Naval Submarine Medical Research Laboratory
NSMRL REPORT 1205 27 MAY 1997

A BIOMEDICAL REVIEW OF THE U.S. NAVY SUBMARINE ESCAPE SYSTEM: 1996

Steven J. Frank, LT, USN
Michael D. Curley, CAPT, MSC, USN
Steven J. Ryder, SURG CDR, RN

19980810 150

Released by
R. G. Walter, CAPT, DC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory

Approved for public release; distribution unlimited

DTIC QUALITY INSPECTED 1

AQ U98-10-2216

A BIOMEDICAL REVIEW

OF

THE U.S. NAVY SUBMARINE ESCAPE SYSTEM:

1996

by

Steven J. Frank, LT, USN
USS BATFISH (SSN-681),

Michael D. Curley, CAPT, MSC, USN, and Steven J. Ryder, SURG CDR, RN,
Naval Submarine Medical Research Laboratory

NSMRL REPORT #1205

Naval Medical Research and Development Command
Research Work Unit 63713N M0099.01A-5201

Approved and Released by

R. G. Walter

R. G. WALTER, CAPT, DC, USN
Commanding Officer
NavSubMedRschLab

Approved for public release; distribution unlimited

SUMMARY PAGE

THE PROBLEM

Escapees from a disabled sunken submarine face many potentially hazardous obstacles to their survival including cold water, toxic gases, nitrogen narcosis, carbon dioxide poisoning, barotrauma, and decompression sickness. A review of the present U.S. Navy submarine escape system capability in combating these potential threats was undertaken.

THE FINDINGS

Present U.S. Navy submarine escape procedures and equipment are inadequate to provide reasonable assurance of escaper survival. Lack of thermal protection for the escaper, complex manual escape trunk procedures, and slow compression of the escape trunk, with resulting exposure to high partial pressures of nitrogen and carbon dioxide, are major obstacles to successful escape. Recommendations include replacing the Steinke Hood with commercially available equipment that provides adequate thermal protection, automating U.S. Navy submarine escape trunks, and introducing realistic, low-risk, cost-efficient training equipment and procedures.

APPLICATION

These findings apply to all current and future classes of U.S. Navy submarines.

ADMINISTRATIVE INFORMATION

This research was carried out under Naval Medical Research and Development Command Work Unit 63713N M0099.01A-5201, "Submarine related decompression problems." The views expressed in this report are those of the authors and do not reflect the official policy or position of the Department of the Navy, Department of Defense, or the U.S. Government. It was approved for publication on 27 May 1997, and has been designated as NSMRL Report # 1205.

Abstract

The current method of escape from United States Navy submarines, the buoyant ascent using the Steinke Hood, was introduced in 1962. Pressurized buoyant ascent training ceased in the United States in the 1970s due to concerns associated with financial costs and health risks. Operating procedures for escaping from U.S. Navy submarines have remained essentially unchanged since World War II. In 1974, Neuman highlighted significant biomedical shortcomings in the escape system: hypothermia, nitrogen narcosis, hypercarbia, barotrauma, and decompression sickness. He attributed these shortcomings to the method of escape and operating procedures. Furthermore, as this review suggests, the current method of submarine escape is no longer practical, because the Steinke Hood provides no thermal protection for the escaper during the escape and while awaiting recovery. Accordingly, citing emerging technology and recent studies, this paper presents biomedical-based recommendations for enhancing survival of escapers by a) overhauling current submarine escape systems and procedures and b) substituting existing thermal protection suits for the Steinke Hood.

Key Words: submarine, escape, rescue, Steinke Hood, medicine, biomedical, SEIE, review

TABLE OF CONTENTS

Page

Summary Page ii

Abstract iii

Objective 1

Introduction 1

Discussion 2

Risks in training for submarine escape (Training issue) 2

Major problems with USN submarine escape practice (effectiveness issues) 3

Summary. 11

Recommendations 14

References 15

Acknowledgements 17

LIST OF TABLES

Table 1. Global water temperature in °F at surface and 600 fsw (183 msw) 7

Table 2. Predicted survival times for exposure water temperatures 11

Table 3. Bottom time limits for U.S. Navy no-decompression air dives 12

OBJECTIVE

The purpose of this paper is to expand and confirm critical assessment of the current United States Navy (USN) submarine escape system from a biomedical perspective and to recommend means of improvement accordingly. This paper will not address the advantages and/or disadvantages of escape versus rescue from a disabled or distressed submarine.

INTRODUCTION

Modern submarines are designed, built, and operated to the highest possible safety standards. While accidents resulting in a submerged disabled submarine (DISSUB) are rare, they have occurred, and the USN should be highly prepared to deal with such an occurrence. There are two means of saving life following a DISSUB. The first, **escape**, occurs when survivors exit the submarine via a hatch and make an ascent to the surface, and the second, **rescue**, occurs when survivors are removed from the submarine by a submersible, e.g., a deep submergence rescue vehicle (DSRV) or Submarine Rescue Chamber (SRC).

