A methodology for collecting donning times of thermal protective immersion suits intended to be worn by passengers on vessels operating in cold environments

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Abstract. Adequate thermal protection for passengers travelling on-board vessels in cold climate regions, such as that provided by thermal protective immersion suits (TPIS), enhances passenger survivability in emergency situations, in particular those requiring the abandonment of the vessel. As emergency abandonment is a time critical process, it is essential to consider the time required to correctly don the TPIS. Testing standards, such as the International Maritime Organization guidelines, require that TPIS must be able to be donned within 2 minutes. Unfortunately, current practices quantifying donning times are questionable and so there is a limited evidence base that reliably quantifies donning times required by typical passengers. This paper presents a test procedure designed to reliably quantify the time required by test subjects to don the TPIS. Furthermore, the procedure assesses the donning correctness – a TPIS that is incorrectly donned is unlikely to offer appropriate thermal protection. The paper will also discuss the deficiencies in current practices to assess required donning time.

1. Introduction

The safe operation of passenger vessels in cold environment includes the provision of thermal protection for all persons on-board in case of an emergency situation, in particular those requiring the abandonment of the vessel. Thermal protection can be enhanced by using additional warm clothing, ranging from woolen underwear to thermal protective immersion suits (TPIS), that are designed to keep the body as dry as possible upon immersion in water. For Arctic regions, the Polar Code of the International Maritime Organization (IMO) [1] regulates the provision of immersion suits or thermal protective aids, in addition to local regulations.

Emergency abandonment is a time-critical event. Thus, it is vital to carefully plan and evaluate emergency response procedures to be prepared as best as possible for a safe and efficient abandonment. This includes considerations concerning the thermal protection and the impact it might have on the evacuation process. One of the factors, that may impact the evacuation process, is the time required to don appropriate thermal protection. For example, the IMO International Life-Saving Appliance (LSA) Code [2] regulates the donning time for immersion suits to be within 2 minutes. The IMO stipulates that the time required to assemble passengers as part of an evacuation cannot exceed 30 minutes [3], and so the 2-minutes donning requirement constitutes almost 7% of the assembly time.

In addition, only a correctly donned TPIS will provide the expected adequate thermal protection. However, TPIS can vary significantly in design and complexity. For example, the design of TPIS's usually adopt a one-size-fits-all approach, which allows for a rapid distribution and aims at quick donning [4], but often adjustment straps need to be provided to shorten or lengthen parts of the suit to achieve a better fit for a larger range of individual body sizes. The number of straps and fasteners increase the amount of donning tasks that need to be performed, which in turn may lead to longer donning times, and enable a higher rate of donning mistakes that can be made. Furthermore, not all donning mistakes necessarily compromise the thermal protection, but they might have other undesirable effects on the evacuation process. An ill-fitting suit might impair someone's ability to walk towards the assembly station prior to abandonment and add time to the evacuation process.

Design and test standards for TPIS, such as defined by the International Organization for Standardization (ISO) or IMO, regulate and control allowable donning times, donning correctness, and walking performances while wearing the TPIS. The ISO and IMO 2-minutes donning requirement is tested using six human test subjects of varying defined height, weight, and gender. The requirement includes the time to unpack and don the immersion suit without assistance after receiving a demonstration [5, 6]. This includes the donning of a lifejacket if the immersion suit is to be worn in conjunction with a lifejacket. ISO defines an air temperature requirement of (20 ± 2) °C for this test. In addition, both standards define a second test to be performed at an ambient temperature of -30 °C, where ISO limits the donning time to five minutes and IMO to a "reasonable time". The small sample size of only six adult participants, which are healthy and able-bodied, cannot represent the large and varying populations onboard passenger ships. It is thus questionable if the ISO/IMO test protocol is a good assessment of the time required by a typical passenger to don TPIS and even more questionable if the simple pass/fail criteria from testing standards is appropriate in the evaluation and planning of emergency response procedures.

Furthermore, within the ISO/IMO test protocol, the level of experience of the participants in donning an immersion suit, either the specific product or a similar type, is not clearly defined nor required to be controlled. ISO requires the test subjects to be familiar with the use of the suit, whereas IMO does not define any donning experience requirement. However, several donning experiments have clearly demonstrated that prior experience of donning protective equipment positively impacts performance. Vaughan MacDonald et al. [7] demonstrated a clear learning effect between the first and second donning attempt for infant lifejackets. This reflected in fewer donning mistakes made and a shorter donning time. They also discussed that lifejackets with a less complex design, for example less fastenings, might not benefit from the learning effect as much as more complex lifejackets, that require a higher number of sub-tasks, simply because there is less room for improvement. A learning effect for donning immersion suits was demonstrated by Mallam et al. [8], who recorded donning times of two types of marine abandonment immersion suits in both static and simulated dynamic conditions in varying lighting combinations. Their study clearly demonstrated that learning effects lead to a reduction in donning times and donning mistakes.

