SUBMARINE RESCUE AND ESCAPE: AN OVERVIEW

In the collection of the
U.S. Naval Undersea Museum

NUM.2018.024.007

UNITED STATES NAVAL
UNDERSEA
MUSEUM

SUBMARINE ESCAPE AND RESCUE: AN OVERVIEW

LCDR DALE M. MOLÉ, MC, USN

JANUARY 1990

Approved by Capt J. B. Johnston, USN
Commander, Submarine Development Group One

TABLE OF CONTENTS

Acknowledgements iii

INTRODUCTION 1

DISSUB SURVIVAL 3

I. Distress Signals 3

Radio 3

Sonar 3

Visual 4

II. Staying Alive - Threats to Survival 4

Oxygen: Too Little or Too Much 4

Nitrogen 5

Carbon Dioxide 5

Carbon Monoxide 5

Chlorine 6

Hypothermia 6

Food and Water 6

Injuries 6

III. Staying Alive - Crew Efforts to Prolong Survival Time 7

SUBMARINE ESCAPE 8

Compression 9

Time On the Bottom 9

Ascent to the Surface 10

Escape History 10

British Escape System 12

SURFACE SURVIVAL 13

THE DEEP SUBMERGENCE RESCUE SYSTEM 15

DSRV 15

ASR 17

MOSUB 18

ASSOCIATED RESCUE ASSETS 19

SRC 19

DSV 21

ROV 21

SUBMARINE RESCUE 23

Shallow Water Rescue 24

Initial Rendezvous and Mating 24

Injured Crewmembers 25

Arctic Operations 25

PRESSURIZED RESCUE 25

Pressurized Rescue Transfer Procedures 26

The ASR-21 Class 27

The SSN 637 Class MOSUB 28

ESCAPE vs RESCUE 29

FOREIGN RESCUE AND ESCAPE SYSTEMS 30

British Royal Navy 30

Japanese Maritime Self-Defense Force 31

Italian Navy 31

French Navy 32

Swedish Navy 32

Soviet Navy 33

West German Navy 34

Acknowledgements

I would like to take this opportunity to thank CDR John F. Carson, MC, for the hours of proof reading and the many constructive editorial comments which he freely provided.

I would also like to thank HMCS(DV) Randy Featherston for the hours spent helping me organize and print the text and graphics using the Ventura Desktop Publishing Software.

Finally, I would to express my appreciation to my wife, Susen and my daughter, Megen, for their understanding of the countless hours I spent by myself pouring over books and articles in the preparation of this thesis, while many household projects were awaiting my attention.

INTRODUCTION

Given the paucity of recent U.S. Navy submarine disasters, with the exception of the USS BONEFISH, one might conclude it is not prudent to devote too much of the Navy's resources, both time and money, to submarine rescue or escape. Submarine sailors, as well as airline passengers, wisely do not spend much time pondering the possibility that they may be embarking on a one way trip. Statistically speaking, submarine and commercial airline travel is very safe. Nevertheless, submarines and submariners have not yet reached the state of infallibility.

From the turn of the century through 1971, there were 101 non-combat related submarine sinkings. Almost 2500 lives were lost, the majority by Great Britain, France, and the United States. Most of the subsunk incidents were in water shallower than three hundred feet (37).

Aboard U.S. submarines between calendar years 1982 through 1986 there were reports of 132 fires, 62 collisions (the majority occurring while entering or leaving port), 56 incidents of flooding (with seawater systems being the most frequent source), 68 ordnance related explosive mishaps, 12 non-ordnance related explosive mishaps, and 12 groundings (1).

It is frequently argued that since U.S. submarines spend 95 percent of their time operating in waters deeper than the hull crush depth, discussions of escape or rescue are for the comfort of wives and mothers back home. Nevertheless, the chance of a mishap is much greater while the submarine is over the continental shelf because of the increased risks associated with sea trials, diving and surfacing, and transiting with open hatches and other hull penetrations in areas with greater sea traffic density, such as near major seaports. The American people and their elected representatives would consider it unthinkable that a submarine with survivors might someday be on the bottom, intact, without adequate means to effect their rescue. Should any doubt exist regarding this point, one has only to consider the public hand-wringing following the CHALLENGER Space Shuttle disaster.

The problem of saving submariners is by no means a recent one. In 1851, Wilhelm Bauer achieved the dubious distinction of being the first to make a free escape from a sunken submarine after his all iron craft sank out of control. He was entombed for five hours before finally persuading the two other crewmen to flood the submarine further until the pressure was equalized and the hatch could be opened (2).

In what must be one of the more remarkable escape stories, Stoker Petty Officer Brown found himself alone behind a watertight bulkhead in the engine room after His Majesty's Submarine (E-41) collided with another and sank in thirty feet of water. Brown began flooding the engine room in order to equalize the pressure, which would allow him to open the hatch. During this process "things went rather badly." The rising water shorted some of the energized electrical circuits, shocking Brown severely whenever he touched any metal. The battery compartments flooded with seawater, producing chlorine gas. As the pressure started to equalize, the hatch would pop open, release a bubble of air, then slam shut. This process was repeated several times and on one occasion, much to the dismay of Petty Officer Brown, the hatch slammed shut on his hand, crushing his fingers. With typical British Bulldog tenacity he finally managed to effect his escape when the air in the engine room was almost exhausted (38, 27).

The most successful submarine rescue in U.S. Naval history occurred on 24 May 1939 when thirty-three crewmen were rescued from the forward torpedo room of the USS SQUALUS (SS-192) as she sat on the bottom in 234 feet of seawater utilizing the Submarine Rescue Chamber (3).

On the fateful morning of 10 April 1963, USS THRESHER (SSN-593) disappeared in 8400 feet of water off the New England coast, carrying 129 men to a sudden, violent death. This produced a reaction never before witnessed following a submarine tragedy. Within two weeks, the Secretary of the Navy formed the Deep Submergence Systems Review Group (DSSRG), which conducted a year long study of submarine rescue and deep ocean recovery and recommended a five year, 333 million dollar effort to develop a new submarine rescue and deep submergence program (4).

The Chief of Naval Operations (CNO) promulgated SOR 46-15R1 which stated the need for a system with the "capability to (A) locate a submerged submarine in distress, (B) accomplish reliable personnel escape and optimize survival possibilities from a submarine bottomed at 600 foot depths, and (C) rescue personnel from depths of 2000 feet" (5).

The rescue mission envelope was further defined as follows:

(A) The rescue vehicle will be able to mate to the disabled submarine (DISSUB) at roll and pitch angles as great as 45 degrees, (B) the maximum tolerable steady bottom current will be one knot with up to two knot currents about the hatches, (C) the optical system must provide useful information in murky waters with visibility as low as 3 feet, (D) the rescue system must be able to conduct a successful rescue from a DISSUB with internal pressures ranging from 0.8 to 5 atmospheres absolute and from one which contains a toxic atmosphere, and finally (E) the rescue system must be able to accommodate up to 144 men.

Within two years the DSSRG had drawn up plans for a Deep Submergence Rescue Vehicle (DSRV) as well as all of the associated logistics. Twelve months later a contract was awarded to Lockheed Missiles and Space Company in Sunnyvale, California to build the first two vehicles. The original concept involved six DSRVs, ten ASR-21 class support ships, twenty-four mother submarines and three rescue homeports (San Diego, New London, and Charleston).

In 1970, the Navy took delivery of the first DSRV. It was, and remains today, the most complex and sophisticated deep submergence vehicle in the world. The DSRV estimated cost of $3 million apiece had ballooned to $43 million by delivery. Because of budget restraints, instead of funding six DSRV's, the Navy was having considerable difficultly funding two. The sense of urgency and the emotions surrounding the 1963 THRESHER disaster were absent from the research and development funding circles by the late 1960's. "So much so, in fact, that the 1968 sinking of another U.S. Navy submarine, SCORPION, in 10,000 feet of water passed with barely more than a ripple of concern relative to THRESHER."(52)

In November 1970, the NURESARS Study Project Report recommended the planned rescue program be reduced to two DSRVs, two ASRs, one rescue homeport and nineteen mother submarines because of "technical and funding problems." This report also recommended phasing out the "obsolescent" SRC and canceling research on an escape suit since... "the Steinke Hood escape system will probably be adequate to meet the Navy's requirements for undersea escape operations." (6)

The first DSRV was launched on 24 January 1970 and was commissioned on 6 August 1971 at a cost of $43,000,000. DSRV-2 was launched on 1 May 1971 and commissioned on 11 July 1972 at a cost of $23,000,000. Following a six week factory test, both ships underwent extensive sea trials and were finally accepted by the Navy in 1977.

In 1975 SOR 46-15R2 was issued containing several major modifications. "*The requirement that the rescue system should be capable of rescuing survivors from a submarine that has an internal pressure of up to five atmospheres absolute is to be held in abeyance...until such time as the medical, engineering and material problems have been resolved. The requirement that the rescue submersible be capable of trans porting 24 survivors is held in abeyance (caused by buoyancy problems which were later corrected)...the existing capability of 17 (AVALON) and 19 (MYSTIC) rescuees per trip is accept able. The requirement to accomplish personnel escape from* *a submarine bottomed at depths to 850 feet and the requirement to optimize surface survival possibilities following abandonment of a surfaced or submerged submarine have been held in abeyance. The requirement of the DSRS to be capable of responding to any normal submarine operating area within 24 hours is held in abeyance. The requirement that checkout procedures must insure a probability of successful operation greater than 0.8 for the particular mission involved and with the required launch time is a goal and not a mandatory requirement for fleet delivery."* (7)

This monograph is written for the submarine officer community and addresses medical and engineering concerns regarding the ability to rescue survivors from a submarine mishap which has exceeded the damage control capabilities of the boat and its crew. The majority of the medical problems associated with submarine escape and rescue in general, and pressurized submarine rescue in particular, have been resolved. Further improvement of the U.S. Navy's escape and rescue capability now depends upon the desire to address the remaining engineering issues.

DISSUB SURVIVAL

When a submarine sinks to the bottom, any survivors entombed within will have to make difficult decisions while under extreme psychological and physiological stress. Their most immediate goals will be to alert search and rescue (SAR) forces as to their fate and remain alive until assistance arrives.

I. Distress Signals

Submarines in distress have a variety of methods by which they can signal for help. These methods can be generally categorized as radio, sonar, or visual.

Radio

All U.S. submarines carry emergency radio transmitting buoys which are designed to be released through the submarine's signal ejector. The T-347 and T-616 buoys transmit a CW signal "SOS SUB SUNK SOS" on the international distress frequencies of 121.5 and 243.0 MHz. Their transmissions can be heard as far as 100 miles by aircraft flying at 10,000 feet or higher. The AN/BST-1 (CLARINET MERLIN), another radio buoy carried by some submarines, can be instructed to transmit a distress signal sequentially on four different frequencies for approximately 12 minutes out of every hour. The message will repeat for about 72 hours until the battery is exhausted. A new system of UHF satellite communication buoys being installed will allow a disabled submarine to immediately make its situation known via the Search and Rescue Satellite System (SARSAT).

Sonar

Sonar and other acoustic means of signaling have limitations with regard to range, but are very useful once SAR forces are in the general area.

The Submarine Distress Sonar System (AN/BQN-13) emits a 3.5 KHz omnidirectional 100 millisecond pulse every 5 seconds and is designed to be used as a homing beacon for the DSRV. Two units are installed aboard submarines and are located near each of the escape trunks. Each unit is self contained and operates on a 26 volt DC battery, which with a full charge can sustain continuous operation for a minimum of 15 days. The 5 watt acoustic output has a range of 10 nautical miles in state 4 seas.

The submarine's standard sonar equipment could also be used, if operable, to send out distress calls as well as information regarding location and condition.

In addition to the standard UQC-1 underwater telephone, there is an emergency underwater telephone (AN/BQC) installed aboard all U.S. submarines. Not only will it transmit voice, but special provision has been made which allows it to generate a 24 KHz homing signal.

Simply tapping on the hull is a well proven method which has been in use as long as submarines have been sinking. Its primary disadvantage is the greatly increased oxygen use and carbon dioxide production by the sender.

Visual

Submarines carry pyrotechnics (signal flares) to signal their condition and position. As recently as August 1988, signal flares were successfully used to establish that a submarine had sunk, that personnel onboard were alive, and the illumination produced aided in the location of survivors in the water (40).

Submarines can also release dye, oil, debris, or air into the water to assist SAR forces in their location efforts.

II. Staying Alive - Threats to Survival

Oxygen: Too Little or Too Much

Life exists within a relatively narrow range of oxygen partial pressures. Too much oxygen can be just a life threatening as too little.

The concentration of oxygen normally present in air is 21 percent. Since one atmosphere absolute (ata) is equivalent to 760 Torr, the partial pressure of oxygen is 760 times 0.21 or 160 Torr. Expressed in ata this would be 1 ata times 0.21 or 0.21 ata. If the atmospheric pressure were doubled to a total pressure of 1520 Torr, or two atmospheres absolute, the partial pressure of oxygen could be expressed as (1520 Torr X 0.21) 320 Torr or (2 ata X 0.21) 0.42 ata.

The partial pressure of oxygen, not the absolute percentage, determines whether life is to be sustained or extinguished. Perhaps this is best illustrated by an anecdote from the SEALAB (Man-In-The-Sea) project. The partial pressure of oxygen in the SEALAB habitat was maintained at 0.3 ata. Since the total pressure was about 7 atmospheres, the oxygen concentration was approximately 4 percent. Captain George Bond, MC, USN, the project's director, told the aquanauts that smoking would be impossible, but they insisted on taking tobacco with them anyway and discovered, much to their disgust, not only would tobacco not burn, but matches would not even light in an atmosphere with such a low percentage of oxygen (41).

Conversely, as one ascends through the atmosphere, although the concentration of oxygen remains the same, it's partial pressure falls as the total atmospheric pressure decreases. By the time one reaches an altitude equivalent to Denver (5,000 feet), the partial pressure of oxygen has fallen to 0.175 ata. The air on Pikes Peak (14,100 feet) has an oxygen partial pressure of 0.123 ata. To achieve a similar partial pressure at sea level, one would have to breath a gas mixture containing only 12.3 percent oxygen.

As the survivors aboard a submarine in distress breath up the available oxygen, it's partial pressure begins to fall, resulting in the appearance of the signs and symptoms of hypoxia or lack of oxygen. The objective signs of hypoxia include increased breathing rate and depth, cyanosis (a bluish discoloration of the skin), mental confusion, poor judgment, a loss of muscle coordination and unconsciousness. The subjective symptoms include breathlessness, apprehension, headache, dizziness, blurred or tunnel vision, mood changes, numbness and tingling (50).

Studies performed by the U.S. Army Research Institute of Environmental Medicine indicate an oxygen partial pressure of 0.17 ata does not adversely effect cognitive functioning or mood states, further reduction to 0.13 ata produces short-term decrements in cognitive function and mood (42).

Exposures to low partial pressures of oxygen (less than 0.15 ata) lasting longer than several hours can produce symptoms of Acute Mountain Sickness (AMS). This usually afflicts 15 to 17 percent of the normal population and is characterized by headache, fatigue, shortness of breath and sometimes nausea and vomiting. Should the partial pressure of oxygen continue to fall, High-Altitude Pulmonary Edema (the lungs filling with body fluids) can occur giving pneumonia type symptoms. High-Altitude Cerebral Edema (swelling of the brain) may also occur insidiously within twenty-four to thirty-six hours, causing mental confusion, hallucinations and coma (43).

Pulmonary oxygen toxicity results from prolonged exposure to high oxygen partial pressures in excess of 0.5 ata. The original DSRV design upper pressure limit of 5 ata was based on the assumption that the DISSUB crew could not survive breathing 5 ata air (oxygen partial pressure of 1.05 ata) for longer than 48 hours (44). Although this assumption was later proven to be false, there is no doubt that high partial pressures of oxygen can damage delicate lung membranes.