During the past three decades, the USN has concentrated its' research, development, and operational resources on developing submarine rescue as the principal means of saving lives following the sinking of a submarine. The USN spends approximately fifteen million dollars a year in upgrading and maintaining a DSRV program in the event that a DISSUB rescue is required. As a result of the USN focus on rescue, the current method of submarine escape using the Steinke Hood remains essentially unchanged since the 1960s.

Though rescue is the preferred method of saving life, it is essential to have an effective escape system because survivors may be forced to conduct an escape before rescue forces arrive on site. Operational conditions and engineering difficulties may prevent successful transfer of survivors from the DISSUB to the rescue vehicle. Furthermore, logistical considerations may impose a delay of up to five days in the transport of the DSRV to the DISSUB, and environmental conditions in the DISSUB may deteriorate as a result of fire, flooding, hypoxia, rising CO_2 and pressure, to the extent that an escape is imperative for crew survival. For example, on 26 August 1988, the B.A.P. PACOCHA (former USS ATULE, SS-403, transferred to Peru in 1974) sunk to a keel depth of 140 feet of seawater (fsw) (43 msw) in 5 min as a result of a collision during a surface transit to its home port. The United States fly-away McCann rescue system (i.e., SRC) was activated, but aborted in transit when deterioration of the atmosphere within the PACOCHA led to the decision to use buoyant escape techniques (1). Therefore, efforts to improve the current methods of submarine escape should be further developed.

To make escape a viable and realistic option for the USN, this paper proposes replacing the Steinke Hood with advanced thermal protection suits (e.g., the British Mk 10 Submarine Escape and Immersion Equipment [SEIE]) on USN submarines as soon as possible, modifying existing USN submarine escape trunks to accommodate a more automated system similar to that used by the Royal Navy, and incorporating automated systems into design of the New Attack

Submarine (NSSN). In addition, development and installation of low-risk, cost-efficient training, equipment and procedures to support introduction of the advanced suits are recommended.

DISCUSSION

In 1974, then LT T.S. Neuman, MC, USNR, wrote a thesis titled Submarine Escape Training in the U.S.: A Re-Evaluation (2). In his paper, Dr. Neuman reviewed practices associated with USN submarine escape training and operation. He concluded that the use of the Steinke Hood as the method of submarine escape was no longer practical and that pressurized submarine escape tower training was too costly in terms of men and material and should be terminated. The importance of Dr. Neuman's thesis is implied by the USN's subsequent decision to abandon free and buoyant ascent tower training for submariners. No official correspondence outlining the rationale for the decision to terminate buoyant ascent training has been located, though many anecdotes survive.

Due to the significance of Dr. Neuman's thesis and in light of recent studies and emerging technology, this paper analyzes several assumptions made by Dr. Neuman in arriving at his conclusions. These assumptions will serve as departure points for this paper's updated analysis on the USN submarine escape system. Of Dr. Neuman's seven assumptions this paper revisits, one is a *training issue*, and the remaining six are *effectiveness issues*. This paper focuses on the effectiveness of current USN submarine escape practices. Dr. Neuman's paraphrased assumptions and the pare number of their location is his thesis are in italics, followed by our critical assessment of his assumptions.

Risks in training for submarine escape (Training issue)

> *There is a small but significant morbidity and mortality associated with tower training due to an air embolism which is not justified. (Neuman, p. 12)*

In the training tower, the escape trainees did not operate the escape trunk and did not encounter simulated sea conditions. Therefore, the escape training functioned primarily as a psychological screening test and rite of passage. Dr. Neuman concludes, "The Navy is risking approximately 3,000 lives per year and spending more than 200,000 dollars a year on a psychological test of unproven validity and reliability to weed out 3% of the failures, while ignoring entirely the problem of submarine escape . . . The Steinke Hood is clearly not the solution to the problem." (2)

Dr. Neuman reported that in 1973, 3,405 men ascended from the U.S. Navy escape tower at Submarine Base New London. A total of 442 (13%) were screened out of the submarine program: 300 of the 442 were unable to withstand the pressure testing, while the final 142 men failed during water training. Ninety percent (128 of the 142 men) failed due to their inability to breathe in a Steinke Hood in 5 - 6 fsw. Therefore, 14 out of 3,405 men (0.41%) were screened out of the submarine program due to their inability to conduct the escape tower ascent (2).

We concur with Dr. Neuman's opinion that the use of pressurized submarine escape training primarily as a psychological screening tool for submarine service is inappropriate due to lack of scientific or other evidence that validates its use in this way. Moreover, given the relative success of alternative, less expensive screening methods that have been in place since pressurized training was discontinued, reinstitution of pressurized training solely for psychological screening is unnecessary.

