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Submarine Surface Abandonment Trials

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ABSTRACT

This report presents the results of the Surface Abandonment Trials held on 17 June 2008 in Pearl Harbor, Hawaii. The trials were based upon a single, credible, pre-determined, surface abandonment scenario and followed the procedures laid down in the U.S. Navy Ship Systems Manual (SSM)¹ utilizing the safety equipment already in service onboard submarines (Mk 10 SEIE suit and Mk 18 life raft) and the two candidates for the successor SEIE suit (Mk 11 SEIE suit and bfa Amphiprion SPES). The four trials simulated the abandonment of a submarine on the surface and were conducted from a submarine in harbor. Eighteen (18) volunteer subjects (sixteen (16) ship's personnel and two (2) SUBSCHOL instructors) participated in the trials including two rush abandonments and two normal abandonments. This report provides an analysis of the trials and makes recommendations for the modification of the existing class SSM's, surface abandonment equipment and for future surface abandonment research.

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INTRODUCTION

Although the design and operating procedures associated with modern submarines are such that the probability of any major incident is considered to be remote, there are a number of scenarios, of varying probability, that may require a submarine crew to rapidly abandon the vessel on the surface. These scenarios include a major fire, progressive uncontrollable flooding, a significant atmospheric contamination, or a radiological incident.

The credibility of an ongoing requirement for surface abandonment procedures and equipment is evidenced by a number of recorded submarine incidents which have resulted in some or all of the crew having to abandon the vessel on the surface. These incidents include the abandonment of the USS *Bonefish* in April 1988, during which 89 survivors were forced to abandon the submarine, and the sinking of the Peruvian submarine the BAP *Pacocha* in August 1988 when 23 members of the crew managed to abandon the vessel, on the surface, before the submarine sank. A more recent example is the flooding of the USS *Dolphin* in 2002 when the entire crew was forced to abandon the submarine on the surface.

Other incidents such as the groundings of HMS *Trafalgar* and the USS *San Francisco*, in which both submarines sustained significant damage but managed to return to port, and the fire aboard HMCS *Chicoutimi*, could also have conceivably resulted in the need to abandon the submarine on the surface. Furthermore, modeling conducted for the UK Royal Navy has shown that in 23% of incidents leading to the loss of a submarine, some or all of the crew will have the opportunity to abandon the vessel on the surface².

The rapid and safe abandonment of a submarine is likely to be enhanced by a pre-determined and appropriately rehearsed procedure that identifies the best procedures and routes of evacuation and provides adequate safety equipment (having taken into account the probability of the full range of credible scenarios that may result in an attempted abandonment). However, current U.S. Navy Abandon Ship Procedures are not routinely exercised aboard submarines, and the personal protective equipment that is currently in service, including the Mk10 SEIE suit and Mk18 life raft, has not previously been evaluated for use in a surface abandonment.

In any surface abandonment there are a number of factors which influence the likelihood of a successful surface abandonment. These factors can be grouped into 4 phases:

Pre-abandonment. (Scenario dependent factors.)

Survival. (Survival of the incident/accident leading to surface abandonment.)

Evacuation. (Requirement for survivor to be fit to self-evacuate, with assistance if available, and to identify a useable exit and conduct a safe exit from the submarine and a safe entry into the water.)

Post abandonment. (The survival of the hazards present after abandonment, until rescue, such as hypothermia and drowning.)

To maximize the potential for survival of an accident leading to surface abandonment, survival factors need to be addressed across all of these phases taking into account the full spectrum of credible accident scenarios. However, an examination of all phases of abandonment is not possible in a single small scale study and other methods such as abandonment modeling are more appropriate. This study was an examination of limited factors, principally evacuation factors, in two rush abandonment trials and two normal abandonment trials. Pre-abandonment factors, survival factors were not addressed, and the results of this study should be interpreted in the light of these limitations.

METHODS, ASSUMPTIONS, AND PROCEDURES

The study recorded objective data on the human performance of U.S. Navy submariners (the time taken to complete an abandonment, using the safety equipment that is currently in service) during a series of four simulated surface abandonment trials (two rush abandonments and two normal abandonments) from the USS *Charlotte* SSN 766, a 688 class submarine, on 17 June 2008 while she was moored alongside in Pearl Harbor. Subjective opinion was also gathered from formal debriefs of participants, directing staff, and observers.