Breathing 0.6 ata oxygen produces respiratory symptoms in the majority of humans in less than 24 hours (45). The earliest symptom is usually a mild irritation of the trachea (windpipe) which is aggravated by deep inspiration. A progressively worsening cough develops and each breath becomes painful. The Forced Vital Capacity (the maximum volume of air which can be exhaled after one deep breath) decreases as some of the alveoli (air sacks) within the lung collapse and others develop thickening of their walls, making the lungs stiffer and impeding the uptake of oxygen by the blood stream (46). If this process continues, death will be the final outcome.

At the Naval Submarine Medical Research Laboratory, twelve healthy subjects were exposed to 5 ata air for forty-eight hours. All suffered significant symptoms and had large decrements of their Forced Vital Capacities. All completely recovered after the experiment, demonstrating that exposure to 5 ata air can be safely tolerated for forty-eight hours (47).

Another ameliorating factor is the gradually decreasing partial pressure of oxygen as the crew "breathes down" or uses oxygen, the rate of decrease depending on the compartment volume and the number of survivors.

Nitrogen

Nitrogen comprises seventy-nine percent of our atmosphere and is generally considered an inert (metabolically inactive) gas. When breathed at increased pressure, however, it produces a narcotic effect in a dose dependent fashion, i.e., the higher the partial pressure of nitrogen the greater the narcosis. Nitrogen narcosis causes both cognitive and psychomotor disturbances. Breathing air at 4 to 7 ata causes delayed response to auditory and visual stimuli, impaired neuro muscular coordination, a loss of clear thinking and a tendency toward idea fixation. The effect is similar to ethanol (alcohol) intoxication and it can significantly impair the abilities of the DISSUB crew to take the necessary steps to insure their survival.

Carbon Dioxide

Carbon dioxide comprises only 0.001 ata or one-tenth of one percent of the atmosphere. It is a by-product of cellular metabolism and for each standard cubic foot of oxygen consumed an almost equal amount of carbon dioxide is produced.

In humans, the partial pressure of carbon dioxide stimulates breathing and as it's partial pressure increases so does the rate and depth of breathing. At 0.03 ata the rate and depth of breathing is doubled. As the partial pressure increases to 0.05 ata, headache, mental confusion and a lack of coordination become apparent. If the carbon dioxide level climbs past 0.10 ata, unconsciousness is soon followed by death.

Carbon Monoxide

Carbon monoxide is a colorless, tasteless, odorless gas that binds to hemoglobin with an affinity 218 times that of oxygen. By preventing hemoglobin from carrying oxygen to the tissues, elevated carbon monoxide levels will result in dizziness, headache, unconsciousness and death. The production of carbon monoxide is usually associated with incomplete combustion, i.e., cigarette smoke. It is also produced by human metabolic processes at a rate of 0.3 to 1.0 milliliter per hour, which may be enough to cause concern when a large number of people are crowded into a small enclosed space (48).

Chlorine

The flooding of battery compartments with seawater has long been dreaded by submariners. The chlorine gas produced is lethal at high concentrations and can cause lung irritation (pneumonitis) at low concentrations. Subsequent exposure to higher than normal oxygen partial pressures or an increase in gas density, as is the case in a pressurized SUBSUNK scenario, would exacerbate the lung damage caused by chlorine gas and could further reduce the chances of survival (49).

Hypothermia

In a majority of cases, the DISSUB will be without a significant source of electrical power. In all but the most tropical waters, the internal submarine temperature will begin to fall until an equilibrium is reached with the ambient ocean temperature. The rate of cooling depends upon the compartment size, number of survivors, the amount of hull insulation, and the temperature of any machinery in the compartment prior to the mishap.

It has been estimated that the internal temperature will fall exponentially to sea temperature with a time constant of 14.2 hours (51) or in the worst case could approach ambient ocean temperature in about 30 hours (16). This projection is supported by the experience of the USS SQUALUS crew who saw the temperature drop in their submarine to about 45 degrees Fahrenheit in less than 40 hours (53). A notable exception to this rule occurred during the recent B.A.P. PACOHCA disaster when the internal temperature rose from 70 to 77 degrees Fahrenheit despite an estimated water temperature of only 52 degrees Fahrenheit (40).

Since a flooding casualty is usually required to send most submarines to the ocean floor, wet clothing is expected on at least some of the survivors and it may increase conductive body heat loss by as much as five fold, hastening the onset of hypothermia.

The body will attempt to maintain it's normal core temperature by a number of adaptive mechanisms, the most obvious being shivering thermogenesis or heat production by involuntary muscle contractions. Shivering can increase metabolic heat production by 2 to 5 times. Unfortunately, the increased heat production is accompanied by a 3 to 4 fold increase in oxygen consumption and an equivalent increase in carbon dioxide production (54). Respiratory rates will also increase with shivering. While this is of little concern at normal atmospheric pressure, at elevated pressures the respiratory heat loss may be increased by 3 to 6 fold (57).

Hypothermia depresses the central nervous system, resulting in impaired consciousness, confusion, and disorientation. One of the earliest manifestations of hypothermia is poor judgment. The mildly hypothermic person may fail to take appropriate corrective measures to lessen his heat loss (55).

As the body continues to cool, there is a progressive decrease in the level of consciousness, pulse and respiration. The most common terminal event is ventricular fibrillation, where the heart muscle twitches but produces no useful cardiac output.

Food and Water

In most survival situations, a source of food and water becomes critical to continued survival. Submarine disasters are the exception with the most immediate survival limiting factors being the carbon dioxide and oxygen levels in the submarine.

The soon to be ratified NATO Standardization Agreement (STANAG) 1301 requires that each escape compartment have a means of providing 500 milliliters of water per man per day (no water to be consumed during the first 24 hours) and enough glucose (barley sugar) to supply 400 kilocalories per man per day (56).

Injuries

Some injuries are to be expected in association with a submarine disaster and may be the direct result of the initiating event, i.e. explosion or collision, or may be sustained as the crew engages in damage control efforts or escapes from flooding compartments.

STANAG 1319, as yet unratified by the United States, addresses the minimum requirements for medical stores in submarine escape compartments. These medical stores are intended to provide for the initial treatment of serious injuries such as fractures, significant lacerations, major bleeding, and burns. The quantity provided is to be sufficient to treat 5 percent of the crew for up to 48 hours prior to escape or rescue (58).

The possibility of radiation injury exists aboard nuclear powered submarines or those carrying nuclear weapons. This would include:

(a) Acute irradiation of the whole body or a part thereof;

(b) Internal contamination as a result of inhalation or ingestion of radioactive material;

(c) External contamination of skin, hair, or clothing (49).

Medical treatment of serious non-radiation injuries should over ride any immediate decontamination concerns.

III. Staying Alive - Crew Efforts to Prolong Survival Time

"Time", reflected aloud Sir Leonard Redshaw, Chairman of Vickers Shipbuilding Group, when he heard of the sinking of the submersible PISCES III, "the history of submarine accidents is the running out of time." (60)

Crew actions taken after a submarine mishap can have a significant effect upon survival time. Estimates of crew survival aboard U.S. submarines, assuming the nuclear reactor is not capable of producing power, range from as little as 3 hours to as long as 150 hours (51).

Oxygen can be obtained from the ship's oxygen bank, assuming it was undamaged during the mishap. Chlorate candles, consisting of sodium chlorate (82-88%), barium peroxide (3%) and a binding material, provide 115 standard cubic feet of emergency oxygen when ignited. Medical and welding oxygen supplies can also be utilized. Oxygen Breathing Apparatus (OBA) aboard may supply small amounts of additional oxygen. The ship's service air banks can be used at the expense of increasing pressure in the submarine and incurring or increasing a decompression obligation for the crew.

Carbon dioxide appears to be the limiting factor in most submarine survival situations and is removed, in emergency conditions, by chemical combination with a solid absorbent. U.S. submarines use pelletized lithium hydroxide to remove carbon dioxide. If battery power is available, electrical blowers can circulate the submarine atmosphere through lithium hydroxide canisters. A much less efficient method involves opening the canisters and spreading a thin layer of lithium hydroxide over all horizontal surfaces. Unfortunately, this also produces a caustic dust which is very irritating to eyes and mucous membranes of the nose, mouth and lungs. This may also alter the environment of the individual lithium hydroxide pellets to temperature and humidity conditions less than optimal for maximum carbon dioxide absorption.

The British have developed man-powered carbon dioxide scrubbers which work very well in unpressurized scenarios, but are much less efficient when utilized in pressurized situations (39).

The French Navy utilizes carbon dioxide absorbing curtains or bags containing sodasorb which can be hung from the overhead. Preliminary reports indicated these to be very effective. (59).

Should the oxygen level become too low or the carbon dioxide level too high, the crew can don emergency breathing apparatus (EBA) as a last resort. This will result in an increase in internal pressure since the EBA exhausts directly into the submarine cabin. The EBA regulator is designed to provide air at ambient pressure, therfore each breath will require more air than the proceeding one and the cabin pressure will increase in an exponential fashion.

In a 1986 report, the Naval Medical Research Institute presented recommendations regarding crew actions to maximize survival time. These estimates assumed no power would be available to run oxygen generating or normal carbon dioxide removal equipment, the submarine temperature would fall exponentially with time, adequate atmosphere monitoring equipment would be available, and death would occur when the carbon dioxide or oxygen levels reach 0.10 ata. Their recommendations were:

(1) The carbon dioxide level be kept as low as possible by initially using all available lithium hydroxide. This results in a very progressive increase in carbon dioxide which is more favorable for physiological adaptation.

(2) The oxygen partial pressure be kept at 0.20 ata (152 Torr) by bleeding pure oxygen sources into the compartment.

(3) After all sources of pure oxygen have been exhausted, the oxygen partial pressure should be allowed to fall to 0.16 ata.

(4) Burn chlorate candles to maintain the oxygen partial pressure at 0.16 ata.

(5) If air banks are available, determine which will occur first: a fall in oxygen to 0.16 ata or a rise in carbon dioxide to 0.075 ata (a level at which significant symptoms would be expected.)

(6) If the oxygen reaches 0.16 ata before carbon dioxide rises to 0.075 ata, then bleed the air banks to maintain the oxygen at 0.16 ata. The last source of oxygen to be used is compressed air.

(7) If the carbon dioxide reaches 0.075 ata before oxygen falls to 0.16 ata, don emergency breathing apparatus.

The rate of oxygen consumption and carbon dioxide production is greatly influenced by the body's thermal balance. The reducation of metabolic rate would have a major influence upon survival time, i.e., if the metabolic rate was decreased by 50 percent, the survival time would double.

Metabolic energy expenditure can be reduced by eliminating all unnecessary activity (including talking) and loss of body heat. If possible the survivors should be in a recumbent position, huddled next to a shipmate to conserve body heat. Sleep should be encouraged, for psychological as well as physiological reasons.

If battery power is available, the ship's regenerative carbon dioxide scrubber should be used at regular intervals. For planning purposes, the storing of additional lithium hydroxide supplies is of higher priority than additional chlorate candles. (51)

SUBMARINE ESCAPE

Escape was the earliest method used to save submarine crews. Even today, when the commanding officer or senior survivor decides it is time to "give the submarine back to the taxpayers", escape offers the advantage of removing the crew from hazards onboard the submarine, i.e. toxic gases, elevated atmospheric pressure, radioactive contamination, etc., which could otherwise complicate or prevent successful rescue.

The major disadvantage of escape is exposing a submariner, who has already experienced severe physical and psychological stresses, to the ambient ocean environment, which for a deep escape would mean great pressures, intense cold, and profound darkness. If he survives his journey to the surface, he is then confronted with the hazards of survival at sea.

To appreciate the physiological problems involved with submarine escape, the escape sequence can be divided into three parts: Compression in the escape trunk, time in the trunk while at maximal depth, and decompression or ascent to the surface.

Compression

During the compression phase the internal DISSUB pressure in the escape trunk is equalized to the ambient ocean pressure to allow egress of submarine personnel. Prior to pressurization, the escape trunk is flooded with sea water to a predetermined level, usually chest high. This allows more rapid pressurization of the remaining air bubble and reduces the quantity of air required to pressurize to ambient pressure. Aboard U.S. submarines, pressurization is accomplished by utilizing compressed air from the submarine's air banks. Once started, the pressurization must be performed expeditiously. In an escape from 450 feet the compression should be accomplished within 20 seconds to prevent toxic gas effects and decompression sickness. This rapid pressurization presents a problem for air filled spaces of the body. The primary physiologic consequence of this rapid change in pressure is barotrauma to the eardrums or sinuses; the lungs are equalized by simply inhaling. Some individuals cannot equalize their middle ears rapidly and will suffer an ear squeeze or, at worst, rupture an eardrum or two. With very rapid compression rates, eardrum rupture is reported to be relatively painless (29). In fact, during a recent British submarine escape exercise, one escaper was unaware he had rupture an eardrum until he experienced vertigo while relaxing in a motel swimming pool the following day (73). Rupture of the round window of the inner ear may occur if the escaper is overly aggressive while attempting to equalize his middle ears. If cold water enters the middle ear through a ruptured eardrum, disorientation, vertigo, nausea and vomiting may occur. Blocked sinuses will fill with blood after excruciating but fleeting pain, and should cause no immediate problems.

Time On the Bottom

The next phase in the escape sequence is the time at maximal pressure or the time on the bottom -- the interval between the end of compression and the beginning of ascent. The main physiological concerns during this phase are the toxic and narcotic effects of breathing air at elevated pressures. While in the escape trunk, the escapers breath a mixture of DISSUB compartment air and compressed air from the submarine's air banks.

Oxygen at elevated partial pressures is toxic to the central nervous system. Symptoms can range from tunnel vision, muscle twitching, and uneasiness to hallucinations, grand mal seizures, and death. The time until onset is inversely proportional to the inspired partial pressure of oxygen (32).

Breathing air, which normally contains 79 percent nitrogen, produces a narcotic effect equivalent to the intoxication of one dry martini for each additional 50 feet of seawater (FSW) increase in pressure (32). Volunteers compressed to 500 FSW in 20 seconds showed a 15 percent decrease in simple two choice reaction times (35).

Unfortunately, USN escape trunks are anything but simple. Thirty-eight different steps must be performed by the escapers from inside the trunk for each escape cycle (28). In egress studies conducted from 4 man trunks, it took well over one minute for the last man to exit (30). For escapes deeper than 300 FSW, the third or fourth man in the trunk may be too impaired by nitrogen narcosis to successfully escape.

Assuming escape will probably not commence immediately after the submarine has sunk but attempted only as a last resort, waste gas levels could be quite high in the DISSUB and the escape trunk. Carbon dioxide and carbon monoxide, which are toxic when present in sufficient concentrations at normal pressures, become rapidly lethal when their effective concentration is increased by compression.

Fortunately, most of the medical problems encountered when breathing air (a) high pressures do not manifest themselves immediately. There is a latent period before the onset of symptoms, whose duration is inversely related to the partial pressure of the gas in question and the time required for this increased partial pressure to reach the sensitive organs.

Ascent to the Surface

The final phase is the decompression or ascent phase, which begins when the escaper starts to rise through the water. The two major medical problems which may be encountered during this phase are Arterial Gas Embolism (AGE) and Decompression Sickness (DCS), more commonly known as the "Bends."

Arterial Gas Embolism can occur for several reasons, but for the purposes of this discussion it is the result of the pressure/volume relationship expressed by Boyle's Law, i.e. the volume of a gas is inversely proportional to the external pressure to which it is subjected. As the escaper ascends, the external water pressure decreases causing the air in his lungs to expand. Should he hold his breath or have an obstruction preventing the free flow of air, such as an old calcification or pneumonia scar, the expanding volume of air could increase to the point of pulmonary (lung) overinflation and rupture, forcing air into major blood vessels and forming bubbles which could then migrate to the brain causing Cerebral Arterial Gas Embolism (CAGE). This air bubble blocks the flow of blood to a part of the brain, causing death to brain tissue and resulting in permanent disability or death. These bubbles could also migrate to the coronary arteries which supply blood to the heart, possibly causing death within minutes (30).