The experience of other navies conducting ascent training in preparation for actual escape is germane. In a study of the Japanese Maritime Self-Defense Force training, Ikeda and Oiwa reported no embolic accidents in 14,798 conventional Steinke Hood ascents from a depth of approximately 33 fsw (10 msw) (3). The Japanese use mechanical means to control the rate of ascent. The British Royal Navy (RN) currently conducts training using buoyant ascents with SEIE from 30 and 60 fsw (9 and 18 msw), and hooded ascents from 100 fsw. Prior to 1975, training also included a buoyant ascent from 100 fsw (30 msw). In 1994, Benton et al. Reported that between 1954 and 1993 there were 5 deaths in 277,147 ascents, a rate of 1 per 55,429 (4). Of the 5 deaths cited in the report, all occurred prior to 1975. An additional fatality in RN escape training occurred in 1995 from a gas embolism following a 100-fsw hooded ascent. For pulmonary barotrauma and neurological decompression sickness (DCS) associated with RN escape training, the most hazardous current profile was the 60-fsw buoyant ascent, which displayed an incident rate of 0.45/1000 ascents.

In recent correspondence, Dr. Neuman re-affirms his conviction that because the present method of U.S. Navy escape provides little likelihood of affording safe submarine escape, there is negligible benefit to tower training even if the risk associated with tower training is small (5).

Major problems with USN submarine escape practice (effectiveness issues)

Compression

> *(I) A compression time of twenty seconds to 600 feet indicates the 'maximum possible' escape depth. (Neuman, p. 6)*

The "maximum possible" escape depth is currently greater than 600 fsw (183 msw). Over the last two decades, the British continued improvement of submarine escape by using SEIE. The RN demonstrated that rapid compression in 20 s to 625 fsw (190 msw) is achievable (6), and that the technique of hooded escape is practical in both sea tests to depths of 600 fsw (183 msw), and in laboratory tests to a simulated depth of 625 fsw (190 msw) (7). From additional studies using goat trials, the RN concluded with reasonable confidence that safe escapes can be achieved from 750 fsw (228 msw) (8). In addition, escapes from depths of 900 and 950 fsw (274 and 289 msw) may be possible with a majority of crew surviving; however, the authors also note that there would certainly be casualties requiring urgent recompression. Unfortunately, empirical data to estimate the incidence and severity of human DCS from such great depths are lacking.

Current equipment on board USN submarines is unable to conduct the extremely rapid pressurization executed by the RN in their automated trials.

(II) It is exceedingly unlikely that an individual who has never been trained in high speed compression will be able to compress to 600 fsw in twenty seconds. (Neuman, p. 7)

This assumption is plausible from a U.S. Navy perspective, given the 1974 and current U.S. Navy submarine escape trunk operating procedures. These procedures require the escaper to manually control compression by performing multiple steps (9). However, operation of an escape system similar to the British Hood Inflation System (HIS) requires minimal action (i.e., insert fitting valve and hold) by the escaper rendering a high speed compression procedure practical.

Furthermore, there appear to be no physiological reasons why high speed compression cannot be accomplished. During a study of 20 volunteers conducting 112 simulated escapes from sunken submarines in a pressure chamber at the Royal Naval Physiological Laboratory, the following data were obtained: 0 cases of air embolism 4 DCS, a few cases of mild itching, and 5 cases of otic barotrauma, one of the latter resulting in a perforated tympanic membrane (8). These individuals had never been trained in high speed compression and they were able to withstand the rapid compression with minor complications that would not have affected their ability to continue with the submarine escape.

High speed compression rates are desirable because they shorten the exposure time to high pressure nitrogen. Faster compression results in less nitrogen absorbed into tissue and, correspondingly, the risk of subsequent DCS is reduced. The British system allows rapid pressurization by flooding directly from the sea, while the USN system is pressurized using air. Air is more compressible and, therefore, compression is slower than when using sea water. Further, in the British system compression begins when the water reaches the level of the vent drain, thus reducing the air space to be pressurized and significantly accelerating compression.

(III) Nitrogen, at a partial pressure equivalent to 600 feet, will render an individual completely disoriented if not unconscious in seconds. (Neuman, p. 7)

Nitrogen narcosis is experienced at 600 fsw (183 msw) following a 20-second rapid compression and a 3-second bottom time. The physiological effects of nitrogen at high pressure vary with the depth of the escaper and the time the escaper remains at that depth. A rapid automated system minimizes the potential deleterious effects of inert gas narcosis on escaper survival. Numerous human trials have been conducted at simulated depths of 500, 550, 600, and 625 fsw (152, 167, 183, 190 msw) with a 20-second compression, 3-second bottom time, and a rate of ascent of 8.5 fsw (2.6 msw) per second. The results of the study were that no subject felt any untoward effect of nitrogen narcosis during this rapid cycle (8). How long the subjects would remain unimpaired beyond 3 s either by subjective or objective measurement is not known, but continued use of a complex, nonautomated system encourages slower compression,

longer bottom time, and potential rise of behavioral impairment due to narcosis. As discussed further below, under ideal conditions using the current USN system, 71 s are (theoretically) required to flood the trunk, effect compression, and exit the trunk from a depth of 600 fsw (183 msw). Nitrogen narcosis may impair performance under these conditions.

(IV) Carbon dioxide toxicity (hypercapnia) would probably represent the depth limiting factor.

