation stability. As manufacturers apply the standard requirements for suit system floatation they address only the minimum requirement “pass/fail” and they don’t delve into the details of performance required of the equipment. This results in a suit system that meets standard requirements but for which the environment and the human components are not fully understood. The example of a performance-based approach will read more like the following:

Goal: Determine the stability and floatation characteristics of a suit system for the population distribution it intends to fit and for the weather conditions predominant in the area of operation.

How to meet the goal: initially perform floatation stability measured in calm water for a number of participants that is both representative of the wearer population and in sufficient numbers to be statistically reliable. Mark on each participant's suit the location of the point of application of the disturbing force. For each participant measure the suit's reserve buoyancy after the air is purged in order to establish the individual subject/suit baseline. Measure each individual suit system/subject water plane, the angle that the legs below the knee make with the horizontal plane, the freeboard and the face plane angle. After the calm water baseline floatation characteristics are reliably established test the stability and floatation functionality of the suit system in a range of environmental conditions composed of wind and waves as an approximation to a real sea state and for different orientations in order to establish the dynamic characteristics of the suit system.

The manufacturer, instead of meeting a bare minimum, will get insight into the stability and floatation characteristics of the design and will be in a position to effect changes that maximize the performance of the suit system, taking into consideration the human and the environment.

3.4 General knowledge gaps across major topics

In this sub-section we will identify the knowledge gaps identified by reviewing the Canadian dealing with immersion and abandonment suit systems.

CAN/CGSB-65.16-2005 Section 6.8: Donning Time - Current CGSB testing standards require that immersion suits be donned while on a stable platform. For helicopter transportation suit system, this does not present much of an issue, as most suits are donned while at the helicopter terminal, or on the offshore installation itself. Assess donning of the suit on a stable surface may lead to an overestimation of performance for marine abandonment suits. These suits are often donned during an emergency (e.g. a vessel sinking), where the people may not be situated on a stable surface. Unstable surfaces due to vessel motion may result in a degradation of performance in the ability to done the suit.

CAN/CGSB-65.17-1999 Section 6.1.9.2: Mobility and Hand Dexterity - CGSB testing standards require that all hand dexterity tests be performed in water "not less than

18°C”. Vincent and Tipton have found that hand immersion in 5°C for as little as two minutes can produce significant reductions in maximum voluntary grip strength in an unprotected hand [21]. Given that temperatures in the North Atlantic can drop to below 0°C during certain periods of the year, it is extremely important to conduct standard tests in water that has a temperature similar to that of the area of operation. There may be a surprisingly large degradation in expected performance of hand dexterity if tests are only conducted in “warm” water.

Additionally, there is no requirement in the current CGSB standards for people to be able to manipulate a replica of the buckle used for the seat restraints on the helicopter.

CAN/CGSB-65.17-1999 Section 8.1.3.7: Stability and Floating Characteristics - CGSB testing standards require that all flotation and stability tests be performed in calm water pools. It is unknown at this time how wave motion will influence the stability and floating characteristics of immersion suit systems. It is possible that the orientation of the person to the waves (feet first, head first, side on etc.) may also change their stability in the water.

CAN/CGSB-65.17-1999 Section 8.1.4: Vertical Positioning - In order for an immersion suit system to pass the CGSB vertical positioning tests, a study volunteer must be able to stand vertical in the water for 2 minutes, unassisted. Similar to the previous ones, these tests are to be conducted in calm water pools. It is unknown how wave action will affect the ability of a person to maintain a vertical position in the water.

CAN/CGSB-65.17-1999 Section 8.1.6.1:Water Ingress - CGSB testing standards require that water ingress be calculated to determine the volume of water to add before the thermal protective tests. The water ingress evaluation is composed of two parts: a jump from not less then 3m, and a 60 min swim in calm water. Work conducted by the CORD Group Ltd. has shown the potential for the calm water swimming tests to underestimate the amount of water leakage into a suit [5-6]. When the swimming tests were performed in conditions with wind and waves, the suits allowed more water leakage to occur due to the environmental conditions proving to be more challenging to the immersion suit seals.

CAN/CGSB-65.17-1999 Section 8.1.6.2: Thermal Protection - manikins - Testing standards for manikins require them to be immersed in 40cm waves, at a water temperature not less than 3°C different from the manikin skin temperature. There is no specific reason given for requiring a wave height of 40cm for this test. Work conducted by NRC-IOT has shown that an environment consisting of both wind and waves will cause a greater amount of heat flow compared to either condition by itself [14].

CAN/CGSB-65.17-1999 Section 8.1.7: Thermal Protection –humans - The testing standards prescribed for humans are less strenuous than those for manikins. Humans are to be immersed in calm, circulating 2°C water. Previous work by NRC-IOT has shown that the heat lost in the current prescribed test conditions is significantly less than in an environment that has both wind and waves. Without a significant change in temperature, wind and waves can increase the heat lost to an environment by as much as 37% compared to immersions in calm water [14-15].