The other major problem caused by decreasing ambient pressure is Decompression Sickness (DCS). Body tissues contain a certain amount of dissolved nitrogen which is in equilibrium with the partial pressure of nitrogen in the atmosphere. If the atmosphere is compressed, the partial pressure of nitrogen increases and the tissues absorb more of this inert gas, a process known as "on-gassing." If the surrounding pressure decreases, the absorbed nitrogen comes out as the tissues "off-gas." As long as the pressure reduction is gradual, the nitrogen stays in solution. If the pressure is reduced too rapidly, then nitrogen bubbles are formed. The physical process is very similar to that observed when uncorking champagne or rapidly opening a carbonated beverage. These bubbles can form in tissues, such as muscle and brain, or they can form in blood vessels where they can cause blockage or embolization.

A simple method for evaluating nitrogen absorption and the risk of DCS during escape is through the use of the Depth Time Multiple (DTM) as proposed by K.W. Donald, which can be simply calculated by the following formula:

$$\text{DTM} = \text{Depth} + \text{CT}/3 + \text{TOB} + \text{AT}/2,$$

where Depth is the maximum escape trunk depth in atmospheres absolute, CT is the compression time is seconds, TOB is the time at maximal pressure, and AT is the ascent time. If an individual were to escape from 450 FSW (14.6 ata) with a compression time of 20 seconds, a time on the bottom of 5 seconds and an ascent time of 60 seconds, his Depth Time Multiple would be 608 atmosphere- seconds. Human trials, utilizing escape profiles which produced DTMs of up to 1330 atmosphere-seconds, have shown that 1200 atmosphere-seconds is near the upper safe limit. Some cases of DCS can be expected even if the DTM is less than 1200 atmosphere-seconds (2). It must be emphasized the formula assumes that pressure is doubled in constant time and that there was no previous exposure to elevated atmospheric pressure, as would be the case in a pressurized SUBSUNK scenario.

Escape History

In 1903, R.H. Davis, manager of an English diving apparatus company, devised the first submarine escape "lung". It was rather crude, somewhat complicated and proved to be ineffective for the average submariner (25).

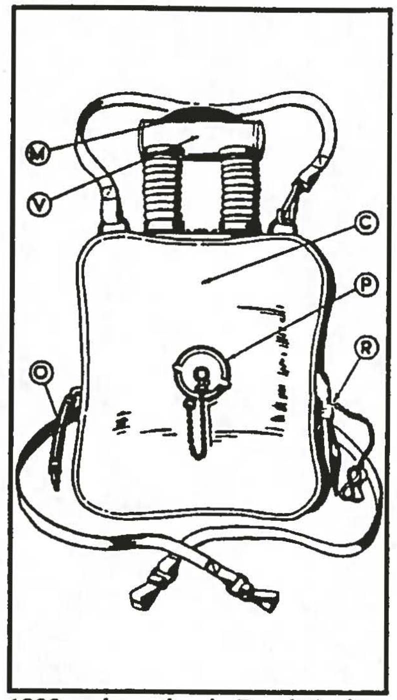
Not to be out done by the British, the Germans also developed a submarine escape apparatus during the First World War which was just as bulky, complicated and impractical as the Davis Lung. There were no serious efforts to train submariners in its use.

The first truly successful escape appliance was the "Momsen Lung", designed and tested by Lieutenant Charles Momsen, USN, in 1928. After his idea for a Submarine Rescue Chamber had been officially rejected, he decided to develop a means of escape from below rather than rescue from above. The idea was that a rubber bag or "lung" strapped to the chest and filled with oxygen would provide breathing gas at a pressure equal to that of the surrounding sea water and also supply positive buoyancy to help ascend to the surface.

Working with engineer and friend Frank Hobson, but without funds or official sanction, Momsen built the first working model from scrounged materials. All of the rubber came from old inner tubes, which resulted in a large red patch decorating Momsen's first apparatus. "The bag, made of rubber and resembling nothing so much as a hot water bottle, hung around the neck with additional straps around the waist. A canister of soda lime inside it filtered out the carbon dioxide. Leading to the mouthpiece were two tubes, one to breath in the oxygen and the other to exhale it. A valve on the bottom side of the bag automatically allowed excess oxygen to escape as the pressure decreased during an ascent. Between the mouthpiece and the tubes there was a second valve which would retain the oxygen still in the bag once the surface was reached, so that it could serve as an emergency life preserver. That, aside from a noseclip, was it." (3)

The first test took place after normal working hours in the model boat basin at the Washington Navy Yard on 25 February 1928. Almost one year later, Momsen made an ascent from 207 feet in the open ocean during testing, for which he received the Distinguished Service Medal and the Navy's decision to let contracts for seven thousand lungs.

It soon became evident that placing the Momsen Lung in the hands of untrained submariners was a recipe for disaster when two deaths and twelve serious injuries resulted from men "practicing" with the apparatus. Studies at Harvard Medical School concluded the problem stemmed from the natural reaction of untrained personnel to breath-hold when their faces were immersed in water (25). To prevent this undesirable outcome, two 135 foot submarine escape training towers were built, one in New London in



1930 and another in Pearl Harbor in 1932. Each held between 230,000 to 250,000 gallons of water which was kept at a comfortable 92 degrees Fahrenheit. Submariners were trained to make 100 foot ascents in the towers.

The Momsen Lung continued to be the primary method of submarine escape until it was replaced by buoyant ascent in 1956. Though an improvement upon previous escape appliances, the Momsen Lung was still too complicated and it's use too skill intensive. The Ruck-Keene Committee concluded in 1946, after investigating survival from British, German, and American submarine sinkings, that the odds of successful escape were greatest when the escaper made a free ascent unencumbered by the presently available escape apparatus.

For free ascent (escape without apparatus), the escaper relies upon the natural buoyancy of air in his lungs to carry him toward the surface. If he exhales too slowly he risks CAGE, too fast and he sinks. The average unclad human body has less than 5 pounds positive buoyancy and even when actively swimming can only attain ascent rates of 2 to 3 feet per second (16).

Although free ascent has been successfully accomplished, it is generally recognized that providing additional buoyancy and a means of breathing greatly increases the chances for survival. The buoyant ascent technique involves training submariners to rise to the surface with the aid of an inflated life vest while continuously exhaling to prevent lung rupture and CAGE. This method was personally tested by CAPT George Bond, MC, USN from depths of 302 feet of seawater (31).

During ascent to the surface, especially from deep escapes, some test subjects felt a strong desire to breath. The solution to this problem came in the form of a hood which is attached to the inflatable vest and maintains a bubble of air around the escaper's head. Designed and developed by CDR E. H. Steinke, USN, it became the primary U.S. Navy escape apparatus in 1963. The vest is charged with compressed air while the escape trunk is equalized to ambient sea pressure. In deep escapes, the escaper is able to breath the expanding fresh air which is vented from the vest into the hood as he ascends. The Steinke Hood keeps the head dry and therefore the escaper is less likely to panic and breath-hold during ascent. This may help explain why the Navy never had a fatality during Steinke Hood training (33). Once on the surface the escaper can unzip and remove the hood or in inclement weather can breath through a built-in snorkel device.

Despite the 1970 NURESARS Study Project Report recommendation that the "Steinke Hood escape system will probably be adequate to meet the Navy's requirements for undersea escape operations" (6), such is not the case, as was eruditely pointed out in the thesis paper by LT Tom Neuman. He explained the absurdity of "trying to operate an escape trunk while immersed in 4 degree Centigrade water up to the neck (regardless of the time of year, deeper than a few hundred feet the water temperature is fairly uniformly 4 - 5 degrees Centigrade) with an atmosphere that contains 5 - 10 percent carbon dioxide, as well as anesthetic levels of nitrogen..." (27) Unfortunately, instead of developing a system which would permit escape from depths deeper than 100 feet, the Navy decided to abolish escape training while retaining the escape system (26).

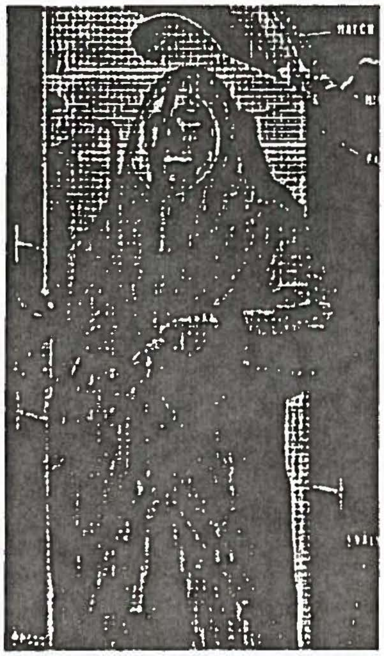
Nevertheless, the current Escape Bill for U.S. submarines recognizes two methods of individual escape: Buoyant Ascent Breathing (Steinke Hood) and Buoyant Ascent Blowing (Life jacket only). There are 118 hooded escape appliances stowed in the bow compartment and an equal number stowed in the engine room. Escape trunk familiarization is required for submarine qualification and annually the crew watches an escape training video.

British Escape System

The British have been developing an individual escape system which essentially gives them the ability to make successful ascents from a submarine bottomed anywhere on the continental shelf to depths of 600 feet. Since the primary limiting factors for deep escape are oxygen toxicity, nitrogen narcosis, and decompression sickness, the rationale has been to increase the speed of the compression and ascent phases, and decrease the time spent at maximal pressure.

The British escape system has proven so successful, many other navies adopted it for use. It consists of a Submarine Escape Immersion Suit (SEIS), which completely encloses the escaper in a water-tight exposure suit, and a one or two man escape tower.

The rubberized cotton suit has a double walled insulating layer which is inflated upon reaching the surface. It is designed to provide sufficient thermal protection to allow over five hours of survival in minus two degree Centigrade water.



The escape towers are located in the forward and aft compartments and are just large enough for two escapers to stand erect. Egress is from a top hatch which can be set to an open, shut or idle position from inside the submarine. The escaper enters the tower from below. He plugs his hood and stole inflation hose into a spring loaded receptacle supplied by the Hood Inflation System (HIS valve) which provides air at between one and two psi over ambient from a dedicated source of clean high pressure air (39).

"The entry hatch is closed from below and the tenders begin flooding the tower from the sea. During this initial flooding, a vent located 27 inches below the upper hatch allows air to be displaced into the submarine and prevents pressurization of the tower. After 10-15 seconds, the water reaches the vent and appears in the compartment below. The tenders immediately shut the vent valve and the tower begins to equalize with sea pressure through the flood valve. The sizes of the pipes and valves are such that the pressurization of the tower proceeds at a geometric rate, doubling every 4 to 5 seconds. The average time to 600 FSW is 21 seconds. The escaper needs only to hold his charging connection in the HIS receptacle to receive air during compression. Since the hatch has earlier been set to idle, it opens immediately upon equalization because the air bubble and the buoyant escaper lift it. Even an unconscious escaper will float out quickly, because the air charging connection is spring-loaded and there are no internal obstructions in the tower to trap him. The time from equalization to emerging from the hatch is less than 5 seconds." (36)

SURFACE SURVIVAL

Having successfully escaped from a surfaced or submerged submarine, the submariner must now survive at sea until help arrives.

Remaining afloat is the most immediate concern. If the escaper has made a buoyant ascent from a submerged submarine, his escape appliance will provide sufficient flotation. If he has abandoned a submarine on the surface, he may have to rely upon swimming skills or inflated clothing. Although life jackets are available, they are not always utilized.

During the recent USS BONEFISH incident, most of the crew standing on the outer casing were without life jackets. As the submarine rolled with the swells, a few crewmen fell off the casing and had to tread water until rescued by helicopter. Among the swimmers were several suffering inhalation injuries as a result of breathing toxic fire fumes and were least able to struggle to stay afloat (61). Luckily there were no deaths in this group.

Before the Peruvian submarine B.A.P. PACOCHA sank in August 1988, twenty-three crewmen escaped. Most had life vests or used Steinke Hoods as buoyancy devices. Of these escapers, three succumbed to exposure or drowning. (40)

In rough seas it is difficult to maintain airway freeboard (the distance between the water surface and the mouth) even with flotation equipment. There have been numerous accounts of seamen in life vests drowning in rough seas. The Steinke Hood makes provision for this eventuality with it's built-in snorkel device which allows the escaper to breath while still hooded.

Immersion hypothermia becomes the next major obstacle to survival. Conductive heat loss for an individual immersed in water is 25 times greater than for a nude individual in air at an identical temperature. Sudden immersion in cold water produces an initial hyperventilation which also increases respiratory heat loss.

The most famous case of immersion hypothermia is that of the SS Titanic, which sank on 14 April 1912. Most of the 1,498 people who died in the near freezing water were wearing life jackets, yet they did not survive the two hours required for help to arrive.

Despite the admonition to U.S. submariners to wear extra clothing while escaping in the hopes it "...will act as a loose wet suit and will protect you from exposure after surfacing" (62), multiple layers of clothing, which provide excellent insulation in cold air, are rendered ineffective by immersion in water (63).

Even after leaving the water, wet clothing decreases survival odds. During the 1982 Falklands War, the Argentine cruiser General Belgrano sank in 5 degree Centigrade water. Some sailors perished from cold exposure even after climbing into life rafts.

If the escaper is British, he will be floating on the surface cocooned in a double layer, insulated, waterproof Submarine Escape and Immersion Suit (SEIS) designed to allow him to survive in North Atlantic waters up to 24 hours.

Early support for British survivors is provided by the Subsunk Parachute Assistance Group (SPAG) which is capable of dropping medical supplies and personnel into the rescue area along with as many 25 man life rafts as required to remove the entire DISSUB crew from the water. In addition there are First Reaction Stores, including a recompression chamber, which are predeployed at Plymouth, Rosyth, Portsmouth, Faslane, Portland, Gibraltar, and the Falkland Islands. (49)

The U. S. Navy considered developing a submarine escape suit, but decided against using that approach.

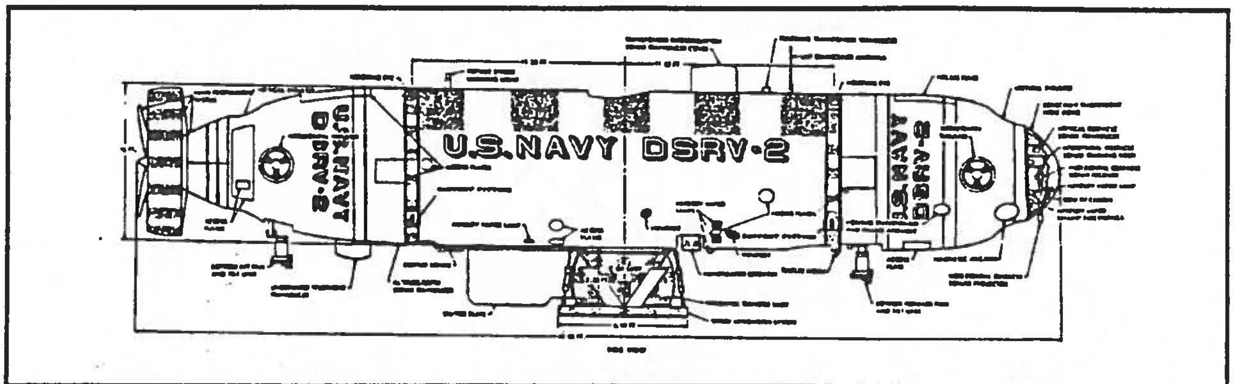
The Steinke Hood provides little thermal protection, both during ascent and while surfaced. While the escape trunk is flooding with near freezing water, cold receptors deep in the skin are providing a irresistibly strong respiratory drive during the first one or two minutes of immersion. Lung ventilation will increase up to five fold (63), which is precisely the opposite of what is desirable.