The study performed by Mallam et al. [8] is one of the few studies published in the academic literature describing donning performance of immersion suits. In addition to measuring the donning times of two types of marine abandonment immersion suits, the study protocol explored the impact of environment on donning performance. Donning experiments were conducted in both static and simulated dynamic conditions with varying lighting combinations. Both suit models were of insulated type with buoyancy material and approved by Transport Canada. A total of 32 participants (18 males, 14 females) of young age (22.9 ±2 years) were recruited. Participants had no prior experience of donning an immersion suit nor did they have a maritime background. The participants were split into two equally sized groups of 16 participants and each group was assigned one type of immersion suit. Written instructions were provided prior the trials. Six experimental conditions were defined, including one baseline, which represented the first trial and was repeated after the other 5 experimental conditions as a seventh trial. Thus, each participant was asked to don their assigned immersion suit seven times in varying conditions.

Apart from reporting a clear learning effect, the study also found that the two types of immersion suits produced significantly different results in overall donning times, although they were of similar design. This is an important finding, as it suggests that small variations in design can significantly impact donning performance. Furthermore, a minimum number of tasks were defined, that were judged to be the bare minimum to provide thermal protection to a minimal extent and effective flotation in cold water. The donning times for those essential tasks were not significantly different between the two suit designs. The difference lay in secondary tasks, such as putting on gloves and attaching the face shield.

The study reported an overall mean donning time below the 2-minutes criteria specified by the testing standards by IMO and ISO. However, in 26.1% of all the donning trials, the donning time was above the 2-minutes criteria. This time includes the time derived from all the donning trials, including the donning times of participants that have donned the suit one, two, three, four, five, and six times before. The donning times are therefore strongly biased by the learning effect previously identified. Unfortunately, the individual donning times for the first trials are not reported for each suit. The only data reported is that the mean donning time was over two minutes for one suit design and under two minutes for the other suit type. Referring to the ISO/IMO testing standards, IMO provides no allowance for failure, while ISO allows for an error rate of about 16% for the first donning attempt, i.e., 1 out of 6 participants may fail for the suit to be considered to pass the performance criteria. Clearly, both suits would be considered to fail the ISO/IMO criteria.

Furthermore, donning task errors were reported, with individual error rates up to 56.3%. However, the paper does not report how many participants managed to don the suit correctly at first attempt. The highest error rates were found for tasks that require fine motor skills, associated with the defined secondary tasks. Secondary tasks also accounted for a larger percentage of total donning time. This indicates that the suit design and its specific performance requirements must be seen as part of an overall survival demand. For example, to increase immediate survivability, it may be more important to abandon the vessel as rapidly as possible rather than spending time ensuring that all the Velcro tags are fastened. Clearly, this assessment cannot be made during the emergency situation, and certainly not by passengers, but should rather be performed during the evaluation of evacuation options and design of evacuation procedures and taken into consideration when choosing adequate protection equipment.

Clearly, a reliable survival suit testing protocol is required to demonstrate the suitability of immersion suits meeting the performance requirements established by the ISO/IMO. Furthermore, it is essential to establish an evidence base that reliably quantifies donning times for TPIS required by typical passengers that can be used in passenger ship evacuation analysis. In this paper we present and describe a test procedure designed to reliably quantify the time required by test subjects to don TPIS that addresses the weaknesses described in previous studies and in the ISO/IMO test procedure.

2. Research project objectives

The collection of donning performance data for TPIS is part of the ARCEVAC (ARCtic and Antarctic EVACuation) research project. It is a collaborative project between the Western Norway University of Applied Sciences (HVL) and UiT The Arctic University of Norway. The project objective is to develop three datasets quantifying the impact of TPIS on passenger evacuation performance and identify and quantify the impact of TPIS on passenger ship evacuation using advanced evacuation modelling.

Providing thermal protective equipment for passengers' onboard ships operating in cold environments is expected to enhance survivability in case of an emergency abandonment situation and is a mandatory requirement of the IMO [ref]. Furthermore, assessing the emergency evacuation performance of large passenger ships is also an IMO mandatory requirement, assessed during the design phase of the vessel [3]. However, the anticipated impact of the required thermal protective equipment on individual and overall evacuation performance is currently not required. This is due, in part to the lack of appropriate evidence bases quantifying the impact of TPIS on passenger performance. Addressing this problem are the three ARCEVAC datasets concerning, TPIS donning times, the impact of TPIS on passenger speeds while ascending/descending stairs and the impact of TPIs on passenger walking speeds along corridors at angles of heel.

3. Methodology

3.1. Ethical review

The use of human test subjects in any research study requires careful consideration of the experimental set-up and the experimental procedures in order to minimize any potential harm to test subjects. This ranges from physical and mental harm to personal data protection. A risk assessment was performed prior to the experiments and measures taken to minimize any risk. This resulted in targeting able-bodied, healthy participants of adult age between 18 and 72 years only. In additional, all participants were informed about the test procedure and their right to stop and withdraw from the data collection at any time during the experiment or after. All participants gave written consent prior to their participation. Furthermore, it is essential to ensure that experimental data, in particular data relating to personal information is handled in an appropriate manner. A data storage and handling plan was established following the guidelines provided by HVL. The data collection was notified to NSD – Norwegian centre for research data.

