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Assessment of Life Saving Appliances Regulatory Requirements – Human Factors Knowledge Gaps

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Abstract— Life saving appliances are used throughout Canada and around the world every day by a large number of individuals who work or travel over open water. Personnel rely on these life saving appliances to help provide protection from harsh environments, and reduce the risk of injury or death in the event of a marine accident. Due to their importance in helping to save lives at sea, life saving appliances are built and tested according to specific standards and regulations to ensure that they provide the level of performance required.

Unfortunately, life saving appliances do not always perform as expected which can lead to unexpected injuries or loss of life. Given that life saving appliances must meet specific performance goals as prescribed by standards and regulations, it is often these goals that fall short of what is actually needed during a marine accident. A knowledge gap is created when the testing conditions, as outlined in a standard or regulation, do not accurately reflect those conditions found during a marine accident. As a result, a life saving appliance will often meet performance goals that are below those required to prevent an injury or loss of life during an actual marine accident.

The Canadian regulation: "Life Saving Equipment Regulations" C.R.C., c. 1436 was reviewed and possible knowledge gaps with respect to human factors were identified. The goals and requirements for life saving appliances in the regulation were compared against existing work done in the area of marine safety to determine if what was prescribed adequately reflected what could be found during a marine accident.

There were many gaps identified in the regulation, commonly caused by prescriptive wording specifying conditions not commonly found during a marine accident. These knowledge gaps will widen as conditions become more severe than what is prescribed in the regulations possibly leading to even further decrease in life saving appliance performance than what is already measured.

Keywords— human factors; regulations; lifesaving appliances; knowledge gaps.

I. INTRODUCTION

Every day many Canadians work or travel over open water, the majority of which is cold enough to cause injury or death in a few hours or even a few minutes. In the event of an accident or disaster on or over open water, personnel rely on Life Saving Appliances (LSA) to protect them from these harsh conditions while they await rescue. Some LSA, such as lifeboats, are designed to keep personnel out of the water altogether and allow them to transit from the site of the accident to a place of safety. Other LSA, such as immersion suits, are designed to help prolong the survival of people in the water who are exposed to these harsh elements while they await rescue. Regardless of the type of LSA being used, their main goal is to help increase the chance of survival during a marine accident and prevent the loss of life.

Given the critical importance of LSA in helping to prevent the loss of life at sea, many regulations and standards have been created with the intention of specifying how these technologies should work, as well as which types are required for specific marine vessels and installations. The expectation is that by using the appropriate piece of LSA as prescribed in the regulation or standard, the probability of loss of life in a marine accident will be reduced.

Unfortunately, LSA do not always perform as expected and this will often result in what Tipton referred to as "surprisingly poor performance in a real accident" (13). In the paper "Immersion fatalities: hazardous responses and dangerous discrepancies", Tipton outlines what can cause an immersion suit to exhibit such poor performance often leading to fatalities at sea (13). Even though immersion suits are the main focus of the paper by Tipton, the overall message is broader than that: when regulatory bodies, LSA manufacturers and policy makers fail to take into account the factors that can significantly impact the performance of LSA it may result in a loss of life at sea (Figure 1). Interestingly, Tipton stated that while the probability of "surprisingly poor performance" exists, there is no such phenomenon as "surprisingly good performance"; immersion suits/LSA either work the way they are intended to or not at all.

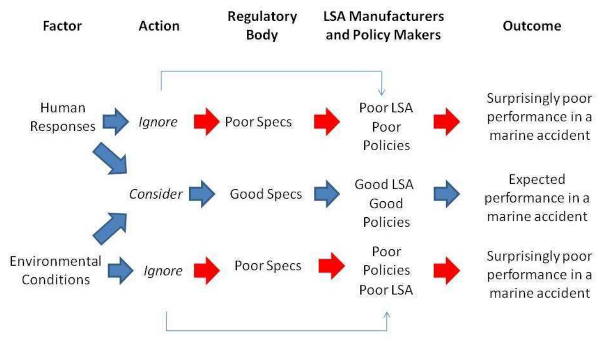

Figure 1. How the inclusion or exclusion of external factors can influence LSA design (adapted from (13)).