A fifth planned trial to test evacuation of SUBSCHOL instructors via the sail of the submarine was planned, however, this trial was forced to be cancelled by the Principal Investigator (PI) as the safety equipment provided did not allow subjects to be belayed by a top rope from the bridge (as required by NSMRL's Institutional Review Board (IRB)).

Recruitment

All of the volunteer subjects that participated in the study were male, military, personnel who were confirmed to be operationally fit. The principal pool from which subjects were recruited was the crew of the USS *Charlotte*, the submarine that hosted the trial. Recruiting from the submarine crew had the benefit that subjects were familiar with the 688 class of submarine. Two SUBSCHOL instructors, both career divers also volunteered to participate in the trials as subjects assessing the two potential successor SEIE suits.

Recruitment and briefing took place on the host submarine and in the SUBRON 1 conference room on 16 June 2008. A total of twenty volunteers (eighteen personnel drawn from the crew of the USS *Charlotte* and two SUBSCHOL instructors) were initially recruited and they received briefs from the PI and from PMS 394 RE (Naval Sea Systems Command). At the briefing potential subjects were given the opportunity to ask any questions before they were asked to give their written consent to participate in the trial. The request for volunteers was not done in the presence of senior officers of the host submarine to avoid the potential for coercion. The medical documents of all volunteers were reviewed by the medical monitor to confirm that they were operationally fit for duty.

Two of the crew members of the USS *Charlotte*, who initially volunteered, were unable to participate in the trials conducted on 17 June 2008, for undisclosed reasons, and therefore a total of eighteen subjects participated in the abandonment trials.

Methods

Subjects drawn from the crew of the USS *Charlotte* all used the Mk 10 SEIE suits that are currently in service with the U.S. Navy; however, the two SUBSCHOL instructors that participated in the trials used the two potential successors to the Mk 10 SEIE suit (the RFA Mk 11 SEIE suit and the bfa Amphiprion SPES SEIE suit and their respective life rafts).

Subjects were each assigned a subject number, which was used for the duration of the trials. They were issued with pre-printed, high visibility, adhesive labels with a number

corresponding to their study number to be worn for all trials. Duplicate labels were available in the event that any numbers became detached.

Subjects were assigned an appropriate duty station after the exercise brief. The areas were assigned with the approval of the submarine's Commanding Officer and were contingent upon the areas of the submarine that could be accessed due to the material state of the submarine and the specialization of participants (who were assigned to a duty station with which they were familiar). Participants used the same "duty station" for all of the trials. Subject locations were as per Table 1.

Table 1. Assigned Duty Stations.

Duty Stations	Number of subjects
Control room	4
Torpedo room	4
Machinery room	4
11 man berthing compartment	3
Crews mess	3

On the day prior to the trials, all subjects were provided with a short brief by the two SUBSCHOL instructors to familiarize them with the use of the Mk 10 SEIE suit and Mk 18 life raft (those ratings who had been trained at the Nuclear Power School rather than SUBSCHOL were wholly unfamiliar with escape equipment having received no prior training).

On 17 June a total of four abandonment trials were conducted including two rush abandonments and two normal abandonments. The first three runs (both rush abandonments and the first normal abandonment) were conducted while wearing Emergency Air Breathing (EAB) masks. As the study was limited to a total of 22 Mk 10 SEIE suits, 2 Mk 11 SEIE suits and 2 bfa Amphiprion suits and there was no facility available locally to re-pack the suits to factory standards, the unpacking and donning of suits from their valises was demonstrated solely during the first normal abandonment trial.

Five NSMRL researchers collected objective data, the time in minutes and nearest second to complete set tasks or reach a pre-determined location. The researchers were provided with a stopwatch which was zeroed before the start of each trial and started on hearing the instigating broadcast pipe which was relayed on 1MC. Researchers selected appropriate locations which allowed the observation of study subjects without impeding their escape. All abandonment trials were instigated by a broadcast over the 1MC net.

Accident Scenario

All four abandonment trials were carried out to the same background accident scenario, which includes the following pre-abandonment conditions:

- The submarine was cruising on the surface in daylight hours and in a collision rendering propulsion with steering inoperable and “dead in the water”. The collision caused a tear in the bow prompting uncontrollable flooding into the main ballast tanks necessitating abandonment. (No attempt was made to simulate this condition).
- The collision also caused an uncontrollable Class C fire requiring the use of EAB masks (although masks were not used for the second normal abandonment). The submarine remained in normal lighting and in the interests of safety, visibility was not compromised.
- The upper and lower hatches at Forward Escape Trunk (FET) were closed and rigged as if in “Rig for Dive” situation.
- The exercise sea state was four; with a wave height of seven feet. Given the freeboard of a 688 class submarine this would be likely to compromise the use of hatches, although this was not simulated.
- Subjects used the Forward Escape Trunk (FET) as the sole route of egress.

