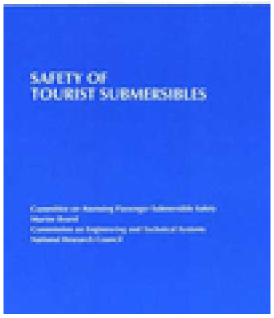

Safety of Tourist Submersibles

Committee on Assessing Passenger Submersible
Safety, National Research Council

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Committee on Assessing Passenger Submersible Safety
Marine Board
Commission on Engineering and Technical Systems
National Research Council

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MARINE BOARD

Preface

The U.S. Coast Guard is required to regulate commercial marine operations in the interest of public safety. Development of an expanding commercial passenger-carrying submarine ("tourist submersible") industry has led recently to the development of new regulations for this special class of vessel and to a need for new inspection and certification requirements in Coast Guard field offices. At present there are seven tourist submersibles operating under the jurisdiction of the Coast Guard. The Coast Guard recognizes that its experience in this area is limited, and that the industry presents novel features, both technologically and operationally. Therefore, the Coast Guard asked the Marine Board to review and assess the hazards involved in tourist submersible development and operations, and to advise them of the approaches that might best be used to ensure public safety.

A committee was formed to include experts in all of the technical aspects of naval architecture for submersibles and deep submergence, technologies which have developed primarily over the last 30 years for research, military, or industrial purposes, but which have seen very few public commercial applications.

The committee also included experts in systems safety, human factors, as well as an expert in management of cruise ship businesses. Members of this committee visited two current operations in U.S. waters, visited the assembly plant of a currently active builder-operator, and viewed presentations by experts in fire prevention, acrylic material properties, and life support systems. All members of the committee made one or more dives in a tourist submersible. Special briefings and discussions with the American Bureau of Shipping and the Coast Guard were also undertaken. Three meetings of the full committee were held. This report presents the committee's findings and its conclusions and recommendations.

ACKNOWLEDGMENTS

The committee appreciates the support of Commander Stephen L. Johnson, U.S. Coast Guard, who served as liaison representative. He was particularly helpful and responsible in providing the committee with data and documentation about passenger submersible certification. Mr. Brian Van Mook of the American Bureau of Shipping responded to the committee's requests for nonproprietary classification information. Mr. John Pritzlaff served as the liaison with the Society of Naval Architects and Marine Engineers (SNAME), which has provided much of the leadership in non-military submersibles standards development for over two decades. In addition, Mr. Pritzlaff's extensive library and photographs of submersibles worldwide comprised a rich resource to be tapped for this report. His suggestions and efforts are much appreciated.

The committee also recognizes the cooperation of Sub-Aquatics, Incorporated, in the organization and support of the committee's visits to their operations at St. Thomas, U.S. Virgin Islands, Hawaii, and vessel construction at Tacoma, Washington. Mr. John Witney, Vice President of Engineering, Sub

Aquatics, Incorporated, and Mr. Jack McMahon, Manager of their St. Thomas operations, were particularly helpful, candid, and responsive to the committee's inquiries. Dr. Edward M. Briggs, of Southwest Research Institute, provided technical background concerning the use of acrylics in pressure vessels for human occupancy. Dr. Graham Hawkes, Deep Ocean Engineering, Incorporated, provided insight concerning stiffened cylinder theory and buckling.

Contents

Executive Summary

"Tourist submersibles" are commercially operated passenger-carrying submarines; they are used to conduct underwater sightseeing excursions at oceanside resorts and other tourist centers. Some tourist submersibles are converted research or industrial work vessels of a type known as deep submergence vehicles (DSVs). These are typically small vessels carrying a pilot and 2-3 passengers (although 6-8-passenger conversions of these submersibles will be launched beginning in 1990), which were designed to dive to great depths. Other larger vessels are built-for-the-purpose submersibles usually carrying 25-49 passengers and are designed to operate in shallow water at depths no greater than 150 feet.

As a large-scale recreational enterprise, this industry is less than a decade old. Seven tourist submersibles are currently* in operation in U.S. waters or in locations where the Coast Guard is responsible for safety (the U.S. Virgin Islands, Hawaii, Guam, Rota Island [Mariana Islands], and Saipan); this is the largest number of submersibles under one jurisdiction. Internationally, 18 other submersibles are operating in waters as diverse as the Cayman Islands and Switzerland. More are expected in the near future.

Of the handful of builders of built-for-the-purpose tourist submersibles, two have already left the business, along with at least two operators. Given the newness of the industry, investment capital can be difficult to obtain, and initial and operating costs are high. Ticket sales must remain close to seating capacity on a sustained basis if a venture is to succeed. Little time is available for maintenance. Nevertheless, the industry leaders have shown that a well-planned, well-run operation can succeed financially. The realized and potential financial return from successful operations makes this an attractive new business development area with moderate expansion expected. Such expansion will be limited by availability of diving areas that offer good views, easy access, and market conditions.

The American Bureau of Shipping (ABS) is the predominant technical organization in the United States for classification of ships. Worldwide, there are at least 17 ship classification societies, although only 7 command the majority of classification activity, viz., ABS, Lloyd's Registry of Shipping (U.K.), Det norske Veritas (Norway), Germanisher Lloyd (Germany), Bureau Veritas (France), Soviet Registry (USSR), and Nippon Kaiji Kyoka (Japan). The ABS has been the classification agency for all U.S. tourist submersibles to date and in fact has classed all but one of the tourist submarines currently in operation. Det norske Veritas is a non-U.S. classification agent for two submersibles now under construction.

The U.S. Coast Guard is responsible for certification that vessels operate in U.S. waters meet technical and safety standards. The Coast Guard relies extensively (but not exclusively) on the ABS

* As of December 1989.

technical rules, particularly in regard to the design of structures, and on assurance that new vessels comply with these rules. Construction inspections and periodic inspections thereafter are conducted jointly where possible.

The Coast Guard maintains direct surveillance and approval of all operating vessels at the local level through the Captain of the Port (COTP) and the Officer in Charge, Marine Inspection (OCMI) (often they are the same person). Their cognizance includes approval of both technical and diving aspects of the operation of tourist submersibles. However, these officers have a wide scope of responsibilities and are not necessarily technically expert with regard to these new and sophisticated vessels. Current Coast Guard criteria for approval of the submersibles and their operations are based on those for surface craft of comparable size. This imposes on the COTP and OCMI, as well as on the individual Coast Guard inspector, the need to exercise judgment in areas that may be safety-critical. There have been no serious accidents to date aboard these vessels, although there have been several "near-misses," which have been quickly and successfully responded to. Current operational and technical activities appear to be, for the most part, professional and conscientious with regard to safety.

However, the entry into the market of operators who have little or no experience in the operation of these vessels, combined with the probability of availability of lower-priced, second-hand vessels, gives rise to a concern that current standards might not be upheld in the future. Also, new submersible designs are being developed, while at the same time the innovative use of materials such as acrylics in hulls is being explored.

Given these impending changes, the primary concern of the committee is that the Coast Guard develop a set of regulations or standards, procedures, and tests that will ensure that future submersible builders and operators meet and maintain the same or better standards found in operations observed to date. Given this concern, the committee chose to include in its scope of assessment an examination of all aspects of the systems, including design of the submersible, support systems, operating and maintenance considerations, crew qualifications and passenger management. It is evident that both the Coast Guard and ABS are headed in the right direction with revisions of rules [*] and the Coast Guard's proposed circular for interpretation of existing regulations (see Appendix A). Continued close cooperation between the Coast Guard and ABS is essential. Additionally, rules developed for the U.S. industry and submersibles under U.S. cognizance may be relevant and useful to foreign tourist submersible operations.

Specific areas of concern, discussed in detail in the report, and the committee's recommendations regarding those concerns, are presented below.

COAST GUARD'S CENTRAL AUTHORITY AND SUBMERSIBLE TECHNOLOGY

There is need for a center of technical expertise regarding submersible applications. This expertise has largely been in place in (de facto) U.S. Coast Guard Headquarters to assist in the certification of the present generators of submersibles. The continuity and enhancement of this Headquarters capability are needed for this unique type of vessel and associated system.

- *To facilitate the maintenance of high standards in submersible vessel design, construction, and operation, the Coast Guard should establish the institutional responsibility in Headquarters—i.e., responsibility attached to specific personnel for the technical support of tourist submersible certification.* This will assist in achieving consistency in the implementation of requirements, the application of engineering judgment, and the determination of tradeoff decisions, while helping to focus attention on the enhancement of safety in these vessels.

At present, the Coast Guard has few personnel with technical expertise in tourist submersibles. (Some Coast Guard personnel have such expertise, but duty rotation spreads them too thin.) The Coast

[*] ABS Rules were published after completion of this report; earlier proposed classification rules were reviewed by the committee.

Guard needs to develop a better depth of technically capable personnel for use in certification, and inspection of tourist submersibles. The committee recognizes that the number of submersibles under Coast Guard jurisdiction is unlikely to be large enough to justify training a large staff (compared, for example, to the staff needed to support merchant shipping inspection). This is one of the reasons for having a few specialists, located at Headquarters, who may be possibly supplemented by experts from the Navy, ABS, or by consultants.

INSPECTION AND TESTS AFTER CONSTRUCTION

- Inspection (both initially and periodically through the life of the submersible) is crucial for ensuring safety. The inspection function for vessels is performed by Coast Guard local personnel and ABS surveyors who are well versed in surface vessel technology and inspection standards. These inspectors are working with surface ships on which structural and safety-related problems are commonly encountered and resolved. The technical and operating environments for submersibles present different inspection constraints with less scope for judgment by the local inspector. *The inspection program should be defined by the Coast Guard early in the design phase of each class of submersible. To provide their expert input, Coast Guard Headquarters personnel, from the office designated to provide continuity of expertise in submersible technologies, should participate in the inspections along with the local Coast Guard inspector force*.

  Circularity of cylindrical hulls is a critical factor in safety. It is checked on the construction process, but only on a specific-case basis, in periodic inspections. Inspectors should be alert to signs of damage or distortion and should call for a circularity check if any variation is indicated. *A circularity check should be a required part of each 18-month mandated survey or special survey*.
- The pressure vessel components of a submersible undergo an unusually large number of cycles of pressurization/depressurization. *Testing is recommended to establish fatigue failure limits and aging parameters for all new pressure-resistant materials used in tourist submersibles-including especially, at present, acrylic materials to be used in hulls and viewports, and rules should incorporate the required replacement criteria reflecting the results of fatigue tests*.
- The Coast Guard should establish a firm requirement that rules be applied and enforced consistently, with a formal procedure for approval of variances to the rules. *Field inspectors and the local Coast Guard OCMI should be given guidance on which items in the Coast Guard regulations or rules are subject to judgment and require Headquarters' concurrence and which are truly "go/no-go*."

OPERATIONAL CHAIN-OF-COMMAND

Particularly during emergency and rescue operations, rapid response and concise communications internal to the organization and external with assisting personnel and organizations are essential to the protection of life. A clearly established, documented, and tested chain-of-command is essential to assuring safety under emergency conditions. Present regulations and guidelines do not provide for documentation and testing within contingency plans.

- *There is a need to provide clearly defined chain-of-command/decision-making procedures for all operations, especially for emergency conditions. Periodic exercising of the chain-of-command under simulated emergency conditions should be required.*

SYSTEM REDUNDANCY AND CERTIFICATION TESTING

- The tourist submersible operator must ensure a significantly higher level of reliability, compared to most surface vessels, for those systems that are critical to the safety of life. Redundancy of critical components and systems provides one means of increasing reliability. For example, rapid deballasting capability, such as droppable solid ballast weights, would provide backup for the normally used ballast tank system.

ABS rules require two independent means of deballasting; the Coast Guard requires that sufficient jettison ballast (i.e., drop weight) must be provided for emergency ascent and that this capability be tested in the water, if possible. *The Coast Guard drop weight requirements and the ABS rules may not be consistent and should be clarified*. In addition, the committee observed that some deballasting redundant system tests required by the Coast Guard are not being provided by the builders or operators. *The Coast Guard, in its certification process, should require that all operating systems—especially those that are safety-critical—be functionally tested to design specifications as required in the certification requirements. For example, critical ballast control systems, such as the drop-weight system employed on many submersibles should be tested by dropping the weights in actual operating conditions. The Coast Guard should consider requiring full testing of this system at sea in at least one vessel of each class. There should be a safe, manual alternative means of dropping the weights from the interior of the submersible. In submersibles operating to depths of less than 150 feet, there should also be provision for divers to drop weights from the exterior of the vessel*

HAZARDS ANALYSIS AND CERTIFICATION REQUIREMENTS

The identification and establishment of hazards to the submersible crew and passengers are basic to the design, certification, test, and inspection plans and processes. This hazard analysis, to be useful, should address all components of systems that the submersible is intended to operate.

- *The Coast Guard should require that every new design or significant alterations be subjected to a hazard analysis and failure modes and effects analysis*. Analyses should encompass the entire marine system—the support systems, ferry boat, escort boat, emergency rescue capability and facilities, as well as crew training and qualification and passenger management.

QUALITY CONTROL RECORD KEEPING

- Quality control (QC) standards and documentation arc important to safety. QC includes record keeping. Such record keeping is clearly needed in areas deemed critical to submersible safety. *The Coast Guard needs to formalize the QC record keeping system for submersibles, establishing what records are kept, who maintains them, and where* .

FLAMMABILITY AND FIRE SUPPRESSION

- *The Coast Guard should include a requirement in their regulations that the selection of materials associated with electrical equipment and wiring and the interior of the submersible should include consideration of flammability properties, including their ease of ignition and flame spread, as well as the composition of combustion products. In its development of these material requirements, the Coast Guard should consider Navy and NASA experience. The design should preclude the use of materials that exhibit low flash or fire points. Flammability considerations should include specific caution given to passengers entering the submersible to not have any combustible fluids on their person.*

- The gas Halon is used in current fire suppression systems aboard some (possibly all) tourist submersibles and is accepted as the least risk option in most emergency scenarios considered as possibly occurring on submersibles that can rapidly ascend to the surface. However, Halon could present possible safety and health problems and should be reconsidered by the Coast Guard and ABS. In addition, since Halon contributes to the ozone hole phenomenon, it is likely to be eliminated as an easily available product within a few years. *Because nitrogen gas is nontoxic, consideration should be given to the development and testing of a nitrogen-based fire-suppression system as a possible replacement for Halon-based systems*.

EMERGENCY RESCUE

- *The Coast Guard should establish a uniform set of vessel design requirements related to the use of emergency rescue equipment*. This should include fixed attachment points for lifting tools by another submersible or remotely operated vehicles (ROVs), as well as fittings for connection of hoses from the surface. Consideration should be given to requiring standard hatches (or adaptors) that can be outfitted with mating rings for rescue on at least one hatch.

PASSENGER MANAGEMENT

- Given the large numbers of passengers and their general unfamiliarity with the submersible environment, passenger management is an important area of operational safety. *The Coast Guard (as part of their requirements) should establish planning and training guidelines for passenger management during both normal and emergency operations, covering operations ashore and en route to and from the submersible, as well as underwater* .

SMALL PASSENGER TOURIST SUBMERSIBLES

- There is a category of small, deep-diving submersibles that will be covered only be ABS classification and insurance-related restrictions, not by Coast Guard certification and inspection requirements. These submersibles, carrying six or fewer passengers, come only under current small-boat safety rules, which the committee believes are inadequate to ensure the safety of tourist submersibles. *The Coast Guard should establish a special category for these submersibles, to include licensing of the pilots, and closely monitor this emerging segment of the industry* . The Coast Guard may require special statutory authority to extend regulatory coverage.

Even though the number of submersibles in U.S.-controlled waters is small and not likely to grow dramatically in the near future, the number of passengers involved on an annual basis is quite large. *The Coast Guard should issue their revised regulations or standards as soon as possible, since this will improve the dialogue with builders and operators and provide the best possible climate for safe development of this promising new marine industry*.

Although the operators have had varying degrees of difficulty in complying with classification and certification requirements, the submersible operators observed by the committee have evidently given major consideration to safe operations. This positive safety attitude demonstrated by observed operators is clearly in their own interest, since any accident would be a business catastrophe. As operations expand and become more competitive, however, there will be a tendency to cut corners. As noted earlier, it is possible that older vessels sold into the secondary market might enter service under less technically capable operators who are not as committed to safe operations. These concerns are the driving force behind the committee's recommendations for tightening up controls. Now is the time to take the recommended actions.

1

Introduction and Outlook

A ride in a passenger-carrying submarine, or tourist submersible,[*] is both novel and affordable. In just a few short years, nearly three-quarters of a million people have already enjoyed this memorable experience. The potential number of those who might do so is substantial, given the current demographics of the leisure industries. It is a market environment in which there may be a dramatic proliferation of tourist submersibles of different types, depths, and site locations during the next two decades.