The level of performance that LSA technology is required to meet is routinely prescribed by a regulation. These regulations, both national and international, set specific benchmarks for performance that LSA technology should be able to achieve in order for it to be approved for use. In addition to prescribing levels of performance for LSA technologies, regulations also require that seafaring vessels and offshore installations carry specific LSA technologies in order to ensure an adequate level of safety for all persons on board (POB).

A knowledge gap may occur when a regulation requires specific LSA technologies to be carried but their performance is only tested in benign conditions which may not be representative of their intended area of operation. Historically, the majority of LSA technology certification tests are carried out in calm water pools, sheltered harbours, or small inlets for financial, logistical or safety reasons. Few facilities exist in the world that can recreate the harsh environmental conditions that LSA technologies are intended to operate in during their certification process. This potential knowledge gap in performance between the calm water testing conditions and conditions found during most marine accidents may result in “surprisingly poor performance”.

To identify knowledge gaps that may impact a review was performed on the Canadian regulation “Life Saving Equipment Regulations”, C.R.C c. 1436 which governs Canadian or foreign registered vessels operating in Canadian water. The regulation was reviewed against the latest research results available and the resultant knowledge gaps in the performance of LSA technologies were identified (8). A selection of these knowledge gaps related to human factors are presented in this paper.

The actual text from “Life Saving Equipment Regulations”, C.R.C c. 1436 is presented in the following format

“Text from regulation” (Specific section of C.R.C c. 1436)

II. Review of “Life Saving Equipment Regulations” C.R.C, c1436

A. *Anthropometrics*

“A person shall be deemed to weigh 75 kg for the purposes of this schedule and two children under the age of 12 years shall be equated to one person.” (Schedule V, Part 1, Paragraph 4.(2))

Previous work by Reilly and colleagues has demonstrated that the average weight of the offshore population is significantly greater than 75 kg (10). In their study, the researchers found that the mean weight of 42 participants (38 males; 4 females) undergoing HUET training in Nova Scotia, Canada was 87 kg. By gender, the mean weight of the males was 90.5 kg; for females it was 54.5 kg. The 95th percentile weight for the total study sample was 119 kg. The difference in weight between what is prescribed in the regulation and the mean weight of a sample drawn from the offshore population is significant. The mean weight of the total study sample was 16% greater than what is prescribed in the regulation. Additionally, their 95th percentile weight is 59% greater than the prescribed 75 kg weight. This difference in weight can have a “trickle down” effect in the performance of various LSA technologies as many of them, such as lifeboats and liferafts, rely on a weight specification when determining their occupant capacity and launching mechanisms.

For example, a lifeboat may be certified to carry 16 people with the assumption that the mean weight of each person is 75 kg. However, if the actual mean weight of the occupants using the lifeboat was 90.5 kg (the mean weight of the males in the study by Reilly and colleagues), then this could result in the lifeboat being down-rated to carry less than 16 occupants due to their larger size or the lifeboat weighing much more than originally intended. A deficiency in the ability of the evacuation system to evacuate all crew may exist if the lifeboats are not capable of carrying their specified number of occupants. If the lifeboat is heavier than expected, this can result in problems with the lifeboat’s launching and release mechanisms and, in some cases, exceed the allowable safety limits. This potential problem can arise due to the following regulation:

“*For the purposes of this Schedule, in relation to a lifeboat or liferaft, “turning-out condition” means a lifeboat or life raft that is fully equipped but manned only by its launching crew; “working load” and “loaded condition” mean the sum of the weight of the lifeboat or life raft, equipment, blocks and falls, and the number of persons with which the lifeboat or life raft is required to be lowered, each person being considered to weigh 75 kg*.” (Schedule IX, Launching Devices and Recover Arrangements, Part 1, Requirements for Existing Ships.)

As reported by Reilly and colleagues (10), the mean weight of their sampled offshore population was 87 kg; 16% greater than the 75 kg specified in the regulation. A 16 person lifeboat filled with 75 kg individuals would have a total occupant weight of 1200 kg. A 16 person lifeboat filled with 87 kg individuals would have a total occupant weight of 1392 kg. This discrepancy in mean occupant weight can have serious consequences when estimating the total weight of the lifeboat and designing the launching apparatuses for them. These launching apparatuses may underestimate the total weight of the lifeboat by 16%, or more depending on the size of the people. As the occupant capacity of the lifeboat increases, the difference in absolute weight increases as well. A 50 person lifeboat designed to have 75 kg occupants would have a weight of 3750 kg. If the same lifeboat was filled with 87 kg people it would have a weight of 4350 kg; a difference of 600 kg. The larger the capacity of the lifeboat/liferaft, the greater the difference in actual total weight between what would be expected with the prescribed 75 kg for occupants and a more realistic weight for them. It is recommended that the mean weight of 75 kg used in the regulation be replaced with a weight that more representative of a Canadian population.