U.S. submarines have two four-man, carbon dioxide-inflated, collapsible rubber life rafts carried on board: one forward and one aft. The last two escapers are expected to push the life raft through the escape hatch BEFORE making their escape!

Cold water immersion survival time depends upon many factors such as percent body fat, activity, heat loss attenuating positions, sex, age, etc. Table 1 provides only general guidelines

Water Temp (F)	Unconsciousness	Expected Survival
32 to 40	15 to 30 minutes	30 to 90 minutes
40 to 50	30 to 60 minutes	1 to 3 hours
50 to 60	1 to 2 hours	1 to 6 hours
60 to 70	2 to 4 hours	2 to 7 hours
70 to 80	3 to 12 hours	3 hours to indefinite
Over 80	indefinite	indefinite

Table 1



of expected survival for flotation equipped personnel (64).

Assuming the escaper has remained afloat and has not succumbed to hypothermia, his next task is to assist search and rescue forces in their efforts to find him.

Small objects in the water are difficult to spot, even in relatively calm seas, without the aid of signal devices such as mirrors, flares, strobe lights, etc. Despite wearing helmets covered in reflective tape, downed aviators are extremely difficult to visually locate. Darkness compounds the problem, as illustrated by the fate of the initial PACOCHA escapers who floated in darkness for 4 hours in 57 degree Fahrenheit water until they were illuminated by distress flares fired from the stricken submarine (40).

In addition to it's International Orange color, the Steinke Hood has a pocket containing a whistle and sea dye marker. A small light is provided to aid location at night. Once on the surface, escapers are advised to hook themselves together to increase their visual target size.

THE DEEP SUBMERGENCE RESCUE SYSTEM

The Deep Submergence Rescue System (DSRS) consists of two Deep Submergence Rescue Vehicles (DSRV-1 MYSTIC and DSRV-2 AVALON) homeported at the Submarine Rescue Unit (SRU) on Naval Air Station North Island in San Diego, two Submarine Rescue Ships (ASR-21 USS PIGEON in San Diego and ASR-22 USS ORTOLAN in Charleston), and twenty-three (19 U.S. and 4 U.K.) specially modified mother submarines (MOSUB).

When called upon, the DSRV and associated support equipment can be transported to the rescue/embarkation site in the following ways:

LAND - via a specially designed Land Transport Vehicle

AIR - via one C-5A/Band two C-141 A/B or two C-5A/B or four C-141 A/B aircraft furnished of the Military Airlift Command

SEA - aboard a MOSUB/ASR

Once at the rescue site, the DSRV deploys from the MOSUB/ASR to rescue survivors and replenish consumables.

DSRV

The DSRV consists of three interconnected 90 inch diameter HY-140 steel spheres which form the pressure hull and provide an operational depth of 5000 feet of seawater. The forward sphere is the control sphere where the pilot and co-pilot reside. The mid and aft spheres are designed to accommodate one operator and twelve rescuees each. There are water tight hatches between each sphere. A free flooding glass reinforced plastic fairing covers the pressure hull and external equipment such as batteries, hydraulic and ballast systems. A framework of titanium and aluminum members form the principal load bearing structure and syntactic foam sections provide additional buoyancy. Total submerged displacement is about 75,000 pounds with an overall length of 49.3 feet.

Electrical power comes from two 112 volt silver-zinc batteries which are rated at 700 ampere-hours. Once the initial search and reconnaissance has been accomplished, the batteries will supply sufficient power for 2 or 3 round trips per charge. The charge time (5 to 14 hours) depends upon the battery state and charging rate. The DSRV can recharge its batteries while submerged when mated to the aft hatch of the MOSUB. When operating with an ASR, the exhausted batteries can be changed for a fully charged set in about 30 minutes. There is also a 28 volt emergency battery.

A three blade shrouded propeller provides main propulsion for speeds up to 4.1 knots as well as control of both pitch and yaw. At low speeds there are four ducted thruster units which allow control of pitch, yaw, heave and sway and enable the DSRV to hover in currents as great as one knot athwartships.

A mercury trim and list system, containing about 3000 pounds of mercury, controls roll and can also be used to set and hold pitch angles of up to 45 degrees. The mercury can be jettison in an emergency to provide additional buoyancy. The main ballast system provides 6400 pounds of buoyancy for surface operations and a variable ballast system (1400 pounds), powered by a high pressure hydraulic pump, is used to compensate for depth induced buoyancy changes. A transfer ballast system (5664 pounds) accepts water pumped from the transfer skirt during mating. There are seven bags inside the mid and aft spheres, holding a total of 4080 pounds of water, which is drained into the DISSUB to compensate for the weight of the rescuees taken onboard.

Navigation and sensor systems provide long and short range search, position keeping and obstacle avoidance capability. In addition to sonar there are pan and tilt video cameras, periscopes, a mechanical optics column and viewports.

During a rescue operation, the mating system allows the transfer of rescuees from the DISSUB to the midsphere of the DSRV via the transfer skirt. The skirt mating surface is protected by a hydraulically damped and retractable titanium shock mitigation ring. After the skirt and escape hatch mating surfaces are approximated, a sea water pump establishes a 15 pounds per square inch pressure differential between the sea and the interior of the skirt to make a "soft seal". The skirt pressure is equalized with the 1 ata air in the transfer ballast tanks, constituting a "hard seal", and the skirt is dewatered by pumping to the transfer tanks. After draining the rescuee ballast and transferring the rescuees to the DSRV, the process is reversed to allow unmating and return of the DSRV to the MOSUB or ASR. A manipulator arm equipped with a cable cutter is used to clear fouled mating surfaces. The manipulator and the video units can be jettisoned should they become entangled.

Each sphere has an independent life support system. The cabin atmosphere is circulated through scrubber canisters, each containing 4 pounds of pelletized lithium hydroxide, activated charcoal and filter material to remove carbon dioxide as well as other undesirable constituents. The theoretical carbon dioxide combining capacity of a canister is about 29 standard cubic feet or, assuming a carbon dioxide production rate of 0.8 cubic feet per man per hour, about 36 man-hours. In actual use, the nominal rating is 12 man-hours per cartridge (12). The control sphere uses two cartridges with the mid and aft spheres each using three. Carbon dioxide is monitored by polarographic sensors and is usually kept below 6 Torr.

The level of oxygen is monitored by polarographic sensors and oxygen is added to the atmosphere automatically from internally stored removable spheres. The partial pressure of oxygen is maintained in the range of 150 to 160 Torr.

Depending on oxygen consumption and carbon dioxide production rates, life support system endurance ranges from 5.5 hours with a full load of excited rescuees to 2 weeks with only the pilot and copilot onboard (11). In 1971 Lockheed conducted a 13 hour endurance test with 13 resting men sealed in the aft sphere.

Resting oxygen consumption rates gave a calculated endurance of 13.4 hours. The lithium hydroxide canisters were changed at intervals corresponding to 13 man-hour ratings. The carbon dioxide level did not rise above 7 Torr (13).

Because of the possibility of sharing a contaminated atmosphere with the DISSUB, the DSRV has a closed circuit Emergency Breathing System (EBS) which incorporates double hose full face masks. The system was originally designed to maintain a normoxic partial pressure of oxygen (160 Torr) regardless of compartment pressure by utilizing nitrogen from a 3000 pounds per square inch flask as a diluent and pressurization gas. However, on 15 MAY 1970 while conducting life support system testing, the pilot and copilot were accidentally exposed to 100 percent nitrogen while on the EBS after failing to reposition a switch. Both men became unconscious but were revived with no ill effects after removal of the face masks. To prevent a recurrence, the nitrogen tank is now filled with compressed air.

This solution creates a new problem should the EBS be required while conducting a pressurized rescue. It is designed in such a way that the compressed air in the pressurization tank would be rapidly depleted. Pure oxygen would then be utilized as the pressurization gas. Exposure to 100 percent oxygen at elevated pressure could produce seizures in the rescuees or the DSRV crew.

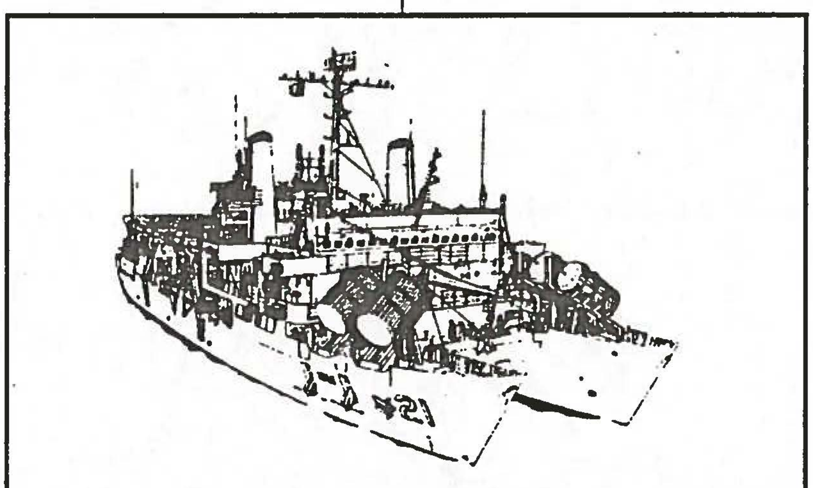
To prevent EBS contamination, total system pressure is maintained at 2 inches of water over ambient to minimize this possibility. Because there was a concern regarding inadvertent cabin pressurization cause by mask leakage, a manned test was conducted. "In a 2 hour test with 13 men breathing on the EBS in the aft sphere, the compartment pressure increased by less than 2 pounds per square inch" (7).

Lithium hydroxide canisters identical to those used in the normal life support system scrub carbon dioxide in the EBS. Since scrubber canisters cannot be changed in a toxic environment, survival time might be as low as 2 hours in the mid and aft spheres (10).

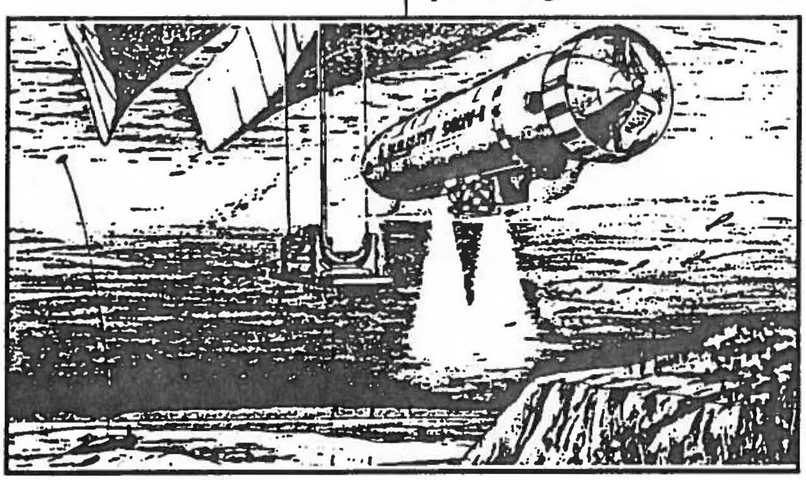
The atmosphere is circulated through heat exchangers which are bonded to the internal surface of the mid and aft spheres. There is a self-contained freon refrigeration unit should the thermal load become too great. Electrical resistance heaters, originally installed to provide heat for cold water operations, were removed after they proved to be ineffective (11).

ASR

The two ASR-21 class submarine rescue ships are major elements of the Deep Submergence Rescue System. The USS PIGEON (ASR-21) and the USS ORTOLAN (ASR-22) are 4950 ton twin hull catamaran type surface ships specifically designed to transport, launch, and recover the DSRVs. They are 251 feet in length overall, with a molded beam of 86 feet and a navigational draft of 28 feet 6 inches. Powered by four 12 cylinder diesel engines, they have a top speed of 15 knots and a cruising range of 13,800 nautical miles at 11.5 knots. The ASR has a command and control platform for surface supported deep submergence operations and is equipped with modern radio, radar, electronic navigation and underwater communica-



tions equipment. A sensor suite provides data required for real-time control of rescue operations and includes a high resolution three dimensional sonar tracking system. An underwater video surveillance system allows monitoring of DSRV submerged launch and recovery, which occurs at 125 feet below the surface in seas up to state 3 and employs an electro-hydraulic bridge crane weight handling system rated at 175,000 pounds. The ASR can also perform surface DSRV recovery in calm seas for shallow water operations. A Level III, Class 4 Helo deck capable of accommodating a gross weight of up to 14,000 pounds is available to support helicopter operations. The ship's sickbay is a five bed medical facility with advanced cardiac and trauma life support capability which would prove invaluable when treating casualties.



In addition to supporting DSRV operations, the ASR can deploy the Submarine Rescue Chamber (SRC) which was used so successfully in the USS SQUALUS rescue mission. She also provides a complete range of diving capabilities ranging from SCUBA, deep sea air and mixed gas to the dual complex Mk2 Mod 1 Saturation Diving System capable of supporting saturation dives to 850 feet of seawater. In the event of a pressurized rescue, the Deck Decompression Chambers (DDC) can be used to decompress rescuees. Although at one time thought was given to utilizing a dynamic positioning system for station keeping (24), the ASRs currently use a four-point moor to depths of 1200 feet when conducting diving operations.

In addition to her primary mission of submarine rescue, the ASR can be used for deep ocean search, location and recovery; deep submergence vehicle (DSV) support; acoustic navigation and positioning; submarine sea trial escort; target and weapons recovery services; and open ocean towing.

The USS PIGEON and USS ORTOLAN support the Naval School of Deep Diving Systems as the Navy's only saturation diving training platforms. Students are given the opportunity to apply classroom theory to actual open water saturation diving operations, which not only reinforces what they have spent many weeks learning, but also allows them to qualify on the many different saturation diving watch stations.

The ASR namesakes were among a group of five rescue and salvage vessels assigned to key submarine commands around the world and collectively called the "bird boats" (FALCON, MALLARD, ORTOLAN, WIDGEON, and PIGEON), which were converted World War One minesweepers. Beginning in 1929 their commanding officers were required to have both submarine and diving backgrounds, an important requirement still existing today.

MOSUB

The mother submarine (MOSUB) concept employs one of 19 specially modified 637 class attack submarines (U.S.) or one of 4 specially modified RESOLUTION Class fleet ballistic missile submarines (U.K.). The SHIPALT SSN 852 modifications included foundations for DSRV pylons, wiring penetrations and mounting brackets for a TV system to allow monitoring of the forward and aft MOSUB rescue seat areas from the control room, services for DSRV battery charging and instrument checkout units, sound powered phone connections in the escape trunks, and provision for the air decompression of approximately 80 men in the forward compartment. Plans were also provided for painting temporary orientation markings on the sail, fairwater planes, upper rudder extremities, and around the hatches. Although original plans included converting some of the SSN 594 class boats for use as MOSUBS, revision 1 of SHIPALT 852 deleted these hulls from applicability and removed the requirement for air decompression of rescuees in the forward compartment (17). Forward compartment modifications had been completed on eleven submarines prior to revision 1 (SSN 649, 662, 666 through 673, and 686).

ASSOCIATED RESCUE ASSETS

Associated rescue assets are those systems which augment the mission of the DSRS or, in certain scenarios, could be used instead of the DSRV. These systems include the Submarine Rescue Chamber (SRC), Deep Submergence Vehicles (DSV), and Remotely Operated Vehicles (ROV).