3.2. Test facilities and equipment

The donning trials were part of a greater data collection, as mentioned above. Thus, the choice of test facilities was influenced by the methodology of the other data collection activities. For example, as test subjects participated in a range of activities, not only the donning trials, the donning test location had to be in the vicinity of the other test locations. Nevertheless, the following general criteria were used in order to evaluate the options: availability for the duration of the experiment, appropriate accessibility for the participants, adequate size, possibility to provide instructions to the participants prior and post experiment, possibility for the participants to fill out questionnaires, and possibility to install video cameras to clearly record the entire donning process.

The donning trials were executed at three different locations in Norway: at the ARCOS safety centre in Tromsø, at the Faculty of Science at The Arctic University of Norway in Tromsø (UiT) and at the ResQ safety centre in Haugesund. The donning trials at the two locations in Tromsø took place simultaneously over a duration of 6 days. Some participants were at both locations and donned one of the two suits, that were used in this project, at each location. It was carefully recorded, which suit had been donned, so that the participants would don each type of suit only once, enabling potential learning effects to be explored.

The donning took place inside on a smooth flat floor. A square of 3m x 3m was marked on the floor. The size of the various cohorts varied from 2 to 15 participants and so the minimum floor space available for participants to don the TPIS was 0.6m^2. For comparison, the minimum required deck space for assembly areas is 0.35m^{2}pp [9, Chapter III, Part B, Regulation 25.2] (see Figure 1). The donning process was recorded using two GoPro HERO6 cameras installed on opposite sides of the rooms. External battery packs were used to ensure battery functionality throughout the day.

Figure 1. Experiment locations from left to right: ARCOS centre, Faculty of Science at UiT, and ResQ centre

3.3. Thermal protective immersion suit

To the best knowledge of the authors, reliable donning performance data for any kind of TPIS is not publicly available in the academic literature. Furthermore, as demonstrated by Mallam et al. [8], even

apparently similar TPIS can result in significantly different donning times. Thus, collecting donning performance data of any kind of TPIS is beneficial towards the understanding of donning performances and which factors influence it. For the purposes of this study, a TPIS that was approved for use in cold regions and designed for installation onboard passenger vessels was selected – see Figure 2. The selected TPIS is a non-insulated immersion suit without integrated buoyancy. The suit is approved in accordance with SOLAS' LSA Code Med/1.5a [2] as designed to be used with additional approved lifejacket. It can be used within the survival kit as required by the Polar Code or installed as an additional thermal protective aid. The suit can be vacuum packed to minimize the storage space and extend the service interval.

The immersion suit is a one-piece overall made of PU-coated nylon and comprises of integrated socks (boots), adjustable ankle straps, an insulated neoprene hood, integrated 5-finger gloves, and a soft non-waterproof front zipper with a wide gusset underneath for sealing. The passenger can wear their shoes either inside or outside the suit. General information and donning instructions with figures are printed on the vacuum-packaging, but not on the suit itself (see Figure 2).

Figure 2: Picture of unpacked immersion suit (left) and vacuum-packed suit (right)

Due to a limited amount of new, vacuum-packed suits (n = 25), unpacked suits had to be re-used for a large part of participants. Before every new trial cohort, the used suits were folded together with the zipper and gusset strap opened, ankle straps untied, leg and arm sleeves entangled, and containing as little air as possible. Thus, only a limited number of trials incorporated the time required to open the packaging.

3.4. Recruitment process and participants

The aim of the recruitment process was to target a representative population composition, referring to a wide range in age, height, weight, and gender. Furthermore, naïve test subjects were targeted. It is assumed, that the majority of passengers onboard cruise and ferry vessels are inexperienced in donning TPIS. As highlighted earlier, participants with experience in donning a particular or similar type of TPIS, are likely to produce significantly different performance data than inexperienced participants.

Participants from the general public between 18 and 72 years were recruited. It was required that participants had no physical limitations or conditions that seriously impaired their movement or vision. Participants were recruited through the local media, social media and word of mouth. A media plan was established, involving the Division of Communication and External Relations at HVL. Local newspapers were contacted, a recruitment video produced to be shared on social media and word-of-mouth advertising encouraged. In total, 96 participants (67 males; 29 females) donned the uninsulated immersion suit at all three locations (see Annex Section 3.0).

3.5. Experimental procedure

The donning trials were designed to provide an evidence base addressing a number of key questions:

1. Does the method of instruction impact donning performance?
2. Is donning performance influenced by age and gender?
3. How quickly can the particular TPIS be donned?
4. What type and how many donning errors are incurred during the donning process?