(a) Fleet Ballistic Missile submarines' carbon dioxide levels are usually between 1.0-1.5%.
(b) Between six & seven atmospheres, incapacitation would occur.
(c) Immediate unconsciousness occurs in an atmosphere of 10% carbon dioxide.
(d) LT Neuman cites as supporting documentation: "The maximum realistic depth of our present equipment is probably closer to 100 feet rather than 600 feet, and the limiting factor is carbon dioxide toxicity, not decompression sickness. (McMillan) (Neuman, pgs. 7 and 8)

Rapid compression (20 s) with minimal bottom time (3 sec) minimizes the effects of CO_2 toxicity, thus hypercapnia does not represent the depth-limiting factor during escape. Current average CO_2 levels of USN fast attack nuclear submarines with CO_2 scrubbers are approximately 4 torr at 1 ata, corresponding to an average level of 0.5% (data were obtained during a 6-month Mediterranean deployment in 1995). Ballistic missile submarines maintain similar CO_2 levels. Present USN submarine guidance aims to commence a submarine escape prior to CO_2 reaching a dangerously high level, and to complete crew escape before CO_2 levels reach 6% (9).

Compressing the escape trunk with submarine air at 0.5% CO_2 to an escape depth of 600 fsw (183 msw) at 19 ata would raise the CO_2 level to 9.5%. A study on *The Physiological Effects of High Concentrations of Carbon Dioxide* by E. W. Brown (10) presents the following results:

% CO_2	Time (minutes) to the intolerable limit*
6.0	20.5 - 22.0
7.5	3.5 - 6.0
10.4	2.25
12.4	2.0

Note: a. According to the study, none of the subjects could have withstood 10% CO_2 for longer than 10 min without complete stupefication (10). *The intolerable limit is the time that collapse of the subjects would have resulted in approximately one minute.

b. It is possible that the average CO_2 concentrations reported above for USN submarines may be higher in the DISSUB situation if CO_2 scrubbing capability was reduced.

(V) Operating an escape trunk is absurd under the "best circumstances"
(a) 39 °F water
(b) Atmosphere containing 5 - 10% carbon dioxide
(c) Anesthetic levels of nitrogen (Neuman, p. 9)

This assumption by Dr. Neuman omits reference to time, a critical factor to the viability of any escape procedure. A survey of the world's ocean temperatures in the littorals over the four seasons reveals a wide range of temperatures from 1,000 fsw (305 msw) to the surface. This paper concurs with Dr. Neuman's working figure of 39°F (3.9°C) for water temperature as realistic for a depth of 600 fsw (183 msw), the effects of which are discussed below. Moreover, when using the Steinke Hood, it is uncertain that a thermally unprotected escaper will be able to perform the required series of escape trunk actions while immersed in 39°F (3.9°C) water. As noted previously, British studies demonstrated that rapid compression, followed by minimal bottom time (3 s) during submarine escape, will circumvent the problems associated with O_2 toxicity and nitrogen narcosis.

(VI) Submariners must face an inhospitable environment if escape is possible: Seventy seconds of partial immersion in 39 °F water and "champion swimmers" were no longer able to stay afloat. (Neuman, p. 9)

The Steinke Hood offers no method of thermal protection and two intervals during submarine escape and rescue must be addressed when discussing the individual effects of hypothermia and cold water immersion. The first interval encompasses the time the escaper is exposed to seawater from flooding of the escape trunk until reaching the surface. The second interval encompasses the time the escaper is exposed on the surface until he is recovered.

(A) Reaching the surface with a Steinke Hood

The question surrounding the first interval is whether the escaper can reach the surface alive under the most limiting operational conditions with minimal thermal protection using the Steinke Hood. The "most limiting operational conditions" are partially defined by temperature vs. depth data taken during the months of April and September in various littoral regions. These regions include the waters adjacent to Russia, Germany, the former Yugoslavia, Panama, the east and west coasts of the United States, China, Britain, Gibraltar, India, Israel, Libya, Chile, Australia, and Japan. Within likely submarine operating areas, the temperature positions were taken at random for the purpose of defining the most extreme temperature conditions facing an escaper using the Steinke Hood. The unclassified environmental data were accumulated from the Fleet Meteorological Center in Monterey, California. Temperature vs. depth data at 600 fsw (183 msw) were analyzed based on the "No Decompression" *theoretical* escape depth using the Steinke Hood and the *successful* escape depth using the British Mark VII SEIS. The temperatures facing an escaper at 600 fsw (183 msw) range from 32°F (0°C) to 64°F (17.8°C) as is shown below in Table 1.