SRC

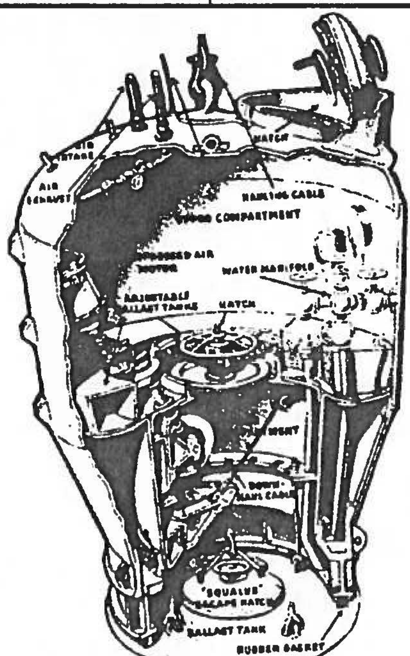
The concept of the Submarine Rescue Chamber first took shape in the fertile mind of Lieutenant Charles Bowers Momsen, USN, after he witnessed the tragic loss of a close friend and Annapolis classmate when the submarine S-51 sank on 25 September 1925. The submarine had been rammed by another vessel while conducting night operations. At the time, submarine design did not include escape trunks and there was no provision for rescue. When S-51 was finally salvaged, Momsen discovered how his friend had met his dead. "...his fingers were pathetically torn; in his final moments before blacking out he had tried to pry open an escape hatch, a hatch shut by more than fifteen tons of ocean pressure." (3)

His suggestion of a rescue chamber was initially rejected by the Bureau of Construction and Repair (later to become NAVSEA) as "impractical from the standpoint of seamanship." Within weeks of this final turndown the submarine S-4 was slashed open after a collision with a Coast Guard destroyer. Her entire crew of 40 men were alive as she lay on the bottom in 110 feet of water. The entombed men beat out hammer taps in hopes of somehow being rescued. After 3 days the hammer taps fell silent, never to be heard again. A Presidential board on submarine safety was convened and Momsen given an opportunity to testify. He quickly won approval to develop his rescue chamber. Lieutenant Commander Allen McCann took over the project while the SRC was undergoing final testing. Although Momsen was largely responsible for its conception, development and testing, his invention was publicly unveiled in 1931 as the "McCann Rescue Chamber"; the result of stepping on too many bureaucratic toes.

The SRC exists today, 58 years later, in a form which is relatively unchanged. Capable of withstanding the pressures of depths as great as 850 feet of seawater, it consists of two chambers separated by a pressure-tight hatch. The upper chamber was designed to house the operators and six rescuees per trip. The lower chamber is open to the sea at the bottom and contains a flat mating surface fitted with a rubber gasket which makes a watertight seal on the DISSUB hatch. An umbilical cable from the ASR supplies air, electricity and communication to the SRC. A Built in Breathing System (BIBS) supplies breathable air for eight occupants should the DISSUB atmosphere be contaminated. Both the ASR and the SRC also have the standard U.S. Navy single sideband underwater telephone to allow communication with the DISSUB. The SRC is connected to the DISSUB by a cable and uses an air powered downhaul winch as well as adjusting chamber buoyancy to control vertical movement. Since U.S. submarines no longer have messenger buoys, a buoyant cable reel system was developed which could be attached to a staple on the submarine hatch by a Deep Submergence Vehicle (DSV).

Should a SUBSUNK occur in a remote area when an ASR is not immediately available, an air transportable system, the Submarine Rescue Fly Away Kit is available. The kit consists of the SRC, a four-point mooring system complete with anchors, spuds, and mooring lines. This enables the use of a ship of opportunity. Just about any ship which can supply 10 amps of 110 volt, 60 Hertz, single phase electrical power for lighting the upper and lower SRC chambers can be used as a support ship. If the ship is unable to handle a 22,000 pound load over the side, the SRC can be rigged for towing to the rescue site.

In a rescue operation, the ASR fixes the position of the DISSUB and establishes a four-point moor over the submarine's escape hatch. After attaching a downhaul cable with a DSV or by using divers, the SRC is lowered into the water. The two SRC operators enter through the top hatch, secure it and prepare for descent. After decreasing buoyancy to 1000 pounds positive, the downhaul winch hauls the SRC into a mating position over the DISSUB escape hatch. Water in the lower chamber is blown out using high pressure air. The lower chamber is then vented to one atmosphere causing the greater external seawater pressure to force it against the rescue seat. After pressures in the upper and lower chambers have been equalized, the lower SRC hatch is opened. Four hold-down turnbuckle rods are then connected to permanently installed fittings around the submarine hatch to further secure the SRC to the submarine. In order to maintain proper buoyancy, the SRC carries portable lead ballast which will be placed in the DISSUB after the rescuees have been taken aboard. Additional life support stores could also be used for ballast. On the return trip the air winch is used as a brake to prevent uncontrolled ascent. Once on the surface, the SRC remains in the water and the rescuees exit through the upper hatch.



Although primarily intended for use in unpressurized rescue operations, under emergency conditions the SRC can be pressurized to a depth equivalent to 290 feet of seawater (14). The operators prefer to maintain a 15 pounds per square inch pressure differential (external sea water to internal SRC) for additional safety (15). Since the water-tight hatches are outward opening, an internal positive pressure of greater than 15 pounds per square inch with respect to the external pressure cannot be safely maintained.

On 24 MAY 1939, the SRC successfully rescued 33 men from the USS SQUALUS (SS-192) after a malfunction of the main air-induction valve resulted in engine room flooding, sending the submarine to the bottom in 243 feet of water. The twenty-six men trapped aft died immediately. The forward compartments had been pressurized to the equivalent of 27 feet of seawater by the flooding aft before the water-tight doors could be closed. Because ambient seawater temperature was 33 degrees Fahrenheit, the submarine quickly cooled and the sailors huddled together trying to stay warm. The submarine sat on the bottom with no list but she had an eleven degree up angle on the bow.

After having been trapped for 40 hours, the survivors were rescued in four trips; seven survivors on the first trip, nine on each of the next two, and eight on the last. It was the weight of the men that determined the number rescued per trip. With nine rescuees aboard the positive buoyancy was just adequate to successfully conduct the rescue.

The following day the downhaul line was switched to the aft escape hatch. The issue of possible survivors aft had to be resolved. The SRC made a fifth trip to the stricken submarine. After making the initial seal and securing the four turnbuckles, air pressure inside the SRC was increased to correspond to the ambient seawater pressure. The submarine escape hatch was slowly opened, only to find that the aft torpedo room was completely flooded. Concerns for the safety of the SRC crew, caused by the narcotic effects of breathing high pressure air, prevented the removal of any bodies. Initial consideration had been given to blowing down the water level in the flooded compartments using air pressure from the attached SRC. At this stage all further rescue attempts were halted (3).

DSV

Depending on the geographic location of the SUBSUNK, a Deep Submergence Vehicle (DSV) could be used to provide assistance to the rescue team. Although not configured to mate with a DISSUB or transfer survivors onboard, a DSV could perform several useful tasks and thereby conserve other rescue assets for the actual rescue. The DSV could conduct the initial survey of the DISSUB or place a Deep Ocean Transponder (DOT) which would allow more efficient use to be made of the DSRV's finite battery power. The DSV could also be utilized to attach the buoyant cable reel system if the SRC is to be utilized and saturation diving support is not available.

Submarine Development Group One presently has two such vehicles homeported in San Diego. DSV TURTLE has a 10,000 foot capability as well as an advanced manipulator system. DSV SEACLIFF has a 20,000 foot capability, but a much less sophisticated manipulator system.

ROV

The British Royal Navy utilizes a Remotely Operated Vehicle (ROV) to resupply life support stores to a DISSUB.

The Unmanned Vehicle Detachment at Submarine Development Group One has several remotely operated systems which might prove useful to rescue efforts. The Kline Side Scan Sonar system would be useful for locating the DISSUB and mapping the surrounding terrain. The RCV-225B is an ROV with realtime video capabilities which would allow the rescuers to conduct a visual survey of the submarine, determine the extent of external damage, and visualize any potential obstructions near the escape hatches which could hamper rescue efforts. The RCV-225B accompanied the rescue mission to Peru in August 1988.

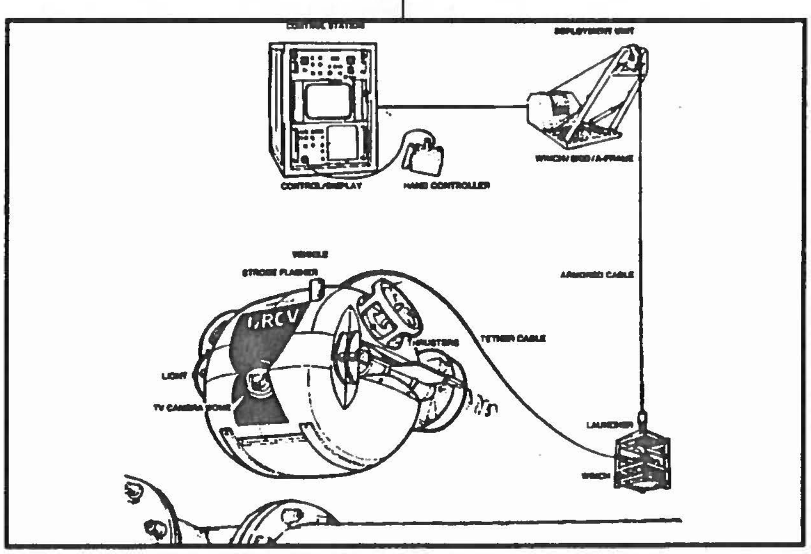


TABLE 2: DSRV/SRC SELECTION CRITERIA

FUNCTION	DSRV	SRC
Depth	The minimum depth capability of the DSRV is a direct function of the sea state, currents, and maneuvering room. The DSRV must be able to effect a seal before the hatch may be opened for installation of turnbuckles for positive holddown. In most cases, an adequate seal can be obtained at depths below 150 feet. For depths shallower than 150 feet, consult Lockheed Report RV-R-0057 "Shallow Water Limitations for DSRV Mated with a Bottomed Submarine." The maximum depth capability of the DSRV is the collapse depth of present submarines.	The minimum depth capability of the SRC is a direct function of sea state and currents to a lesser degree than for the DSRV, since the SRC hauls itself down to the DISSUB hatch on a cable attached to the hatch. Has been used in Sea State 3 conditions. The maximum depth capability for the SRC (RC8-19) is 850 feet.
Orientation	Angles up to ±45 degrees.	Angles up to ± 15 degrees.
Number of rescuees	Up to 24	6
Refurbishment time	Life support, ballast, power—8 to 10 hours if full charging rate is used to replenish batteries.	Ballast—15 minutes
Round trip time (starting time DISSUB located)	The standard mean, trouble free, round trip time, with mate, from the following support ship is: ASR—First trip, 212 minutes Second trip, 207 minutes MS—First trip, 193 minutes Second trip, 188 minutes	In excess of 3 hours to establish a 4-point moor over the DISSUB. The trouble free, round trip time is estimated at 45 minutes. Experience is on the order of 300 minutes average per round trip. Experience indicates that about 3 hours are required to establish a four-point moor over the DISSUB. The average trouble-free round trip, including effecting seal and rescue of six men, is approximately 3 hours (180 minutes).
Endurance (per trip)	Submerged endurance of 4 to 6 hours with 30 percent reserve battery capacity. Sufficient O_2 reserves for 36 hours for crew or about 12 hours for crew and 24 rescuees.	Limited only by support ship's supply capability.
Self-contained	Yes.	No.
Fly-away capability	Yes. C-5A/C-141A/B from SRU to nearest port/airfield.	Yes.
Support ships	ASR-21 Class (see Article 13.3.1) MS (see Article 13.3.6)	ASR Class, single hull; ASR-21 Class; ATA, ATF, ARS Classes; and other ships which have a 15-ton boom capability (for fly-away kit).

FUNCTION	DSRV	SRC
Compatible with decompression requirements	Yes. Can pressurize mid and aft spheres up to five atmospheres. (See note).	Yes. In submerged SRC only. SRC does not mate to DDC.
Offloading rescuees	Need not haul DSRV aboard support ship. This procedure varies with type of support ship.	Does not require hauling SRC out completely.
Response	Initially, response time will be higher because of lack of DSRVs, support ships, and the dispersion of the support ships.	Fly-away kit readily available. Limited by support ship availability.
Communications	Underwater telephone; UHF; observation parts.	Hard wire telephone; underwater telephone; view port.
Special capabilities	Manipulator, external TV and lights, releasable acoustic homing transponders, DISSUB atmosphere sampling kit.	None

NOTE: Requires support ship with decompression capability (ASR 21/22).

FROM REFERENCE (65)

In November 1989, DSV-3 TURTLE became fouled in some lines on the ocean floor in 1300 feet of water. RCV-225 provided topside observers with real-time video, who inturn were able to give rudder orders to TURTLE, allowing her to maneuver free from the entangling cables.

SUBMARINE RESCUE

When an submarine fails to submit an underway accountability report, the authority exercising submarine operational control (SUBOPAUTH) will initiate an EVENT SUBLOOK, the commencement of which will depend upon the submarine's type of accountability period. During this phase the SUBOPAUTH will begin a communications search for delayed messages, initiate a message to the submarine by radio, alert other Naval vessels and commanders in the area as appropriate, and possibly initiate an air search.

EVENT SUBMISS is initiated by the SUBOPAUTH when the safety of the submarine is in doubt or the accountability message is overdue and the actions on the SUBLOOK checklist have been completed. All suitable vessels will be ordered to close the diving position or best estimated position of the missing submarine with all practicable speed and initiate the search as directed by the On Scene Commander (OSC). An aircraft search will be started by at least one aircraft.

EVENT SUBSUNK will be executed by the SUBOPAUTH when a submarine fails to surface promptly following a known accident or there is reason to suspect a submarine has suffered a casualty and requires assistance or when the actions required by the SUBLOOK and SUBMISS phases have been completed. A full-scale air search will be initiated and the search force will be augmented with any additional craft or submarines. A datum will be established for the search, giving the depth in fathoms and indicating how the datum will be marked. (65)

The entire area of probability is searched as soon as possible visually and in combination/coordination with sonar, radar, electronic countermeasures and magnetic anomaly detection equipment. Once the disaster location has been determined, submarine rescue assets will be deployed.

Commander Submarine Development Group One (CSDG-1) is tasked by the Chief of Naval Operations to maintain the Deep Submergence Rescue System (DSRS) in a state of readiness "to provide a quick-reaction, world-wide capability to rescue personnel from a disabled submarine lying on the ocean floor at less than its collapse depth." (66) Upon notification by the SUBOPAUTH, the Force Commander will alert CSDG-1 to the EVENT SUBMISS. Upon notice of EVENT SUBSUNK, and if required, CSDG-1 will arrange transportation of the appropriate DSRS elements (See Table 2) and CSDG-1 personnel to the port nearest the disaster site.(65)

Shallow Water Rescue

One of the many DSRS selection criteria is water depth. Both the SRC and the DSRV can be used in shallow water scenarios. The DSRV is designed primarily for deep water rescue and relies upon hydrostatic forces to maintain a watertight seal between the DSRV and the DISSUB. For every foot of seawater depth, an additional 1000 pounds of hydrostatic force is pressing the mating surfaces of the DSRV and DISSUB together, i.e., at 150 feet of seawater the hydrostatic mating force would be 150,000 pounds.

In shallow water, four titanium holddown turnbuckles, each rated at 50,000 pounds tensile strength, can be utilized to provide additional security when the DSRV is mated to the DISSUB or the for ward hatch of the MOSUB (as would be required for pressurized rescue.) Pylons physically secure the DSRV to the aft hatch of the MOSUB, allowing the MOSUB to safely surface and maneuver while the DSRV is attached.

The minimum submergence depth necessary to prevent the DSRV from overturning off the submarine or sliding and twisting on the submarine's hatch flange depends upon the DISSUB roll and pitch angles, DSRV attitude relative to local currents, sea state, friction coefficients of the mating surfaces, effects of shifting ballast, and the degree internal pressurization of the DISSUB/DSRV.