Performance Measures

The study gathered both objective data (the time required for each subject to complete a particular task or reach a pre-determined location) and the subjective opinions of participants, directing staff and observers in debriefs which followed each trial.

The following data were collected for each participant:

- Name. Rank.
- Assigned subject number.
- Assigned duty location for trials.
- Trial number.

The abandonment times collected included:

- Time taken to move from duty station to the crew’s mess (via a Mk 10 SEIE suit stowage).
- Time to don SEIE suit without the thermal liner (first normal abandonment only). Thermal liners were not worn to reduce heat stress upon participants in accordance with the advice of the IRB.
- Time to exit the crew’s mess.
- Time that each participant enters escape trunk.
- Time that each subject exits trunk and reaches submarine hull.
- Time taken to reach muster point topside (forward of the sail on the starboard side).

Subjective opinions were gathered in post-run debriefs of subjects by observers. Subjective data also included the observation of:

- The material state of SEIE suits after each trial (both normal abandonment trials).
- Method of entry into water (second normal abandonment only).
- Entry into and bailing of the life raft.

- The ability of survivors on the surface to communicate and co-operate; this was limited in scope as a maximum of five subjects were in the water at the same time. (Note that numbers were constrained due to an increase in wind velocity making it unsafe for multiple subjects to remain in the water as only one safety boat and two swimmers were available.)

In order to assist in data collection, a video camera with a time display was positioned to provide video documentation of the surface abandonment evolutions and digital still photographs were also taken.

Data Analysis

Abandonment times to the nearest second were measured for sixteen submariners and two U.S. Navy divers. Most participants abandoned the submarine four times with the exception of a single diver who did not complete the second normal abandonment. For all abandonments, times were recorded at five locations; crew mess arrival, mess departure, start ladder climb, top hatch arrival, and hull muster point. For the two normal abandonments, the crew mess arrival time is also the “start donning suit” time and the crew mess departure time also represents the “complete donning suit” time. A recording error occurred for the normal 1 crew mess arrival and these data were lost.

Statistical analyses were performed with SPSS version 15.0³ and the a priori significance level for acceptance was set at 5% for all tests.

The mean abandonment times from duty station to each designated location were calculated for each trial. Collapsing across locations, overall mean abandonment times were also calculated by each trial. Comparisons in overall abandonment times between the trials were made; however the focus of the analyses was on the differences in abandonment times between the trials at each location most notably the hull muster point. To determine statistical significance, pairwise comparisons were done for all location by trial effects. For the location factor, the first recorded times of mess arrival and start donning suit were excluded from the analyses as these represented slightly different stages in the abandonment procedure depending on the trial. However, the areas labeled “mess departure” and “complete donning suit” are essentially the same location and were included in the analyses. Departure times represent when a subject either physically left the mess or was able to leave the crew’s mess but physically remained in it due to the crowding around the ladder at the bottom of the hatch. In the proceeding analyses, this location is labeled as “mess departure”.

The linear mixed model (LMM) procedure⁴ was used to determine if abandonment times differed between the trials and between trials by location. The LMM was chosen over the conventional general linear model (GLM) because it allows for unbalanced designs or missing data, thereby allowing the data for the diver that did not complete the final trial to be included in the analyses. In addition, the LMM allows the dependent variable (time) to exhibit within-subject correlations and non-constant variance across subjects (thereby reducing the stringency of the homogeneity of variance and sphericity assumptions). After running the model, normality assumptions were checked by plotting the residual’s observed cumulative probability against the expected cumulative probability for the normal distribution.

Interpretation of LMM significance tests are equivalent to a repeated measures ANOVA test. When entering the model subjects were treated as a random factor (to account for subject to subject variation across factor levels as opposed to case to case variation) and location and trial were entered as fixed factors. Missing values were assumed missing completely at random, and the Satterthwaite⁴ approximation for degrees of freedom was used. Significance levels for multiple comparisons used the Bonferroni adjustment which uses the familywise error rate⁴.

RESULTS AND OBSERVATIONS

The results of this study include both objective data (timings) and subjective data (the observations of trial subjects and NSMRL and NAVSEA researchers).