During the year the committee worked on this study (1989) the number of tourist submersibles in the world increased from 16 to 25. This figure includes those vessels currently operating and those under construction and soon to go into operation (firm orders exist for five more). Seven operate under U.S. Coast Guard regulatory jurisdiction, though one is not a U.S.-flag submersible. This is the largest number of tourist submersibles under a single national jurisdiction.

With some extrapolation and adaptation of existing rules for surface vessels, the Coast Guard has certificated five submersibles. However, it is not a routine process; these vessels are unusual in many ways. Given their mode of operation, the number of dive cycles for a given submarine is impressive—perhaps 10 cycles per day on a regular basis. (Other submersibles, used for research and military purposes, would not be subjected to in a lifetime as many cycles as these see in a year.) They are constructed of materials not commonly used in research or military submarines, and employ larger area viewports. Compared with research or work (industrial) submersibles, their passenger count is high, and the passengers are less knowledgeable of the environment and potential hazards. These considerations suggest a need for more comprehensive rules and standards for design, construction, and operation of tourist submersibles.

Development of the tourist submersible industry would be inhibited if safety-related incidents were to generate a public impression that makes the underwater experience aboard one of these vessels either frightening or unattractive to the average potential customer. Investment will also be discouraged if the business is unable to operate with conventional, affordable insurance against liability. Safety should thus be of paramount concern not only to the passengers and the regulators of this industry, but also to the builders and operators.

[*] This report will use the term "tourist submersible" to designate manned submarines employed by private companies to carry a crew and paying passengers on brief underwater sightseeing excursions.

Because this is a new type of marine activity, it is useful to review the current state of the business before considering technical and operational issues in succeeding chapters. This introductory chapter surveys the evolution and present state of the tourist submersible industry, then briefly examines business considerations that may determine its future growth.

NATURE AND STATUS OF THE TOURIST SUBMERSIBLES INDUSTRY

Precursors of Today's Tourist Submersible

Small manned submarines did not originate with the current fleet of tourist submersibles. Over the past three decades nearly 100 deep submergence vehicles (DSVs) have been put into service. The typical DSV carries a crew of three (no passengers) and is used in support of offshore gas and oil development or for oceanographic research. These submersibles have made dives as deep as 11,745 meters (35,800 feet) (the deepest known place in the ocean)—although most operate at depths of 366 meters (approximately 1,200 feet) or less. Because passengers are not carried and crews are small, there has been virtually no government regulation of these operations. However, almost all have been built and maintained according to established rules of the major ship classification societies (see Chapter 2). This has helped them to achieve an excellent safety record. In thousands of dives over a 30-year period, there have been only three fatalities (none included tourist passengers) and no loss of a DSV. Thus, well before the modern (since 1970) tourist submersible appeared on the scene, there was a considerable international body of design expertise and operational experience for small manned submersibles of all types.

The first true tourist submersible was the *AUGUSTE PICCARD* (Figure 1-1). Developed by Dr. Jacques Piccard (whose father, Auguste, invented the bathyscaphe family of submersibles), it was designed to dive to 820 meters (2,500 feet). It was built in Switzerland in the early 1960s, and the American Bureau of Shipping (ABS) reviewed and inspected its design. This submarine was operated at the year-long Swiss National Exposition, held in 1964-1965. It carried 40 passengers, plus a crew of 4, to depths of nearly 250 meters (820 feet) in Lake Geneva. At the fair's end the *AUGUSTE PICCARD* had made 1,112 dives, safely carrying over 32,000 passengers.

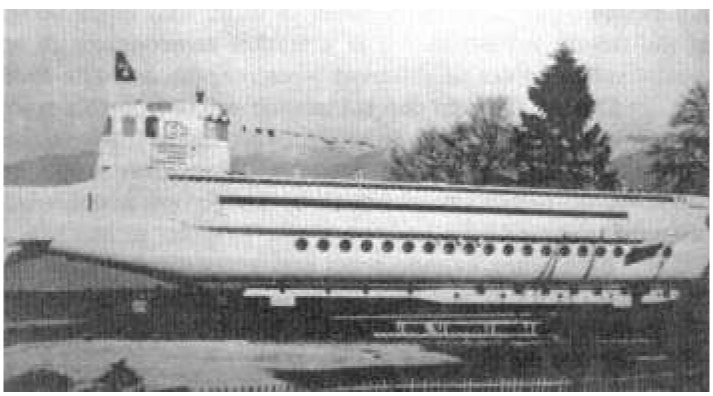

Figure 1-1 The August Piccard demonstrated at the Swiss National Expo in 1964-1965.

Recent Development of the Industry

This is still an infant industry, less than a decade old in presenting entertainment-oriented submerged travel on a large scale. Near term, the focus is on the increasing number of 25- to 50-person tourist submersibles regularly offering rides in shallow waters near resort centers. Eventually a distinctly different group of smaller submersibles will be developed to go to deeper depths, into more exotic underwater environments, and probably will serve a more affluent clientele. This market is presently being served by converted research or work submersibles. Although the operating and technical elements for the undersea experience will have much in common, these latter submersibles are likely to be fewer in number and more exclusive—a "safari" rather than a "jungle theme park" visit.

Table 1-1 lists the tourist submersible "fleet" as of late 1989 (not counting those under construction). Research Submersibles Ltd. (RSL), of Grand Cayman, British West Indies, was first in today's tourist submersible business. In the early 1980s the company purchased several work submersibles, mostly retired

TABLE 1-1 Summary * of Tourist Submersibles Operating in 1989 **

Name	Builder	Year BLT	Pass	Location	Operator
ATLANTIS I	Sub Aquatics Development Corp.	1985	28	Grand Cayman Island	Atlantis Submarines (Cayman) Ltd.
ATLANTIS II	Sub Aquatics Development Corp.	1987	28	Georgetown Barbados	Atlantis Ltd.
ATLANTIS III	Sub Aquatics Development Corp.	1987	46	St Thomas, U.S. Virgin Islands	Atlantis Submarines
ATLANTIS IV	Sub Aquatics Development Corp.	1988	46	Oahu (Waikiki), Hawaii	Atlantis Submarines Hawaii, L.P.
ATLANTIS V	Sub Aquatics Development Corp.	1988	46	Apra Harbor, Guam	Atlantis Submarines Guam
ATLANTIS VII	Sub Aquatics Development Corp.	1989	46	Kona, Island of Hawaii	Atlantis Submarines Hawaii, L.P.
CORAL ADVENTURE (RS-250-4)	Wartsila Laivateollisuus	1988	46	Amami Oshima, Kyushu, Japan	Coral Marine Co., Ltd.
DEEPSUB (PC-1202)	Perry Offshore	1975	10	Cozumel, Mexico	Del Mar Deep Sub
ENTERPRISE (LG-50-2)	Fluid Energy Ltd.	1988	48	St. George, Bermuda	Looking Glass Tours Ltd. Stopped business at end of 1989
GOLDEN TROUT (RS-250-2)	Wartsila Laivateollisuus	1988	46	Lake Simojarvl, Finland/Tennerife, Canary Islands	Finnish Submarine Tours Inc./ SUBTREK S.A.

* Listed alphabetically by name of vessel.

** Based on end of year 1989 information.

from operations in the North Sea, to provide worldwide scientific, salvage, and tourist services. At one time, with 7 units, RSL was the largest owner/operator of DSVs in the world. They were built in the United States by Perry Offshore Corporation (largest manufacturer of submersibles in the world, with 28 built) and in Canada by the former HYCO company (the second largest, with 14 built).

Name	Builder	Year BLT	Pass	Location	Operator
LOOKING GLASS (LG-50-1)	Fluid Energy Ltd.	1988	48	St. Thomas, U.S. Virgin Islands	Submarines Tours Ltd. of St. Thomas. Stopped business March, 1989
MARIEA I (RS-250-1) of N.	Wartsila Laivateol-Co., Ltd.	1987	46	Saipan, Territory Marianas	DOSA Sub-Sea lisuus
MARIEA III (RS-250-3) Co.	Wartsila Laivateol	1988	46	Cheji-do, Korea	Daekuk Subsea lisuus
GOLDEN SALMON (RS-250-5)	Wartsila Laivateollisuus (hull)s with submarine (assembly)	1989	46	Tennerife, Canary Islands/Lake Simojarvl, Finland	SUBTREK, S.A./ Finnish Submarine Tours Inc.
MOGLYN	Mitsubishi Heavy Ind.	1989	40	On'na Village, Okinawa	Japan Submarine Tourism Co., Ltd.
PAU PAU (PC-1201)	Perry Offshore	1975	2	Rota Island, Territory of N. Marianas	Micronesian Investment Corporation
PC-1205	Perry Offshore	1978	2	Grand Cayman, BWI	Research Submersibles, Ltd.
PC-1802	Perry Offshore	1978	3	Grand Cayman, BWI	Research Submersibles, Ltd.

DSV-type submersibles were originally designed to carry a pilot and 2-to 3-man crew. Diver lockout versions carry 2 divers in addition to pilot and crew. Depth capabilities are from 100-500 meters (328-1,640 feet), the depths associated with their application to offshore oil and gas development work. This type of submersible offers a relatively low-cost way to enter the tourist submersible business. However, the worldwide fleet of DSVs is aging and decreasing in numbers. Perry built their last DSV in 1982, and HYCO went into receivership in 1979.*

RSL's passenger operations with DSVs began in 1983; by late 1989 they had made more than 6,500 passenger-carrying dives. For a ticket price of $200 each, two passengers can dive to a depth of 250 meters (820 feet) down the Grand Cayman Wall.

In addition to RSL, there are two other DSV operations, one at Rota Island in the Marianas Islands (Micronesian Investment Corporation) and at Cozumel, Mexico (Del Mar Deep Sub). Both use Perry DSVs. A third operation (also a Perry DSV) is planned by Subsea Tours Inc. for 1990 in the Florida Keys. The Cozumel and Florida Keys submersibles carry 6-8 passengers.

Although RSL was the first company to offer tourist rides in submersibles since *AUGUSTE PICCARD* in 1964, they were not the first to introduce the modern built-for-the-purpose tourist submersible. This was done by Sub Aquatics Development Corporation (SADC) of Canada with their ATLANTIS class (Figure 1-2). Formed in 1983 at Vancouver, SADC's first submarine, *ATLANTIS I*, with a 28-passenger (+2 crew) capacity, was put into service at Grand Cayman Island in January 1986. In March 1987, *ATLANTIS II* (also 28 passengers) began operations at Barbados. In August 1987, Sub Aquatics' third unit, *ATLANTIS III*, began operations at St. Thomas, U.S. Virgin Islands. *ATLANTIS III* is an improved design carrying 46 passengers and a crew of 3. This family of submersibles can operate to a depth of 45 meters (148 feet).

These first three submarines, and their operating companies, are owned by SADC. The operations are now profitable, with gross 1988 sales for the operation at Grand Cayman estimated to be more than $3 million (operating at better than 80 percent of the 28-passenger capacity). Since this one-year gross is about 90 percent of the full cost of that submarine system, the rate of return on investment is attractive.

In August 1988, *ATLANTIS IV* was put into service at Kona, Hawaii; in September 1988, *ATLANTIS V* started operations at Guam. *ATLANTIS VI* is under construction in Canada and will be put into service at Aruba, Netherlands Antilles, in 1990. The U.S.-built *ATLANTIS VII* was delivered to Hawaii, where it became operational in September 1989.

SADC estimates that ATLANTIS submarines will have carried over 600,000 passengers by the end of 1989. This is a remarkable record for a company less than six years old, whose first submarine operation did not begin until 1986.

In 1986, RSL also recognized the limitations of using work submersibles to carry passengers As a result, they joined with the Fluid Energy Ltd. (FEL) company in Scotland and developed the design for the LG-50, a 48-passenger (plus 2-3 crew) tourist submersible. This would be a built-for-the-purpose submersible that could carry a large number of passengers on shallow dives (30-50 meters, or 98-163 feet) with quick turnaround times between dives.

FEL set up a manufacturing facility in Scotland, where it produced two LG-50 series submersibles. As of late 1989, the two companies operating these submarines had failed in business, and the submersibles are out of service. Earlier, RSL/FEL had granted a license to the Finnish shipbuilding company, Wartsila, to build the submersibles (designated by Wartsila as the RS-250). A total of four RS-250 submersibles were built under license at Wartsila's Laivatoellisuus Shipyard. The average cost of these submersibles was about $2.7 million each.

Despite their initial success, Wartsila nevertheless determined that their internal rate of return in this business was inadequate. They terminated the program with a fifth RS-250 hull completed at the Laivateollisuus Shipyard. Meanwhile, in 1988 FEL (the licensor) also experienced financial difficulties and

* Perry and HYCO faced a reduced commercial market due to (1) competition from new unmanned, remotely operated vehicles, (2) improved diving technology permitting deeper work capabilities, and (3) reductions in offshore oil activity during the early 1980s.

went into receivership. Design, engineering, and technical personnel associated with the RS-250 work at Laivateollisuus spun off into two companies: W Sub Welding and Submersibles and SubMarine Oy. W Sub obtained the rights for the RS-250 and the fifth hull, while SubMarine Oy obtained a new tourist submersible design developed by Wartsila (SubMarine Oy calls this design the SM-100.)

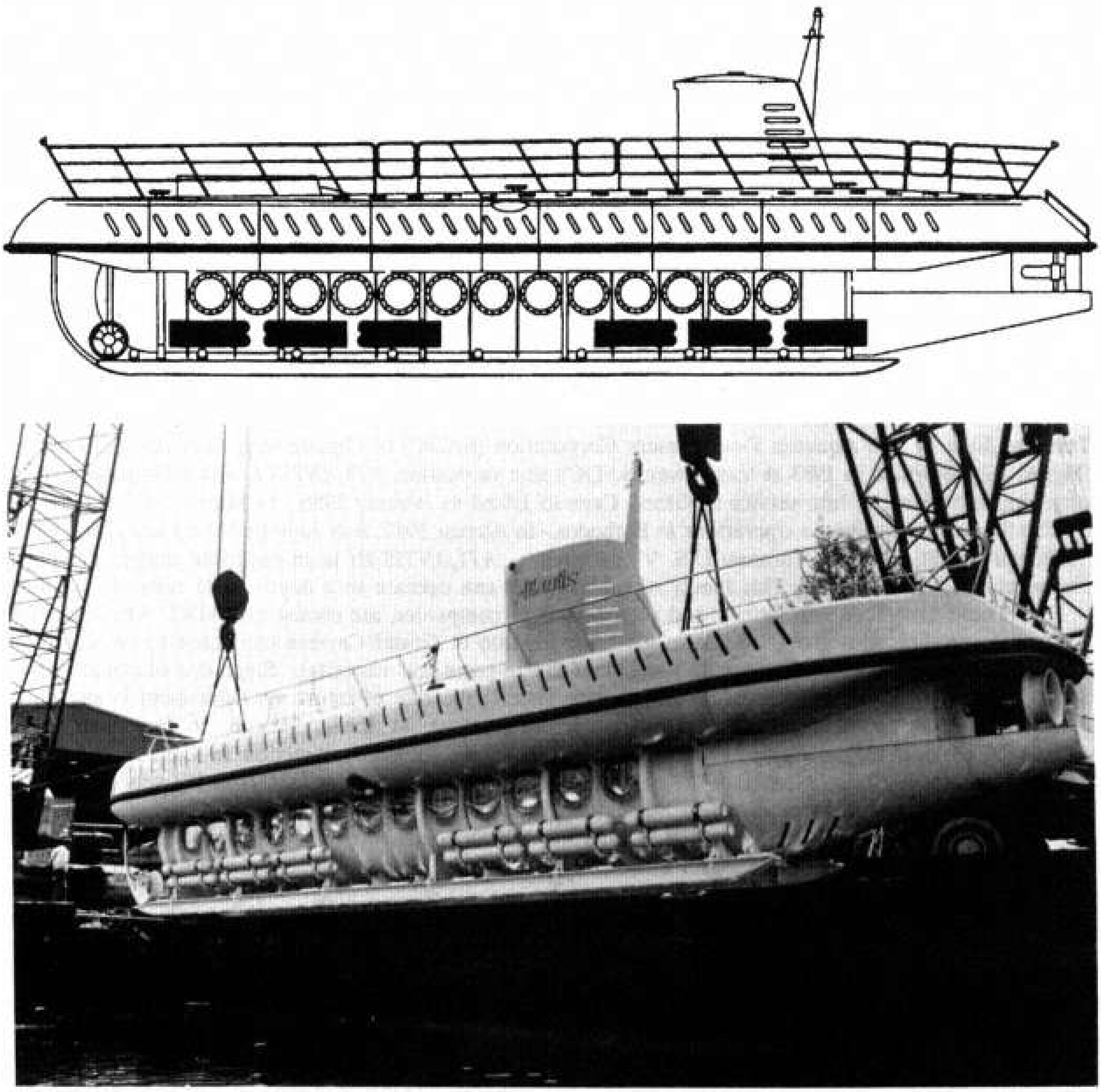

Figure 1-2 Cross-section (top) and photo (bottom) of ATLANTIS class submersibles. Photo courtesy of Don Walsh.