TABLE 1. GLOBAL WATER TEMPERATURE IN °F AT SURFACE AND 600 FSW (183 MSW)		
Coordinates (long-lat)	*600 fsw (183 msw) (°F)*	*Surface (°F)*
003-24 W/36-06 N	58.4	61.6
006-00 W/05-00 N	37.0	37.5
007-30 W/66-30 N	34.9	34.2
008-00 W/64-30 N	34.1	37.0
009-30 W/66-30 N	33.0	34.0
072-01 W/21-46 S	62.3	66.0
072-18 W/39-12 N	49.5	49.7
081-19 W/11-13 N	63.5	81.3
120-12 W/34-18 N	48.6 (520 fsw)	56.3
125-36 W/47-06 N	44.9	49.0
011-24 E/42-00 N	59.4	61.4
018-18 E/30-18 N	62.3	66.0
034-12 E/32-30 N	64.0	67.7
132-30 E/36-18 N	41.3	54.7
139-00 E/55-48 N	32.5 (410 fsw)	39.0

The total USN escape time from 600 fsw (183 msw) can be divided into three phases: (1) time to flood the escape trunk, (2) time of compression and exit from the submarine, and (3) time to reach the surface:

Flooding the escape trunk	11 s
Compression and escape	60 s
Reach surface	86 s
TOTAL TIME :	157 s (2 min 37 s)

(1) Time to Flood the Escape Trunk

The time to flood the escape trunk is based on fully opening a 2.5-inch ball valve at 19 ata (600 fsw) of pressure and flooding the escape trunk to the "bubble line" (estimated at three-quarters of the total volume of 132 ft^3 or 8,448 lb sea water). We can use this formula to calculate the time required: (11)

$$W = CD \times kA \times \sqrt{(2gh)}$$

W = rate of flooding (#/s)

CD = coefficient of discharge (1.0) based on the geometric configuration of the hole and flow resistance with the ball valve fully open

k = weight of seawater (64 #/ft^3)

A = area of the hole in ft^2 (based on fully opening the 2.5" ball valve in the escape trunk)

g = 32 ft/s^2

h = depth in fsw

Escape trunk total volume is 132 ft^3 or 8,448 lb sea water. The "bubble line" is approximately 3/4 of the total volume or 6,336 lb sea water.

Time to flood the escape trunk at depth in seconds = 6,336 / W

(2) Time of Compression and Exit from the Submarine

The time of compression and exit from the escape trunk is based on a 20-second rapid compression of the escaper until he departs from the escape trunk.(12)

(3) Ascent to the Surface

The time to reach the surface is based on an ascent rate of 7 ft/s. (13)

Note that flooding, compression and escape (not including ascent0 under present USN practice in optimal conditions will take a **minimum of 71 s**, versus 20 s with the more automated RN system. Furthermore, these times above are based on escape under ideal conditions such that delay does not occur due to other physiological effects (e.g., hypercapnia, nitrogen narcosis).

Current USN escape procedures are the following:

Upon flooding the escape trunk to the bubble line, the following actions are required by the trunk operator to escape per the subamrine ESCAPE BILL:

- When the trunk is flooded to the bubble line SHUT the FLOOD.
- Ventilate for 10 s using the trunk BLOW.
- Shut the trunk BLOW.
- Shut the trunk VENT.
- Stand by to inflate the hoods and equalize sea pressure.
    a. Each man hold his nose shut through the hood fabric.
    b. On the leader's signal take a deep breath and hold it.
    c. Inflate the hoods instantly.
    d. Open the trunk BLOW rapidly and fully.
    e. Start continuous deep breaths while the trunk is being pressurized.

f. Attempt to equalize at each inhalation.

- Equalize the trunk with sea pressure.
  a. Keep the water level at the bubble line.
  b. Adjust the BLOW, VENT, and FLOOD as required.
  c. Check the mechanical latch indicator to ensure the hatch is loose on the seat.
- Escape hatch, first man.
  a. Take a deep breath and hold it.
  b. Shut and remove the snorkel from his mouth and unsnap the hood charging line.
  c. Shift to normal breathing.

NOTE: EXPEDITE REMAINDER OF PROCEDURE TO PREVENT DEPLETION OF OXYGEN IN HOOD.

d. Keep the torso as erect as possible while entering the escape chute.
e. Crack the escape hatch to prevent a rush of water, allowing the leader to adjust for bubble line water level.
f. Open the Escape Hatch.
g. Signal all clear.
h. Proceed to the escape hatch.
i. Exhale until comfortable.
j. Release hold on the deck.
k. Breathe normally during the ascent to the surface.
l. On the surface shift to snorkel or unzip the hood.
m. The second and third man escape in the above manner.
n. The team leader, who is the last man in the team, hammers signals "OUT" to the compartment, checks the escape hatch seat is clear, and ascends.
o. Each man in sequence shifts from snorkel to hood breathing, KEEPING THE TORSO ERECT to avoid spilling air out of the hood.
p. When the last man has gone SHUT THE ESCAPE HATCH from the compartment (9).

The purposes of listing the escape procedure are 1) to suggest the extensive duration required to conduct escape procedures, and 2) to illustrate the operational requirements by the escaper at a time in which he may be hyperventilating and incapacitated by cold to the point that he would not be able to perform the functions necessary to escape.