Figure 1 shows a four-panel plot of each subject's egress timeline grouped by trial. For both types of trials, wider variability can be seen among subjects during the first abandonment. Labels on the Rush 2 plot identify subjects 5 and 8 who were designated prior to the trials as the subjects responsible for opening and closing the hatch, respectively. As a result, from the "start climb" location on, subject 5 is shown to have the fastest time, and subject 8 has the slowest time for all trials.

The slowest recorded times for the hull muster point are shown in Table 2. These all represent the recorded times for subject 8. The maximum time it took for all 18 subjects to reach the muster point was 17 minutes and 38 seconds during the first normal abandonment. This trial also had the slowest opening lower hatch time which took 2 minutes and 11 seconds.

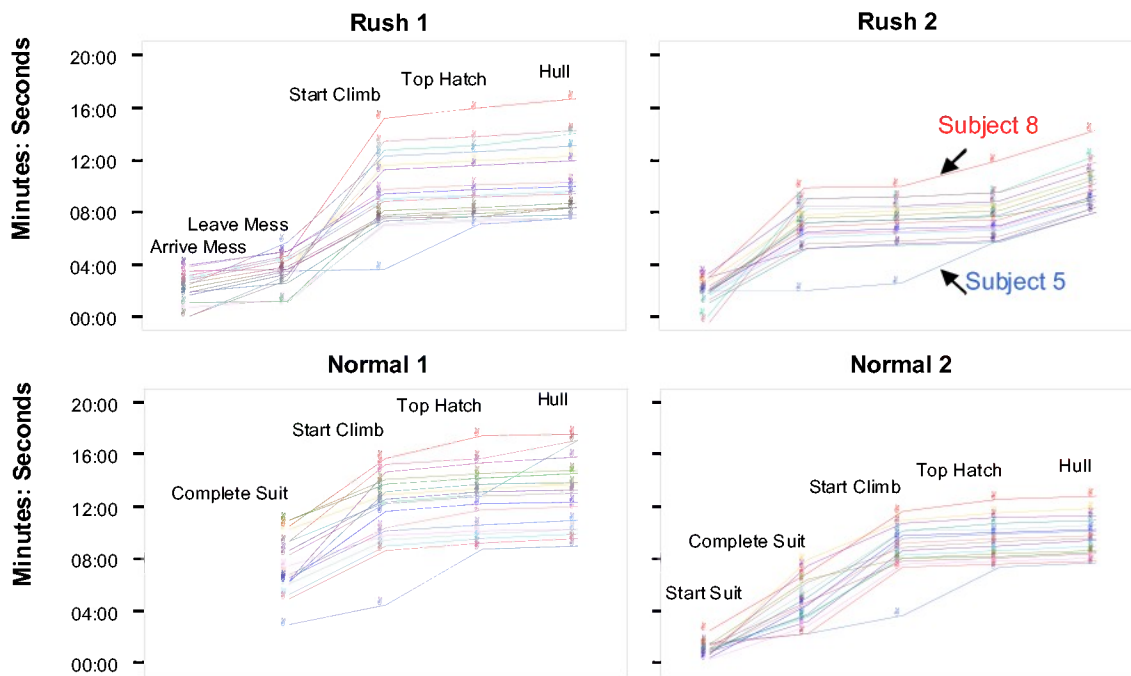


Figure 1. Timelines by subject grouped by trial. Labels for Rush 1 are the same for Rush 2. The Rush 1, Rush 2, and Normal 2 trials included 18 volunteers; only 17 participated in Normal 2. Subject 5 was pre-assigned to open the hatch; subject 8 was pre-assigned to close the hatch.

Table 2. Maximum Times to Hull Muster Point by Trial

Rush 1	Rush 2	Normal 1	Normal 2
16:47	14:20	17:38	12:48

Times are in minutes: seconds. All time are for subject 8 who was assigned to close the hatch.

For each of the four trials, the recorded mean abandonment times from duty station to each location are depicted in Figure 2 and listed in Table 3. Table 3 also shows the overall mean location times for all trials combined. Across trials, the mean egress time from duty station to the hull muster point was 10 minutes and 51 seconds (95% CI: 10:14 – 11:28). When comparing means, the slowest total egress time was 13 minutes and 4 seconds (95% CI: 11:42 – 14:27) for the Normal 1 trial.