In 1989, Mitsubishi Heavy Industries (MHI) completed construction of a tourist submersible at their shipyard in Kobe, Japan. Launched in late summer and put into operation at On'na Village, Okinawa, in December 1989, the *MOGLYN* is a 40-passenger (+3 crew) submersible designed for operations at depths of 20-30 meters (66-98 feet). MHI's major partners in the operating company are Japan Travel Bureau and Japan Airlines.

Figure 1-3 Looking Glass, St. Thomas, U.S. Virgin Islands.

The successful market entry of RSL, Sub Aquatics, Fluid Energy (Figure 1-3) and Wartsila, in only three to four years, encouraged other builders and investors to look carefully at this new business sector. But the experience has amounted to more of a feasibility demonstration than market success for most companies. Among the operators, two operations (St. Thomas and Bermuda) have failed, while two or three other operations appear to be marginal due to poor site selection. (The submersibles selected were simply too large for the tourist market at those sites, or—in some cases—the market was already saturated.)

Among the submersible builders, Fluid Energy and Wartsila have left the business. These two companies accounted for nearly half (seven) of the large tourist submersibles presently in service. In the spring of 1989, HYCO Technologies (which had been acquired by RSL) ceased business. The company has been attempting to refinance its operation and resume development of the 40-passenger *ARIES* and *GEMINI* submersibles which would use transparent (acrylic) hull designs.

Present Tourist Submersible Programs

Although no one knows what the total world market will be for tourist submersibles, estimates made by industry consultants have ranged from 50 to 100 units. Table 1-2 lists submersibles presently under construction or for which firm orders exist. The table illustrates the rate of change occurring in this business.

With the demise of Fluid Energy and Wartsila's tourist submersible construction businesses, Sub Aquatics has virtually a market monopoly for at least a year. These three companies were the only ones who had built-for-the-purpose tourist submersibles in serial production, building a total of 14 among them. Three of them are headquartered in Finland: SubMarine Oy (two SM-100 class), W Submarine and Welding (two RS-250 class), Malmari & Winberg (two MERGO class). The fourth company is International Submarine Engineering (ISE) in Canada, which has built one 36-passenger ODYSSEY (Figure 1-4) class submarine for Saint Martins, Netherlands Antilles, and is now assembling a second for Bali, Indonesia. All of these submarines will enter service in 1990. W Sub also provides technical, spare parts, and training support services to all RS-250 submersibles.

As of 1989, there were three companies building more than one tourist submersible. In Switzerland, the Deep Line Company of Zurich engaged the services of Jacques Piccard to help design the 16-passenger SPT-16 tourist submersible. SPT-16 is being built by Sulzer Brothers Company in Winterthur, Switzerland, and will be operational in early 1990.

A French company, COMEX Marine Parks, has developed a unique tourist submersible design. They propose an acrylic, transparent-hulled vessel, *SEABUS*, which can operate in three modes: free-swimming, tethered, or on underwater rail tracks. COMEX, one of the world's largest commercial diving

TABLE 1-2 Tourist Submersibles Presently Under Construction

Name	Builder	Year BLT	Pass	Location	Operator
ATLANTIS VI	Sub Aquatics Development Corp.	1990	46	Aruba, N.A.	Atlantis Submarines Aruba
MERGO 10	Malmari and Winberg, Finland	1990	10	Sharm ash Shaykh, Egypt	(unknown)
MERGO 10	Malmari and Winberg, Finland	1990	10	Cyprus	(unknown)
ODYSSEY I	International Submarine Engineering, Canada	1990	36	Sint Maartens, N.A.	Submarine Safaris of of Alberta
ODYSSEY (CLASS)	International Submarine Engineering, Canada	1990	36	Bali, Indonesia	International Submarine Safaris
SEAVIEW	Sea View Enterprises, USA	1990	10 or 30	Hawaii	Sea View Enterprises
SEAVIEW	Perry Offshore (PC-12), USA	1990	6	Key Largo, Florida	Subsea Tours, Inc.
SM-100	SubMarine Oy/ FRABECO, Finland/ Belgium	1990	48	Eilat, Israel	SCANDIVE (Norway) & Morris Kahn (Israel)
SM-100	SubMarine Oy/ FRABECO, Finland/ Belgium	1991	48	(unknown)	(unknown)
SPT-16	Sulzer Brothers, Switzerland	1990	16	Swiss Lakes	Deep Line AG

NOTE: This listing is based on best information available at the time of publication of this study. However, the fast changing nature of this business results in changes that are difficult to track. Therefore, this table should be used as a guide to the dynamics of the tourist submersible sector rather than an absolute forecast of what will happen in 1990-1991.

companies, has also had extensive experience with the design, construction, and operation of manned and unmanned submersibles. However, they have not yet built or sold a *SEABUS*. W Sub Welding and Submersibles completed the fifth RS-250 hull, which they obtained from Wartsila, in mid-1989.

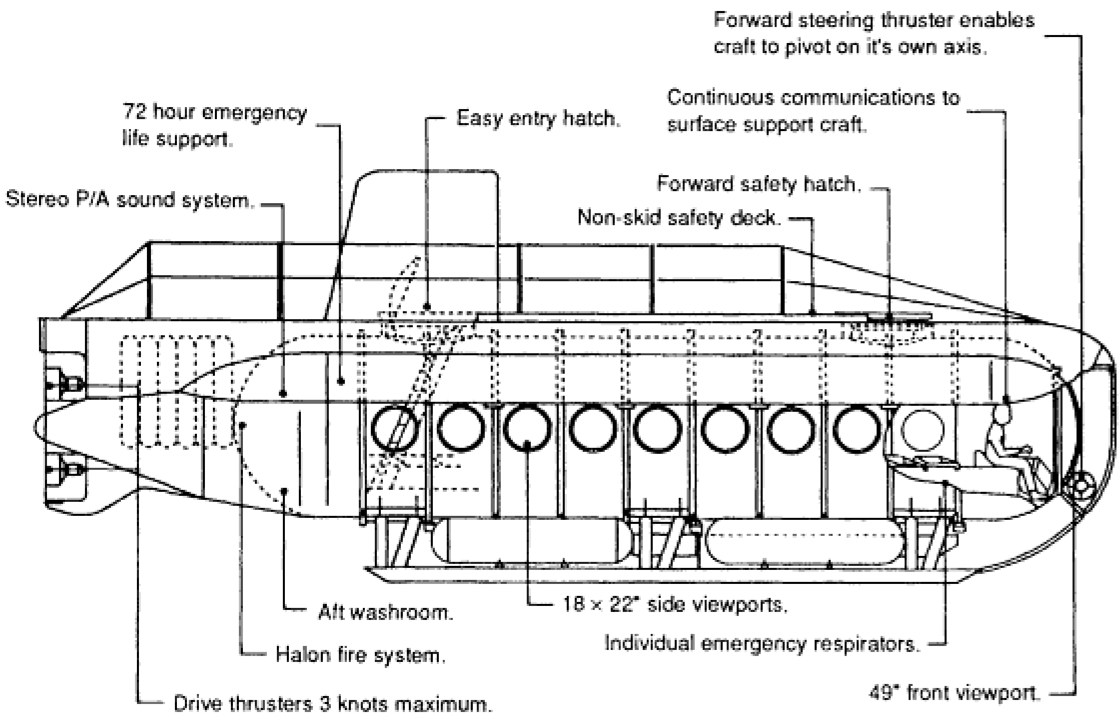

Figure 1-4 Cross-section of the Odyssey class submersible.

In 1989, Sea View Enterprises Company of Hawaii began construction of a 10-passenger tourist submersible in San Diego, California. This design will use an acrylic cylindrical hull with acrylic hemispheric end domes. Some of the hull sections have been completed. If technical questions associated with the use of massive acrylic for submarine hulls can be overcome, this company also proposes to build a 30-passenger version of *SEA VIEW*.

COMEX Marine Parks, Sea View Enterprises, and Hyco Technologies (if they return to the business) all face a number of technical problems since each of their designs use massive acrylic as a pressure hull structure material. These problems are discussed in the next section and in greater detail in Chapter 3.

In Florida, SUBSEA Tours, Inc., is completing conversion of a Perry PC-12 workboat submersible to a tourist submersible. The conversion will increase the capacity to six passengers in addition to the pilot. This DSV should be operational in 1990.

Projected Trends in Tourist Submersible Development

There are three new developmental directions that should be mentioned, even though they are in their earliest stages: (1) the use of acrylic materials, (2) design of deeper diving submersibles, and (3) the trend toward smaller submersibles.

Acrylic Materials

Acrylic has the same index of refraction as seawater. Therefore, a hull made from this material would in theory provide the passenger with an "infinite window" into the sea. However, the distance between theory and practice is considerable.

Acrylics have been approved for use as viewing ports and hemiheads (at the end of metal pressure hulls) for several years. Also, at least five DSVs have been constructed with *spherical* hulls made entirely from acrylic. Recently, designs have been proposed in which cylindrical submersible hulls would be built entirely out of thick-walled acrylic plastic. However, the classification societies have not yet established rules governing design, construction, and testing of this type hull. (See Chapter 3 for further discussion.)

Deeper Diving Submersibles

Some designers are now considering how tourist submersibles can be developed for depths as great as 300-500 meters (975-1,625 feet). This would permit taking passengers into depths beyond the penetration of sunlight, where distinctive life forms are found and where powerful exterior lighting will be required. While more than 80 percent of marine life forms can be seen in the upper 20 meters (65 feet) of the sea, the *adventure* and novelty of visiting the deep ocean can be expected to attract a certain percentage of tourist submersible passengers.

These submersibles will be of a different design and will have less passenger capacity than current shallow-diving submersibles. The design challenge will be to build them at a "per seat cost" that will permit the operator to make an adequate profit while making fewer dives per day and taking fewer passengers per dive.

Smaller Submersibles

The third important developmental trend is also related to small tourist submersibles. Comparisons show that the larger a submersible's passenger capacity, the lower the per-seat cost. Downsizing is nonlinear; that is, a 25-passenger version of a design will cost more than half as much as a 50-passenger version.

Yet there are compelling market reasons to develop tourist submersibles in the 6-20 passenger range. Many resort locations do not have the throughput of tourists necessary to fill a 50-passenger submersible, 6-10 times a day, 6-7 days a week, year-round. (This problem has caused at least one operation to fail.) A small submersible designed for this type of service would have a greater chance of commercial success in such locations.

When it enters service in early 1990, Deep Line's SPT-16 will be the first of this group of tourist submersibles. By the end of 1990 it will have completed a major operational series in five Swiss lakes. At this time the concept of the smaller submersible can be more carefully assessed.

BUSINESS CONSIDERATIONS

Market Development Potential

There appear to be about 50 sites worldwide where natural characteristics like reefs and tourist demographics (numbers and affluence) are favorable for tourist submersible operations. "Location, location, and location" is a crucial consideration for mass-market tourist ventures, submersibles included. Popular tourist destinations for land-based or cruise ship-visited pleasure include scenic islands and seashore resorts, which often have natural underwater attractions. For the tourist submersible, nature can be imaginatively augmented with specially created underwater reefs, shipwrecks, and scuba-diving actors who both perform and offer food to attract marine life.

Factors that resort or hospitality owners consider in presenting entertainment to their visitors include novelty, the time required to participate, appeal to age or sex groupings, safety, and, of late, whether the activity is seen as having a neutral or even positive, rather than negative, impact on the environment. In fact, several current operations are now doing this type of dive site enhancement with excellent results. Against these indices, tourist submersibles are desirable attractions.

Tourist destinations and cruise lines measure the potential of their market by highly refined techniques that consider the numbers of people who can afford to enjoy their services. For example, whereas 3 million North Americans have enjoyed cruising annually, there are 50 to 70 million who might qualify for the experience on the basis of income, age, or status as a consumer of leisure products. By this measure, the number of people who have ridden in tourist submersibles is quite small compared to the potential market.

The undersea trip has developed with certain parallels to recreational air travel like helicopters, balloons, and gliders. The price of a ticket is standard, and is roughly equivalent to that of a snorkeling trip, scuba boat ride, or bus excursion. Further, sales of collateral items on shore offer other opportunities to generate revenues.

Insurance is a factor with significant potential impact on market development and business expansion. The international insurance market has had no real difficulty in providing coverage for tourist submarine operations. Insurance has been available at fair rates for those few programs now operational. The insurance is costly—at least by comparison with other water asset coverages—but this is because the understanding and evaluation of risk are more mature and experience with conventional marine operations is much greater. Premiums appear to be 5 percent (or thereabouts) of value or achievable sales, whereas a cruise or hotel insurance rate would be approximately one third as much. As additional operations are set up in diverse geographic areas, there may be some problems in assessing the on-site risks for the insurance market. However, insurance costs will likely be reasonable if the operator builds the submarine to classification society standards, fully complies with governmental regulations, and follows requisite standards for training and safety that evolve from the classification, certification, and underwriting interaction.

Investment Aspects

It is in the investment dimension where the uniqueness and immaturity of the tourist submersible business are felt. The relative youth of the industry and the uniqueness of each environment—both physical and geopolitical—make the tourist submersible investment a venture capital matter at this juncture. Funds are costly and investors seek a generous return.

Theoretically, at least, generous operating rewards are possible to offset (1) the risks of choosing a specific site and establishing a beachhead to discourage competition, (2) the task of containing costs, and (3) the potential that any accident, however insignificant, will be highly publicized and thus business threatening. But experience has yet to prove these profits achievable on a large scale, and the risks make financing very difficult.

In the current tourist submersible business, almost all the operators and investors are small companies. Many have had no significant previous experience with marine-related tourism. This fact places special emphasis on the importance of review by surveyors and inspectors and control by the classification societies and the Coast Guard. However, the entry of the joint venture made up of the giant Mitsubishi, Japan Airlines, and Japan Travel Bureau companies is significant for this new business sector. It is the first time large companies, with experience in underwater engineering and tourism, have become involved in a significant way.

Among the current players, a high profile is held by one North American firm, SADC, whose design, production acumen, and operating approach appear able to withstand rigorous inquiry. Should market developments move in the current direction of intensified concentration of operators or licensees, then there will be a business challenge to maintain the high and obviously costly standards of the market leader. But the tourist industries are typically characterized by price competition, with a desire to attract customers via lower rates, discounts, and other revenue-reducing incentives. The entrance of competitor firms and designs in the future may introduce pressures on investment return that would have the dual effect of discouraging initial investments in new tourist submersible units and introducing pressures to cut costs in the operation of existing ones.

A variant of this situation exists today where units are available due to financial failure of their original operator. The nature, resources, and operating philosophy of the eventual owner of these units cannot be predicted. Clearly there is the possibility of a cut-rate operation following a bargain purchase which, should it begin to be a trend, will test the mettle of the various regulators who are concerned with the business. The policeman (U.S. Coast Guard) will have to be both statesman and technician and will have the future of the industry in its hands.

Governmental Responsibilities

Throughout the world, almost all seagoing passenger-carrying operations (i.e., surface ships) are under the regulation of governmental agencies. This helps to ensure both public safety and efficient operations at sea. However, present regulatory systems do not explicitly address the carriage of passengers under the sea. Adapting existing rules to an entirely new marine operation has proved difficult.

The U.S. Coast Guard has acquired considerable "on-the-job learning" as a result of having to adapt existing rules for surface vessels to immediate requirements. The Coast Guard is now facing the need to improve guidelines for design, training, operations, and safety for submersible operations. The Coast Guard has inspected and approved operations at St. Thomas, U.S. Virgin Islands (two submersibles); and one each at Kona and Waikiki, Hawaii; Guam, Saipan, and Rota Island.

At St. Thomas, Guam, Saipan, and Rota Island the Coast Guard has been involved in approval of submersible operations at each of these locations even though the operations do not fall under the regulation of the Jones Act (i.e., U.S. citizen built, owned, and manned vessels). For example, the vessel at Saipan was built in Finland and operates under the Panamanian Flag. Nevertheless, since the Territory of Northern Marianas is affiliated with the United States, the Coast Guard has regulatory responsibilities for maritime operations in the territory.

SUMMARY

Growth of the tourist submersible business has been phenomenal. Within the span of half a decade the built-for-the-purpose tourist submersible has been designed, built, and successfully deployed. The number of vessels in service is not large, but the number and throughput rate of passengers are quite large. By the end of 1989, three quarters of a million passengers had made dives with no serious accidents.

Nearly all of the present fleet of 14 large tourist submersibles were put into service in 1988-1989. The operational and technical learning curve has been not only steep but harsh. After only two years, at the end of 1989, two operators and two of the three major manufacturers had left the business. Other operators will probably follow. These business difficulties do not imply limited opportunity in this new sector; rather, they have been due to problems of poor cash flow and bad management as well as a failure of the builders, investors, and operators to understand their market.