Without digressing into an extended engineering discussion, it has been calculated that the DSRV could safely conduct rescue operations at depths less than 100 feet of seawater under certain conditions (67).

Initial Rendezvous and Mating

Once the DISSUB location has been established, an initial survey must be conducted to accurately determine the attitude, depth and condition of the submarine and the escape hatch mating areas. The surrounding ocean bottom topography and currents must also be assessed. If communications have not been established, an inspection will be made for extent of damage, outward appearance of intact sections, indications that an escape attempt has been initiated, or for any signs of life. A close range survey could ideally be conducted by a remotely operated vehicle (ROV) to avoid unnecessary DSRV battery discharge. The survey might also indicate whether rescue is even possible, i.e., not excluded by DISSUB trim and list or submarine position so precarious on a steep slope or escarpment that mating would jeopardize the entire mission.

If communication with the DISSUB has been established, essential information to obtained prior to the initial mating attempt would include the extent of damage (number and location of intact compartments), the condition of the crew (number and location of survivors as well as the extent of any injuries), conditions aboard the DISSUB (internal atmospheric pressure levels, existence of radioactive or toxic contamination, oxygen reserves and carbon dioxide removal capabilities), and other rescue considerations such as DISSUB attitude, stability of position, and recommended hatch for initial mate.

Once the area around the DISSUB hatches have been check and cleared of debris, the DSRV is maneuvered onto the escape trunk mating area. The DSRV will attempt to align itself parallel with any prevailing currents. The procedure for establishing the mate and seal was previously detailed.

If the DISSUB crew is still unable to communicate (uncooperative crew rescue scenario) after the DSRV has mated and dewatered the transfer skirt, an explosive driven stud gun is used to penetrate the upper hatch and obtain atmosphere samples to determine contamination and pressure. If the lower escape trunk hatch is closed, the process is repeated for the lower hatch. Sample analysis can be performed in the DSRV using portable monitoring equipment. The same procedures would be followed if the SRC is utilized.

If the DISSUB is a SSN 688 or a SSBN 726 class submarine, the hatch fairing plates must be removed prior to opening the outer escape trunk hatch. With the fairing attached, the hatch is too large to open within the confines of the transfer skirt. A tool kit carried in both the SRC and the DSRV should hopefully allow removal of the fairing after about 2 hours of work.

For unpressurized rescue scenarios, the transfer of personnel and survival supplies can now begin. The weight of stores unloaded and rescuees taken aboard the DSRV must be accurately tabulated to reduce the need to for making large buoyancy corrections. Rescue ballast is discharged into the DISSUB to compensate for the weight of rescuees taken aboard.

The DSRV was designed to hold up to 24 rescuees, although this has never been operationally tested. It was assumed at the time of design that the average submariner weighed 170 pounds. A recent study involving 670 submariners from 7 patrols revealed an average weight of 176 pounds. Contrary to the widespread belief that submariners gain weight during patrols, the study demonstrated that 64 percent lost or maintained the same weight while underway (68).

Upon return to the MOSUB, the DSRV would preferentially mate to the aft hatch to recharge batteries, if needed, and to replenish life support supplies and rescue ballast.

Injured Crewmembers

The DSRV mid sphere has a hoisting device which is used to board personnel who are stretcher bound or with injuries severe enough to prevent them climbing through the escape trunk.

The triage or sorting of survivors in a rescue situation should adhere to the same guidelines governing any mass causality, i.e., do the most good for the greatest number of people. Those survivors who are unable to sit or are confined to a stretcher must be left until the last trips. One stretcher could displace five or six sitting survivors and once the DSRV leaves the DISSUB there is no guarantee that it will be able to make another trip.

Some consideration should be given to placing a medical officer aboard the DISSUB to care for the injured.

Arctic Operations

Given the increased number submarines operating under the Polar Ice Cap, consideration must be given to conducting an under ice rescue. Since the polar depths are relatively shallow, it is highly likely that a submarine could sink and remain intact with survivors on the bottom.

Although the DSRV has never been tested in Arctic conditions, research and development is currently underway to provide that capability. It is anticipated Arctic exercises will take place within the next few years.

PRESSURIZED RESCUE

In the vast majority of cases, ANY MISHAP CAUSING A SUBMARINE TO SINK WILL PRODUCE SOME DEGREE OF INTERNAL PRESSURIZATION. This can result from flooding, high pressure air leaks, intentional salvage air pressurization, or exhaust from the emergency breathing apparatus (EBA).

EBA exhaust will significantly increase internal DISSUB pressure. Given the two extremes of man/volume ratios for U.S. submarines, it has been calculated internal pressurization high enough to require crew decompression may occur after 15.6 hours of EBA use in the smallest submarines and 26.6 hours of EBA use in the largest (44).

The specter of decompression sickness remains the major impediment to successfully conducting a pressurized rescue.

Exposure to elevated pressure will increase the amount of dissolved nitrogen in the submariner's tissue. When this amount exceeds a specific level, direct return to normal atmospheric pressure is no longer possible without the risk of decompression sickness.

The "Islander I" experiments were conducted to determine what degree of pressurization would still allow direct ascent to 1 ata without the onset of decompression sickness. There were no symptoms among 40 test subjects who were exposed to a 1.7 ata nitrogen-oxygen mixture for 48 hours then decompressed in a one minute ascent to the surface. However, when the experiment was repeated at 1.8 ata, there was a 16 percent incidence of decompression sickness (69). Therefore, prolonged exposure to air at greater than 1.7 ata requires slow decompression of the DISSUB crew.

The time required for decompression depends upon the degree of nitrogen loading of the body tissues and the decompression rate. Since some tissues eliminate or "off gas" nitrogen more slowly than others, the decompression or ascent rate will be controlled by these slower tissues. If the ascent rate is too fast, nitrogen bubbles will form in these tissues producing symptoms of decompression sickness.

Since the U.S. Navy does not conduct air saturation diving operations, i.e. long duration dives where the slow tissues become saturated with nitrogen, no official air saturation decompression tables exist. Studies conducted at the Naval Submarine Medical Research Laboratory suggest the use of U.S. Navy Treatment Table 7 or a calculated schedule based on the partial pressure of oxygen during decompression (47).

Treatment Table 7 is considered to be an heroic life-saving measure for treating severe cases of pressure related diving illnesses and could only be used for saturation exposures of less than sixty feet of seawater or 2.82 ata. Ascent rates are 3 feet per hour while traveling from 60 to 40 feet of seawater, 2 feet per hour between 40 and 20 feet of seawater and 1 foot per hour from 20 feet of seawater to the surface (70). Decompressing from sixty feet of seawater would require 36 hours and 40 minutes. Experience in the use of this table by the Naval Experimental Diving Unit has shown some cases of mild decompression sickness may occur.

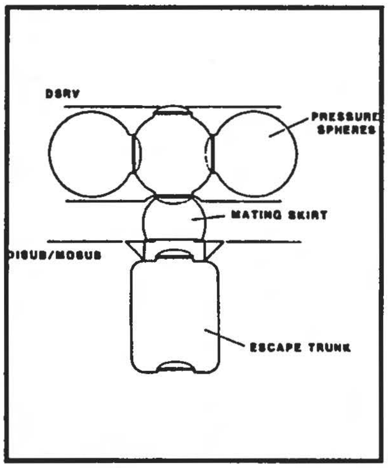
The other option is to calculate a decompression schedule based on the relationship between ascent rate and partial pressure of oxygen as empirically derived by the Naval Submarine Medical Research Laboratory. Namely, the ascent rate in feet of seawater per hour is equal to the partial pressure of oxygen in ata multiplied by a constant (K) which is between 5 and 6. A decompression from sixty feet of seawater would require about 30 hours if the partial pressure of oxygen were kept at 0.4 ata. Out of forty-two trials using this method, only two cases of very mild decompression sickness were produced. (47)

Pressurized Rescue Transfer Procedures

Once the DSRV has mated to the DISSUB, the pressure differential across the DISSUB hatch must be equalized to allow it to be safely opened. This may be accomplished by pressurizing the DSRV from her own compressed air flasks, by using an explosive stud fired through the DISSUB hatch as an equalization valve, or by attempting to "crack open" the DISSUB hatch.

The limited capacity of the DSRV's small compressed air flasks would only provide pressurization of the mid and aft spheres to about 1.8 ata. Extra compressed air could be carried by internally stored scuba tanks, but space constraints would prove prohibitive.

Using the explosive stud gun is both time consuming and not without hazard. If communications have not been established with the DISSUB, this is the only feasible method.



"Cracking" the DISSUB hatch allows rapid, but very poorly controlled equalization and in shallow water may result in the loss of the mating skirt seal.

If communication has been established with the DISSUB and the internal pressure is known, the DSRV mid and aft spheres could be pressurized from the escape trunk prior to the leaving the MOSUB.

When conducting shallow pressurized rescue, careful consideration must be given to using the hold-down turnbuckles, since every 1 ata of internal pressurization will reduce the hydrostatic mating forces by 33,000 pounds.

Once the DSRV has returned to the support platform, the rescuees must be transferred to the decompression compartment or chamber. The personnel transfer and decompression procedures will depend upon whether the ASR-21 Class Submarine Rescue Ship or the SSN 637 Class MOSUB is utilized.

The ASR-21 Class

At present, no method exists for the direct transfer of rescuees from the DSRV to the Deck Decompression Chamber (DDC) of the ASR because of mating incompatibilities. A mating adapter was designed and fabricated, but was never delivered to the Navy because of testing problems.(71). These issues should hopefully be resolved within the near future and therefore provide the ability for the transfer of personnel from the DSRV to the ASR deck decompression chamber under pressure.

If an ASR is utilized for pressurized rescue prior to delivery of the mating adapter, the rescuees will have to be rapidly decompressed to 1 ata and then rapidly recompressed when inside the DDC. In the "SUREX" series of experiments, it was determined that this procedure would probably be well tolerated by the majority of survivors if the DISSUB pressure was no greater than 2.7 ata and the transfer took no longer than 15 minutes (47).

Unfortunately, there are no established procedures for controlled depressuization of the DSRV when not mated to a MOSUB. The DSRV is currently depressurized, after conducting tests which require a 5 pounds per square inch internal pressure, by partially unseating the lower hatch using the taper design of the dogs. Even this small pressure differential produces noticeable binding of the dogging mechanism and it is doubtful the mechanism would be operable at higher pressures.

At pressure ratios greater than 2:1 the gas flow around the hatch would reach sonic velocity with very small degrees of hatch opening producing large flow areas (44). This uncontrolled ascent is very hazardous, often producing a fatal outcome. DSRV-2 AVALON is presently being modified with a transfer trunk equalization system which will allow controlled depressurization of the vehicle.

Each deck decompression chamber should physically hold about 30 rescuees or 60 rescuees per ASR. However, the life support system is routinely used to support only six divers and has never been tested with a greater number of personnel. If the DSRV was able to mate to one of the DDCs, this would provide additional decompression space for another 24 survivors.

The DDC's are usually pressurized with helium for normal diving operations. Since the rescuee's tissues will be saturated with nitrogen, pressurizing the DDC entirely with helium is unacceptable because of a phenomenon known as isobaric counter-diffusion. Tissues already saturated with nitrogen take up helium faster than the nitrogen can be eliminated. This results in a total inert gas partial pressure which exceeds ambient pressure, therefore producing bubbles and symptoms of decompression sickness. It is theoretically possible to pressurize the DDC partially with air and partially with helium, delicately balancing the mixture to keep the inert gas partial pressure low enough to avoid exceeding ambient pressure and producing symptoms.

The other alternative is to pressurize the DDC entirely with air. This presents no problem as long as the saturation depth is less than forty-five feet of seawater. Deeper saturation depths mean oxygen partial pressures above 0.50 ata, which will exacerbate symptoms of pulmonary oxygen toxicity that may already be present among the rescuees. A mitigating factor would be the ability of the rescuees to "breath down" the oxygen partial pressure. If the 1000 cubic feet of DDC volume were occupied by 30 rescuees, the partial pressure of oxygen would be reduce to an acceptable level relatively quickly.

The SSN 637 Class MOSUB

When the MOSUB concept was originally devised, it was anticipated the bow compartment would be utilized as a decompression chamber should the need arise. When the CNO directed that "pressurized rescue be held in abeyance" in 1975, engineering efforts directed toward pressurized rescue were greatly reduced. Pressurized rescue modifications had been made to some of the MOSUBs prior to the CNO prohibition. Portable life support equipment, decompression gauges and control valves are part of the DSRV fly away kit, but are not currently utilized during DSRV submarine rescue exercises.

The bow compartment was to be prepared for pressurization while the MOSUB was enroute to the disaster site, which entailed blocking all vents from the bow compartment and realigning the ship's service piping and structural systems to maintain the desired pressure levels. Once the pressure was known in the DISSUB, the MOSUB bow compartment would be pressurized to one ata less (up to a maximum of 4 ata.) After the DISSUB had mated to the forward hatch, the pressure in the escape trunk would be increased until it was equal to that of the DSRV. After opening the upper escape trunk and lower DSRV hatches, the trunk and DSRV pressure would be lowered until equal to the bow compartment pressure. Personnel transfer would then take place. Once the entire crew had been rescued and spent at least 24 hours at the bow compartment pressure, decompression would commence according to a schedule determined by the Undersea Medical Officer.

The fly away life support equipment included a ventilation package, two carbon dioxide absorber canister fan motors, and an atmosphere analyzer modification kit. The portable ventilation package had a fan to circulate the atmosphere across cooling coils and electrical heaters to help maintain desirable air temperatures. Two 450-volt, 60-cycle, 3-phase fan motors were provided for installation in the ship's carbon dioxide absorber canister receptacles to keep carbon dioxide levels within accept able limits. The atmosphere analyzer modification kit consisted of a length of TYGON tubing which connected decompression needle valve ATM-700 to the calibration connection on the CAMS analyzer console. With the SAMPLE/CALIBRATE selector switch in the CALIBRATE position and the needle valve adjusted until the required flow rate and pressure was obtained, the bow compartment atmosphere could be analyzed.

Oxygen replenishment of the bow compartment atmosphere was to be accomplished manually using gas from oxygen bank No. 1.

The potable water system was to be operational throughout the decompression cycle by increasing the system pressure to 55 pounds per square inch and gagging the relief valves to maintain system pressure. The flushing water tank pressure was to be raised to 60 pounds per square inch and valve PL-700 in the water closet drain line to sanitary tank No.2 was to be closed. When flushing the toilets, the drain and flushing valves were to be momentarily opened then returned to the closed position. (72)

EXERCISE SEDGEMORE 89, a joint U.S./U.K. submarine rescue exercise, was conducted in SEP 1989. The transfer of rescuees from a pressurized DISSUB to the pressurized bow compartment of a MOSUB was sucessfully accomplished for the first time by the British LR5 and demonstrated to be feasible by the American DSRV.

ESCAPE vs RESCUE

Deciding whether to escape or await rescue is influenced by the number of survivors and the extent of their training, the volume of the living space, the nature of the atmosphere, the availability of survival supplies, the depth at which the DISSUB is resting, and known weather conditions on the surface. There are obvious conditions which would favor escape, i.e. delay in rescue force arrival combined with lethal conditions aboard the DISSUB, and obvious conditions which would favor rescue, i.e. ocean depths exceeding 600 feet or operations under the Polar Ice.

Until 1927, the preferred method of saving submarine crews was through rescue by salvage. The entire submarine or at least one end would be raised above the waterline, allowing the crew to be rescued. Around the time of the First World War, 105 submariners had been rescued in four submarine rescue salvage attempts compared to only a handfull of escapers (74). However, it soon became apparent that salvage efforts relied heavily upon weather and sea conditions, as well as time. When the British lost the submarine M1 in 1925, and shortly thereafter the Americans lost the S-51 and the S-4, faith in rescue by salvage was shattered.