During flooding of the trunk, sudden immersion may cause hyperventilation and vasovagal effects (e.g., loss of consciousness) in the thermally unprotected submariner. In 1988, during a buoyant ascent escape using the Steinke Hood in 57°F (14°C) water, crew members of

the B.A.P. PACOCHA noted that the water flooding the escape trunk was so cold that they were sure they would die (1). It is problematic whether a thermally unprotected escaper will be able to perform the required series of trunk actions shortly after immersion in 39°F (3.9°C) water; we believe the lack of proficiency by the escape trunk operator combined with the effects of hyperventilating in the cold escape trunk will lead to an increased state of confusion and probable failures of escape.

The British system is simpler to operate, in addition to providing thermal protection. The escaper dons his suit, climbs into the tower, and inserts the inflator connector into the stole charging valve. He then concentrates on remaining connected to the Hood Inflation System while his colleagues flood the tower from the escape compartment. When pressures are equal the upper hatch should open automatically, as its' weight is balanced by a spring. The escaper leaves the trunk through the hatch, breathing normally from the hood until he reaches the surface. From a depth of 600 fsw (183 msw), the compression and exit phases from the submarine take approximately 20-25 s (6). Escape time in the British system is less affected by sudden exposure to cold water and toxic gases because the SEIS provides thermal protection and the breathing of dedicated BIBs air avoids the problem of breathing compressed submarine air. British submariners who escaped from a submarine during a recent Norwegian fjord exercise reported to the authors that they were not unduly cold in the escape trunk while outfitted in the SEIE.

(B) Surviving on the surface

If the escaper arrives at the surface alive and conscious, the second interval becomes effective. Death from hypothermia is a major concern on the surface. The best evidence of individual survival with flotation in cold water comes from studies of casualties of fighting ships during World War II. Through investigation of naval casualties involving more than 30,000 naval personnel, two thirds of all fatalities were due to drowning or exposure, and the majority of these were as a result of immersion hypothermia (14).

Molnar (15) concluded from eyewitness accounts by survivors that most people died within 6 h after immersion in water at 59°F (15°C), and within 1 h in water at approximately 32°F (0°C) (15). Additionally, a survey of U.S. Navy records by Molnar shows that survival is limited to 10-20 min in 32°F water (15). Further, sudden immersion in water at 32°F (0°C) produces a reflex gasp followed by a 1- to 2-minute period of hyperventilation (16), potentially exacerbating circumstances.

During the rescue of the passengers of the *Titanic*, 1,498 out of 2,201 were reported dead within 2 h after rescuers arrived, even though all of the passengers found dead in the water had life jackets or some flotation device (14). Water temperature was reported to be approximately 39°F. In April 1989 the Soviet submarine Komsomolets sank in the Norwegian Sea. Surface sea temperature was about 38.5°F (3.5°C) and the sea state was 3. Fifty-nine men abandoned ship on the surface, 28 of whom managed to reach a life raft and climb into it. The remainder stayed in the water, but some clung to the raft. Within 75-80 min a support ship rescued 30

survivors (23 from the raft and seven from the water). Twenty-nine perished (5 in the rate and 24 in the water); three of those pulled from the water died later that day. The report does not detail what clothing was being worn at the time of abandonment. Overall mortality for this exposure was 54%, but mortality of those remaining in the water was 87% and those in the raft was 18% (17).

Based on the data in Table 1, year-round surface temperature outside the tropics is about 65°F (16.7°C) and is never much warmer than 59°F (15°C) along the North Atlantic sea routes, Britain, and most of Northern Europe and North America. According to Table 2, survival of individuals immersed for a period of 7 h in water temperature ≤ 70°F (21.1°C) is unlikely (18). From the data in the US Navy Diving Manual, it is anticipated that use of the Steinke Hood alone during escape will lead to death of submariners within 1 hr in 40°F (4.4°C) water due to hypothermia (19).

TABLE 2. PREDICTED SURVIVAL TIMES FOR EXPOSURE WATER TEMPERATURES (18)

Water Temperature °F (°C)	*Time to Exhaustion or Unconsiousness*	*Survival Time*
32.5 (0.3)	< 15 min.	< 15 - 45 min.
32.5 to 40.0 (0.3 to 4.4)	15 - 30 min.	30 - 90 min.
40 to 50 (4.4 to 10.0)	30 - 60 min.	1 - 3 hrs.
50 to 60 (10.0 to 15.6)	1 - 2 hrs.	1 - 6 hrs.
60 to 70 (15.6 to 21.1)	2 - 4 hrs.	2 - 7 hrs.
70 to 80 (21.1 to 26.7)	3 - 12 hrs.	3 hrs. - Indefinite
> 80 (>26.7)	Indefinite	Indefinite

SUMMARY

Once the decision to make an escape has been made, the process must be conducted rapidly and efficiently to minimize physiological effects during escape and to minimize complications while awaiting rescue on the surface. In a DISSUB, pressurization of the affected compartment by high pressure air leaks, flooding, emergency air, and/or oxygen bleed will cause

"No Decompression" limits to be exceeded in a relatively short period of time. This is displayed in Table 3, which is compiled from U.S. Navy Diving Manual data (18).