B. *Evcauation Systems*

"*Lifeboats shall be partially enclosed or totally enclosed.*" (Class II Ships, Section 42, Paragraph 4)

As the name suggests, a partially enclosed lifeboat allows exposure to the outside elements to a certain degree. Often these particular LSA technologies have large openings that can be covered by a tarp to help provide a certain degree of protection from the elements (Figure 2).

FIGURE 2. PARTIALLY ENCLOSED LIFEBOAT[1].

In climates where the air temperature is relatively warm (5-20°C), and the lifeboat occupants are wearing clothing with a high level of thermal insulation, partial exposure to the elements should be acceptable provided that rescue arrives in a few hours. These partially enclosed lifeboats should not be used in colder climates, such as in Canada's Arctic regions where ambient air temperatures can drop to -30°C or lower (Ambient air temperature for Arctic Bay, NU in March 2014[2]). However, the partially enclosed lifeboats and liferafts when exposed to high seas states allow water to enter which may cause the clothing of the participants to become wetted with cold water reducing the thermal protection provided by the clothing ensembles.

Previous work by the National Research Council (NRC) used a modified version of the Cold Exposure Survival Model (CESM) to generate predicted survival times (PST) for 60-70 year old females in -15°C air wearing a variety of clothing ensembles (6). Sixty to 70 year old females were chosen for that project as that demographic represents the "worst" case scenario with respect to the length of time it would take to die from hypothermia; any other demographic (e.g. males; a younger population) would have a longer survival time. When survival time predictions were generated for the 60-70 year old females while wearing a clothing ensemble that consisted of: cotton boxer shorts; long underwear, denim jeans; a flannel shirt; cotton socks; leather shoes; a Helly Hansen soft pile jacket and pants; a Helly Hansen Compass jacket and pants; a Wind River toque and fleece mittens, the PST were 28.7 hours. If the clothing ensemble was wetted, the PST dropped to only 5.7 hours. Various other clothing ensembles that included anti-exposure suits and parkas provided significantly more protection against hypothermia (greater than 36 hours PST), but only if they remained completely dry and not exposed to the wind (6).

The previous work by NRC demonstrates the effect that exposure to Arctic like conditions can have on the ability to survive a marine emergency. A partially enclosed lifeboat will undoubtedly leave its occupants *partially exposed* to the outside elements. The tarps that cover the openings on these lifeboats may possibly block the wind and prevent some water from entering the lifeboat, but it is doubtful they offer much thermal protection. As a result, the occupants of a partially enclosed lifeboat could experience temperatures as low as -30°C, or lower which makes hypothermia a threat to survival. While the 60-70 year old female demographic in the work by Power and Monk represents the "worst case" scenario with regards to perishing from hypothermia, the ambient air temperature used in that work was -15°C; significantly higher than temperatures that can be experienced in the Arctic. Colder temperatures will result in lower PST regardless of the demographic that is used in the predictions. Therefore, it is recommended that partially enclosed lifeboats not be used by any vessel that is transiting through an area where weather conditions present the risk of hypothermia if exposed to them without proper protection. At a minimum, totally enclosed lifeboats should be used in order to increase the probability of

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[1] Image retrieved from: http://dsengco.en.ec21.com/Partially_Enclosed_Lifeboat--2607785_2607793.html

[2] Weather forecast retrieved from http://weather.gc.ca/city/pages/nu-10_metric_e.html

survival of the occupants and reduce the risk of death from hypothermia.

"*Buoyant oars, unless the lifeboat is free-fall"* (Schedule II, Lifeboat Equipment, Item 1.)

Simply specifying "buoyant oars" in the regulation leaves a large amount of room for interpretation on what can be used to fulfill this requirement. The "buoyant oars" that came with a conventional TEMPSC are pictured in Figure 3.