By and large, those builders and operators who remain in the business are competent, professional, and safety-conscious. However, because of the business climate, it is difficult to predict whether those virtues will continue to characterize the industry. There are several tourist submersibles now entering the secondary market, which may be bought by less experienced and perhaps less safety-conscious operators. By the end of 1990, the number of passenger-carrying submersibles in service is expected to be nearly double the count at the end of 1988. Operating locations will expand from 12 to 20, in 12 countries.

These changes mean added pressure for regulatory authorities to develop rules and regulations for tourist submersible design, manufacture, and operations. Fortunately, regulatory frameworks developed by the Coast Guard are widely respected and often adopted as a minimal standard or an "accepted approval" throughout the world. Thus, the Coast Guard's current concern with establishing a more effective regulatory framework for tourist submersibles will be most welcome by other nations facing similar concerns. This has already happened; in late 1989 the Coast Guard and ABCs assisted the government of Bermuda in formulating rules and regulations for passenger submarine operations there.

2

Existing Procedures for Classification and Certification of Tourist Submersibles

The U.S. Code of Federal Regulations (CFR) requires that vessels built in the United States or operating in U.S. waters be certificated by the Coast Guard as being seaworthy and meeting the requirements for safety at sea as well as other regulations stipulated by law. Before they will issue insurance, the insurers require that a vessel meet standards for construction and operation established by the American Bureau of Shipping (ABS) or one of the other recognized classification agencies, e.g., Lloyd's Register of Shipping (U.K.) or Det norske Veritas (DnV) (Norway). When a vessel meets these standards established by a classification society, it is deemed to be "classed." Thus, there are two important terms—*certification* and *classification* —which are sometimes used interchangeably, resulting in some confusion. While there is some overlapping of the plan review and inspections, essentially the U.S. Coast Guard is responsible for certificating that the vessel and every aspect of its operation meet all federal regulations.

Separately, the ABS or other classification agency must state that the vessel complies with its rules (which underwriters interpret as being that the vessel is structurally well designed and built and will be an acceptable insurance risk). In order to classify a vessel, the ABS[*] has established rules to be followed during design and construction.[1] In the case of submersibles, these rules are based in part on the standards established by the American Society of Mechanical Engineers (ASME) governing Pressure Vessels for Human Occupancy (PVH0-1).[2] While the Coast Guard does not require classification, it does use the ABS rules and ASME standards as guides when evaluating vessels for certification. In both organizations, the number of technical personnel involved in certification and classification of submersibles is small.

Since relatively few tourist submersibles have been certificated or classified, the procedures and documentation have been developed with the cooperation of the builders, the ABS, and the Coast Guard. All of the participants report that they have learned from each other and recognize the importance of each player. The interaction has caused them all to have a healthy mutual respect, which is an ideal situation. A recent paper by Coast Guard officers describes the history and current procedures for regulation of tourist submersibles.[3] The details of the Coast Guard plan review for the *ATLANTIS III* submersible are described in a paper published by the Society of Naval Architects and Marine Engineers (SNAME).[4]

In addition to reviewing the design and engineering of the vessel, both the Coast Guard and the classification societies routinely conduct inspections during the construction and at regular intervals during the operation of each vessel. Although technical expertise is concentrated in the headquarters of both ABS and the Coast Guard, inspection of the vessels is conducted through regional offices headed by senior personnel. In general, contact with the organization is through the local inspection offices for all matters; this establishes a single point of contact for a given operation or vessel.

[*] ABS will be used throughout as the U.S. example of a classification society, of which there are some 17 worldwide.

RULES AND REGULATIONS

The Coast Guard has taken a systems approach to certificating submersibles, evaluating the combined design, operation, dive site, and operator qualifications from the conceptual stages through the initial operations. As noted previously, the basic requirements for certification are promulgated in the Code of Federal Regulations under Titles 33 and 46, which contain regulations for many different subjects. The sections that apply to passenger-carrying submersibles (46 CFR, Subchapter T) are referenced in a set of draft guidelines that will be issued by the Coast Guard as a Navigation and Inspection Circular (NAVIC [*]).[5] This draft circular (attached as Appendix A) is thorough and contains amplifying remarks that should prove useful to anyone working in the field. ABS has similar documents available to anyone who requests them. These documents are based on extensive Navy experience with submarine design, with contributions from industry technical societies, especially SNAME and ASME.

DESIGN

Design of submersibles is presently guided entirely by the ABS rules (see reference 1).[**] This comprehensive new document contains detailed information on the design and construction of submersibles. The requirements are in accordance with good engineering practice and have been proven by many tests and experiments. Finite element analysis for structures is a recognized stress analysis method when existing rules are not directly applicable. For most calculations, the formulas to be used are specified in the document. The requirements for hull penetrations are specified in great detail, particularly those for viewports and acrylic domes. The new book of rules results from and reflects the experience gained while designing and building a wide range of submersibles, including some newer ones.

PLAN REVIEW

Engineering computations and plans are prepared by the vessel designer or the shipbuilder. Normally, they would then be presented to the local offices of the Coast Guard (specifically, to the Officer in Charge of Marine Inspection [OCMI]) and the ABS, which—if the plans were for conventional surface vessels—would approve or disapprove them. Tourist submersibles arc considered to be distinctly different and therefore require special attention. Before plans arc submitted, the Coast Guard requires that a proposal describing the concept of each individual submersible to be built (including the draft operations and safety plan for the entire system) be submitted to the Marine Technical and Hazardous Materials Division (G-MTH) at Coast Guard Headquarters. Once this system concept has been reviewed and accepted (the process is referred to as a "system concept review"), the detailed plan is prepared and submitted, with the application for inspection, to the OCMI. The OCMI then forwards his set of plans[***] (in most cases

[*] A Navigation and Inspection Circular (NAVIC) is not part of the CFR. It provides guidance for implementing vessel inspection laws and regulation, but is not part of the regulation.

[**] The Coast Guard will accept design standards imposed by other classification societies only if they can demonstrate equivalence with ABS rules.

[***] Plans include pressure hull strength calculations; construction tolerances; life support and vital system details; buoyancy, stability, and damage calculations; material identification; and power and control systems.

without review) to the Marine Safety Center (G-MSC) in Washington, D.C. (not located at Coast Guard Headquarters), which is the appropriate technical office for review and comment or approval.

The boat designer also forwards the computations and plans directly to ABS headquarters for action by the technical staff, and they are then sent to the ABS surveyor. In both cases, review consists of an engineering investigation, which includes analyses of the method and accuracy of any calculations and the plan's clarity and completeness. When approved for construction, the plans and computations are returned via the local inspection offices to the designer, who will in turn issue them to the shipbuilder. Since the technical offices in the headquarters are small, a few people review the documents for all submersibles. However, these persons are normally Coast Guard commissioned officers who change jobs and locations frequently (every two to four years). This arrangement cannot ensure that there will be continuity of knowledge and policies and their application.

APPLICABILITY

Federal regulations differ by size and class of vessel. (Table 2-1 lists the subchapters of the CFRs relevant to the Coast Guard.) Most passenger-carrying submersibles are in the category of "small passenger vessels." These are defined as being less than 100 gross tons, carrying more than six passengers. They must comply with applicable sections of 46 CFR Subchapter T, "Small Passenger Vessels"; Subchapter S, "Subdivision and Stability"; and Subchapter B, "Merchant Marine Officers and Seamen." Compliance with 33 CFR Part 155, "Oil Pollution Prevention Regulations for Vessels," and 33 CFR Part 159, "Marine Sanitation Devices," is also required. In addition, the COTP may impose special operating requirements under authority of 33 USC Chapter 25, "Ports and Waterways Safety Program," and 33 CFR Part 160, "Ports and Waterways Safety—General." Concerns of the COTP include special operational restrictions, navigational safety, and port security considerations.

Submersibles carrying six or fewer passengers are categorized as "Uninspected Vessels." Although not subject to inspection, they must still meet certain regulations regarding oil pollution, sanitation, boating safety, and manning requirements. Thus, the Coast Guard does have a measure of control over the operation of even this type of vessel, although the requirements do not address this size submersible and do not provide for periodic inspection after the vessel is manufactured. Again, the COTP may place operating restrictions, if the operation is deemed unsafe. A senior officer who has questions of a technical nature that exceed his or her expertise with respect to submersibles can contact the OCMI for consultation.* (In many ports today, it should be noted, a single Coast Guard officer is both COTP and OCMI.) As a minimum, permission to operate will be granted only if the vessel has been designed and built in accordance with recognized industry standards. At this time the recognized standards are the classification societies' rules and technical society standards.

The situation with regard to research and work submersibles is not within the charter of this committee. However, there are concerns about deep-diving work submersibles that have recently been acquired for tourist use and are currently being classed for that purpose through ABS. At this writing, it is unclear what position will be taken regarding the possible derating of these boats due to their age, maintenance practices, and proposed modifications (such as adding viewports by penetrating the hull).

Vessels of 100 or more gross tons are in another category. At the present time, there are no U.S. passenger-carrying submersibles in this size category. When and if they are built, they will be subject to the requirements of 46 CFR Subchapter H, "Passenger Vessels," rather than 46 CFR Subchapter T, "Small Passenger Vessels."

Recreational submersibles are vessels built primarily for recreational use by individuals. At the present time, the only requirements are the rules for boating safety, 33 CFR Parts 173-183 of Subchapter S. The COTP may impose restrictions if there are concerns about the safety of the operators involved.

* The operator may also appeal the COTP's decisions up through the chain of command to Headquarters.

Foreign submersibles (of any size) are ordinarily certificated by the country of registry. This certification is generally recognized by the Coast Guard for vessels other than submersibles. However, because of the uncertain nature of the hazards involved, the OCMI will not permit submersible operation until there is a valid U.S. Certificate of Inspection (COI) issued or Safety of Life at Sea (SOLAS) Passenger Ship Safety Certificate issued.[*] Both Lloyd's Register and Det norske Veritas (DnV) have classed manned submersibles.[6] With the construction of at least eight tourist submersibles in Europe—two of which are presently being classed by DnV[**]—it is desirable for the Coast Guard to maintain a dialogue with classification societies to encourage consistency in the interpretation of various rules.

TABLE 2-1 CFR Coast Guard Regulations Applicable to Tourist Submersibles

Title 33—Navigation and Navigable Waters
Subchapter A-General
Subchapter O-Pollution
Subchapter P-Ports and Waterways Safety
Subchapter S-Boating Safety
Title 46—Shipping
Subchapter A-Procedures Applicable to the Public
Subchapter B-Merchant Marine Officers and Seamen
Subchapter C-Uninspected Vessels
Subchapter F-Marine Engineering
Subchapter H-Passenger Vessels
Subchapter J-Electrical Engineering
Subchapter S-Subdivision and Stability

FINDINGS AND CONCLUSIONS REGARDING CLASSIFICATION AND CERTIFICATION

The ABS rules for passenger-carrying submersibles that were published in 1990 and the proposed Coast Guard guidelines (Appendix A) for certification of passenger submersibles that led to them were reviewed by the committee. These documents appeared to be adequate, and provided sufficient feedback to recognize past deficiencies and account for lessons learned through operational experience. In summary, the committee has not identified anything of significance regarding the rules for certificating these vessels that the Coast Guard has not already identified and focused on.

[*] The latter case is subject to an onboard control verification inspection by the Coast Guard to verify that SOLAS requirements have been met.
[**] Unpublished data provided to the committee by DnV, Houston, July 28, 1989.

There is concern about the safety and the lack of safety-related regulation of submersibles designed to carry six or fewer passengers, which are being designed and/or converted for tourist use. Present Coast Guard rules regarding tourist submersibles (46 CFR Subchapter T) should be amended to include the Subchapter C, "Uninspected Vessel," category of boats. Statutory authority may be required to extend this authority. With approximately 6 already under ABS classification and at least 40 others that could be purchased and modified, there is significant potential for future hazard. Discussions among ABS and other major classification societies would be beneficial since several classification societies have been engaged in development of rules applicable to submersibles for industrial use, or more recently, tourist submersibles under construction.

In the absence of direct application of Coast Guard rules, the basic safety of these smaller submersibles (6 passengers or less) can be assured only through the classification societies, and this will place a special burden on direct operational control by the COTPs.

3

Technical Aspects of System Design

This chapter provides an analysis of the present design, construction, and inspection standards utilized with regard to tourist submersibles. In the case of inspection practices, relatively detailed suggestions are presented for the development of a periodic inspection program specifically for these vessels. The life support systems and emergency rescue equipment aboard these submersibles are also reviewed briefly in this chapter.

DESIGN AND CONSTRUCTION

Compared to workboat DSVs, the technologies employed for the metal-hulled tourist submersibles are conservative and fairly simple. These vessels are shallow* diving (30-50 meters, or 98-164 feet), do not require elaborate operational equipment, and have short mission times. The major differences, when compared to submersible workboats, are the need for adequate life support, emergency equipment for a relatively large number of people (30-50), efficient and safe means of loading/unloading passengers, and the need to withstand a much larger number of dive cycles. Also, the interior of the submersible must be designed from both a business and safety standpoint to provide the passenger with maximum comfort, good viewing opportunities, and a relaxing interior design.

A major consideration in design and construction is that these assets will probably have an operational life of 20-25 years. Consequently, the hulls will have the highest number of diving cycles of any submersible built as they potentially pass through the hands of many owners. Initial design should therefore take into account a long service life as well as simplicity of maintenance and operation.

From a safety standpoint, the emphasis in construction must also be placed on reliability. Highly reliable methods of construction lead to successful and, hence, safer operating systems. "Methods of construction" should be construed to encompass both materials and vehicle fabrication processes.

As described in Chapter 2, the major classification societies—such as the American Bureau of Shipping (ABS), Lloyd's Register, and Det norske Veritas (DnV)—have each established rules for the design and construction of steel-hulled submersibles. To date, all but two tourist submersibles have been built to ABS class, and ABS has the only set of classification rules the Coast Guard recognizes for submersible design. In addition, the American Society for Mechanical Engineers (ASME) has published standards for pressure vessels for human occupancy (PVHO). ABS and the Coast Guard both recognize ASME's standard for PVHO as a satisfactory standard for man-related undersea pressure hulls.

* These submsersibles generally operate in waters where bottom depth does not exceed design operating depth.

The present ABS rules make no major distinction between commercial work submersibles and those used for tourist service. Therefore, there have been few difficulties in classing the limited number of steel-hulled submersibles specifically designed and built for tourist service. ABS is currently revising its rules to add provisions for tourist submersibles.

For main pressure vessel (MPV) design (and hence fabrication), ABS will approve designs based either on ASME for PVHO formulas (Section VIII, 1 or 2), or on ABS' own design formulas, which are based on Windenburg's critical buckling formula.[7]

Design factors of safety (f.o.s.) compare the actual design stress to the yield stress (strength) of the material used. For example, for an f.o.s. Of 1.5:1,

$$\frac{\text{Material Yield Stress}}{\text{Actual Design Stress}} = 1.5$$

An f.o.s. of 3:1 or 4:1 on the material's yield stress is used in PVHO design based on ASME standards, while classification societies such as ABS will accept a minimum of 1.5:1 on the yield stress. The criteria and factors used depend on the designer.[8] Also, the method by which ABS inspects the hull during and after fabrication varies with the design philosophy. For example, if an MPV is designed to PVHO standards, ABS does not require strain gauging of the hull during its hydrostatic (drop) test.[*]

The question concerning the choice of the f.o.s. for submersibles raises complex engineering design issues and variables, such as operational depth limitations related to the capabilities of emergency response and the operating environment for a design, as in the case of military submersibles. The committee views the choice of the passenger submersible f.o.s. as an engineering design issue of concern to both the Coast Guard and the classification societies, but outside the scope of this study.

Materials

To date, nearly all MPVs have been built using steel (either ASTM A516 or the equivalent). The implications are positive, since the specifications for steel are well documented, as are the weld procedures required for fabrication. This experience base with steel tends to enhance reliability.

However, some cautions are in order, particularly in regard to stainless steel. Stainless steel (e.g., Type 304 and Type 316) is used extensively in critical systems, including the oxygen system, the compressed air systems, the ballast systems, and all hull penetrators. Some stainless steel formulations have been shown to be susceptible to both stress corrosion cracking and crevice corrosion cracking.[9] [**] In the submarine environment, where these systems are continually exposed to salt water, both of these forms of attack on the material can occur. Some austenitic stainless steels (Fe-Cr-Ni-Mo alloys), which are highly corrosion-resistant, have been used with a high degree of success in marine applications[10] —although not yet in submersibles. Other materials that are more suitable for this application are the mild steels, the inconel/monel/copper-nickel alloys, and several types of titanium. While titanium is more expensive than other more commonly used materials, it may be cost effective.