The majority of donning data was collected at the two sites in Tromsø. In Tromsø, the ARCEVAC trials took place over a period of six days with up to four cohorts each day. Each cohort was scheduled to last for up to 2 hours. This included the time required for the test subjects to participate in the other two data collection exercises (i.e. walking through a corridor at heel and ascending/descending the stairs). A few additional data points were collected at the site in Haugesund, which took place over a period of 4 months, with one cohort on selected days only.

Following registration, the first data collection activity that the test subjects were involved in was the donning trials. Before the trial, participants were given an information letter, which provided detailed information about the purpose of the trial, what their participation implies, how the information will be handled, that they may withdraw their consent at any time or terminate the donning procedure at any time. This information was given again orally at the beginning of the trials, with the possibility to clarify any issues, before the participants were asked to give written consent. Furthermore, participants were asked to fill out a questionnaire, which collected demographic information and identified any previous experience with donning immersion suits.

Prior to positioning the participants within the marked floor area behind their assigned suit, some of the participants were shown a short (2 min 25 sec) instructional video (in Norwegian) demonstrating how to don the suit correctly (see Annex, Section 1). Furthermore, prior to commencing, a researcher set the scene for the trial and provided the trial instructions using a predefined script. Participants were instructed to imagine that they were at sea onboard a passenger ship sailing in artic waters and the evacuation alarm had just been sounded. The participants were told that they had to don the suit as quickly and as correctly as possible so that they would be ready to safely evacuate the vessel. The task would start once the instructor yelled "GO". Cohorts were placed in different instruction categories (see Section 3.6) and so they may be further instructed to read the donning instructions prior to attempting to don the suit, but only after the "GO" command had been issued. Participants were instructed to indicate that they had completed the task and donned the suit as best as they could by raising their arms above their heads. Participants were instructed to not talk to each other or assist each other during the donning trial, but that they may look at the others around them, keeping in mind, that the others may not be donning the suit correctly. Once the participants were done, a researcher would take them aside and check if the suit was donned correctly, recording any problems. The participants were then given a questionnaire, which explored the participant's opinions concerning the ease of donning the suit, whether they could suggest any improvements to the suit design to ease donning and provide any additional feedback. The complete questionnaire can be found in the Annex, Section 2.

3.6. Instruction categories

Depending on the journey duration of the passenger vessel, either safety briefings or muster drills of passengers are mandatory according to SOLAS [9, Chapter III, Regulation 19]. This includes instructions on how to don protective equipment, either by a visual demonstration or announcement. This can be supplemented by information cards, posters, or video displays. It is, however, not required for passengers to don life vests or other protective equipment during this training, but they might be invited to do so voluntarily. Nevertheless, the safety briefing might not provide the desired proficiency in donning performance. In addition, it is assumed that not all emergency abandonment situations allow for the passengers to read instructions that are provided with the suit due to low lighting or time constraints. Also visual demonstrations or video instructions might not be feasible at that time. Thus, studying the donning performance of test subjects that receive donning instructions in various forms upfront, provides an understanding of the impact instruction and the type of instruction may have on donning performance. For example, it is expected that test subjects not receiving any instructions at all require longer time to don and make more mistakes than test subjects that watched a video instruction upfront. This information can then be utilized during the planning and evaluation of evacuation procedures. Furthermore, the results from the test subjects that do not receive any donning instructions can be used to assess and improve the design of the TPIS with respect to its ability to be donned

intuitively, both correctly and in a reasonable amount of time and can be used in evacuation modelling applications as a plausible worse case.

Four instruction categories were defined based on whether the participants received instructions, and if those instructions were received by reading the donning illustrations on the suit packaging and/or through the video instruction. Thus, the four instruction categories were: *No instructions*, *reading only*, *video only*, and *video and reading*.

Written instructions by the manufacturer were provided on the vacuum-packaging of the suit (see Figure 2 and Annex Section 1b).

3.7. Experimental variables

3.7.1. Observational variables. Several observational variables were defined with the aim to evaluate anticipated donning behaviour or challenges associated with suit accessories. However, some observational variables were added to the list of variables to note once they were observed to occur during several of the donning trials. The observational variables are analyzed and quantified during the analysis of donning videos, and are particularly useful when assessing outliers. Furthermore, it enables an informed recommendation with regards to suit design, design of instructions, or donning procedure.

Study instructions: All suits that were still in their original vacuum-packaging, had donning instructions provided on the packaging. As part of the video analysis it was recorded, if and when the participant looked at the instructions. In particular the following behaviours were defined and noted: Did not study at any time/ Study before first attempt to don/ study only during the donning process/ study before start of donning process and during donning process.

Looking at others: Three states were noted: (A) Does the participant look at others during the donning process, (B) or prior to starting the donning process, (C) and how many times did the participant look at others.

Stance: The participant stance was recorded dependent on its duration. So, it was noted if the participant was standing, sitting on the floor, or sitting on the chair for most of the time during the donning process or for some period. Furthermore, it was recorded if the participant was kneeling or leaning against something for some period.