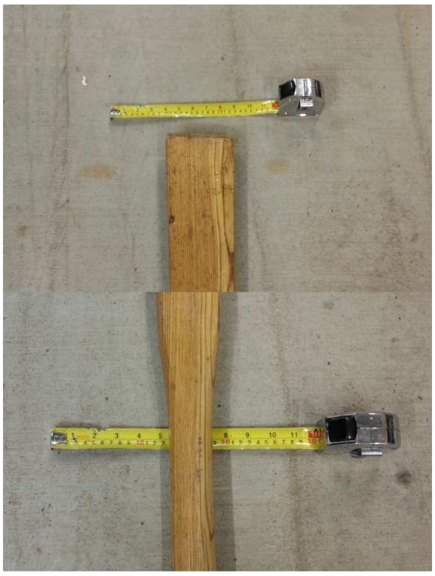

FIGURE 3. BUOYANT OAR THAT CAME WITH A TEMPSC (TOP: PADDLE BLADE. BOTTOM: PADDLE SHAFT).

The maximum width of the blade on the oar is 12 cm; the shaft diameter is 5 cm wide. Experienced coxswains who have driven the associated TEMPSC have commented that they believe these oar would be ineffective in propelling the craft and are only carried on board to satisfy regulations (Personal communication). These oars provide an example of simply following regulations to the letter without giving thought to how they may actually be used during a marine accident. If the regulation had added the phrase "capable of propelling the fully loaded lifeboat at a speed of X knots in mild sea states" after "Buoyant oars", then oars that are more effective at moving the TEMPSC would most likely be included. The fact that freefall lifeboats are excluded is puzzling. Buoyant oars are used for propulsion in the event the engine is not working so it doesn't matter if the lifeboat is of the conventional or freefall type. No explanation is given as to why freefall lifeboats are exempt.

In the same section of the regulation, subsequent text also states the following:

The buoyant oars shall be sufficient in number to enable the complement to make headway in calm seas…. (page 152)

Once again, specifying a (somewhat ambiguous) level of performance in calm water conditions overlooks the effects that wind, waves and ice conditions have on the performance of the LSA technology. Given the small shape of the blade on the oars that came packaged with the TEMPSC (Figure 3), it is not difficult to imagine the challenge TEMPSC occupants would have in using them to propel the craft in any kind of sea state or ice concentration.

"No lifeboat shall be deemed fit to carry more than 60 persons unless it is a motor lifeboat or a mechanically propelled lifeboat." (Schedule V, Lifeboat Standards for Existing Ships, Part I, General Requirements, Paragraph 9)

Continuing on from the previous regulation on buoyant oars, this statement in the regulation suggests that lifeboats capable of carrying 59 people, or less, do not have to have a form of motorized propulsion. It can be inferred from this statement that an acceptable form of propulsion would be the "buoyant oars" discussed in the previous section of this paper. Referring back to the buoyant oars in Figure 3, it is very likely that the lifeboat occupants in a craft rated for 59 people would find it extremely challenging to propel the craft using those oars. Given the physical challenges of rowing a fully loaded lifeboat of any size, it is recommended that all lifeboats be outfitted with some form of motorized propulsion.

"(2) If a ship navigates in waters the temperature of which is 15°C or more, the requirement in respect of the accommodation capacity of the life rafts or inflatable rescue platforms that is referred to in paragraph (1)(d) or (3)(b) may be met by counting not more than 33.33 per cent of the complement of the life raft or inflatable rescue platform as being in the water, holding on to the life raft or inflatable rescue platform." (Class V Ships, Section 17, Paragraph 2)

Having 33.33% of the occupants of a liferaft immersed in the water unnecessarily exposes them to conditions that could decrease their chance of survival. Previous work by Tikuisis generated PST for average individuals (Mass: 73.9 kg; Height: 1.77 m; Body Fat: 17.7%) immersed in varying water temperatures in rough seas with a low level of thermal protection (e.g. boatcrew coverall, floater suit) (12). The PST for these individuals ranged from 7 to ~12 hours. While these PST are relatively long (and physically larger individuals will most likely have longer PST), exposing people to these immersion conditions is an unnecessary risk that should be avoided. Stipulating that a vessel can carry enough liferafts for only 66.6% of its occupants as long as it remains in waters that are 15°C can create potential problems. For example: will vessel operators adhere strictly to the "15°C or warmer" portion of the regulation and only navigate in waters that meet this criteria, or will they occasionally cross into waters that fall below this temperature limit? As water temperature varies above and below 15°C with the season, will vessel operators add/remove liferafts to ensure they meet the requirements?