The British then looked toward submarine escape using the Davis Submerged Escape Apparatus (D.S.E.A.), while the Americans relied upon the Submarine Rescue Chamber; with the Momsen "Lung" to be utilized as a last resort. Successful escapes from the British submarine POSEIDON in 1931 using D.S.E.A., caused great excitement and accelerated British submarine escape efforts. The Americans, flushed with the success of the SQUALUS rescue operation and lacking major peacetime submarine disasters, continued to rely upon rescue as opposed to escape.

On 1 June 1939, HMS THETIS sank in 160 feet of water while undergoing seatrials in Liverpool Bay. Of 103 men aboard, only four successfully escaped. The decision to escape had been delayed in the hopes rescue forces would arrive. When the Ruck-Keene Committee was formed shortly after World War Two, one of it's major recommendations was to discontinue the practice of waiting inside the disabled submarine until rescued. Guidance was to be given the survivors regarding when to escape based upon the number of survivors and the volume of the unflooded compartments.

Of the forty men who successfully escaped from the HMS TRUCULENT when she sank on 12 January 1950, only ten were picked up alive.

The remainder were swept out to sea or died of exposure while awaiting rescue. Soon afterwards the Admiralty Committee gave special attention to developing buoyant suits which protected the escaper's body against the elements as well as keeping him afloat.

Today, the consensus appears to be shifting to rescue as the primary method of saving submariners, with individual escape to be utilized under those circumstances where rescue is impossible or will be significantly delayed. The advantages and disadvantage of escape versus rescue are shown in Table 3.

In 1988, STANAG 1301 was drafted in an attempt to assist the senior survivor of a NATO country DISSUB regarding the decision to escape or await rescue. While addressing many important issues, it did not provide an adequate evaluation of the internal DISSUB time under pressure and failed to include a useful algorithm by which an escape or await rescue decision could be made (77).

FOREIGN RESCUE AND ESCAPE SYSTEMS

The United States is not the only country to possess submarine rescue or escape systems. The following brief survey is not meant to be all inclusive, but is intended to be a representative sampling of work going on in other countries.

British Royal Navy

The close association enjoyed by the U.S. and U.K. Navies extends to the area of submarine rescue. Every three years since 1979 there has been a DSRV fly away exercise to the United Kingdom to jointly practice the techniques of submarine rescue.

Although the Royal Navy has the capability of submarine escape from as deep as 600 feet of seawater, if the pressure in the escape compartment rises above the "safe to escape" limit or if the submarine sinks in water deeper than 600 feet, rescue becomes the only viable option for survival.

Once a distress signal has been received from the DISSUB, the Subsunk Parachute Assistance Group is dropped into the area to provide surface support for any escapers until the arrival of rescue vessels.

One such vessel, HMS CHALLENGER, is 135 meters long and displaces 7700 tons. Designed for deep ocean search and recovery, she has a dynamic positioning ability, integrated navigation control and tracking, a forward speed of 16 knots as well as 4 knots athwartships, and a remotely operated vehicle. She also has a dedicated operations and control center, a "moonpool" for deploying a diving bell and saturation divers, a decompression chamber, a 25 ton main crane and an auxiliary crane for ROV SCORPIO, a helicopter deck and

	ESCAPE			RESCUE		
Factor	Effect	Plus +	Minus -	Effect	Plus +	Minus -
Time	Escape can be made at any time according to circumstances.	/(A)		DSRV arrival will take considerable time and is dependent on a long chain of events.		/
Exposure	Exposure to escape profile pressures, and sea water and weather can radically reduce survival probability.		/	No problems.	/(B)	
Decompression Sickness	Pulmonary barotrauma and bends are probable, and increase with escape depth.		/	Can be conducted at pressure in DISSUB of 1 - 3.3 bars.	/(B)	
DISSUB Environment	Available when atmosphere or pressure becomes untenable.	/		Can be conducted at pressure in DISSUB of 1 - 3.3 bar.	/	
Evacuation Rate	Quickest evacuation from DISSUB possible.	/		Slow evacuation, dependent on DSRV round trip time.		/
Depth	Only proven to 180 metres.		/	Can be mounted at NCD of submarine, provided hull pressure tight.	/	
Psychology	Regular training makes escapees confident of system, but survival after escape an unknown.		/	Waiting time may reduce morale of survivors but knowledge that once DSRV has arrived, survival is near certain, is important.		/
Simplicity	Simple	/		Dependent on complex mix of human and material factors outside DISSUB control.		/
Autonomy	Under direct control of senior survivor	/		Outside control of DISSUB		/
Familiarity	Familiar through regular training.	/		Unfamiliar - but no training required by survivors.	/	
Sea Conditions	Not affected by poor visibility	/		Strong currents and poor visibility could inhibit rescue.		/
Cost	Little maintenance	/		Regular training of pilots on exercising of system required. Regular maintenance needed.		/

(A) The overriding reason for retaining an escape facility.
(B) Prime considerations for retaining a rescue capability as the preferred method, when time is not a factor.

TABLE 3: FROM REF (75)

a 25 ton A-frame for deploying LR5 in conditions up to force 7 winds and sea state 6.

LR5 is a submersible owned and operated by British Underwater Engineering Services and is on permanent charter to the Royal Navy. The 9.6 meter long, 22 ton craft has sonar, video cameras, manipulator arms, and an underwater telephone. She is able to mate to the DISSUB escape hatch in the same manner as the DSRV, but at angles of up to 60 degrees. With an endurance of about 12 hours, an operating depth of 475 meters, and a forward speed of 2 knots, she is operated by a pilot and one crewman. She can rescue nine survivors per trip utilizing the diver lock-out compartment. This compartment can also be utilized to put divers in the water at saturation diving depths. There is presently no method of directly transferring rescuees to the HMS CHALLENGER's decompression chamber under pressure.

SCORPIO is a remotely operated vehicle which can be used to perform the initial DISSUB survey and assist in the actual rescue. It is fitted with a manipulator, sonar, and two video cameras. It has a lift capacity of 90 kilograms, a forward speed of 2.5 knots, and an operational depth of 925 meters. The system, along with a winch and control cabin is air deployable and can be used aboard a ship of opportunity.

The Royal Navy has a brilliantly conceived system of resupplying life support stores to the DISSUB using ROV SCORPIO which enables the survivors to await the arrival of LR5 or the DSRV.

"Resupply emergency life support stores for the disa bled submarine are stowed inside pressure tight containers called pods. The pods are placed into a delivery crate which is lowered onto the seabed near the submarine. On contact with the seabed, the top half of the crate is automatically released and recovered back onto CHALLENGER's deck leaving the pods ready for collec tion. SCORPIO is controlled from the command position on the upper deck. It is driven to the pod crate which has a pinger attached to it to ease location, one of the pods is selected for delivery to the submarine. Within the submarine, the survivors have rigged a pod receiving bag in the escape tower. The tower has been flooded and the upper hatch opened ready to receive the pod. The survivors then shut the upper hatch, drain the tower and unload the pod. Thus emergency air purification stores, food and medical supplies can be provided to sustain the survivors until the next phase of the rescue operation." (18)

Japanese Maritime Self-Defense Force

Japan's Submarine Rescue System consists of the submarine rescue ship CHIYODA and a Deep Submergence Rescue Vehicle very similar to the U.S. Navy's DSRV.

The CHIYODA is a 3700 ton, 112 meter vessel with a deep diving saturation system, a dynamic positioning system, and 3-Dimensional sonar. Two reversible pitch propellers and four side thrusters allow her to maintain position without the use of a four-point moor. Cruising speed is 16 knots with a range of 6,000 nautical miles. The diving system, which consists of two Deck Decompression Chambers and one Personnel Transfer Capsule, can support diving operations to 350 meters.

The DSRV is 12.4 meters long and displaces 40 tons. Three interconnected ultra high tensile strength steel spheres make up the pressure hull. The forward sphere is the control sphere for the pilot and copilot. The mid sphere can hold up to 12 rescuees, while the aft sphere is a machinery space. (22)

Italian Navy

The Italian Navy has one salvage ship, the 3780 ton ANTEO, which carries a Submarine Rescue Chamber and the MSM-1/S submersible named USEL which has been modified to function as a submarine rescue vessel (19). The 10.7 meter long, 31 ton USEL consists of three HY-80 steel compartments connected by two pressure resistant cylinders which can be isolated by water-tight hatches. The forward compartment is occupied by a pilot and a manipulator operator, while the mid compartment has one rescue crewman. The aft compartment contains propulsion and electrical equipment. It can operate in sea state 4 seas and has a maximum operating depth of 600 meters (1,970 feet), but it is limited to a depth of 300 meters when operating in the rescue vehicle mode. The two main propulsion engines give a maximum speed of 4 knots, but for 8 hour endurance the vehicle usually operates at 1.5 knots. Five thrusters allow for precise positioning. Power is supplied by 62 lead acid storage batteries which can be changed in 3 hours and jettisoned for emergency buoyancy.

A skirt attached to the mid compartment allows for dry transfer of up to 10 rescuees from the DISSUB to MSM/1-S per trip. There is no provision for pressurized rescue. (20)

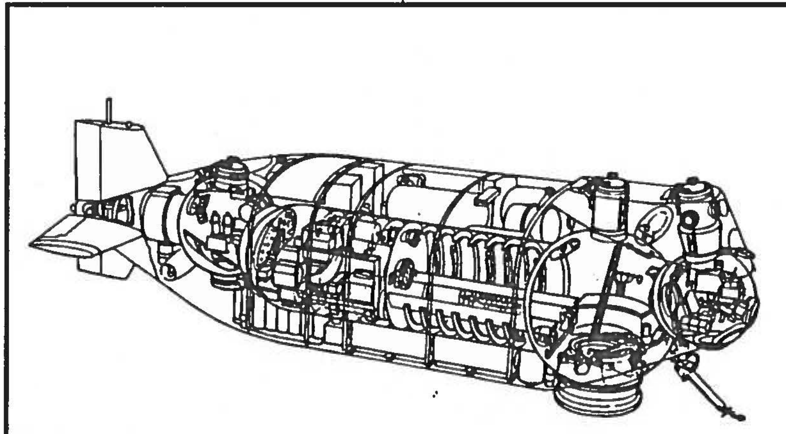
French Navy

The French Navy has a 1,150 ton oceanography research vessel, TRITON, which has a rescue capability. The ship has a 13.5 ton tethered bell with an operational depth of 250 meters (820 feet). She also has a two man, 16 ton submersible named GRIFFON which operates to 600 meters (2000 feet). (19)

The French Navy is modifying some of its ballistic missile submarines to enable them to act as MOSUBS in support of U.S. DSRV operations.

Swedish Navy

The Swedish Navy has a submarine rescue ship, named the BELOS, which displaces 965 tons and is based at the Naval Diving Center 30 kilometers south of Stockholm (19). Until the late 1970's the only methods utilized to save submariners was individual escape and two (McCann) Submarine Rescue Chambers; one on the West Coast of Sweden and one in the Baltic. However, in 1974 it was decided that a Submarine Rescue Vehicle was needed. Since most rescue missions would be conducted in the relatively shallow Baltic, and because project funds were limited, it was decided to make the vehicle as simple as possible. It has been said that simplicity is the ultimate sophistication. Some may argue that point, but simplicity certainly provides the potential for increased reliability.



The Submarine Rescue Vehicle, URF, displaces 49 tons and is 13.5 meters long. The pressure hulls are constructed of HY-130 steel, giving a maximum operating depth of 460 meters (1510 feet) and a maximal rescue depth of 300 meters. Submerged speed is 3 knots with a duration of 40 hours. The vehicle is divided into four compartments. The Operator's Compartment is forward and is normally manned by a crew of two. It maintains an internal pressure of one atmosphere absolute (1 ata). Directly behind it is the Rescue Compartment capable of holding up to 25 rescuees and maintaining internal pressures ranging from 1 to 10 ata. Just aft of the Rescue Compartment is the Auxiliaries Compartment, manned by a single engineer and maintained at 1 ata. Originally there was a Diver's Compartment which could accomodate two divers. This has been modified to allow additional room for another ten rescuees (78). The thirty-five rescuees can be transferred under pressure from the URF to a land based decompression chamber by using a Personnel Transfer Capsule (PTC).

The life support system is manually controlled from the Operator and Auxiliaries Compartment. Oxygen is stored outside the pressure hull and is manually added to maintain a partial pressure of 0.20 ata. Oxygen sensors can be read in each compartment as well as centrally from the Operator and Auxiliaries Compartments. Carbon Dioxide is monitored by Drager chemical absorbent tubes and is removed by sodalime canisters in each compartment. Electric heating and insulation provide temperature control. Life support system endurance is 20 to 25 hours in the Rescue Compartment and 50 to 70 hours in all others.

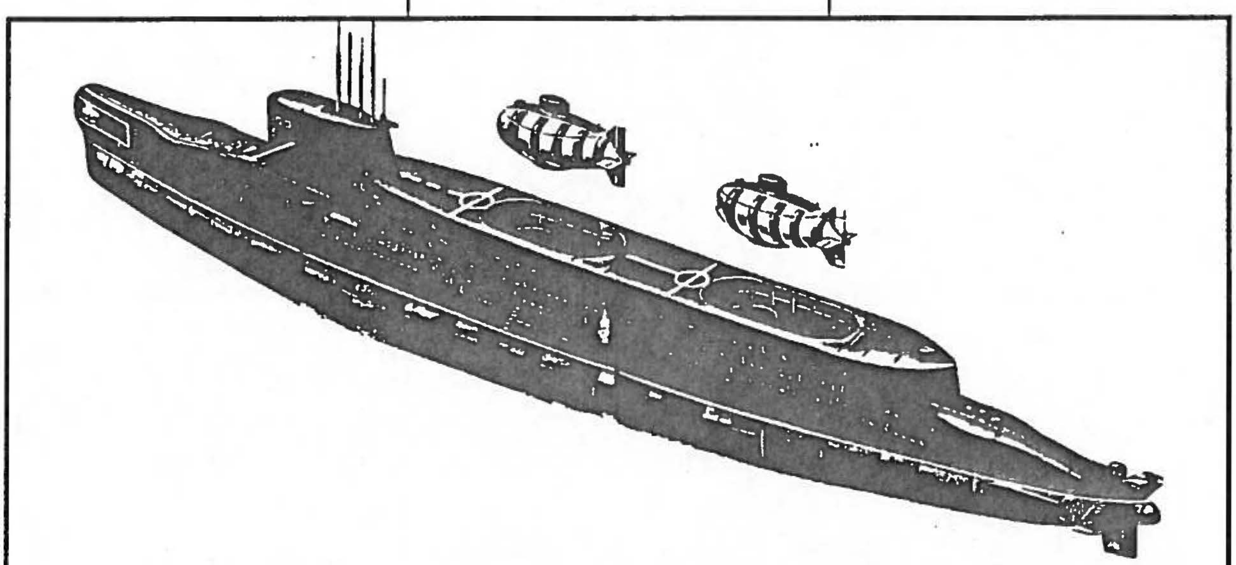
When called out, the URF is moved by road on a low-loader and towed by the BELOS or a ship of opportunity to the rescue site. The URF disconnects from the towing umbilical and proceeds under its own power to the DISSUB. After locating the DISSUB by sonar and then visually, the URF attaches a down haul wire to the escape hatch and winches itself down to a mate. This can be accomplished at angles up to 45 degrees.

In situations where it is impossible to mate with the DISSUB, the URF hovers above the escape hatch with it's rescue compartment pressurized to the ambient seawater pressure. The rescuees then make a free ascent from the DISSUB to the URF. This procedure is deemed feasible to depths of 90 meters (300 feet). This procedure could also be utilized to rescue personnel from underwater habitats, sunken ships, and submersibles where docking is not possible (21).