Shoe status: Seven possible shoe conditions were defined: (1) The participant kept the shoes on throughout, (2) took the shoes off after the trial started and before reading instructions, (3) took the shoes off after reading instructions, (4) took the shoes off after attempting to put the suit on with shoes on, (5) took the shoes off after observing others, (6) took shoes off and put them back on after donning the suit, or (7) took shoes off and did not put them back on after donning the suit. Several cases may be applicable and were recorded in the order they occurred.

Difficulties with putting arms and/or legs into sleeves: It was recorded if the participant struggled with getting their arms and/or legs into the suit. “Struggle” was defined as in hesitates, or it seems to not be a simple action of putting the arms/legs in. For example, a struggle can be if the legs of the suit are twisted, and the participant cannot simply slide their legs in easily but needs to adjust the suit.

Difficulties with pulling the zipper up: This variable recorded if the participant experienced problems when pulling the zipper up and what kind of difficulties they encountered. It does not record, if the zipper was correctly pulled all the way, just whether there were any problems. The definition of “difficulties” is that the zipper stops moving upwards without reaching its final position. Defined difficulties were due to zipper getting stuck while both sides of the zipper align and no object was stuck in the zipper, something was stuck in the zipper, the participants hair was an issue, the zipper broke while donning, zipper was already broken, or the gusset and/or gusset strap was an issue.

Difficulties with hair and hood: It was noted that long hair may cause inconvenience while attempting to pull on the hood. Thus, it was recorded if the participant needed to re-adjust or take off and put on the hood several times due to issues associated with hair.

Difficulties with glasses: It was noted that some participants had problems pulling on the hood if they wore glasses. Thus, it was recorded if the participant experienced difficulties putting on the hood

because of their glasses. For example, if they had to take their glasses off to put on the hood or if the glasses got in the way while putting on the hood.

3.7.2. *Time measurements.* As part of the video analysis the timing of several key events were identified. To ensure that these times could be consistently measured, a precise set of definitions were created to unambiguously identify the event times. Four Scenarios (S) were considered; S1: Participant first studies instructions then opens packaging, S2: Participant first opens packaging and then studies instructions, S3: No clear distinction between opening packaging and studying instructions, and S4: Participant had a used suit without packaging or instructions.

Total duration: This is the time, for each participant, from start to end of the donning trial. The start-time was defined as the moment when the word "GO" (first frame) can be heard on the video recording. The end-time was identified when the participant raised their hands above their head. This is precisely defined when the hand reached the highest level and come to a stop. If participants did not raise their arms, another meaningful end-time was determined, and its explanation noted. In case of abandoning the donning attempt, the last donning activity undertaken was recorded as well as the extent of the donning process achieved by the participant.

Study instructions: Two events were measured, the "duration of initial study time" and "study instruction count". The first measures the time a participant looks at the instructions before starting to don the suit. The start was marked by the word "GO" (S1) or the end of the package opening (S2). The end was marked by the participant opening the packaging (S1) or when the participant started to unfold the suit (S2). Any overlap of reading instructions and opening the packaging was recorded (S3). The number of times a participant looked at the instructions was also noted ("study instruction count"). A new count started when a participant completed a non-study activity, e.g. fastened a strap. A new count did not start when the participant looked away from the instructions and then back without performing some physical donning action. Note, participants may have looked at the instructions after unfolding the suit. However, this time was not recorded, but included in the instruction count.

Duration of package opening: The starting point of opening the packaging was marked by the point when the participant had stopped reading the instructions and held the packaging in both hands in order to tear open the packaging (S1), or by the word "GO" (S2). The opening task ended when the suit was completely removed from the packaging. If the participant opens the packaging and reads the instructions simultaneously, the time was measured from when the participant starts opening the packaging and the overlap recorded (S3).

Donning time: For S4 (used suits) the donning time equals the "total duration". For all other scenarios (new suits), the donning time was determined by subtracting the "duration of initial study time" and "duration of package opening" from the "total duration". Participants, that had an overlap of reading instructions and opening the packaging, the overlap was taken into consideration.

3.7.3. Level of donning correctness. The level of donning correctness was measured by defining five separate attributes that needed to be satisfied after the participant indicated the end of the donning process. For each attribute, that was not satisfied correctly, the participant received a "donning point". The greater the number of donning points, the more incorrect the final state of donning achieved. The order in which the attributes were satisfied was not considered important. The five attributes were as follows:

- Shoes: Shoes must be on, either inside or outside the suit
- Ankle straps: Both ankle straps must be closed.
- Hood: Hood must be worn over the head.
- Gusset strap: Gusset strap must be fastened. Participant must have made an effort to fasten it, however, how much it was fastened was not assessed.
- Zipper: Zipper must be closed all the way.

3.8. Data extraction and analysis

The video recordings were extracted from the video camera and prepared for video analysis using Adobe Premier Pro CC 2019. Time measurements and observational data was extracted from the edited video-files using Premier Pro and recorded in a Microsoft Excel spread sheet according to the variables defined in Section 3.7. Similarly, the data from the questionnaires were transferred to an Excel spread sheet for analysis. The statistical analysis was conducted using IBM SPSS Statistics version 27 (hereafter called SPSS).