Aluminum

Utilization of other types of material for the MPV presents additional problems. Aluminum is the second most popular choice for submersible construction material; but, depending on the series of aluminum

[*] In the drop test, a hull is lowered in water to 1.25 times the design depth for 1 hour to test its capacity to withstand hydrostatic pressure.
[**] W. W. Kirk, International Nickel Laboratory, personal correspondence with C. M. Jones, October 1989.

selected, it may prove problematic with respect to its weldability. The 5000 series aluminums, such as 5083 or 5456, are excellent materials in the pre- and post-weld condition. This series has not indicated susceptibility to early onset of stress and fatigue or cracking in the heat-affected zones in the material on either side of the welds. Series 6000 and 7000 aluminums are quite the opposite. Due to its availability and corrosion resistance, 6061-T6 has been utilized extensively in the submersible industry, both commercially and by the U.S. Navy (with disappointing results). The post-weld condition of the material in the heat-affected area has exhibited tendencies to crack under stress levels far below those predicted.

This problem has been brought to the forefront by the Naval Sea Systems Command (NAVSEA), which has issued instructions[*] that 6061-T6 will not be used for structural purposes when it must be welded without first being reviewed on a case-by-case basis. It is noted that the ABS allows a maximum stress of 9,000 psi for 6061 aluminum, versus the 8,000 psi the U.S. Navy allows for repair work on existing structures. NAVSEA's requirement for specific case-by-case technical review does seem prudent and presumably would be mirrored by the Coast Guard and ABS in their review processes.

Acrylics

Other candidate materials include thermoplastic materials such as acrylic. Acrylic spheres have been utilized on five submersibles to date. The thickness required for the Johnson Sea-Link submersibles' new spheres has been increased from 4 in. to 5 in. by ASME's PVHO. The original spheres were designed with a 20-year life expectancy but showed signs of failure within 15 years of service. This problem is a particular concern with plastics or composite materials utilized as pressure vessels subject to external (hydrostatic) pressure.

To date, three manufacturers have presented designs utilizing acrylic for the MPV. However, the classification societies have not established rules governing design, construction, and testing of this type of hull. To further compound the problem, HYCO Technology's *ARIES, SEAVIEW* , and COMEX's proposed *SEABUS* are proposed as cylindrical (not spherical) pressure vessels. No relevant test or operational histories exist here, since the history is based entirely on spherical shapes such as the U.S. Navy's NEMO submersible or the Johnson Sea-Link research submersibles.

If large area or extensive use of acrylics as a principal structural material is to be approved and rules for it written, the analytical and testing work will have to be contracted and paid for by the organization requesting the rules. It will be expensive and might require test-to-failure of a full-sized hull section, as well as development of extensive fatigue data. Even if acrylic hull standards are developed, the potential market for this type of submersible may be greatly diminished by the time this can be accomplished. The best operating locations may be already taken by steel-hulled submersibles before the first acrylic hull submersible enters tourist service.

There is another related problem with immediate significance. Present rules, based on PVHO standards, call for replacing all acrylic viewports after 10,000 diving cycles or 10 years in service (unless a potential designer/fabricator can demonstrate, via testing, that either or both criteria should be extended for their application). At an average cycle rate of nearly 2,000 dives per year, the viewports would have to be changed after 5 years. (Private research is being conducted by Sub Aquatics to extend the time period specified by those rules.) If the 10-year or 10,000-cycle requirement were extrapolated to massive acrylic hulls, the entire hull would have to be replaced. This cost factor alone might be reason enough to stop any further consideration of this hull material.

The classification societies and the certificating agency—the Coast Guard—must be specifically careful to ensure the adequacy of design and particularly cautious in their interpretation of test data, since the *ARIES, SEAVIEW*, and *SEABUS* (Comex) applications break new ground in the utilization of acrylic material. As noted earlier, materials such as steel, with an extensive history of use in these areas, exhibit

[*] Letters from Commander NAVSEA to Lockheed Advanced Marine Systems: paragraph 2, letter dated May 17, 1985; and paragraph 4, letter dated April 1, 1988.

their individual weaknesses in ways that are well understood; newer materials such as acrylic or composite materials will likely exhibit new problems. For example, some experts ascribe little validity to scale model testing of acrylic hulls, believing that acrylic does not scale representationally.

A U.S. Navy technical expert[*] has suggested to PVHO that designers and builders of acrylic-hulled tourist submersibles build a minimum of two scale models (approximately 1/4 or larger) for testing. Under this proposal, one model would be tested to destruction to validate the design calculations. The second model would be subjected to the maximum number of pressure cycles that can be withstood through its destruction. In this context, a pressure cycle would replicate a dive cycle. The maximum number of cycles derived from the test would then be used to determine the replacement interval. In contrast to the opinion mentioned above, this expert believes that acrylic scales very well, with scale effects being reasonable. These contrasting views simply reflect the lack of wide experience with these materials and the uncertainty facing the regulatory agencies.

Flammability Considerations

The selection of materials associated with electrical equipment and wiring and the interior of the submersible should include consideration of flammability properties, including ease of ignition, flame spread, and composition of combustion products. The design should proscribe the use of materials that exhibit low flash or fire points. In addition, any potential fire should be restricted to minimal, well-defined, isolated areas within the submersible without propagation paths. Material selection should minimize the toxic hazard associated with combustion products.

A National Aeronautics and Space Administration Handbook[11] provides criteria governing materials selection, evaluation, and control. The Coast Guard will find this handbook useful as a guide.

Structure

The predominant method of hull construction used in U.S. operational submersibles is to reinforce cylindrical shell sections with external ring stiffeners. The rules for designing main pressure vessels using ring stiffeners are well known. The external ring stiffener approach maximizes the internal volume available to passengers without sacrificing the additional strength required for the stiffeners. Some European designs offer a variation by allowing the stiffeners to penetrate the continuous shelf plate. In the tourist submersibles observed by the committee, the stiffeners did not penetrate through the cylindrical shell. It is well that they did not. Such penetration could present numerous problems with regard to maintaining a true cylindrical cross-section, and allowable local deviations from circularity could be exceeded. Additional problems presented by allowing stiffeners to penetrate the MPV shell occur in welding. The number of welds in the MPV would increase by a factor of two (at the minimum) with penetration. This doubles the possibility of failure due to poor welding, shell pressure cycle, fatigue, early onset of buckling, or general instability.

Materials selection is also crucial for maintaining structural integrity. For example, 6061 aluminum, which is susceptible to cracking after heating, is widely utilized as exostructure material for tourist submersibles. The exostructure is the framing around the MPV that supports the superstructure (deck and conning tower) and encloses the ballast tanks. When the tourist submersible surfaces to unload and load passengers, there is always contact (impact) with its tender vessel (the ferry boat). Depending on wind and wave action and the relative position (to the ferry boat) of the submersible when it surfaces, the impact forces can replicate minor collisions. It is possible that a collision during operations could exert the force required to buckle the submersible's exostructure and, through it, deform the pressure hull. The damage might appear minor during a visual inspection, but could be more critical in reality.

[*] Dr. Jerry Stachiw, Head, Materials Technical Staff, Naval Ocean Systems Center, San Diego, CA (personal correspondence).

If the exostructure, as it collapses, damages the shell of the MPV by causing it to deform permanently, catastrophic failure is only one step away. With a permanent set (deflection) in the MPV shell, the circularity of the shell is compromised. If the dimensional irregularity caused by this impact is greater than the percentages allowed by classifying agencies, a classical buckling failure could occur—if, for instance, the submersible were to dive to a depth close to its design (or operating) depth. The amount of allowable deviation from the design diameter (or dimensions) is small; ABS allows 1.0 percent of the design diameter.

This possibility, coupled with various construction methods (e.g., some European designs) places special emphasis on the need for close inspection during annual surveys. At present, ABS rules state that during special surveys (done at approximately 3-year intervals) the surveyor "could call" for critical dimensional checks. Since tourist submersibles are drydocked on land during mandated surveys every 18 months and are basically disassembled for inspection, it would be a relatively simple task to check the hull circularity and verify that it is within the allowable limits.

Pressure Cycling

Tourist submersibles operating in resort areas such as Grand Cayman and the Virgin Islands can average 6 dives per day, 6 days a week. This yields a total of 1,872 cycles per year, which is an extremely high number compared to experience with work submersibles and Navy deep submergence rescue vehicles (DSRVs). Military and industrial submersibles would not see that number of cycles in their lifetime. For example, the two U.S. Navy DSRVs average less than 100 dives (cycles) per year.

Increased pressure cycling causes structural fatigue to appear at earlier stages than the expected design life. This was evidenced by an Aloha Airlines 737, which lost its forward cabin roof inflight in a 1988 accident. Because these aircraft island-hop, they undergo a higher than average number of pressure cycles during their operational life. The same case can be made for submersibles. In this connection, it is noted that ABS requires only 1 or 2 cycles of hydrostatic testing, while the Naval Sea Systems Command requires a minimum of 10 cycles. While such testing is adequate to verify basic design parameters, it does not—even at 10 cycles—address the fatigue problem. Increased cycling in operation will eventually lead to fatigue failures, which emphasizes the need for intensified inspection and testing of vehicles that have been in service for several years.

There is a sufficient data base on steels to predict performance with a given number of pressure cycles. There is not an adequate data base for predicting performance of new materials—particularly acrylics.

Redundant and Backup Systems

The safety of a system is partly a function of its reliability; that is, that the subsystem or component will be available and operate on demand. System reliability, in turn, can be partly a function of system redundancy or backup availability. While a less than perfect subsystem or component operational reliability is usually acceptable in the commercial working industry where human safety is less at risk, the tourist submersible industry requires a significantly higher reliability for each subsystem. This can be achieved only by having a substantial reserve or a dedicated emergency backup system.

Strict redundancy is accomplished by duplicating critical components, such as with an extra set of gauges, communications gear, and secondary sources of compressed air that are directly accessible. Other systems may be provided with a backup capability different in design from the primary system. For example, there is a requirement to carry sufficient solid ballast (usually lead or concrete) to be utilized as drop weights. This is needed in the event that the submersible is grounded by flooding of its largest pressure vessel, aside from the main personnel capsule. The drop weight system on one submersible visited by the committee (ATLANTIS class) is activated by a hand-driven hydraulic pump, and this activation arrangement may be common to other tourist submersibles now in operation. In current designs that were observed, there is no provision for a backup in case the hydraulic pump fails. Further, the system can be activated only from inside. Other methods of drop weight release, utilized in work submersibles, are pyro-ignited links, cable cutters, etc.

The committee observed that the drop weight system on the ATLANTIS submersible was not actually tested in situ; that is, the weights were not dropped. Since the first response to an emergency during diving—as pointed out to the committee by several operators—is to surface immediately, the ability to release ballast rapidly is critical, either as water blown out of tanks or as release of weights. Full testing of the drop weight system at sea in at least one vessel of each class would provide significant improvement in safety assurance. In addition, further assurance would be provided by having a manual backup for dropping the weights from inside the vessel. In submersibles whose operating depth is 150 feet or less, the drop weight system should also incorporate a feature that allows divers to jettison the weights from outside the hull.

Stability

If a tourist submersible grounds due to a system failure and the drop weights must be jettisoned, the Coast Guard does not specify a minimum required stability. The minimum stability required to recover a submersible in its normally upright (trim) attitude is governed by the Metacentric Height (see Appendix A). For a submersible to remain upright while submerged and thus exhibit positive stability, the center of buoyancy must be vertically located above the center of gravity while submerged (see Appendix A, Enclosure 2, Figure 1). The center of buoyancy can be below the center of gravity while the submersible is on the surface if the Metacentric Height is positive. Stability is an important parameter; its adequacy could be verified in a simulated (test) emergency ascent. The test envisioned would both test the ability of the drop weight system to function properly in water and verify that the stability required is adequate to guarantee that the attitude of the submersible during recovery is upright and not severely inclined. Emergency trim control could also compensate for the possibility of unusual loading in case of an event that would cause passengers to retreat to one location in the hull, and a simulated test could include this loading variable.

Quality Control

While the submersible construction observed by the committee was conducted with quality control (QC) standards, it is essential that requirements to assure quality standards be established and maintained for the industry as a whole. QC standards and detailed documentation are important for ensuring safety. Based on site visits and observations, the committee is concerned about the present level of recordkeeping by the manufacturers. The Coast Guard should formalize the QC system, establishing what records must be kept and who should to keep them.

Conclusions and Recommendations Regarding Design and Construction

The method of tourist submersible design used within both the domestic and international industry is still maturing; hence, there are inconsistencies in industry design standards between those of the certification and classification agencies—e.g., factors of safety utilized in pressure vessel design, design parameter terminology, extent of data required during post-construction hydrostatic tests, and selection of materials used.

The Coast Guard should reevaluate the areas of inconsistency with ABS (indicating a lack of adequate definition) that exist in tourist submersible design procedure, material selection, and testing. Discussions between ABS, Lloyd's Register, and DnV could be of value in the course of the Coast Guard's assessment.

System redundancy is prevalent in most designs. In one notable exception however, the drop weight systems, which are critical in the event of a pressure vessel (non-main pressure vessel [MPV]) flood, did not have a backup externally operable release on the vessels, the committee observed.

The drop weight system for each submersible design should be tested in situ by vessel designer and manufacturer. The simulated emergency ascent test should account for the possibility of passenger overloading in one area of the submersible.

The present main pressure vessel (MPV) design used for tourist submersibles in service in the United States uses a ring-stiffened cylinder where the stiffeners do not extend into the pressure vessel. Submersibles that use other MPV designs may become available for use in U.S. waters. In some cases these submersibles may utilize stiffeners that penetrate the MPV shells imposing additional strength and maintenance problems. This potential concern places greater emphasis on inspecting and maintaining hull dimensional accuracy.

To ensure that structural failure due to shell buckling or general instability does not occur from either repeated impacts (collisions) with the submersible's tender (ferry boat) or because of problems inherent with designs that allow stiffeners that penetrate the main pressure vessel, greater emphasis should be placed on post-construction inspection and critical dimensional checks during 18-month surveys. Special attention should be given to symptoms of fatigue. Failure in aging submersibles also should be a part of the survey.

There is a serious lack of information on the performance of acrylics in repetitive loading such as is experienced on tourist submersibles.

Expanded testing is needed to validate design criteria. This testing should be done by the designer or manufacturer proposing to use acrylic materials to the extent that they may pose significant questions about the integrity of the main pressure vessel. Both the Coast Guard and ABS should provide guidance in the planning and conduct of such tests.

LIFE SUPPORT SYSTEMS

Air Supply/Regeneration

ABS rules require that the onboard air system be sized for 72 hours plus a normal dive.[1] The normal dive is usually counted as one full day. Adequate overcapacity in air required to blow the ballast tanks and in onboard battery capacity (for emergency power) is required and was built into the systems observed by the committee.

Air tank capacity for blowing tanks must be adequate for at least the number of dives projected between recharging opportunities. In addition, some excess should be provided for emergencies. This air provides the primary means of returning to the surface. The air system design (valves, strainers, etc.), as well as total capacity, therefore merits special attention.

The onboard carbon dioxide (CO_2) scrubber system (Soda Sorb and blower motors) is essential in maintaining the quality of the air. According to ABS rules, the allowable CO_2 limit is 0.5 percent of gross. Redundancy is provided by arranging alternative circulation patterns in the event of scrubber system failure and by providing extra capacity for scrubber reactants. Adequate sizing in the basic scrubber designs is essential; this capacity must be tested and any deviation from classification requirements observed and rectified. A problem of this nature was evidenced during a joint Coast Guard and ABS inspection of a tourist submersible in Guam on April 6, 1988. In that case, the CO_2 level during the second scrubber test was greater than 0.5 percent (due to improperly installed fans); but the result was approved based on first test results that were less than 0.5 percent.*

Fire Suppression

Fire suppression in confined spaces, where humans are present, is difficult. Heat build-up is very rapid, especially with closed hatches, in which case the temperature can pass 100°C in less than 40 seconds. Under these conditions, smoke rapidly obscures visibility, hindering both fire-fighting and escape. Carbon monoxide (CO) is also an immediate problem, as it affects decision-making capability long before it affects motor functions. The present Coast Guard requirement is simply for an approved, portable fire suppression system. The current systems in use on submersibles are an interim response in the absence of a specified fire-suppression system.

The requirement for a fire suppression system illustrates a problem in that all the available options have various safety and health concerns associated with them. For example, use of the gas Halon is currently the prevalent method; the ATLANTIS class of submersibles uses Halon 1301 as a fire suppressant. This gas is effective for the purpose but has several drawbacks, including decomposition resulting in acidic byproducts, limitations on breathability for humans (10 min. at 6 percent maximum), and the fact that the Halon cannot be removed by carbon filters. Despite these deficiencies, Halon 1301 is the best available short-term fire-suppression alternative when the time to surfacing is only a few minutes. Halon is a fluorocarbon and for that reason will probably be phased out within a few years. **

The committee noted that nitrogen is an alternative fire suppressant currently under study by the Office of Naval Research and the Naval Research Laboratory. Nitrogen is nontoxic and merits consideration as the primary fire-suppressant gas. Like other alternatives, nitrogen has inherent control problems and will require highly engineered control systems.

Emergency Breathing Apparatus

Another illustration of the differences and complexity of submersibles compared to surface vessels is the need for emergency air purification or air supply. ABS rules for submersibles require emergency breathing life support for the duration of the dive or two hours, whichever is longer. (In the case of tourist submersibles, the two-hour requirement pertains.) Currently there is no Coast Guard standard for devices to meet this need.