Soviet Navy

The Soviet submarine rescue program is unique in that the submersible rescue vehicles are carried by specially designed salvage and rescue submarines. The India class mother submarine was first completed in 1979. She is diesel powered, 348 feet long and displaces 4800 tons. She has an exceptionally fine bow form which allows her to make a high speed surface transit to the disaster area. A bulge on the bow above the water line is thought to house passive sonar. Two rescue submersibles are carried in deck wells set in the raised hull casing aft of the sail. One India class MOSUB is assigned to the Northern Fleet and one to the Pacific Fleet.

Two types of rescue submersibles have been observed in the deck wells. One is 37 feet long and has small rotating shrouded propellers on either side of its after section. The other is 40 feet long and has a single shrouded



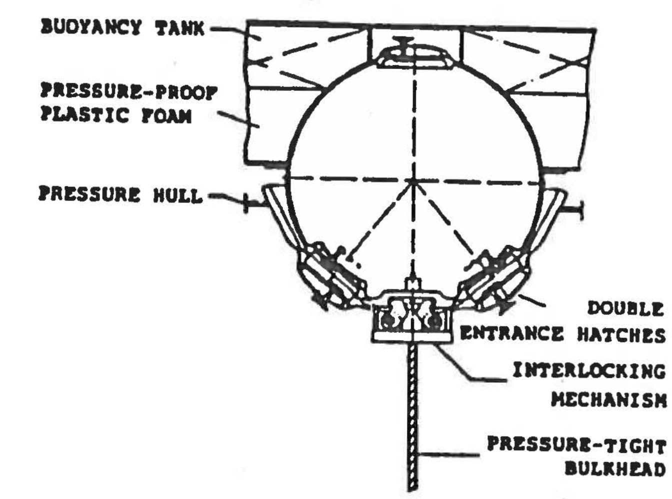
propeller. Both have cruciform tail control surfaces, a large circular mating hatch below and a smaller hatch on top. They are believed to have forward looking optical systems and search and navigation sonars. It is thought that their pressure hulls consist of two titanium spheres; the forward sphere to house controls and a two or three man crew, and the aft sphere to accommodate 12-15 survivors. Both types of vehicles are painted with distinctive red, orange and white stripes.

A rescue sphere, similar in concept to that manufactured by West Germany, is utilized by some classes of Soviet submarines. Recently, off the coast of Norway, several Soviet submariners successfully escaped from a sinking Mike class submarine via a rescue sphere.

The Soviets have submarine rescue surface ships. The 22,500 ton ELBRUS is the only ship of her type in the world with ice-breaking capability. This enables her to support TYPHOON class SSBN operating areas. Other submarine rescue ships include on 10,000 ton NERA class, eight 3,200 ton PRUT class, and eleven of the 930 ton VALDAY class ships. (19)

West German Navy

The German Navy has developed an interesting concept in submarine rescue, the Rescue Sphere. It can be thought of as an ejection seat for submarines (an



appealing idea to a Flight Surgeon), however the rescue sphere cannot be released while the submarine is sinking. While the Germans have yet to build a submarine for their own Navy utilizing this concept, they are building four HDW type 1500 submarines with rescue spheres for the Indian Navy.

The HY-80 steel rescue sphere is 2.6 meters in diameter and sits in a depression above the pressure-tight bulkhead separating the forward and aft compartment. It was designed so that it's test depth is just reached at the calculated collapse depth of the submarine hull.

The sphere can hold 40 crewmen and provide 9 hours of air when completely sealed. With a dry weight of 13 tons, it ascends to the surface at about 1.2 meters per second when fully loaded. Once on the surface a fresh air supply mast can be deployed or in calm seas the top hatch can be opened, allowing some survivors to crawl out on the buoyancy tank. Should decompression be required, there is enough air to allow a decompression schedule of up to 4 hours. Each crew member exhales into his own carbon dioxide scrubber apparatus and the atmosphere is monitored using Drager test equipment. There are emergency rations for six days. Sea keeping tests have shown the rescue sphere to be absolutely uncapsizable and demonstrated it can be towed at speeds of 4 to 5 knots even in rough seas. (23)

BIBLIOGRAPHY

(1) U.S. Navy, *Submarine Force Mishap Statistical Summary Calender Years 1982 through 1986*, Submarine Safety Programs Directorate, Naval Safety Center, Norfolk, 1988

(2) Donald, K., Submarine Escape Breathing Air, *Extrait du Bulletin europeen de Physiopathologie Respiratoire*, Vol 15 - 1979

(3) Maas, P., *The Rescuer*, Harper & Row, New York, 1967

(4) Bentley, J., *The Thresher Disaster*, Doubleday, New York, 1975

(5) U.S. Navy, *Deep Submergence -- Submarine Location, Escape and Rescue System, Specific Operational Requirement (SOR) 46-15R1*, 28 OCT 1964

(6) U.S. Navy, *Deep Submergence Systems Program Rescue System Design and Performance Requirements, DSSP TD-1, Revision A*, 12 MAY 1967

(7) U.S. Navy, A Comparative Analysis of System Effectiveness vs Cost for Alternative Combinations of Currently Approved & Future Proposed Navy Undersea Rescue and Escape Systems, *NURESARS Study Project Report*, NOV 1970

(8) U.S. Navy, *Deep Submergence -- Submarine Location, Escape and Rescue Systems, Specific Operational Requirement (SOR) 46-15R2*, CNO ltr of 16 OCT 1975

(9) Hall, D., and Linaweaver, P., *Medical Aspects of Small Submersible Operations*, Undersea Medical Society, Bethesda, 1974

(10) Green, J., OIC AVALON (DSRV-2), personal communication, 1988

(11) O'Brian, P., OIC MYSTIC (DSRV-1), personal communication, 1988

(12) Li, Y. and Sudolnik, A., *Deep Submergence Rescue Vehicle Life Support Systems*, American Institute of Aeronautics and Astronautics Paper 70-526, MAY 1970

(13) Lockheed Missles and Space Company, *DSRV-1 Test Report Life Support System 24 hour Manned Test (LMSC-D177665)*, Locheed Aircraft, 1971

(14) U.S. Navy, Submarine Rescue Chamber/ASR System, *Disabled Submarine*, Naval Sea Systems Command, JAN 1986

(15) Goins, D., Diving Officer, Commander Submarine Developmnet Group 1, personal communication, 1988

(16) Eckenhoff, R., Submarine Escape and Rescue in 1980, *Submarine Medical Officer Qualification Thesis*, 1980

(17) U.S. Navy, *SHIPALT SSN 852 R1*, DSRV Rescue Modification Revision 1, 1975

(18) Steiner, A., *Submarine Escape and Rescue - Assistance Available From Military and Commercial Submersible Escape Systems*, Ministry of Defence (Navy), 1987

(19) Miller, D. and Jordan, J., *Modem Submarine Warfare*, Military Press, New York, 1987

(20) Adkisson, G., *The Italian Navy Mini-Submarine MSM/1-S*, Office of Naval Research Branch Office, London, 1988

(21) Muren, A. and Onnermark, J., *Swedish Rescue Concept*, Swedish Royal Navy

(22) JMDF, *The Deep Diving System of Japanese Maritime Self-Defense Force*, 1985

(23) Abels, F., *The Rescue Sphere - A Rescue System for Submarines*, Joint International Conference of Escape, Survival, Rescue at Sea, 1986

(24) Appleby, R., Commanding Officer, USS PIGEON (ASR-21), personal communication, 1987

(25) Ellsberg, E., *Men Under The Sea*, Dodd, Mead & Co, New York, 1939

(26) Goad, R., Force Medical Officer, Commander Submarine Force, U.S. Pacific Fleet, personal communication, 1989

(27) Neuman, T., Submarine Escape Training in the U.S.: A Re-Evaluation, *Submarine Medical Officer Qualification Thesis*, MAR 1974

(28) U.S. Navy, *Escape Bill for SSN 637 Class Submarines*, change one

(29) Robinson, A., Royal Australian Navy Submarine Medical Officer, personal communication, 1988

(30) Greene, K., *Causes Of Death In Submarine Escape Training Casualties: Analysis Of Cases and Review Of The Literature*, AMTE, Physiological Laboratory, Alverstoke, JUL 1978

(31) Gell, C. and Parker, J., International Workshop on Escape and Survival from Submersibles, *NSMRL Report Number 794*, 1972

(32) Edmonds, C., Lowry, C. and Pennefather, J., Nitrogen Narcosis, In *Diving and Subaquatic Medicine*, Diving Medical Centre, Australia, 1984

(33) Kent, M., Emergency Ascent Training Workshop, Undersea Medical Society, Bethesda, 1979

(34) U.S. Navy, Emergency Equipment, In *Ship Information Book, Volume 7*, Naval Sea Systems Command, NOV 1983

(35) Behnke, A., Inert Gas Narcosis, In *The Physician's Guide to Diving Medicine*, Plenum Press, New York, 1984

(36) Flynn, E., Submarine Escape and Rescue, In *Diving Medical Officer Student Guide*, Naval Technical Training Command, 1981

(37) Somers, C., Submarine Disasters in Peacetime, 1900 to 1971, *United States Naval Institute Proceedings*, Naval Review Issue, MAY 1972

(38) Shilling, C., Escape and Rescue - Submarines, In *The Physician's Guide to Diving Medicine*, Plenum Press, New York, 1984

(39) Raffaelli, P., Senior Medical Officer (Submarine Medicine), Institute of Naval Medicine, Undersea Medicine Division, Alverstoke, personal communication, 1989

(40) Carson, J. and Harvey, C., *The B.A.P. PACOCHA (SS-48) Collision: The Escape and Medical Recompression Treatment of Survivors*, 1989

(41) Carhart, H., *Impact of Low Oxygen on Fire Safety in Submarines, Navy Technology Center for Safety and Survivability*, Naval Research Laboratory

(42) Shukitt, B., *Cognitive Performance, Mood States, and Altitude Symptomatology in 13 - 21 Percent Oxygen Environments*, U.S. Army Research Institute of Environmental Medicine, Technical Report T18-88, JUN 1988

(43) Houston, C., *Going Higher: The Story of Man and Altitude*, Little, Brown & Co, Boston, 1987

(44) Schmidt, T., *Pressurized Submarine Rescue: A Technical Review of Existing and Required Capabilities, Hardware and Procedures*, Revision A, Lockheed Advanced Marine Systems, San Diego, APR 1986

(45) Dougherty, J., Styer, D., Eckenhoff, R. and Hunter, W., *The Effects of Hyperbaric and Hyperoxic Conditions On Pulmonary Function During Prolonged Hyperbaric Chamber Air Saturation Dives*, Undersea Biomedical Research, 1981

(46) Edmonds, C., Lowry, C., and Pennefather, J., Oxygen Toxicity, In *Diving and Subaquatic Medicine*, Diving Medical Centre, Australia, 1984

(47) Eckenhoff, R., *Pressurized Submarine Rescue*, Naval Submarine Medical Research Laboratory, Groton, JUN 1984

(48) Shilling, C. and Faiman, M., Physics and Physical Effects of Diving, In *The Physician's Guide to Diving Medicine*, Plenum Press, New York, 1984

(49) Adkission, G. and Raffaelli, P., *SUBSUNK: Notes for Medical Officers*, Institute of Naval Medicine, Alverstoke, 1988

(50) Sheffield, P. and Heimbach, R., Respiratory Physiology, In *Fundamentals of Aerospace Medicine*, Lea & Febiger, Philadelphia, 1985

(51) Hart, B., *Estimates of the Survival Time of Men Awaiting Rescue in a Disabled Nuclear Submarine*, Naval Medical Research Institute, Bethesda, FEB 1986

(52) Busby, F., *Manned Submersibles*, Office of the Oceanographer of the Navy, 1976

(53) Behnke, A. and Willmon, T., U.S.S. SQUALUS: Medical Aspects of the Rescue and Salvage Operations and the Use of Oxygen in Deep-Sea Diving, *U.S. Naval Medical Bulletin*, JAN 1939

(54) Danzl, D., Pozos, R. and Hamlet, M., Accidental Hypothermia, In *Management of Wilderness and Environmental Emergencies*, C.V. Mosby Company, St. Louis, 1989

(55) U.S. Public Health Service, Hypothermia Prevention, In *Morbidity and Mortality Weekly Report*, U.S. Department of Health and Human Services, Washington, 23 DEC 1988

(56) North Atlantic Treaty Organization, Mimimum Conditions for Survival in a Distressed Submarine Prior to Escape or Rescue, *STANAG 1301*

(57) Schmidt, T., Thermal Condsiderations of Survival in Emergency Hyperbaric Situations, In *Thermal Constraints in Diving*, Undersea Medical Society, Bethesda, 1981

(58) North Atlantic Treaty Organization, *Minimum Requirements for Medical Stores in Submarine Escape Compartments*, STANAG 1319

(59) Bodilis, H. and Giacomoni, L., *Use of Containers to Provide Life Support Stores to Distressed Submarines,* Presented at the Sixth Tripartite Meeting, Washington, D.C.

(60) Chapman, R., *No Time On Our Side*, W.W. Norton & Company, New York, 1975

(61) Dervay, J., Flight Surgeon, USS JOHN F KENNEDY (CV-67), personal communication, 1988

(62) Sharp, V., The Nightmare of Submarine Escape: How to Get Out Alive, In *Fathom Magazine*, Naval Safety Center, Norfolk, APR/MAY 1989

(63) Steinman, A. and Hayward, J., Cold-Water Immersion, In *Management of Wilderness and Environmental Emergencies,* C.V. Mosby, St. Louis, 1989

(64) Perez, M., To Sink or Swim - or Both, In *Safetyline*, Naval Safety Center, Norfolk

(65) U.S. Navy, Submarine Disaster SAR Operations, In *Navy Search and Rescue (SAR) Manual*, Naval Warfare Publication 19-1, JUL 1983

(66) U.S. Navy, Deep Submergence Rescue System (DSRS) Deployment Scenario, CNO ltr of 24 AUG 1987

(67) Mahr, F., *Shallow Water Limitations For DSRV Mated With A Bottomed Submarine*, Lockheed Advanced Marine Systems, SEP 1968

(68) Bondi, K. and Beare, A., *Body Weight Changes Before and After Submarine Patrols,* Report Number 1062, Naval Submarine Medical Research Laboratory, New London, SEP 1985

(69) Bell, P., Harrison, J., Page, K. and Summerfield, M., An Effect Of Carbon Dioxide On The Maximum Safe Direct Decompression To 1 Bar From Oxygen-Nitrogen Saturation, In *Undersea Biomedical Research,* Vol. 13, No. 4, DEC 1986

(70) *U.S. Navy Diving Manual*, Revision 1, Navy Department, Washington, D.C., JUN 1985

(71) November, S., Engineer for Lockheed Advanced Marine Systems, personal communication, APR 1989

(72) U.S. Navy, DSRV/Mother Submarine Rescue Operations, In *USS PINTADO (SSN 672) Ship Infor-martion Book,* Vol. 7, Naval Sea Systems Command, NOV 1983

(73) Whiteside, R., Submarine Escape and Rescue Officer, British Royal Navy, personal communication, 1989

(74) Shelford, W., *SUBSUNK: The Story of Submarine Escape*, Doubleday and Company Publishers, New York, 1960

(75) Davis, R., *Deep Diving and Submarine Operations*, sixth edition, Siebe, Gorman & Co, Ltd, London, 1955

(76) Wilson, D., *Submarine Escape and Rescue: A Review of Recent Developments in the Royal Navy*, In Naval Submarines: Vol II, Papers 13 - 24, The Royal Institution of Naval Architects, London, 1983

(77) U.S. Navy, Ratification of NATO Standardization Agreements, Commander Submarine Development Group 1 ltr of 12 SEP 1988

(78) Edman, U., Captian, Royal Swedish Navy, 1st Submarine Flotilla, personal communication, SEP 1989