To ensure homogeneity, the inter-rater reliability was tested. Twenty participants from varying cohorts, that displayed a broad variety of behaviour and performance variables, were chosen and their data extracted. The same twenty participants were then given to another researcher to extract the data based on the same definitions. The Intraclass Correlation Coefficient (ICC) and Cohen's Kappa were calculated for interval and ratio (e.g. study count, total duration, etc.), and nominal (e.g. stance, shoes status, ankle strap fastened, etc.) measurements, respectively. ICC estimates and their 95% confident intervals were calculated using SPSS based on absolute agreement, 2-way mixed-effects model. An excellent level of agreement on average (ICC = 0.918) was found. Cohen's Kappa was calculated using SPSS for the nominal measurements. The interrater reliability for the raters was found to be strong (Kappa = 0.830) on average.

4. Preliminary results and discussion

The data extraction and analysis are still in progress at the time of writing this paper. However, some preliminary results are presented. Most data points refer to participants donning a used, unpacked suit, without any instructions available. Thus, the donning time is reported excluding the time it takes to open the packaging and without reading instructions for a sample size of 65 data points. The donning time probability distribution appears to be a log-normal distribution as it can be seen in Figure 3.

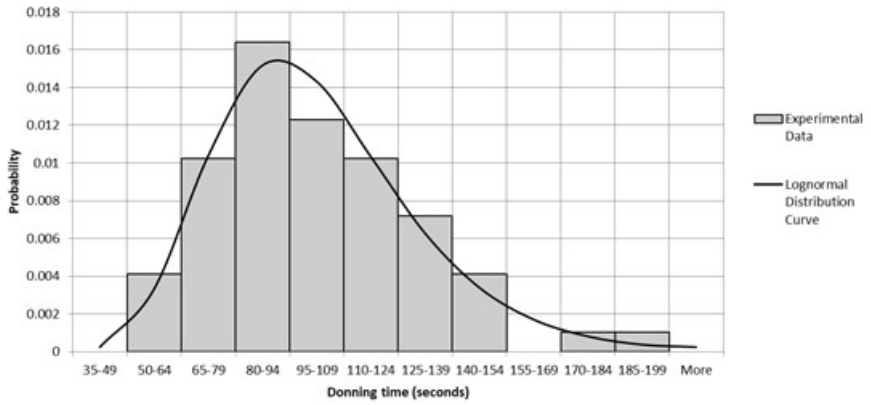

Figure 3: Probability distribution for donning times in seconds

Noteworthy, early results suggest that over 30% had a donning time above the 2-minutes requirement as specified by the testing standards by IMO and ISO. This excludes the time it took to open the packaging, reading instruction, and donning the lifejacket that is to be used together with the immersion suit. Preliminary results from analysing total times from the smaller sample group of participants that had a vacuum-packed suit, suggest a failure rate of 50%. The majority of participants agreed that the suit was easy or very easy to don. Nevertheless, over 60% of all participants made at least one donning error. Interestingly, the participant that had the written instructions available during the whole donning process made as many donning errors on average than the participants that had no instructions available. Participants that received the video instruction upfront made significantly fewer donning errors on average.

Analysis of the video footage of the donning process and comments provided by the participant questionnaires, suggests a significant difficulty experienced by the participants relates to the suit zipper. Video analysis suggests that 13% (11/84) of the zippers broke during the donning process. A broken

zipper means that the suit cannot be sealed reducing the thermal protection offered by the suit and significantly impacting the buoyancy of the wearer. Furthermore, the zipper can only be closed once the passenger is wearing the protective gloves. The gloves are made from a thick rubber material and are quite large in order to accommodate a wide range of hand sizes. Both these features made it difficult for many participants to get a good grip of the zipper in order to close it. This contributed to prolonging the donning process and/or contributed to the errors associated with suit donning.

5. Conclusion

A methodology to collect donning performance data for TPIS intended to be worn by passengers onboard vessels travelling in cold environments was presented in this paper. The performance data includes donning times and donning correctness. The proposed methodology is intended to address shortcomings in the standard ISO/IMO test procedures (e.g. small sample size, lack of control of prior knowledge) and previous studies (e.g. impact of prior learning) and to provide an evidence base suitable for use in evacuation analysis using advanced evacuation modelling.

Using the proposed test procedures, preliminary results from a study involving 65 participants donning a non-insulated immersion suit without integrated buoyancy approved for use in cold regions, demonstrated that about 50% of the participants took longer than the ISO/IMO stipulated 2 min maximum to don the suit. This does not include the time required to don the lifejacket required to be worn together with the suit. Furthermore, over 60% of participants made at least one donning error.