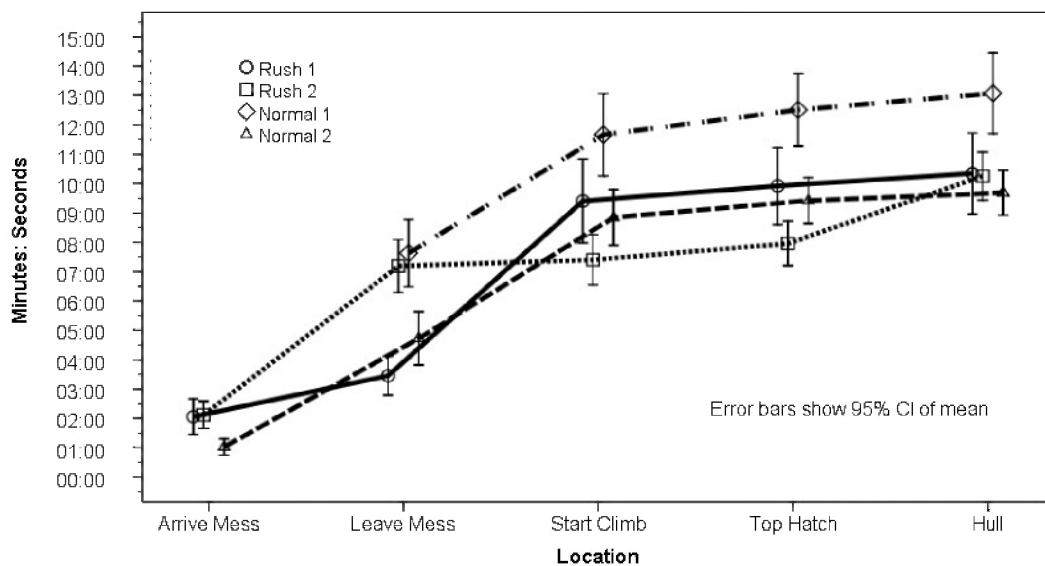


Figure 2. Mean abandonment times by trial. Arrive at mess is also the start donning suit time for Normal 2. The Rush 1, Rush 2, and Normal 2 trials included 18 volunteers; only 17 participated in Normal 2.

Table 3. Abandonment Times from Duty Station^{*} by Location and Trial

Trial	Mean	95% Confidence Interval			n
Arrive Mess ^{*,†}					
Rush 1	2:03	1:27	to	2:39	18
Rush 2	2:07	1:39	to	2:35	18
Normal 2	1:01	0:45	to	1:18	17
MEAN	1:44	1:27	to	2:02	53
Leave Mess					
Rush 1	3:27	2:47	to	4:07	18
Rush 2	7:11	6:17	to	8:05	18
Normal 1	7:37	6:29	to	8:46	18
Normal 2	4:43	3:49	to	5:38	17
MEAN	5:45	5:10	to	6:21	71
Start Ladder Climb					
Rush 1	9:24	7:58	to	10:49	18
Rush 2	7:24	6:32	to	8:15	18
Normal 1	11:39	10:15	to	13:04	18
Normal 2	8:50	7:53	to	9:47	17
MEAN	9:20	8:40	to	9:59	71
Top Hatch Arrival					
Rush 1	9:55	8:36	to	11:13	18
Rush 2	7:57	7:12	to	8:43	18
Normal 1	12:30	11:17	to	13:44	18
Normal 2	9:25	8:38	to	10:11	17
MEAN	9:57	9:20	to	10:35	71
Hull Muster Point					
Rush 1	10:20	8:57	to	11:43	18
Rush 2	10:15	9:26	to	11:04	18
Normal 1	13:04	11:42	to	14:27	18
Normal 2	9:41	8:55	to	10:27	17
MEAN	10:51	10:14	to	11:28	71

Times are recorded as minutes:seconds.

^{*}Via Mk10 SEIE suit stowage for Rush 1 and 2.

[†]A recording error occurred for the Normal 1 crew mess arrival and these data were lost.

Overall mean abandonment times were found to differ by trial ($F_{3,251} = 71.3$; $P < .001$). Pairwise comparisons in Table 4 show that with a mean difference of 5 seconds, the overall times for the two rush abandonments did not differ significantly ($P > .99$). However, the first normal abandonment (requiring the unpacking and donning of the suit) was about 3 minutes slower than the second normal abandonment and both rush trials ($P < .001$). No other differences were found between average trial times.