There are two aspects to the problem of emergency breathing apparatus: viz., providing emergency breathing for the passengers and crew (pilot and attendant). Emergency breathing requirements for passengers, in the event of a fire or loss of power with attendant failure of the air regeneration system, are usually met via individual units. One builder examined by the committee elected to solve this problem by providing an MSA (Mine Safety Appliances Company) rebreather device designed to remove carbon monoxide by oxidation and with the ability to remove certain other particulate materials via a filter. The device does not, however, remove other contaminants besides CO and will not support life if oxygen levels are too low or if for any other reason the atmosphere itself will not support life.

The crew is provided with a full face mask, air fed, so that they breathe off the high-pressure air system. Thus, they have a life support system that will last as long as there is high-pressure air.

The MSA self-rescuer may well be the best available solution to the problem of emergency breathing for passengers in the event of a fire. However, since the device does not provide air, it does not

* Rapidraft Letter from Commander USCG Section Marianas to Commander USCG Washington, DC, April 19, 1988, regarding the completed quarterly control verification exam of the MARIEA I submersible.

** This is a problem of much broader scope than tourist submersibles, as Halon is used as a fire suppressant on many vessels.

appear to satisfy the rules as they exist at this time. The alternative of using air-fed masks for passengers presents a problem of pressurization of the compartment; sufficient exposure to the pressurized atmosphere would require passengers to be treated for decompression upon rescue, although this would not be a problem if the submersible is able to execute the prescribed emergency ascent to the surface within a minute or two. Also, air-fed masks are not portable, perhaps making evacuation of passengers on the surface more difficult.

This issue needs further attention—particularly as to whether the MSA rebreather meets both the letter and intent of the ABS rules. Perhaps the most troubling possibility is the risk of fire. The atmospheric contamination in such an event is extreme and creates an immediately life-threatening situation. Therefore, every possible precaution must be taken to avoid fire, to minimize the toxic byproducts of any fire should one start, and to provide a breathing apparatus that will protect every passenger from inhaling toxic contaminants and smoke.

Personal Flotation

Finally, the committee observed that the inflatable life jackets used on *ATLANTIS* are not Coast Guard approved. Indeed, the Coast Guard has not approved any inflatable life jackets for such service, in part because no user has been willing to pay the cost of testing and approval. (Noninflatable jackets are not compatible with the storage and access constraints of submersibles.) The use of inflatable jackets in this context is in line with airline practice, and while not specifically approved for general use they have been accepted in current submersible operations. Moreover, aircraft-type inflatable jackets lend a familiarity derived from air travel and therefore may provide some psychological benefits in understanding and accepting their presence and use. This approach to personal flotation is compatible with an operating profile in which an attending surface craft is present at all times.

Conclusions and Recommendations Regarding Life Support

The gas Halon, used in current fire-suppression systems, presents possible safety and health problems.

Because nitrogen gas is nontoxic, consideration should be given to the development of a nitrogen-based fire-suppression system, as a possible replacement for the Halon-based systems.

There is an indication that CO_2 absorption systems (scrubbers) used on some tourist submersibles have occasionally been unable to maintain CO_2 below required levels. These systems either lacked sufficient capacity or were incorrectly installed; these deficiencies were overcome by reversing the airflow pattern.

The Coast Guard should require that CO_2 *absorption systems have adequate capacity and redundancy, in accordance with a hazards analysis, and should enforce this requirement in design and periodic inspection. Failure of this system could result in injury or fatality to passengers* .

The current rebreather devices for providing emergency air supply for passengers do not satisfy ABS rules and are not adequate protection against some types of atmospheric contamination.

The Coast Guard, in cooperation with ABS, should promulgate standards on emergency breathing requirements and systems for tourist submersibles. All participants—Coast Guard, ABS, and the users—should agree on the application of those rules.

Inflatable life jackets used aboard tourist submersibles are not Coast Guard-approved, although the Coast Guard is currently accepting them.

The Coast Guard should consider testing and approving one or more inflatable life vests.

INSPECTION

The U.S. Coast Guard routinely conducts periodic inspections of surface vessels to ensure compliance with safety and pollution abatement requirements as defined by Coast Guard regulations. These inspections are conducted by personnel at the local level. They are effective because of the knowledge and training of the inspectors and because application of the rules results in similar systems and equipment on most vessels. Years of experience with surface ships has allowed the Coast Guard to develop an inspection program under which the local inspectors are sufficiently knowledgeable to work directly between the rules and the hardware without interpretation difficulties.

Inspection of tourist submersibles is not so straightforward and routine because of the relative newness of these vessels and the relative lack of experience with them on the part of Coast Guard inspectors. A number of vehicle inspections take place at different stages in the life of a tourist submersible. They include: construction and post-construction inspections; periodic certification inspections and reinspections; and quarterly control exams (for foreign-built vessels).

Construction Inspection

During MPV construction, which could last 2-3 months, the classification society is on-site weekly. In addition, spot (surprise) inspections occur at random intervals. Almost every inspection taking place during construction includes participants from both the Coast Guard and the classifying society (e.g., ABS). This phase of construction is critical, since the main pressure vessel is the single most important structural component of the submersible. The entire construction (or assembly) period could last as long as 12 months. The final assembly (after all subsystem components are assembled) takes 5-6 weeks. During the vehicle construction period there are 25-40 inspection visits. When Coast Guard personnel are not available they will utilize the information gathered by the classification agency.

Among the MPV tests witnessed or performed are critical dimensional checks, material tests, hydrostatic tests, and functional tests. Before the hydrostatic (drop) test is done, radiographic and ultrasonic testing is performed. After the hydrostatic test, ABS performs another dimensional check and non-destructive inspection (dye penetrant and magnetic particle) examination of all welds to ensure compliance with the specified procedure.

Periodic Inspections

Organized periodic inspections are an important aspect of maintaining safety in tourist submersible operations. In general, all vessels carrying passengers must have on board a valid Coast Guard certificate of inspection (COI). A COI is issued by the cognizant Coast Guard Officer in Charge of Marine Inspection after an inspector has examined the vessel and determined that it is in satisfactory condition and fit for the service for which it is intended and that it complies with the applicable regulations. (This is the "certification" process described in Chapter 2.)

A COI for small passenger vessels less than 20 meters (65 feet) in length (all existing tourist submersibles are in this category) is valid for three years. At least two reinspections must be made within the triennial period. When possible, these reinspections will be made at approximately equal intervals between triennial inspections for certification.

ABS also conducts annual and special surveys of tourist submersibles. During the annual surveys the hull is usually examined for significant damage. The air and hydraulic systems are inspected, the vessel is repainted, and the superstructure is repaired. There is no requirement in ABS rules for a critical dimensional check, although special ABS surveys that occur every three years "could call" (according to the guidelines) for such checks. In the committee's view, annual and special surveys should include dimensional checks to confirm the roundness or circularity of the MPV.

Tourist submersibles represent a new challenge for the Coast Guard inspection system. Although these vessels have much in common with surface craft, the major differences may mean that the expertise of local inspectors could be insufficient to ensure adequate periodic safety reviews. In addition to the unique aspects of submersibles as a group, it is also reasonable to expect substantial differences between the designs of various manufacturers. In time, some level of standardization is likely to occur—particularly in safety-related areas; but at present, each vessel could meet the regulations in different ways, so that a valid inspection may require detailed design knowledge on the part of Coast Guard inspectors beyond what the present system provides.

The U.S. Navy's deep diving submersibles and saturation diving systems present a similar situation. Inspection and certification of these facilities are done by a specialized group of auditors backed by a second group of specialized engineers. Inspections by local personnel are conducted but they are preliminary to a visit by the NAVSEA 92Q Certification Audit Team from Washington, D.C. This procedure works well for the Navy, but is contrary to the Coast Guard's proven local inspection procedure.

Continuation of local Coast Guard inspections appears desirable and reasonable since local inspectors can provide information about the local operational environment. The use of local Coast Guard inspectors can be satisfactory if the inspectors can be given adequate information on the submersible to be inspected to make the transition from the regulations to design and operational details. The participation of Headquarters personnel expert in submersibles (possibly with input from Marine Safety Center personnel) would ensure that effective, thorough inspections were made.

The current inspection procedures appear to be adequate to maintain safe operations on systems that are essentially new. The committee has reviewed extensive experience with Navy-controlled deep-diving systems and several research submersibles and has developed an outline of inspection requirements, which is intended to help the Coast Guard and ABS in their review and development of their respective inspection procedures, as tourist submersible operations expand and become more routine.

In brief, the committee believes that the designs of tourist submarines and their method of operation are unique enough to require detailed knowledge on the part of an inspector to ensure an adequate safety review. This requirement can be met by providing a detailed inspection plan generated as part of the initial approval process and encompassing the program's equipment, operational procedures, and training programs. The inspectors should rarely be required to make technical judgments. Instead, the inspection plan should contain the necessary pass/fail criteria for each approved item or system. The specific points and criteria contained within the inspection plan should be derived from a formal hazard analysis (see Chapter 4).

As with the initial system approval, periodic inspections represent a major effort on the part of both the Coast Guard and the operators. Great care must be taken to limit the inspection criteria to those items and procedures of real importance to the safety of the passengers and operational personnel. In addition, operational inspections should be part of the inspection protocol. Inspections conducted while the vessel is moored at the dock on the surface capture the vessel in a passive mode; an active operational mode is more indicative of the actual status of the vessel.

The committee's suggested inspection plan is described in greater detail in Appendix B.

For foreign-built vessels, which are outside the Coast Guard certification procedure, quarterly control verification exams are conducted jointly by the Coast Guard and the classifying agency. The Coast Guard issues a certificate, CG-4504, "Control Verification for Foreign Vessels," to those foreign vessels it finds to be in compliance with SOLAS regulations. This form of inspection is essential for determining whether the vessel maintains its classification or certification. Because the SOLAS regulations for passenger vessels apply to ships on international voyages, their applicability to submersibles (which do not make such voyages) is highly questionable. However, they do provide the agencies with a means of spot-checking the subsystem effectiveness and reliability of foreign-built vessels.

Conclusions and Recommendations Regarding Inspection

Inspection, both initially during construction and then continually throughout the operational life of the vessel, is extremely important for ensuring the safety of passengers and crew.

The inspection plan for a given class of submersible should be defined early in the design phase, with consultation taking place among the Coast Guard, the classification society, and the prospective operator. The development of inspection plans and criteria should be based in large part on the results of a formal hazard analysis (see Chapter 4).

Continuation of local Coast Guard inspections appears desirable and reasonable. However, inspectors need to have detailed technical information and knowledge regarding the specific class and design they are inspecting. The inspection plan can provide much of this information.

Personnel from Coast Guard Headquarters and the Marine Safety Center should be available to provide additional in-depth familiarity with tourist submersibles systems and operations.

The inspection protocol should include functional tests of critical systems, which must first be defined in the inspection plan. Hull circularity is considered to be an essential factor in this plan.

Specific criteria for passing or failing each inspection point must be clearly established and firmly adhered to.

Inspectors and COTPs should not be permitted to deviate from the established criteria, except in the case of specific items that are identified as such in the inspection plan (and usually with a requirement for specific concurrence at higher levels).

4

System Safety Issues

A major reason for the committee's—and the Coast Guard's—interest in the safety of tourist submersibles is that when a surface vessel finds itself in trouble, as a last recourse its passengers can depart the ship and swim away. Because this mode of personal escape is impossible for the passengers of a submersible (in most accident scenarios, at least), submersibles must have an additional margin of safety. Achieving this level of safety for tourist submersibles is significantly more difficult since problems that are often troublesome for surface craft may be catastrophic for the tourist submersible and its crew and passengers.

The goals of the Coast Guard and the passenger submersible operator are identical: the design, construction, maintenance, and operation of a safe system. Because it has been recognized that there are inherent safety risks associated with the operation of passenger submersibles, a safe system can be described as one in which the likelihood of occurrence of all identifiable hazardous events is maintained at an acceptable level as determined by the Coast Guard. To achieve this safety goal, the passenger submersible industry can benefit from an awareness of contemporary safety programs implemented by other federal agencies, such as the Departments of Defense and Transportation, NASA, the Federal Aviation Administration, and the Department of Energy, for similar systems and risk concerns. These programs prescribe certain minimum standards for the procedures and practices that should be applied to identify, assess, and manage safety risks. In particular, these contemporary safety programs include objectives for the hazard analysis and safety review process that should be considered by the Coast Guard.

SYSTEM SAFETY HAZARD ANALYSIS

During 1988, a Passenger Submersible Safety Project was initiated by the Coast Guard with the Department of Transportation (DOT) Transportation System Center in Cambridge, Massachusetts. The purpose of this study was to assist the Coast Guard in identifying potential safety issues associated with tourist submersible operations. A preliminary hazard analysis of a representative tourist submersible system was performed, and fault tree analyses were developed for a selected list of undesired events (failure scenarios). A draft of the report, dated April 1989, and the final report,[12] published in August 1989, were made available to the committee.

The DOT report identified some serious safety issues, such as the need for a fire detection system and redundancy for several subsystems, for which the hazard control (i.e., recommended action) reference is given as TBD (To Be Determined). The report indicated that these areas did not appear to be adequately covered by existing codes, standards, or regulations; in some cases the safety issues related to training, operations, maintenance, and documentation needs. These findings point to a need for the Coast Guard to establish specific requirements and criteria for these hazard controls, as recommended by the DOT report, for inclusion in the Coast Guard's circular (i.e., NVIC) on passenger-carrying submersibles.[13]

The assessment of safety risks depends on the thoroughness and quality of the hazard analysis information. As is stated in the Transportation System Center's report: "Although a number of potential hazards and causal effects were identified, this initial effort identified only a limited portion of the hazards that may exist." The DOT effort was a top-level generic systems review-, an expanded and more detailed analysis would provide greater insight into additional hazards, causal factors, hazard control measures, and associated safety risks for a specific system design.

As an example, the generic review identified an explosion hazard associated with the oxygen storage cylinder. For a specific submersible design, a hazard analysis should also address the explosion hazard associated with other components of the oxygen system and their physical location on the submersible. The hazard analysis should address specific hazards relating to the various valve designs, piping configurations, materials of construction, etc., considering factors such as the compatibility of metallic and soft materials (seals) with oxygen, contamination from fretting or galling of material, isolation of components, and physical separation of parts intended to provide redundancy.

The Coast Guard should require that the submersible designer perform a detailed hazard analysis to provide a more complete and accurate evaluation of safety risks associated with the specific design and operational plan. Implementation of the hazard analysis requirement would add a function not normally a component of the Coast Guard's certification process. However, this requirement would enable both the Coast Guard and designers to concentrate on resolving the most important problems for any given design.

Single-point failure analysis should receive particular emphasis in analyzing for safety criticality. The objective should be the elimination of single-point failures that could lead to a catastrophic accident. If single-point failures cannot be eliminated, rigorous tests, inspections, and procedural controls should be required to ensure that an accident does not occur. A very close interface between reliability and safety exists in the prediction and monitoring of equipment failures, e.g., sensors, indicators, alarms, life support, and emergency systems. Detailed failure modes and effects analysis, criticality determinations, and subsystem hazard analysis may be warranted to establish requirements for backup and parallel redundancy and to ensure that redundant systems are truly redundant and do not have any common failure modes. In addition, reliability analysis has applicability in identifying life-limited items (such as acrylic viewports) in order to establish needs for spares and replacement schedules for continued safe operation.

The hazard analysis process should be implemented during the design phase. The cost of alternative hazard controls can be expected to be significantly lower for submersibles in the design phase than for those that are already in operation. In the design phase the hazard analysis can provide an assessment of the safety of the design prior to construction, and design changes (if warranted) can be more easily incorporated. Since there are already operational vessels, hazard analysis applied after the fact should carefully guard against justifying and supporting the existing design. An objective approach is needed to weigh the acceptability of a level of safety in which procedures may be used to control the hazards and *reduce* risks, as compared with an approach that would *eliminate* the risk but require costly design changes.

Finally, the certification review process should ensure that the criteria for hazard controls are built into the construction, operation, maintenance and survey plan, procedures, and activities. The development of inspection plans and criteria in large measure should be based on the hazard analysis results and an understanding of the safety-critical elements of the system.

To provide continuing assurance that the hazard control measures have been implemented, the Coast Guard should be knowledgeable about the fabrication processes that can degrade designed-in safety and reliability, so that the appropriate inspections and tests can be performed or witnessed. The OCMI, in particular, should be apprised of the safety concerns of the submersible system that affect vessel operations and maintenance to verify that hazard control measures are still in place in failure reports, maintenance documentation, and vessel operation. The OCMI should schedule periodic visits to the operational site and monitor the operations under way for early indications of problems. Equipment failures should be reviewed as to their cause and resolution and to determine if they have exceeded an unacceptable failure rate. False alarms with sensors and indicators for safety systems are particularly important areas for the Coast Guard to review, because operators could become complacent about emergency warnings if too many false alarms, from OCMI or another office, occur. In order for this to be accomplished, a trouble and failure reporting system (T&FRS) must be in place. The establishment and operation of a T&FRS need not be a burden if it is applied selectively to the critical systems identified in the hazard analysis.