Detailed analysis of the collected performance data continues with a focus of the impact of the method of instruction on donning time and donning correctness, the impact of age and gender on donning performance and the nature and type of donning errors. However, given the high number of incorrect donning and the impact this may have on survival, issues associated with suit design and passenger training/instruction should be reconsidered. With respect to passenger briefing, careful consideration should be given to the method used to instruct the passengers in the correct donning procedures (video or written instructions) and whether passengers should be given the opportunity to don the suit as part of the pre-cruise assembly drill.

Understanding the effect of TPIS donning performance on emergency evacuation performance and integrating this knowledge into passenger ship layout, operational management, and training procedures, will enable improvement in evacuation performance and enhance passenger survivability. Conversely, incorporating and assessing the impact of individual passenger evacuation performance while wearing TPIS immersion suits on the overall vessel evacuation performance, enables an assessment of the acceptance criteria in current design guidelines for immersion suits. However, donning times are likely to be suit specific, which requires collection of donning times specific to the suit in a controlled manner as suggested in this paper.

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Appendix

This appendix presents supplementary material associated with the paper. The material is presented in three sections, Section 1 concerns the methods employed to instruct the trial participants in the correct procedures to don the thermal protective immersion suits (TPIS), Section 2 concerns the post trial questionnaire developed explore participant's opinions concerning the ease of donning the suit and Section 3 concerns the demographics of the trial participants.

Section 1: Methods used to instruct the participants in donning procedures
Essentially two methods were used to instruct the participants, an instructional video and printed guidance. Both these methods are briefly described here.

Section 1a: Video Instruction
Video instruction was provided by a short video (2 min 25 s in duration) developed by the research team. The video showed a safety instructor from the ARCOS safety centre in Tromsø demonstrating the donning process and providing verbal commentary in Norwegian. All participants that saw the video instruction spoke Norwegian. The video instruction from the manufacturer was not available at the time of the trials.

Sequential pictures of the video instruction are provided in supplementary material Figure 1 (SM Fig. 1). The numbering in the following description refers to the numbers in the sequential pictures within SM Fig. 1. The safety instructor begins by pointing out the written instructions on the packaging (1) and the tear point for opening the packaging. He tears open the packaging (2), takes out the suit and unfolds it (3). He steps into the suit opening at the top with legs first and mentions, that it is beneficial to have shoes and clothing on as it provides more insulation. He slides down the right foot into the sleeve completely (4), before repeating the same with the left foot (5). He points out the Velcro ankle straps and closes them on both sides (6). He then pulls the suit further up and slides the right arm into the sleeve and the right hand into the glove (7). He turns slightly to grab the other sleeve and slides the left arm into the sleeve and the hand into the glove (8). The inner gusset fabric connecting to the hood was slightly twisted, which was entangled by the instructor (9). He then commenced to tighten the inner gusset strap (10). Afterwards, he grabs the zipper and pulls it up with the right hand, while stuffing the excess gusset fabric and gusset strap inside the suit (11). The zipper was closed until just below the chin, when he grabs the hood to pull it over the head (12). He then grabs the zipper again and attempts to pull it further up (13). However, the zipper does not glide easily and after a couple of determined movements up and down, the zipper breaks and detaches from one side (14). After a short, surprised hesitation by the instructor, he takes his arms up to mark the end of the donning process (15).

Although the zipper breaks in the instructional video and the instructor stands with a half-closed zipper at the end, all steps of the donning process were demonstrated. It is clearly visible, that the zipper had broken and the suit cannot be closed further. Furthermore, it was mentioned to the participants to close the zipper all the way. Thus, it is assumed, that the breakage of the zipper in the instructional video does not adversely influence the donning performance of the participants.

SM Figure 1: Sequential images captured from the instructional donning video

Section 1b: Written Instruction

Written instructions by the manufacturer were provided on the vacuum-packaging of the suit as seen in SM Fig. 2. It consists of eight illustrations showing a drawn figure in various stages of the donning process. Short instructional text was provided in four languages (Norwegian, English, German and French) and printed next to the pictures. Three of the illustrations are instructions referring to the life jacket, which was not available to the participants.

SM Figure 2: Donning instructions as printed on the suit packaging

Section 2: Post trial questionnaire

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No:
Donning:

ARCEVAC Questionnaire – Putting on the survival suit

As part of the research component of the exercise that you just participated in, the ARCEVAC team would greatly appreciate if you could complete the following questionnaire. Your contribution to this research will improve passenger safety and survivability in the extreme conditions associated with evacuation in Polar waters.

Please note that there are NO right or wrong answers, we want your honest opinion to all the questions.

Please check ☑ ***a single answer*** *for each question, unless instructed otherwise.*

Once completed ***please return this questionnaire*** *to a member of the research team.*

1) Which option best describes your footwear?

☐ ☐ ☐ ☐ ☐

2) Have you worn this type of survival suit before? Yes ☐ No ☐

3) How easy was it for you to put on the survival suit?