Additionally, the humans used for these tests are specified to be between 160-185cm tall and not more than 10% over or underweight. It is unknown at this time if the anthropometric characteristics prescribed for these tests are representative of the offshore work force that will have to use these suits.

4.0 Suggested Safety Approaches and Emerging Technologies

There currently exists a knowledge gap between the results observed in the current prescribed testing standards for immersion suit systems, and their performance in real world conditions. As discussed throughout this report, a large body of work has shown that this current knowledge gap can result in surprisingly large degradations in the performance of humans in immersion suits during real world accidents. This knowledge gap is the greatest threat to the safety of people who work and travel over the ocean since it results in an level of uncertainty of the performance of Life Saving Appliances (LSA); uncertainty that often leads to injuries and fatalities.

Due to their nature, prescriptive based standards can create the knowledge gaps that will often result in poor performance of LSA. When a standard prescribes a specific set of test conditions and values to be obtained, it creates a focused avenue for the performance of the LSA. Testing standards, either due to technical limitations or lack of information, will rarely prescribe for tests to be conducted in the conditions that LSA will be used in. The underlying assumption is that if a LSA passes a prescribed test, then it will exhibit the same level of performance in any situation. It is rare that when a LSA fails in a spectacular fashion in a real world situation, that the merit of the test that it passed for approval is questioned. Instead, the LSA itself is given an intense level of scrutiny and will no doubt undergo some level of redesign, only to be evaluated by the same prescribed tests that the first LSA passed. There will still be no indication that the "new" LSA will perform significantly better in real world conditions compared to the older design, since it will still be evaluated by the same test that the latter passed.

In his article "Ship/Rig Personnel Abandonment and Helicopter Crew/Passenger Immersion Suits: The Requirements in the North Atlantic", Brooks discussed the problems involved in manufacturing a immersion suits that are both dry and comfortable [3]. Brooks thought that it would be "inappropriate to legislate towards or away from specific design concepts, such as types of seals to be used.", with the understanding that doing so would result in excluding helpful innovations [3]. In a similar fashion, moving away from standards that prescribe the test conditions to performance based ones would be the best approach to addressing the current knowledge gap. As stated by Tipton, LSA should be tested in the conditions that they will ultimately be used in so that an accurate level of performance can be assessed [19].

A shift from prescriptive based standards to performance based ones would improve the safety of everyone who uses the LSA that they govern. For example, the current CGSB thermal protective tests using humans require that a suit prevent a drop of 2°C or more in deep body temperature in 6 hours while the person is immersed in calm, circulating 2°C water. Assuming that the suit has passed all the other tests, it is now approved for use anywhere in Canada. This suit can now be used off the West coast of British Columbia, in a sheltered harbour in P.E.I., in the Arctic Circle, and off the East Coast of Newfoundland. The average environmental conditions vary greatly in each of these locations, yet the suit is expected to perform to an acceptable level in each of them based on prescribed testing conditions that do not match any of them.

By shifting to a performance based standard, the testing certification for the immersion suits would change, eliminating the knowledge gap of their performance. If we were to change the prescriptive based tests in the previous example to performance based, they would read something like the following

"The suit must prevent a 2°C drop in deep body temperature in conditions representative of the area of operation for the amount of time it would take search and rescue to respond. The size distribution of the test subjects should have anthropometric dimensions equal to that of the workforce using the suit. "

Allowing the area of operation, response time of search and rescue assets, and size of the people using the LSA to set the conditions for the testing standard, a large amount of uncertainty would be eliminated on how it would perform with the people using it.

The best way to eliminate risk due to uncertainty in immersion suit performance is to test in the most realistic, representative conditions possible with people who will be ultimately using them. This would pose a series of logistical challenges since it would require a constant assessment of the conditions that people use LSA in, and the ability to accurately simulate them in a controlled fashion. As well, it would require constant monitoring of the ever-changing population who use the LSA. It is recommended that further research be conducted in the following areas to help increase the safety of the offshore workforce:

1.) The cost and feasibility to shift from prescriptive based regulations to performance based.
2.) New fabrics and materials for immersion suits that would allow for increased performance in realistic conditions. This would include the use of “intelligent” fabrics that change their properties based on temperature, suit seals that would allow an assessment of their water tight integrity, and reinforcing existing materials.
3.) The redesign of the suits thermal balance during flight by including “suit vents” as a way of keeping the user more comfortable while keeping the integrity of the suit system.
4.) Holistic design of the transportation environment and all the components of the suit system so they work together as one, e.g. redesign of seat buckles that can be operated with the gloves donned.
5.) Development of training simulators for helicopter emergency operations, escape, evacuation and rescue.
6.) Re-evaluation of the risks associated with each seat on the airframe. Re-evaluation of the “fit-for-purpose” of the airframe for operation in east coast of Canada given the impairment caused by the auxiliary fuel tank.
7.) Continuous monitoring and assessment of the offshore work force’s anthropometrics and physical capabilities. By keeping an on-going database of these parameters, this information can be fed back to the standards and manufacturers to allow for further refinement of the LSA, airframe passageways, seat sizes, etc.

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