TABLE 3. BOTTOM TIME LIMITS FOR U.S. NAVY NO-DECOMPRESSION AIR DIVES

Depth (fsw)	*Time (min:sec)*
50	100:00
100	25:00
200	3:45
300	2:00
375	1:30
425	1:15
475	1:00
525	:30

The increased compartment pressure will lead to nitrogen saturation of the crew's tissues resulting in DCS of the escaper following a rapid ascent to the surface. Without decompression stops on the ascent to the surface, DCS will occur as witnessed in the most recent submarine escapes in 1988, from the Peruvian submarine B.A.P. PACOCHA (1). The PACOCHA was involved in a collision with a merchant while transiting on the surface, and sunk to a depth of 140 fsw (43 msw) in 5 min. Twenty-three men escaped into the water as the boat sank, and prior to arrival of help 2.4 h later, 3 of these men died of exposure in 57°F (13.9°C) water. Twenty-two of the crew survived in the PACOCHA and conducted buoyant escapes with Steinke Hoods approximately 18 h later; twenty developed DCS. A USN Assist Team visited the Peruvian Navy to interview the survivors, analyze the lessons learned, and make recommendations for consideration by both countries. The following lesson learned and recommendation directly supports the necessity to remove Steinke Hoods from USN submarines:

"The Steinke Hood and life vests do not give adequate protection from thermal stress in cold water . . . (and) consideration should be given to adopting the British Submarine Escape and Immersion Suits (SEIS) for use in isolated or wartime situations. Major modifications of escape trunks would be necessary to adopt existing submarines to exploit the full 200-meter escape potential of the suit. However, its potential for increasing survival potential in cold water could be realized with only minor escape trunk modification in existing submarines"(1).

The senior survivor must make his decision to escape while taking into account many considerations, including compartment pressurization, hypothermia, CO_2, air embolism, ear drum rupture, O_2 depletion, and toxic gases. Upon making the decision to escape, the submariners are confronted with the following Steinke Hood limitations: survival in the cold water with minimal thermal protection (minimal implying the inadequate insulation of their clothes), and the Steinke Hood operational limits. While survival in cold water has been discussed extensively above, an additional constraint is that the Steinke Hood has only been successfully used to a depth of 318 fsw (97 msw) and simulated to a depth of 450 fsw (137 msw). (20)

Hypothermia, the instantaneous effects of cold water immersion, and escape depth limitations are the driving factors that require replacement of the Steinke Hood, currently deployed on USN submarines, with equipment similar to the British Mark 10 SEIE or the Swedish Mark VIII SEIS. The need to replace the Steinke Hood on submarines due to its lack of thermal protection has been noted a number of times over the last three decades. During a conference on "Medical Problems of Submarine Survivors" by Submarine Development Group One in November 1978, the following recommendation (Priority A) was made:

"There is a definite problem in a disabled submarine with cold and subsequent hypothermia and death of survivors of the original accident. It is, therefore, strongly recommended that Submarine Escape and Survival Equipment (EASE) suits be provided to all submarines in lieu of the Steinke Hood. Not only does the EASE suit provide for a better chance of survival after escape, it could be also used to protect survivors (from the effect of cold) while awaiting rescue." (21)

Nine immersion experiments with a modified version of the Beaufort Mark 8 SEIE were carried out in 40°F (4.4°C) water. Tests show that survival in good condition for 12 h in an intact suit is realistic. Moreover, the physiological measurements indicate that survival for 24 h would be possible if the submariner is unhurt and able to keep his suit well inflated and dry inside. (22)

It is of interest to note that the RN has increased its research and development in submarine escape vice rescue, and the British Mark 8 and Mark 10 SEIE are currently deployed on their submarines. The development of the British Mark 10 SEIE provides escape and survival equipment with breathing gas, buoyancy, and exposure protection for submarine personnel escaping from the continental shelf and beyond. The Mark 10 SEIE specifications require 24 h of survival under conditions that could vary from 90°F (32.2°C) water with 85°F (29.4°C) air, still air and calm sea, to 29°F (-1.7°C) water with 10°F (-12.2°C) air, 30-knot wind speed and a sea state of 6.

Upon further analysis of Dr. Neuman's assumptions, the heart of the argument to replace the Steinke Hood must be focused on the hypothermic conditions that the submariner would face from the time that flooding of the escape trunk commences to the time of rescue. The Steinke Hood affords no method of thermal protection, and for this reason alone, the current method of submarine escape is no longer practical.

RECOMMENDATIONS

1. Replace the Steinke Hod with equipment providing adequate thermal protection, e.g., the British Mk 10 SEIE, on U.S. Navy submarines as soon as possible.

2. Modify existing U.S. Navy submarine escape trunks (i.e., 637, 688, 726, SEAWOLF classes) to accommodate an automated system similar to that used by the Royal Navy, and incorporate automated system into the design of NSSN.

3. Develop and install more realistic, low-risk, cost-efficient equipment and training procedures to support introduction of new escape equipment.