Very difficult ☐
Difficult ☐
Neither difficult nor easy ☐
Easy ☐
Very easy ☐

4) Would you have found it easier to put on the survival suit if:

a) You were given verbal instructions? Yes ☐ No ☐ Don't Know ☐
b) You were shown a visual demonstration? Yes ☐ No ☐ Don't Know ☐
c) Someone physically assisted you? Yes ☐ No ☐ Don't Know ☐
d) Some other aspect, please explain:

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- Continue on next page. -

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No:

5) Do you think you put the survival suit on correctly? Yes ☐ No ☐ Don't Know ☐

6) Imagine you were at sea and experiencing rough conditions. Do you think this would have an impact on how quickly you could put the survival suit on?

No influence ☐

Would increase time slightly (less than double) ☐

Would increase time significantly (more than double) ☐

Don't know ☐

Any other comments:

7) Do you think wearing the survival suit will have an impact on your ability to

a) Walk along a corridor Yes ☐ No ☐ Don't know ☐

b) Walk up stairs Yes ☐ No ☐ Don't know ☐

c) Walk down stairs Yes ☐ No ☐ Don't know ☐

8) Do you have any suggestions as to how to improve the survival suit? For example, changes to the design that could make it easier to put it on?

9) Please feel free to write any additional comments:

Please return this questionnaire *to a member of the research team.*

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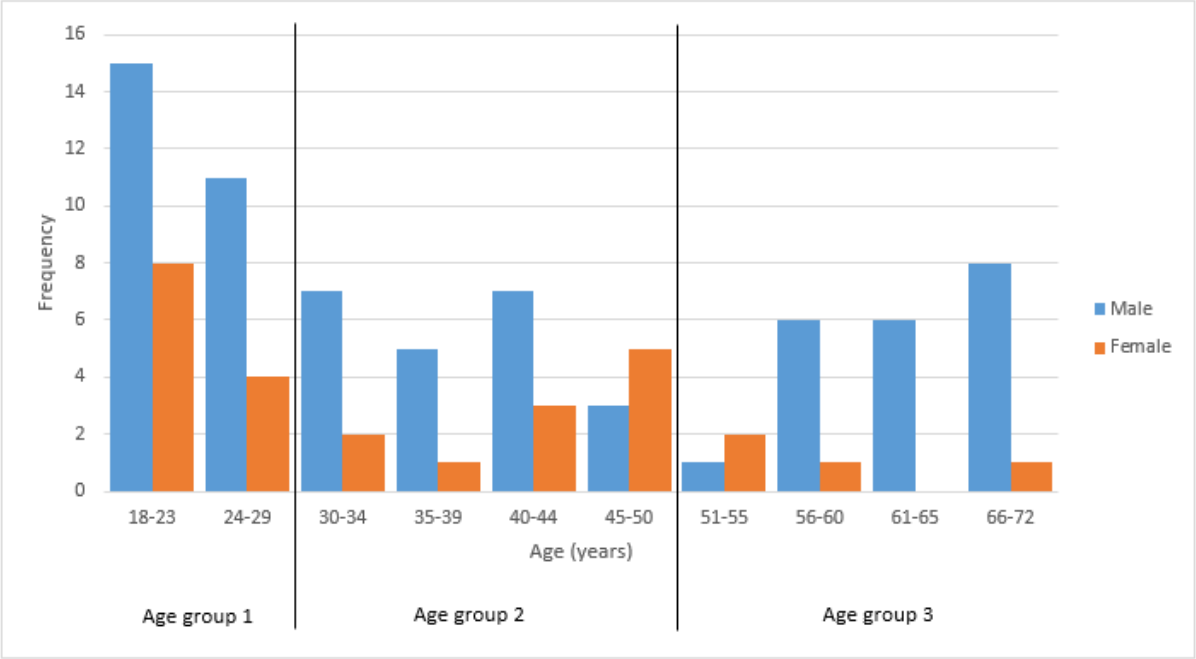
Note, that participants who saw the instruction video upfront, received a questionnaire with a slightly modified question number 4. Instead of answer alternative "b) you were shown a visual demonstration", following alternative was presented:

4)	Would you have found it easier to put on the survival suit if:			
a)	You were given verbal instructions?	Yes ☐	No ☐	Don't Know ☐
b)	You were shown a live demonstration?	Yes ☐	No ☐	Don't Know ☐
c)	Someone physically assisted you?	Yes ☐	No ☐	Don't Know ☐
d)	Some other aspect, please explain:			

Section 3: The trial participants

In the donning trial conducted using the procedures described, a total of 96 test subjects were recruited, 67 males and 29 females. These participants all donned the non-insulated immersion suit without integrated buoyancy (TPIS) at thee three test locations. The participants were divided into three age groups: AG1 = 18-29 years (yrs), n = 40; AG2 = 30-50 yrs, n = 31; AG3 = 51-72 yrs, n = 25. The age distribution is presented in SM Fig. 3. Note, in SM Fig.3 the age bins are generally 5 years except for the bins in Age group 1 and the last bins for Age group 2 and Age group 3.



SM Figure 3: Age distribution of participants