This could create a situation where a vessel operator may only have enough liferafts for 66.6% of the occupants in the warmer summer months when the water temperature is above 15°C, but may forget to add more as the weather, and subsequently the water temperature, drop in the cooler winter months of the year below the threshold. Also, what if one or more of the liferafts constituting the 66.66% gets damaged by the incident causing the emergency evacuation?

Coupling the total liferaft occupant capacity to a value that can fluctuate depending on the time of year and location of the vessel creates an unnecessary level of risk. It is recommended that this be removed from the regulation and that all vessels should carry enough liferafts for everyone on board.

"A Class A emergency pack for life rafts consists of:.....(g) two buoyant paddles." (Schedule I, Equipment for Life Rafts and Inflatable Rescue Platforms Class A (SOLAS) Emergency Pack, Paragraph 1.)

Similar to the previous section discussing the "buoyant oars" that need to be included on board a lifeboat, specifying only "buoyant paddles" for liferafts creates a performance gap. The paddles that are included in the liferaft can be made from plastic and measure ~1.5 m in length (Figure 4).

FIGURE 4. STANDARD PLASTIC PADDLE FOUND IN A LIFERAFT EMERGENCY PACK.[3]

Previous work conducted by NRC investigated the ability of participants to paddle a 16 person liferaft (ballasted to 75% capacity with 75 kg people) both in calm water, and in waves (5). It was found that the young, healthy participants were only able to paddle the liferaft a mean distance of 23.7 m in calm water, and reported feeling "exhausted" afterwards. Remarkably, out of the 66 trials that were performed during the trials, the standard issue plastic paddle broke five times during normal paddling motions.

Not only do these plastic paddles have questionable durability, the size of them also makes their practicality questionable for larger sized liferafts. A Zodiac 150 person liferaft has a freeboard height of ~1.1m from the water line to the top of the upper buoyancy chamber. Figure 5 provides a visual comparison between the size of the buoyant paddles that came included with a 150 person liferaft, and the liferaft itself.

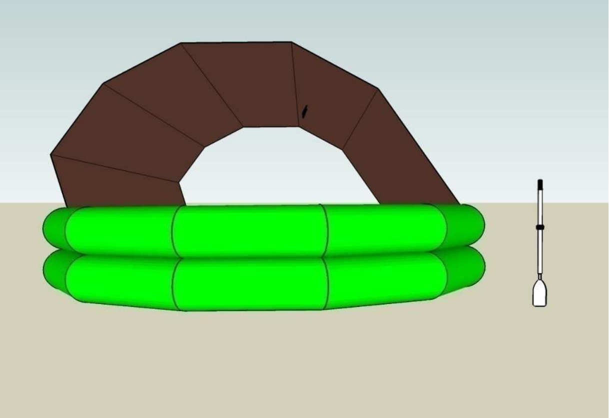

FIGURE 5. CONCEPTUAL DRAWING OF A L50 PERSON LIFERAFT AND THE PADDLE THAT WAS PACKAGED WITH IT.

As seen in Figure 5, the liferaft buoyancy chambers are ~ 73% of the height of the paddle itself; leaving only a height difference of ~40 cm between the two. This small difference in height makes it very challenging for a person to lean over the sides of the liferaft and have the paddle enter the water to make the proper paddling propelling motions. However, this problem may be only trivial when considering the sheer absurdity in one or two people trying to propel a fully loaded 150 person liferaft (15m long; 5m wide; and 3m high, with a full complement displacement of over 10 tonnes) with these plastic paddles.

The prescriptive nature of simply having "buoyant paddles" listed as necessary equipment for a liferaft highlights the inadequacies of this style of regulation. Vessel operators can include plastic, buoyant paddles in any size of liferaft and then simply "check the box" on having included them because the regulation required them to do so. Little thought is given to how effective these paddles actually are, or if including them is even logical (such as in the case of the 150 person liferaft). More consideration should be given to not only the quality of the equipment being included with LSA, but also if it is even practical to do so.

"*Every passenger ship shall have an evacuation procedure for the safe evacuation of the complement from the ship within 30 minutes after the abandon-ship signal is given."* (Part III, Operational Requirements and Equipment Standards, Life Saving Equipment Plans, Evacuation Procedures, Paragraph 111.)