SAFETY REVIEW

Separately from the hazard analysis performed by the builder, Coast Guard review, approval, and certification should constitute an independent safety review to improve the identification, analysis, and elimination or control of hazards. The Coast Guard approval process should provide for a thorough evaluation of safety risks to ensure that there are no significant residual risks.

From the viewpoint of the customer (the tourist), certification of the tourist submersible by the Coast Guard provides assurance that the dive will be completely safe. One operator's brochure indicates that the "vessel is equipped with redundant U.S.C.G. approved safety features throughout." Coast Guard safety review and certification procedures for tourist submersibles must warrant this public trust.

The level of safety risk acceptable for tourist submersibles is currently indicated by the Coast Guard as "safety at least equivalent to that required for a surface craft of similar size and service."[14] The documentation indicates that this equivalence may be achieved in part through a combination of design requirements and operational procedures. Since there are various design and operational tradeoffs, there needs to be a consistent approach for determining the resultant safety level. Further, the approach would need to be consistent in its comparison of the safety level of the submersible with that for surface craft. It is not clear how that safety level and measure of equivalency will be demonstrated because procedures do not currently exist for accomplishing such an assessment. It may be necessary to express a risk acceptability objective that provides criteria that could be more easily measured—e.g., "No single-point failure or human error shall result in a catastrophic hazard." The accomplishment of this objective can be validated by documenting a formal hazard analysis.

The committee noted (see Chapter 3) that some submersibles were operating with variances to ABS rules and Coast Guard guidelines—including, for example, the use of a rebreather instead of an emergency breathing system, and use of inflatable personal flotation devices that were not Coast Guard approved. No documentation could be provided that addressed the rationale for these variances, their safety impact, or the formal approval of the variances by the Coast Guard. In approving the submersible design and operations, there will be some difficult safety decisions that the Coast Guard will need to make in approving variances to design and operational safety requirements and in reviewing other aspects of the system for which there are no requirements; the approach to making these decisions needs to be consistent and documented.

It is to be expected that situations will arise where requirements do not exist and, because there is no known precedent, a determination on acceptability will need to be based on professional judgment. Safety problems could arise here because, since the system is new and unique, the OCMI approves the design and operation and the variances to requirements without having the proper background information. In the case of variances and situations where there are no requirements, there should be a formal procedure describing when the OCMI or the District Office should contact Coast Guard Headquarters for review and approval. As it stands now, it is possible for the Headquarters to be unaware of a safety issue unless it is brought to Headquarters' attention through an appeal route. This issue impacts directly on the inspection process, and it was therefore addressed in Chapter 3 as well (see "Inspections).

Tourist submersibles are new and unique in their design, operation, and hazard scenarios. They affect such large potential populations and are subject to so many facets of the industry practice that should be in the certification review that the Coast Guard needs to strengthen its resources and utilize its existing capability within Headquarters to ensure consistency in the certification review and approval. Greater Headquarters involvement in tourist submersibles, as compared to surface vessel certification, has already been initiated with the requirement that Headquarters conduct a system concept review before detailed design review is carried out by the Marine Safety Center (MSC). This approach should be extended to cover the entire scope of safety policy setting, review, approval, and oversight responsibility and to focus on continued efforts to enhance tourist submersible safety. In addition, MSC technical personnel provide one source of Headquarters expertise that the Coast Guard could use to participate in construction inspections and support annual surveys and recertification inspections.

Safety is a pervasive concern from concept to scrapping. In addition, the concept of "system safety" goes beyond the vessel itself to encompass all the elements of the business that are actively engaged in support or operation of the submersible where customers are involved. The discussion in this chapter has focused primarily on the submersible itself; however, the committee examined the question of safety as a whole-system problem. Aspects of safety apart from the submersible are addressed in Appendix C.

Aside from safety criteria that are applicable to the design and operation of tourist submersibles, there are other concerns relating to programmatic procedures and practices. Program elements such as quality assurance, configuration management, and procedure change control are essential to the entire safety assurance process. Other aspects of operational readiness that are important elements of safety assurance include personnel qualifications, maintenance, calibration, and failure reporting and resolution. With regard to equipment maintenance and calibration, it may be necessary to specify minimum standards for personnel and the workplace to ensure that work is performed properly. For each of these areas, industry standards could be imposed by the Coast Guard on the tourist submersible operator, where appropriate, to ensure that the safety envisioned for the operational life of the system during initial design and operation planning is achieved and maintained.

RECOMMENDATIONS REGARDING SYSTEM SAFETY

The Coast Guard should pursue the establishment of safety requirements and criteria for hazard controls in areas posing serious safety implications (as recommended by the DOT report, "Passenger Carrying Submersibles: System Safety Analysis") where there presently are none.

The Coast Guard should require a formal hazard analysis and implement a process to provide for: early identification and evaluation of hazards associated with each specific tourist submersible configuration and operation (especially single-point failures); the timely incorporation of risk reduction measures to ensure an acceptable level of risk; and continued emphasis on hazard control verification during fabrication, operation, and maintenance.

The Coast Guard should establish a formal procedure for approval of variances to its regulations, including its NVIC guidelines. Field inspectors and OCMIs must be given guidance on which items in the regulations or circular (NVIC) or rules are subject to judgment and require Headquarters' concurrence and which are truly "go/no-go."

Responsibility for tourist submersible certification is now focused on a limited staff at Coast Guard Headquarters. The Coast Guard should strengthen this focus and consolidate it organizationally, within one office and within responsibilities under specified billets in that office. This focus is required to ensure consistency in the implementation of requirements, application of engineering judgment, evaluation of safety tradeoffs, and approval of variances, and also to enable a focus on areas of safety enhancements.

Hazard analysis, safety review, and review of operational safety should be extended to all aspects of the system that affect tourist safety, including the design of all facilities associated with the operation of the business as a marine system.

Standards and guidelines should be set or established by the Coast Guard for use by the tourist submersible organization for quality assurance, configuration management, procedure change control, maintenance, calibration, and training to ensure that the safety reviewed for the initial design and operation planning is achieved and maintained .

In order to provide basic information to Coast Guard inspectors, a trouble and failure reporting system (T&FRS), administered by the operator, should be established and cover critical systems as agreed upon between the Coast Guard and the operators as a result of the outcome of a hazards analysis.

5

Operational and Administrative Considerations

Apart from safety issues associated with system design and operation, there are also a variety of background issues dealing with the qualification of personnel, the management of passengers, and contingency planning for dealing with emergencies. These clearly are also matters essential to the safety of tourist submersible operations.

MANNING, TRAINING, AND LICENSING

Manning, training, and licensing do not of themselves present operational hazards affecting passengers, crews, or property. However, the selection of unreliable or unqualified personnel, inadequate training, or inadequate licensing procedures could result in operational hazards. The safety of the passengers and crew as well as the protection of property involved in tourist submersible operations requires careful attention to personnel selection, training programs, and licensing procedures.

Manning

The OCMI determines the manning requirements for a particular vessel and specifies the minimum complement on the vessel's certificate of inspection.* These requirements vary depending on the type of submersible and the operation envisioned.

The contents of a required "manning and licensing proposal" will be discussed later in this section (see "Licensing"). In order to fulfill the requirement for such a proposal, management should first formulate a complete operational scenario, then design an organization with a clearcut chain of command capable of carrying it out. The organizational chart should cite the title of each position and the responsibilities, authority, and duties that go with it.

The most probable basic operational scenario will include provisions for a ferry vessel to carry passengers to and from the operating site, a surface support safety boat to follow the submersible and maintain communications, and the submersible itself.

In the committee's view, the tourist submersible should carry a minimum of two qualified operations personnel, at least one of whom must be licensed by the Coast Guard. A third crewman may be provided to aid in passenger management and assist in emergencies. The configuration of the individual submersible and its complexity may dictate additional personnel.

Since the ferry vessel can be expected to carry at least six passengers, the master must be licensed as a master of an inspected vessel of appropriate tonnage.

* In accordance with 46 CFR paragraph 15.501.

The ferry vessel should have at least one crewman in addition to the master who can handle lines and provide crowd control and who is qualified to operate the vessel if the master is incapacitated. The surface support safety boat should be manned by a minimum of two crewmen, both of whom are qualified to operate the boat and its communications equipment. In addition, there are two qualified divers operating from the support boat, both equipped with necessary diving gear. One diver maintains visual contact with the other diver who is attending or accompanying the submersible.

As backup for emergency rescue, submersible operators should assure that either an additional support diving team (at least two persons) or a remotely operated vehicle (ROV) will be rapidly available. The ROV will be essential should these entrapment circumstances extend in time and depth beyond diver capability.

Training

Training of submersible operators has been addressed in other reviews. For example, a comprehensive analysis is presented in Section D of *Safety and Operational Guidelines for Undersea Vehicles*, published by the Marine Technology Society (MTS) in 1974.[15] This treatise, although 16 years old, is considered to offer an excellent and still contemporary guide to development and approval of training plans. The committee's views on training needs, using the MTS guidelines as a starting point, are presented in Appendix D. It is important to note, however, that the committee has added recommendations that address "criterion-referenced" or "competency-based" training standards (Appendix D, page D-l). Competency-based training standards provide for:

- determining what level of competency is needed,
- establishing a standard for measuring that level of competency, and
- training to that level.

Training time—such as a two-week standard—does not guarantee a level of competency. Rather, some agreed-upon standard is needed that provides a level of competency established as being adequate for safety and operational need.

Basic indoctrination of crew members should thoroughly familiarize the trainee with the basic concepts, hardware, and principles of operation of every system and subsystem aboard the vessel. Concurrently, operational training beginning with a maintenance apprenticeship aboard the submersible and advancing to an apprenticeship under the chief pilot should provide the trainee with on-the-job experience leading to a full capability to operate the vessel competently in solo mode under all expected operating conditions.

In brief, the selection and training of all members of a submersible operating team must be done with the same care and attention to detail given to the design of the pressure hull or life support system. There is no substitute for the understanding imparted through training and subsequent experience.

Licensing

Paragraph 10.201 of 46 CFR covers the general requirements for licensing of personnel for surface vessels, including age, experience, character references and recommendations, physical examination, citizenship, training, and professional examination.

The Coast Guard has prepared a draft navigation and inspection circular that addresses the requirements for licensing masters of tourist submersibles.[16] The draft circular requires "that individuals serving as master or mate on inspected submersibles will be required to possess the appropriate license" and "that license must authorize service on inspected passenger carrying vessels of similar gross tonnage and route." In the case of currently operated tourist submersibles, this is a 100-ton near coastal license, which must contain an endorsement for the submersible or class of submersibles to be operated. The draft circular also provides for the local OCMI to approve a "manning and licensing proposal" submitted by the company operating the submersible and based on levels of personnel training, qualifications, and number of personnel required for safe vessel operation.

The draft circular requires that an individual complete a training program approved by the local OCMI at a regional examination center. The training program requirements include vessel systems, vessel operations, emergency procedures, and "hands on" qualification dives. To obtain a license, the applicant is required to pass an examination that is vessel-specific and prepared by the Coast Guard after studying the specific vessel's operation and technical manuals. In the committee's view, the applicant should be required to demonstrate his ability to perform all required operations.

The circular also addresses approval by the Coast Guard of levels of personnel training and qualifications as well as the number of personnel considered necessary for safe operation. In view of the fact that the safety of the passengers depends on the interaction of the vessels and crews—not just in the sense of the "rules of the road," but in the minute coordination of all operational assets and personnel—the Coast Guard should also require that the manning and training level of the total system be addressed in the required manning and licensing proposal.

The circular contains several other requirements that should be clarified. Chapter 10, Section C, paragraph 1, states that "normally two licensed individuals will be required so as to ensure the vessel can be safety operated under all conditions, including incapacitation of the master." If this means two licensed masters, it exceeds the requirements for surface vessels and would seem to impose an unnecessary hardship for the manning of tourist submersibles. Paragraph 3 states that "individuals serving as master or mate on inspected submersibles will be required to possess the appropriate license." There is no mention anywhere else of a mate's license for submersibles; the mention of mate should be eliminated or explained.

Finally neither the draft circular nor 46 CFR addresses specific physical requirements other than visual acuity and color sense. For a submersible pilot the physical requirements should be at least the equivalent of a Federal Aviation Administration's third class medical certificate.[*]

Recommendations Relating to Manning, Training, and Licensing

Manning of the tourist submersible, ferry, and surface support safety boat must account for the possibility of incapacitation of the master by including at least one other individual who is qualified (through accredited training, practical demonstration, or formal examination) to operate the vessel

References in the Coast Guard draft circular to requirements for "two licensed individuals" onboard each vessel and for licensed mates need to be clarified or corrected.

The current licensing examination for tourist operations is a book exam. This examination should also require a demonstration that the trainee is capable of performing all operations to an acceptable level of competency.

The Coast Guard should require that vessel manning and licensing proposals address the manning and training levels of the total marine system (the submersible, ferry boat, and all support vessels), including support crews.

Physical requirements for submersible pilots should be at least the equivalent of an FAA third class medical certificate (i.e., the minimum requirements for pilots of private aircraft).

[*] The FAA third class medical certificate is required of pilots of small, private aircraft. It certifies that the individual is in good health, with properly corrected eyesight and no predilection for sudden serious illness.

PASSENGER MANAGEMENT

Proper passenger management during the entire system operation (ashore, on a transfer boat, and on a submersible) is an essential element of safety. Even if an abnormal or emergency event is satisfactorily mitigated from the standpoint of equipment, it is equally important that injury or emotional trauma to the passengers be avoided or minimized. Passenger management cannot be left to common sense, but must be planned for in every phase of operations—normal, emergency, ashore, and sea.

Passenger management includes such responsibilities as indoctrination, passenger movement, and passenger behavior control. In all cases, the objective is to ensure the safety and well-being of the passengers. Passenger management planning must consider what kinds of passengers they are likely to serve: they probably have never been on a submersible before; they do not necessarily know how to swim; they can range in age from the very young to the elderly; they may have disabilities such as hearing loss, heart disease, shortness of breath, etc.; they may not speak English; and they will be naive about the operation and hazards of submersibles.

Normal Operations

Normal operations have been characterized in a preliminary Coast Guard policy statement as procedures for: "submerging and surfacing, surface operations, underwater operations (visibility, currents, communications, surface traffic, etc.), and ferrying and transferring passengers."[17] Normal operations and their impact on passenger management issues can be discussed in terms of shore site, ferry boat, and submersible operations.

Shore Site

Shore site operations consist of activities in which passengers may make inquiries, purchase tickets, and rendezvous for the trip to the submersible. This is the first opportunity for the company to reduce passenger anxiety and instill confidence in the professional and safe operations of the entire organization.

There should be no particular direct hazards at the shore site, but the first passenger indoctrination should be given here to initiate their safety awareness. Topics to be covered should include such things as:

- general description of operations;
- the environment aboard the submersible (e.g., air conditioned, with purified air);
- prohibition against smoking or possession of cigarette lighters (should be given to crew attendant before the voyage), eating, or drinking on the submersible;
- any restrictions on age, illnesses, or disabilities; and
- how to proceed to the ferry boat.

This initial passenger indoctrination should be a required part of the total safety operation, and the indoctrination topics should be described in the operations manual and safety plan.

Ferry Boat

Most operations will require a ferry boat to transfer passengers from the shore to the submersible — although, if site conditions were appropriate, passengers could board the submersible directly from a dock.

Assuming a ferry boat is involved, the principal activities during this phase would be to safely board and seat the passengers, brief them on safety considerations of the ferry boat trip and its facilities, brief them on safety considerations for embarking to the submersible, and carry out the safe embarking procedures. Similar activities are required for the return trip from the submersible, but special consideration must be given to the situation in which passengers are embarking and debarking at the same time.

In the opinion of the committee, the most dangerous activity during normal operations is the transfer of passengers in both directions between the submersible and the ferry boat. The amount of hazard involved in this activity is a function of several things: (1) the match between the decks of the ferry boat and the submersible, (2) the roll or motion of the two platforms due to sea conditions, (3) availability of brows (a gangplank usually fitted with rollers), (4) assistance provided by the crew members, (5) environmental conditions (e.g., light, rain, wind, etc.), and (6) the degree to which the passengers comply with instructions. Obviously, this activity is a question of practicing what is preached during the indoctrination prior to the boarding process.

One final potential hazard is a function of the capacity of the ferry boat vis-a-vis (1) the number of passengers on board the ferry boat and (2) the number of passengers debarking from the submersible. This can present a problem in passenger management when there is a full load on the submersible and a full load on the ferry. Embarking and debarking passengers should be separated on the ferry boat, should debark and embark from different locations, and should debark and embark at approximately the same rate. Ideally, the ferry boat's capacity should be at least twice that of the submersible, including crew.