Table 4. Comparisons between Trials for Mean Abandonment Times

Comparison	Mean Difference	95% C.I. of Difference	P
Rush 1 – Rush 2	0:05	-0:35 to 0:44	>.99
Rush 1 – Normal 1	-2:56	-3:36 to -2:17	<.001
Rush 1 – Normal 2	0:00	-0:40 to 0:40	>.99
Rush 2 – Normal 1	-3:01	-3:41 to -2:22	<.001
Rush 2 – Normal 2	-0:05	-0:45 to 0:36	>.99
Normal 1 – Normal 2	2:57	2:16 to 3:37	<.001

Times are minutes:seconds.

A trial by location interaction was also found ($F_{9,251} = 10.8$; $P < .001$). Pairwise comparisons were done between trials for the leave mess, start ladder climb, top hatch arrival, and hull muster point locations. Trial effects were found for all four locations. Table 5 lists the comparisons that were made and shows where significant effects were found. Differences found between trials for the hull muster point times are similar to those found in the overall mean abandonment times.

Subjective Findings

SEIE Suits

Two personnel, both with large feet (U.S. size 13 plus) stated that they found difficulty donning a Mk 10 SEIE suit while wearing footwear and one needed to remove his footwear to don the suit. These difficulties mirror those experienced by the UK in their surface abandonment trial². The two options for a successor SEIE suit address the problem of personnel with large feet donning a suit by better dusting of inside of suit to prevent sticking together of suit legs and an increase in foot size to cater for an increased range of sizes of boot and should reduce this problem.

SEIE suits were worn without thermal liners to reduce heat stress in participants given the higher temperatures and humidity experienced in Hawaii. Therefore times to don SEIE suits did not include the time required to put on liners; however, conversely, donning a SEIE suit without wearing a liner may take additional time due to increased friction between skin and clothing and the SEIE suit. Investigators do not consider that this had a significant overall effect on the total time taken to don a SEIE suit and complete a surface abandonment.

The concerns that the SEIE suit may be damaged during the process of leaving the submarine by snagging on fixtures and fittings or by walking on anti-skid coating were not substantiated and all eighteen suits used in this trial (16 Mk 10 SEIE suits, 1 Mk 11 SEIE suit, and 1 bfa Amphiprion suit) were undamaged and fully serviceable when examined after each of the normal abandonment trials.

EAB

Unlike other EAB manifolds on the USS Charlotte which were marked with luminous paint; the two single-point EAB connections in the escape trunk had no marking to aid in identification in conditions of reduced visibility; although these conditions were not simulated in these trials it is considered likely that this would have hampered the identification of the EAB couplings in conditions of reduced lighting . In addition there were no 25' whips located in the vicinity of the escape trunk. Moving between couplings while wearing EAB proved difficult as EAB connections and other survival equipment needed to be carried, as there was no mechanism to attach EAB to clothing or slings to free hands and facilitate movement, particularly when climbing ladders.

Table 5. Comparisons between Trials by Location for Mean Abandonment Times

Comparison	Mean Difference	95% C.I. of Difference	P
Leave Mess			
Rush 1 – Rush 2	-3:44	-5:03 to -2:25	<.001
Rush 1 – Normal 1	-4:11	-5:30 to -2:51	<.001
Rush 1 – Normal 2	-1:23	-2:43 to -0:03	.039
Rush 2 – Normal 1	0:27	-1:46 to 0:53	>.99
Rush 2 – Normal 2	2:21	1:01 to 3:41	<.001
Normal 1 – Normal 2	2:48	1:27 to 4:08	<.001
Start Ladder Climb			
Rush 1 – Rush 2	2:00	0:41 to 3:19	<.001
Rush 1 – Normal 1	-2:16	-3:35 to -0:57	<.001
Rush 1 – Normal 2	0:27	0:53 to 1:47	>.99
Rush 2 – Normal 1	-4:16	-5:35 to -2:57	<.001
Rush 2 – Normal 2	-1:33	-2:54 to -0:13	.014
Normal 1 – Normal 2	2:43	1:22 to 4:03	<.001
Top Hatch Arrival			
Rush 1 – Rush 2	1:58	0:39 to 3:17	.001
Rush 1 – Normal 1	-2:36	-3:55 to -1:16	<.001
Rush 1 – Normal 2	0:23	0:57 to 1:44	>.99
Rush 2 – Normal 1	-4:33	-5:52 to -3:14	<.001
Rush 2 – Normal 2	-1:34	-2:55 to -0:14	.012
Normal 1 – Normal 2	2:59	1:39 to 4:19	<.001
Hull Muster Point			
Rush 1 – Rush 2	0:05	-1:14 to 1:24	>.99
Rush 1 – Normal 1	-2:44	-4:03 to -1:25	<.001
Rush 1 – Normal 2	0:33	0:48 to 1:53	>.99
Rush 2 – Normal 1	-2:49	-4:08 to -1:30	<.001
Rush 2 – Normal 2	0:27	0:53 to 1:48	>.99
Normal 1 – Normal 2	3:17	1:56 to 4:37	<.001