There are a variety of methods for evacuating passengers from a ship and it is often the number of people on board that

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[3] Image retrieved from: Petrie, L. *The Effects of Towing on Human Performance in a Liferaft*. Unpublished Master's thesis, Memorial University, Newfoundland and Labrador, Canada. 2007.

determines is the method used. For low capacity vessels, a lifeboat can be used; the challenges with launching them have been discussed earlier. For higher capacity vessels such as ferries and cruise ships, inflatable liferafts are more commonly used since in their packed state they have a lower physical footprint compared to a lifeboat of an equal size. Once inflated in the water, the next challenge is moving the passengers from the vessel to the deployed liferafts. Slides and chutes are often used on high capacity vessels to evacuate the passengers to the liferafts.

Previous work by NRC has shown that slides and chutes may not be effective in evacuating high capacity vessels in the required 30 minutes as specified by the regulation. Twelve to 18 young healthy participants were instructed to use a standard marine evacuation slide and chute, cross a collection platform, and then enter a liferaft. They performed these tasks in calm water, and then in Beaufort 3 and 4 sea states[4] to replicate the evacuation of a ferry that had a passenger and crew complement of 2100 people (11).

In order to evacuate a 2100 person ferry equipped with six slides in 30 minutes as per the regulation, it was calculated that each person had to have an evacuation time limit of 5.14 seconds to descend the slide/chute, cross the collection platform, and then board the liferaft. It was found that the participants took 12.6 s when using the slide, and 9.9 s when using the chute, in calm water. The Beaufort conditions resulted in similar times for the slide (from 10.7 to 12.7 s), but caused increased times for the chute (12. 4 s in Beaufort 4). The results from this study found that when young, healthy participants used slides and chutes to simulate a marine evacuation, the amount of time required to do so was greater than what would be needed to evacuate a 2100 person ferry equipped with six slides in 30 minutes. Elderly passengers, or those with physical disabilities/injuries, may take even longer as they may not be as physically capable as the young participants in the NRC study as they may have pre-existing physical conditions that reduce, or even prevent, them from using the slide and/or chute as effectively.

The text that exists in the regulation does not refer to a specific size of passenger ship; only that they should be evacuated in 30 minutes after the abandon ship signal is given. Based on the evacuation time of 12.7 s reported by NRC for their participants using the evacuation slide in Beaufort 4 sea (11), then a single slide would only be able to evacuate ~142 people in the 30 minute time limit. The total number of passengers on board a ship would therefore dictate the number of slides/chutes needed to evacuate the ship in under 30 minutes; a higher capacity ship would require a greater number of slides/chutes to accomplish this.

While this section of the regulation is not necessarily a gap since it is possible to evacuate a passenger ship in 30 minutes if the appropriate amount of evacuation systems are in place, it is perhaps not as stringent as it could possibly be. This section of the regulation makes no reference to any specific kind of weather condition in which the 30 minute evacuation time is to be achieved. The participants in the NRC study experienced great physical difficulty in crossing the collection platform to the liferaft due to the motion of the waves. The participants also found it difficult to enter the liferaft as its vertical position relative to the collection platform became out of phase which resulted in them having to jump from the platform to the liferaft. This method of entering the liferaft was very different from calm water conditions when the participants were simply able to step from the collection platform to the liferaft. Without specifying the condition in which the 30 minute evacuation time should be completed, a performance gap is created and the effects that weather have on the ability of people to successfully use the evacuation systems are overlooked.

C. Survivability

"*The thermal conductivity of the material from which a thermal protective aid is constructed shall not be more than 0.25 W/(m·K).*" (Schedule XIII, Thermal Protective Aids, Paragraph 1).

The gap that exists in this section of the regulation pertaining to Thermal Protective Aids is not readily apparent, but can have a major impact on performance. The key term is "thermal conductivity" which is the property of a material to conduct heat; the higher the value the higher the rate of heat transfer through the material. By specifying an upper limit (0.25 W/(m·K)) for thermal conductivity, the regulation ensures that no material to be used conducts heat at a higher rate. However, this is a large oversight on the part of the regulation as just specifying thermal conductivity does not provide a specific level of thermal protection.