REFERENCES

1. Harvey, C., Carson, J. The B.A.P. PACOCHA (SS-48) Collision: The Escape and Medical Recompression Treatment of Survivors. NSMRL Special Report SP89-1, Naval Submarine Medical Research Laboratory, Groton, CT, 1989.

2. Neuman, T.S. Submarine Escape Training in the U.S.: A Re-Evaluation. Naval Undersea Medical Institute Thesis, Naval Undersea Medical Institute, Groton, CT, 1974.

3. Ikeda, T., and Oiwa, H. "Safe Individual Submarine Escape Training: Over 14,700 Uneventful Ascents in the Maritime Self-Defense Force." In: Proceedings - 20th Annual Meeting of the European Underwater and Baromedical Society on Diving and Hyperbaric Medicine, Cimstit, M., ed. Hyperbaric Medical and Research Center (HITAM), Istanbul, Turkey, 1994.

4. Benton, P.J., Woodfine, J.D., and Francis, T.J.R. A review of spirometry and UK submarine escape training tanks incidents (1954-1003) using objective diagnostic criteria. INM R94011, Institute of Naval Medicine, Alverstoke, UK, 1994.

5. Dr. T.S. Neuman letter, Subj: Submarine Escape, July 16, 1996 (on file in the Naval Submarine Medical Research Laboratory, Groton, CT library).

6. Bernard, E.E.P., Eaton, W.J., and Snow, R.E. Experiments in Submarine Escape. Rapid Compression of Men to 625 Feet. Royal Naval Physiological Laboratory, Alverstoke, UK, 1973.

7. Bell, P.Y., Burgess, D.W., Summerfield, M., and Towse, E.J. "The effect of presaturation on the maximum submarine escape depth of goats and the implications for human research." Underwater Physiology VIII, pgs 241-247, Undersea Medical Society, Inc., Bethesda, MD 1984.

8. Donald, K.W. Submarine Escape Breathing Air. A Review and Analysis of Animal and Human Experiments by the Royal Navy, 15, 739-754, 1979.

9. U.S. Navy, SSN 637 ESCAPE BILL, Change 1, pgs 3218-1 to 3218-10.

10. Brown, E.W. "The Physiological Effects of High Concentrations of Carbon Dioxide." United States Naval Medical Bulletin, Vol. XXVIII, No. 3, pgs 523-553, 1930.

11. COMSUBLANT INSTRUCTION, 5400 Series, FLOODING BILL.

12. Hall, D.A. and Summit, J.K. Simulated Deep Submarine Escape from 495 Feet of Sea Water, MF 12-524-006-9025, Report Number 617, Naval Submarine Medical Center, Submarine Base, Groton, CT, 1970.

13. S9086-T9-STM-00/CH-594, Individual Escape Using the Rescue/Escape Trunk. Chapter 4, NAVSEA Technical Manual, Washington, DC.

14. Keatinge, W.R. Survival in Cold Water. Blackwell, Oxford, England, 1969.

15. Molnar, G.W. "Survival of Hypothermia by Men Immersed in the Ocean." Journal of the American Medical Association, 131:1046-1050, 1946.

16. Cooper, I.E., Martin, S., and Ruben, P. "Respiratory and other Responses of Subjects Immersed in Cold Water." Journal of Applied Physiology, 40:903, 1976.

17. "Organization of medical aid to victims of the sinking of the nuclear submarine Kosomolets". Military Medical Journal #11, p. 28-32, Nov 1989 (Canadian translation).

18. Perez, M. "To sink or swim -- or both." Safety Line, Naval Safety Center, Norfolk, VA, 1985.

19. U.S. Navy Diving Manual Vol. 1, Chapter 4, pgs 4-15, Figure 4-9. Naval Sea Systems Command, Washington, DC, 1993.

20. Steinke, H.E., and Huey, E.P. "Conduct of a fleet operation investigation of a modified submarine escape appliance." Project Report of Project F/O S2 FY61. NAVSUBSCOL, 25 May 1961.

21. Vorosmarti, J. Report on Conference on Medical Problems of Submarine Survivors. Submarine Development Group One, San Diego, CA, 1978.

22. Larson, A., Gennser, M., Ornhagen, H. Test of a Modified Mark 8 Submarine Escape and Immersion Suit. National Defense Research Establishment, Department of Human Studies, Sweden, FOA Report C50090-5.1, 1991.

ACKNOWLEDGMENTS

The authors express their appreciation to Dr. Tom Neuman for his original work, and for his helpful comments on this paper. Constructive reviews were received from CAPTs Henry Schwartz, John Murray, David Sack, CDR T.J. Reilly (Commanding Officer, USS BATFISH SSN-681), and Chiefs Barnes and Lambertsen, U. S. Navy. Our thanks to Ms. Ellen Perkins for manuscript assistance and Mrs. Elaine Gaucher for research assistance. The assertions and opinions contained herein are the private views of the authors and are not to be construed as reflecting the official policy of the United States Navy. This work was supported by Chief of Naval Operations (CNO-873) through Naval Medical Research and Development Command project No. 63706N.M0099.01A.5602.