Times are minutes:seconds. Only 17 subjects participated in the Normal 2 trial, therefore comparisons including the Normal 2 trial are based on estimated marginal means by computing the predicted value of the cell.

Hatch Opening

Significant time and effort was required to open the upper hatch using the hydraulic hand pump (Table 6); the hatch had not been recently groomed and it was found that an excessive number of cycles of the pump were needed to fully charge the accumulator. This resulted in

significant delays to egress from the submarine and required personnel who were otherwise fully prepared to abandon ship to remain in muster locations or passageways until the route of egress was clear impeding the movement of other personnel. During the second trial the upper hatch was pushed open manually allowing for faster egress;. however the hatch would be at risk of closure if subject to wave slap or rolling of the submarine (any sea state greater than 1).

Table 6. Time Taken to Open Hatch for each Abandonment Trial.

Rush 1	Rush 2	Normal 1	Normal 2
0:04:36	0:03:04	0:04:10	0:03:38

Times are minutes:seconds.

DISCUSSION

For most locations, the variability of both the rush and normal trials decreased from the first to second trial. This suggests that with only one practice trial, time needed to escape is more predictable. While the two rush abandonments show virtually no difference in the final hull muster times, the added task of unpacking and donning the SEIE suit was shown to add about three minutes to final abandonment times for the first normal abandonment when compared to all three other trials. This may be due to both the unfamiliarity of the suit, and perhaps difficulty in mobility and vision once the suit was on. This effect is likely to be compound in conditions of reduced visibility such as smoke or reduced lighting although there was no assessment of this variable in these trials. This finding also suggests that training and familiarity with SEIE suits may shorten abandonment times. Also, EAB masks were used during the first normal trial (and both rush abandonments) but not the second normal abandonment which likely contributed further to the egress duration during the first normal abandonment.

For the normal trials, during which the suits were worn, overcrowding was even more apparent due to the additional space required with the suits. This is likely to also occur in a real abandonment scenario. Although more hatches may be accessible and used, in a scenario with most of the crew fit to abandon, severe bottlenecks (as occurred when exiting the crews mess and at the bottom of the ladder) are likely to occur creating much slower times than demonstrated during these trials especially with an untrained crew. During this small scale trial it was clear that the exit to the crews mess and the bottom of the ladder were key choke points; it is likely that in a full scale abandonment there would be other choke points.

Both rush abandonments showed mean arrival times to the mess within four seconds of each other, however, it's unclear why the mean leave mess times for the Rush 2 trial is on average nearly four minutes slower than the first rush trial. As one observer noted, a possible explanation could be that many volunteers remained in the mess area until they could see the hatch was opened, after which they would leave the mess and proceed up the hatch.

Due to a likely practice effect, despite the added task of unpacking and donning the SEIE suit, the first normal abandonment times are likely to be faster than what would be expected had this been the first trial. Although the EAB was not worn and the suits were already unpacked, the three minute reduction in time from the first to the second normal abandonment could also be attributed to practice. This suggests that training and improved familiarity with SEIE suits may significantly shorten abandonment times.

Unfortunately, the start times for unpacking the suit in the first normal trial were lost so the actual time required to unpack and don the suit for the first time is unavailable. However, based on the normal two recorded times, after a practice run, time to don suit can be estimated at under four minutes, assuming ready access to SEIE suits and their rapid distribution.

The submarine crew followed the 688 class abandon ship procedure which outlines the duties of key personnel and the procedures to be undertaken when abandoning the submarine; however the study, as conducted, suffered from several limitations:

For the purposes of this trial, all study subjects were treated as though they had survived the initial incident without injury and the trials did not address the issue of injured personnel who may require assistance to evacuate or the evacuation of other “Key Personnel Functional Groups” required to continue their duties as a surface abandonment takes place. Such Key Personnel Functional Groups include:

- Injured personnel
- First aiders and medical personnel
- Firefighting teams
- Damage control teams
- The Command team

The trial was limited in scope as it included eighteen subjects representing a small (14%) fraction of the full complement (143) of a LOS ANGELES class submarine. This may have reduced the potential for subjects impeding each other’s progress or for more severe “bottlenecks” or choke points occurring. However, bottlenecks may be reduced or avoided in a real scenario during which submariners are able to abandon ship using at least more than one hatch opening.