The level of thermal protection provided by a garment or clothing ensemble is commonly expressed in thermal resistance ($(m^2 \cdot W)/K$) or a clo value[5]. To calculate thermal resistance (R), the thickness of the material (L) is divided by its thermal conductivity (k):

$$R = L / k \tag{1}$$

Clo value is calculated by dividing thermal resistance by 0.155.

$$\text{Clo} = \text{R} / 0.155 \tag{2}$$

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[4] Beaufort 3 conditions: wind speed: 3.69 $m \cdot s^{-1}$; significant wave height: 0.30 m. Beaufort 4 conditions: wind speed 4.24 $m \cdot s^{-1}$; significant wave height: 0.67 m.

[5] 1 clo = 1 clo is equal to the amount of insulation required to keep a seated person comfortable in 21°C air, 50% or less relative humidity, and an air movement speed of $0.1 m \cdot s^{-1}$. 1 clo = $0.155°C \cdot m^2 \cdot W^{-1}$.

By only specifying thermal conductivity for the material, the *amount* of the material required (*L*) to calculate thermal resistance (R) is not given. This could, in theory, allow a manufacturer to use the smallest amount of appropriate material (thermal conductivity = 0.25W/(m·K)) in construction of the thermal protective aid. This would result in the range of protection provided by a thermal protective aid to vary widely, impacting the survival time range of the people. Figure 3 provides predicted survival times, as generated by the CESM, for 50th percentile 60 – 70 year old females in -15°C air for a material with a thermal conductivity of 0.25 W/(m·K) across a range of thicknesses.

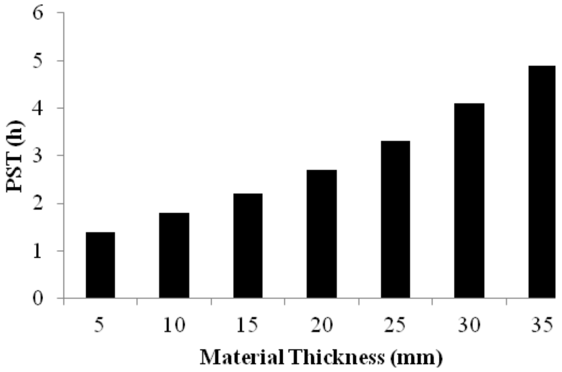

Figure 3. Predicted survival times (PST) in hours (h) for a range of thicknesses for a material with a thermal conductivity of 0.25 W/(m·K).

The range of protection, and subsequently survival time, provided by the material can vary depending on how much of it is used. By only specifying thermal conductivity, and not thermal resistance or clo value, in the regulation the level of protection provided by thermal protective aids can range from a very short time to a much longer one.

"*Immersion suits – Sections 3 to 9 of Canadian General Standards Board Standard CAN/CGSB-65.16-M89, published in February 1989 and entitled Marine Abandonment Immersion Suit Systems.*" (Part III, Operational Requirements and Equipment Standards, Equipment Requiring Board Approval, Paragraph 121.)

The standard the regulation refers to is out of date. The new standard is CAN/CGSB-65.16-2005 entitled *Immersion Suit Systems*.

Immersion suits approved to CAN/CGSB-65.16-2005 should prevent a 2°C drop in deep body temperatures in human participants in a 6 hour period when a person is in 2°C calm, circulating water; or have an in situ clo of 0.75 when measured by a thermal manikin in 40cm waves (1). Similar to previous sections in the regulation, the specified test conditions for immersion suits when using humans overlooks the impact that environmental conditions can have on LSA performance. Previous work by NRC has shown that immersions in wind and waves can increase heat flow by up to 37% compared to calm water (9), which can result in a ~50% decrease in predicted survival time (7). By specifying only "calm, circulating water" for the human tests, the significant impact of wind and waves on the amount of thermal protection provided by the immersion suits is overlooked, which can possibly lead to the "unexpected, poor performance" as described by Tipton (13).

The level of thermal protection provided by immersion suits can be considered adequate when dealing with areas of operation that are located off the west and east coasts of Canada where search and rescue (SAR) times are significantly less than 6 hours. Problems will arise however when the intended area of operation moves further north, and the ability for SAR assets to reach the area is limited. Previous work by NRC quantified the estimated exposure time for specific locations in the Canadian Arctic (3). It was found that the specific location, time of year, and local weather conditions (including sea ice coverage) influenced the length of the exposure time, and if a sea- or air-based SAR asset was to be used. For a moderately active shipping area in the Arctic, exposure times ranged anywhere from 14 to 131 hours (3). The predicted survival time for a 50th percentile 60-70 year old female in a 0.75 clo immersion suit in 0°C water is 9.4 hours. Given that the expected minimum exposure time in the Arctic region of Canada is much greater than the predicted survival time, the use of just an immersion suit is not sufficient to ensure survival in these regions. In order to ensure survival in the Arctic, or in any remote region where exposure time is high (> 6 hours), immersion suits must be used in conjunction with other LSA technologies that exceed the performance of current ones (e.g. lifeboats or liferafts) to ensure that people can survive until rescue.

"A Class A emergency pack for liferafts consists of: .....(p) for each member of the complement, a food ration totaling not less than 10, 000 kJ in air tight packaging and stowed in a water tight container showing an expiry date...(r) the following water supplies: (i) a rustproof watertight container or individually sealed units containing 1.5 L of fresh water for each member of the complement, or....."(Schedule I, Equipment for Liferafts and Inflatable Rescue Platforms, Class A Emergency Pack, Paragraph 1, Sections p and r.)

The gap that exists here in the regulation is that there no time frame given for how long the food and water supplies in a Class A emergency pack are supposed to last. An average male will consume ~ 10, 040 kJ (2400 Calories) in food a day (2), which suggests that the food rations will be consumed in one day. However, death from starvation can take anywhere from 40 – 60 days (2) which suggests that liferaft occupants could, in theory, survive for extended periods of time without food while awaiting rescue. The larger concern is the limited water supply. The minimum water requirement for a human is 1 L per day (2). Under normal circumstances, the 1.5 L provided in the liferaft would meet the minimum water requirements for 1.5 days. It is difficult to estimate how much water is required by people in a survival situation as water conservation strategies can be adopted. Previous work by McCance and colleagues found that the critical volume of water for survival was between 0.11 – 0.22 L (4). Based on this evidence, it is possible that the 1.5 L of water provided in the Class A pack could ensure survival for almost 7 days. Given the upper limit of the exposure time range of 131 hours (5.45 days), liferaft occupants could survive until rescue, in theory, if they practiced water conservation efforts.

The 10,000 kJ food rations and 1.5 L of drinking water per person are values are similar to the daily requirements for each for an average individual; possibly suggesting that a Class A pack is only providing enough sustenance for 24 hours if no conservation efforts are practiced. Since exposure time in the Canadian Arctic can sometimes last up to several days (3), a Class A emergency pack will only ensure survival of the liferaft occupants if conservation efforts are used. As previously mentioned, many seafarers are physically larger than what is considered "average" by regulations an may require additional food and water.

III. CONCLUSION AND RECOMMENDATIONS

This paper presented a select few human factors knowledge gaps in the regulation "Life Saving Equipment Regulations", C.R.C c. 1436. These knowledge gaps are often created when the prescriptive nature of the regulation does not take into account the more severe conditions than calm, circulating water that can occur during a marine accident; or have an inaccurate representation of a key measure (i.e. the mass of an average human) that can have a "trickle down" effect on the LSA governed by the regulation.

The human factor knowledge gaps presented here may grow to have a wider impact as marine activity increase in the Arctic. These gaps were quantified using data from research that replicated the environmental conditions of the current area of operations, such as the wind speeds and wave heights in the Atlantic Ocean. The harsh conditions in the Arctic will require a higher level of LSA performance as temperatures will be much colder, environmental hazards will be more severe (e.g. wind, waves, and ice covered waters) and exposure will time will be significantly greater. A first step towards addressing these new knowledge gaps in LSA performance that could exist in the Arctic would be to quantify the environmental conditions such as temperature, ice coverage, wind speeds, wave heights, etc. Once the environment has been quantified, future research could be performed in controlled settings that closely replicate the Arctic conditions to quantify the impact of the environment on performance. The length of time required for the LSA to maintain a level of performance in Arctic like conditions can then be specified as the expected duration that a SAR asset with rescuing capabilities will take to reach the emergency providing a better measure of LSA performance. A more accurate assessment of LSA performance would identify knowledge gaps which can then feed back to regulations and operational procedures allowing them to be modified to ensure expected performance.

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