The limited scope of the trial did not allow the assessment of multiple variables and therefore specific recommendations on potentially important factors such as the best routines for coping with reduced visibility, the prompt distribution of SEIE suits throughout the submarine and routines for assisting injured personnel cannot be made. An assessment the full spectrum of variables in surface abandonment could be better addressed through additional studies using evacuation modeling techniques⁵.

Hatch Opening

The time taken to open the hatch using the hydraulic hand pump was a significant factor delaying escape from the submarine. The hatch was on every occasion, opened by the same “A-ganger”, rather than the first subject to arrive at the hatch. This may have resulted in an artificial delay to hatch opening. As a result, all subsequent times from start ladder climb were dependent on the actions of a single person. If this were the procedure in a real life scenario and the designated A-ganger was injured or otherwise delayed crucial time to abandon would be wasted. Furthermore, to aid in a prompt abandonment, all personnel should be well versed in the hatch opening procedure.

CONCLUSIONS AND RECOMMENDATIONS

Standard setting

The Abandon Ship procedures listed within the Ship Service Manuals have not been subject to previous exercises, trials, or other validation. Also there is no current standard for the time in which the full complement of a submarine should be capable of abandoning ship to which study data can be compared. Therefore the authors recommend that the U.S. Navy consider developing an appropriate standard or requirement for time needed to abandon each class of submarine.

It is recommended that NSMRL be tasked and funded to conduct a review of data from historic surface abandonments and other abandonment studies (including those of foreign navies) which can be used to form the basis for recommending a standard which should be forwarded to the Submarine Escape and Rescue Review Group (SERRG) for endorsement. Future research should also be conducted to evaluate the time for the full complement of a submarine to abandon ship. Surface abandonment modeling⁵ represents a cost-effective method of evaluating the potential benefit across multiple scenarios. It is recommended that this methodology be used to form the foundation of future surface abandonment research before validating models by conducting a full complement abandonment trial from a submarine alongside.

Egress

Further, research and development efforts should be focused upon improving the egress of survivors from the submarine to include:

- The evaluation of methods to maximize the usability of access hatches in the event of moderate and high sea-states.
- An assessment of the inflatable freeboard extenders to avoid water entering the boat through the open hatch. These inflatable freeboard extenders are currently under development and have recently been trialed by the Royal Navy and the Royal Netherlands Navy.
- The development of methods for safe and rapid egress via the sail should be considered including an assessment of the feasibility of escape slides or tunnels for surface abandonment via the sail.
- Improved methods for carrying survival equipment and stores including EAB, SEIE suits Submarine Emergency Positioning Indicating Beacons (SEPIRBs), other survival equipment and food should be investigated.

EAB System

The EAB system should be evaluated to ensure that the placement of EAB manifolds and 25-foot whips does not result in unnecessary bottlenecks that will delay egress from the submarine. Potential methods for inflating and checking the SEIE suit stole while breathing on EAB should also be investigated.

Revisions to Procedure

The SSM Abandon Ship procedures should be revised, including recommendations for:

- Suitable locations to don SEIE suits during an abandonment, and revised advice on survival equipment and provisions for surface survival.
- Identification of preferred egress points depending on the situational environment.
- The SEIE Mk10 donning instructions should be modified to incorporate advice on the procedure for detaching SEIE suit gloves to improve the range of motion during surface abandonment for sailors with long arms.
- The procurement of the next generation SEIE suits should address the issue of reduced mobility while wearing a SEIE suit and should provide improvements in this area.

Training

Improvements to current training have the potential to significantly improve surface abandonment. We recommend that SUBSCOL and NSMRL be jointly tasked with the development of a surface abandonment training package. Other recommendations on training include:

- A Submarine on Board Training (SOBT) module should be developed for periodic execution by submarines to provide a means for training, reviewing and testing surface abandonment procedures.
- All abandon ship training drills conducted as SOBT training should use the equipment that is currently in service to familiarize personnel with equipment and provide realistic training.
- Submarine squadrons should be provided with appropriate material to support abandon ship training including SEIE suits.

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