The safety of ferry boat passengers is governed by existing regulations in 46 CFR Subchapter T, "Small Passenger Vessels" (less than 100 gross tons). These requirements are also the only ones in effect for submersibles and are obviously not directly applicable. New guidelines or regulations governing the issues raised above must be developed. The Coast Guard has included in the draft navigation and inspection circular two proposed requirements for railings under Section F, "Rails and Guards."[18]

Submersible Operations

Once the passengers are aboard and the debarking passengers are safely on the ferry boat and away from the submersible, the submarine phase of operations can begin. The principal activity concerning passenger management is a briefing (or series of briefings) concerning (1) the safety and life support equipment, (2) unusual or unexpected occurrences or sensations (e.g., noises, sitting on the bottom, and sudden shifts in direction or floor angle), (3) expected passenger behavior in the event of any abnormal or emergency situation, particularly emphasizing the possibility of rapid ascent and evacuation, and (4) debarkation procedures and safety.

A number of regulations or technical considerations relate to passenger management during the submersible phase of operations. These are briefly noted below:

- The Coast Guard has suggested a separation (e.g., a partition) between the control area and the passenger area to prevent passengers from interfering with operator performance.[19] The basis for this requirement is not clear. All tourist submersibles observed have a large, circular viewing area in the front for the pilot to see through for navigation. Passengers can also look down and see out through the front of the submersible, which may be reassuring as well as enjoyable. Both passenger viewing and pilot security needs can be met by a partial transparent bulkhead.
- The need for life support equipment is obvious and the requirement well documented in the draft circular.[20] Rebreathing equipment is discussed in Chapter 3.
- The requirement for passenger indoctrination is identified in another recent Coast Guard document as follows: "passengers are to be trained by the crew members in the use of personal lifesaving equipment under any expected emergency condition."[21] It is assumed the use of the word "training" is satisfied by thorough briefings and does not require practice (as it does not in airline operations with similar briefings). It should be noted, however, that a later draft version of this document appears to have omitted the requirement concerning passenger training.

- The Coast Guard has a requirement in the operations manual and safety plan for emergency procedures for "evacuation out of and off the vessel."[22] The committee also notes that the interior design of the submersible should ensure efficient flow of passengers in the event that evacuation is required; however, no such requirement currently exists.

Abnormal or Emergency Operations

The Coast Guard has defined emergency operations as those emanating from scenarios such as inability to surface, loss of power, controllable leakage of hull, collision, and/or evacuation out of and off the vessel.[23] The need to consider abnormal and emergency situations as part of the Coast Guard responsibility has been stated by Johnson and Veentjer.[24] Some issues that affect passenger management considerations are paraphrased below.

Considering the unique operating parameters of a submersible, there are certain areas where the Coast Guard will focus particular attention. For example:

- Escape and rescue from a submerged vessel will be difficult and hazardous, so the submersible must be capable of returning to the surface in the event of failure of any system except the main pressure hull.
- Access to lifesaving equipment and means of exiting the submersible on the surface may also be difficult. Adequate freeboard and stability should be available on the surface to permit the safe debarkation of passengers under the worst expected surface conditions.
- During the time it takes to surface and evacuate, provisions should be made for personnel protection from hazards such as smoke or toxic vapors in the event of a fire, or flooding in the case of hull damage.

For purposes of the present report, abnormal and emergency operations as they affect passenger management can be discussed in relation to seven hazard scenarios in the system safety analysis developed by the Transportation Systems Center for the Coast Guard.[25] These scenarios are fire, flooding, inability to ascend or descend, collision, vessel isolation, air contamination, and passenger illness or injury. In each of these cases the predominant action is immediate surfacing. Crew training and passenger indoctrination are the essential ingredients in maintaining passenger calm and orderly behavior while surfacing and evacuation are carried out—generally requiring on the order of one minute for operations with a 50-meter (165 feet) depth.

Special Considerations

There are certain special considerations for passenger management that must be part of the operating manual and emergency plan as they apply to a particular operation. The following are typical special considerations:

- *Night diving*. If diving is to be performed at night, special indoctrination, lighting for embarking and debarking, and other appropriate considerations must be planned.
- *Non-English speaking passengers*. If there are passengers aboard who cannot understand the briefing or instructions, they should be accompanied by someone who can interpret for them, or else they should not be permitted to board the submersible.
- *Passenger-caused incident*. The possibility of passenger-caused incidents (e.g., claustrophobia-induced panic, accidental activation of controls, or injury) has been identified by the Coast Guard.[26]
- *Maximum occupancy*. The Coast Guard has stated that "the maximum occupancy for passenger submersibles and submersibles intended for recreational purposes is not to exceed the number obtained by dividing the net internal volume of the vehicle in cubic feet by 53, or the number obtained by dividing the

net internal volume in cubic meters by 1.5."[27] The basis of these numbers is not known. However, comparable volumetric requirements have been determined by the National Aeronautics and Space Administration [28] as (1) 31 cubic feet to accommodate the body motion envelope of the 95th-percentile American male (page 8.6-4), and (2) 53 cubic feet for sleeping compartments on long-duration space missions (page 10.4-3). The latter requirement indicated that the Coast Guard's 53-cubic-foot allotment is fully adequate for short-duration stays underwater, on the order of one hour. In any event, passenger occupancy should never exceed the available designated seating on the submersible.

Some of the unusual and unlikely events, which are listed within the special considerations, cannot be individually anticipated or trained for. General training in first aid and crisis management, together with a confident crew, should be sufficient to handle most situations.

Operations Manual and Safety Plan

An operations manual and safety plan are required by the Coast Guard for review whenever jurisdiction has been established and a contract has been awarded for construction.[29] Specific requirements for the "plan" view are identified in the preliminary Coast Guard policy statement[30] and draft navigation and inspection circular.[31] A similar requirement has been stated by ABS.[32] The content specified by the Coast Guard or ABS is essentially the same. It includes:

- support craft functions and capabilities;
- normal operating procedures;
- emergency procedures;
- mooring and operational area proposals;
- dive site location; and
- minimum amounts of air, oxygen, and battery power that must be available before commencing any dive.

ABS rules also place limitations on "sea state"—the acceptable envelope of weather and water conditions in which the vessel may operate. The Coast Guard requires compliance with those rules.

There are no specific requirements that address passenger management issues. However, it should be noted that the System Safety Analysis Report prepared by the Transportation Systems Center addresses the topic of operational countermeasures (i.e., to counteract hazards), and specifically recommends that "guidelines should be established regarding passenger indoctrination." The committee believes that the operations manual and safety plan should contain a specific section on passenger management dealing with all of the issues previously discussed in this chapter for normal and emergency operations ashore and at sea.

Training in Passenger Management

Passenger management for both normal and emergency operations will be facilitated greatly by proper design of the submersible and availability of appropriate procedures in the operations manual and safety plan. However, the effectiveness of passenger management by the submersible crew will be dominated by the training the crew has received. The Coast Guard appears to require very little in the way of passenger management training. The only requirement identified by the committee during review of available documents was in a draft update of "Rules for Underwater Systems and Vehicles."[33] Paragraph 12.17, "Training of Operations Personnel," provides some guidance for training of the submersible's crew. In very general terms, the document states that the crew must be fully capable of performing tasks related to emergency procedures and is to be fully aware of the submersible's capabilities in order to maximize the safety of the dive under the expected conditions. It is also stated that the crew should be aware of the physiological effects of breathing the onboard emergency gas mixtures under the submersible's environmental and hyperbaric conditions. These statements (while in draft form) relate only vaguely to passenger management.

The System Safety Analysis Report (Transportation System Center, 1989) recommends that "training programs should be developed for all safety-related phases of the tourist submersible operation."[34] The report further states that the training program should clearly represent a systems approach to training (this is presumed to mean competency-based training, in which capability must be demonstrated). A training assessment, if performed, would determine the need for passenger management training by the crew.

The requirements implied by the recommendations below should be included in the operations manual and incorporated in the training of personnel.

Recommendations Relating to Passenger Management

Embarking and debarking the submersible are the most dangerous activities during normal operations. Special diligence should be exercised by the Coast Guard in reviewing and approving the process proposed, including design features, procedures, and crew training.

Passenger indoctrination should occur at least three times, as indicated below and detailed in the text:

- *shore site—initial safety awareness*;
- *ferry boat: (1) ferry boat safety, and (2) submersible embarkation safety; and*
- *submersible: (1) use of safety and life support equipment, (2) unusual or unexpected occurrences or sensations, (3) expected passenger behavior in the event of an abnormal or emergency condition, and (4) debarkation safety*.

The operations manual and safety plan should contain a separate section on passenger management. (The topics in that section could follow the general structure of this section of the report.)

A training needs analysis should be done to determine learning objectives and curriculum requirements for a competency-based training program in passenger management The curriculum should include, as a minimum :

- *basic first aid*,
- *life support requirements and equipment*,
- *passenger management and emergency procedures*,
- *crisis management, and*
- *passenger safety indoctrination*.

EMERGENCY RESPONSE PLANNING

Importance of Contingency Planning and Preparation

The purpose of contingency plans for use in the event of an emergency is to make possible a rapid and safe response to the emergency. A secondary purpose or benefit is that, in the proper development of such plans, and during the various reviews by levels of management, frequently ways are found to make operations safer by either eliminating hazards or providing improved response. Several examples of sound emergency and contingency response plans can be cited.[35] 3637

Fortunately, tourist submersibles have not yet been called upon to carry out an emergency response, although there is considerable experience with emergencies for other types of submersibles. This experience base, along with the substantial experience acquired by the U.S. Navy and Coast Guard in handling maritime emergencies of all kinds, has led to some well-established principles. Perhaps the most important of these is that when an emergency occurs, an established plan of action for all hands is absolutely vital. This section emphasizes the need for such plans and urges the Coast Guard to require and exercise the plans for all operations of this kind.

The committee observed an encouraging degree of confidence on the part of operators that they could operate safely under all expected conditions; but this confidence should not be allowed to divert operators' attention from the need to know how to respond when the unexpected but inevitable accident Occurs.

An analysis of submarine operations indicates that, with some indeterminate frequency, and even with the best precautions, accidents will occur. The U.S. Navy has periodically lost submarines, as have other navies—most recently the Soviet Navy.[38] As of late summer 1989, the U.S. Navy was assisting the Peruvian Navy in the salvage of one of their submarines that was lost in a collision with a surface ship. Research and work submersibles have also been involved in accidents, some of them fatal.

The ability of people to respond properly and quickly in the event of an emergency is greatly improved by adequate prior planning and preparation.[39] For example, the success of the airport emergency response personnel in Sioux City, Iowa, in minimizing fatalities associated with a DC-10 crash in the summer of 1989 has been widely credited to the planning and drills previously conducted there.

Frequently the outcome of an emergency is determined by the actions taken immediately after the accident. In nearly all emergency situations involving the sea, time is critical.[40] Thus, proper planning will facilitate response and reduce the final costs in the event of an emergency.

Nature of Contingency Plans

Contingency plans should be compatible with, and follow the procedures of, the National Search and Rescue Plan if other than local assistance may be required. (See Appendix F for this plan and the U.S. Navy submarine missing/lost instructions.)

Contingency plans provide an opportunity to examine possible accident scenarios, and to determine an optimum course of action. They enable others to review and contribute to emergency response. Frequently, a side benefit is the opportunity to eliminate hazards, and for management to make key decisions that will lessen the impact of emergency situations.

Proper plans should not only address those things that could happen to the submersible in operation, but should also contain plans for external events such as hurricanes. They should make provisions for loss of the support craft as well as loss of the submersible. Above all, emergency response planning must consider the nature of accidents and emergency situations, and the human errors and failures that can lead to them, as well as the possibility of simultaneous accidents involving more than one aspect of the operation. For example, a serious accident (such as a collision) involving both the submersible and the ferry or surface safety support boat might be far more significant than one involving just one of these vessels.

Appendix E presents a discussion of what a contingency plan for submersibles ought to encompass, including the necessary drills and training. Submersible design and operational features that will affect emergency response are also outlined in the appendix. (Most significant among these are salvage air fittings to permit hoses to be run from the surface to a submerged vessel, standard mating rings for attaching a decompression chamber to the submersible after salvage, and standard lifting attachments to which a remotely operated vehicle [ROV] can be attached.)

Recommendations Relating to Emergency Response

The Coast Guard should require a written and approved emergency response plan for each operating submersible, using Appendix E as a guide. This plan should be exercised by each operator on a regular basis (perhaps quarterly). This exercise need not be a full-blown exercise every time. Some of the exercises might well be ones in which the participants ensure that the recall list works, after which the key participants gather *at the designated command center and discuss the actions they would take in the event of an actual casualty. An occasional full exercise involving all equipment and personnel is necessary to ensure that all participants are aware of what they are expected to do.*

There is a need to define a clear chain of command and responsibility for decision making for all operations (including operators and the Coast Guard). This is especially important for emergency conditions. Exercise of the emergency response plan would help to clarify and consolidate the definition of roles. During an emergency, time is critical; there is no time for confusion over areas of responsibility.

The submersible should be equipped with external air hose fittings (high and low) and lifting attachments to provide means for rapid retrieval of a downed submersible. In addition, a standard mating ring and/or adaptor is recommended should a decompression chamber need to be attached.

ROV availability on short notice should be a part of the response plan.

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Appendix A

Draft of U.S. Coast Guard Circular on Passenger Submersibles

U.S. Department of Transportation
United States Coast Guard

Commandant (G-MTH) United States Coast Guard

MAILING ADDRESS
2100 2nd Street, SW Washington, DC 20593-0001 (202) 267-2997
COMDTPUB P16700.4 NVIC

NAVIGATION AND VESSEL INSPECTION CIRCULAR NO.

Subj: Guidance for Certification of Passenger Carrying Submersibles

1. PURPOSE. This circular provides guidance for certification of passenger carrying submersibles under Title 46, Code of Federal Regulations, Subchapter T - Small Passenger Vessels (under 100 Gross Tons) (46 CFR Parts 175-187).

2. DISCUSSION.

a. Non-military submersibles have been used for several decades in the industrial, experimental and research fields. Submersibles had not been used in any commercial service for which the existing inspection statutes and regulations would apply until 1987 when the first passenger carrying submersible to be certificated by the U.S. Coast Guard went into operation in St. Thomas, U.S. Virgin Islands. Two other passenger submersibles had already been operating in the Cayman Islands and Barbados (outside U.S. Jurisdiction) beginning in 1986.

b. For operations under U.S. Jurisdiction, the inspection statutes of U.S. Code Title 46 - Shipping (46 USC) and the regulations in 46 CFR Subchapter T - Small Passenger Vessels (46 CFR Parts 175-187) apply to any submersible less than 100 gross tons carrying more than six passengers. Since the regulations were developed primarily with surface craft in mind, many of the requirements cannot be applied to or may otherwise be inappropriate for submersibles. Additionally, there are many measures not in the regulations which must be applied to attain an equivalent level of safety to that of surface craft and otherwise minimize any inherent hazards of underwater operation.

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c. There has also been much interest regarding the operation of smaller submersibles carrying six or fewer passengers. To date, only a few such operations exist. Such vessels are not subject to present inspection laws. However, they are subject to regulation as uninspected vessels under 46 CFR Subchapter C-Uninspected Vessels (46 CFR Parts 24-26). These submersibles must also be designed and constructed to a recognized industry standard for safe underwater operation. Additionally, they may be subject to special local operating restrictions as may be imposed by the Captain of the Port (COTP) relative to navigation safety, port safety and security, and vessel traffic considerations.

d. Recreational submersibles must comply with 33 CFR, Subchapter S (Boating Safety). Undocumented submersibles (i.e., those not having federal documentation) with propulsion equipment, must be numbered in accordance with the federal numbering system or the numbering system of the state in which the submersible will be principally operated. When a submersible is involved in a collision, accident, or casualty, the operator is required to report such occurrences to the appropriate OCMI or state authorities, and to render all possible assistance to others involved in such incidents. 33 CFR 155 (Oil Pollution Prevention Regulations for Vessels) and 33 CFR 159 (Marine Sanitation Devices) also apply to recreational submersibles. Voluntary reports of submersible operations in or near U.S. waters may be made to the nearest Coast Guard Operations Center. Inquiries about the extent of such reports and other questions that cannot be resolved locally should be directed to Commandant (G-NRS) at (commercial/FTS) 202/8-267-1948. These reports are intended for informative use in search and rescue (SAR) activities only.

e. Enclosure (l) to this circular provides general guidance relative to the inspection and certification requirements for submersibles, primarily those carrying more than six passengers. This document does not stand alone, i.e., it makes reference to the applicable regulations and to the appropriate industry standards. Designers, builders and operators must also be familiar with and use the referenced materials.

f. Submersible technology is not new, but its application in the passenger carrying industry is still very much under study. Although we have established a safe baseline, as this industry grows we will see many technological advances which will have to be carefully considered in view of safety. We have initiated a number of studies from which we are likely to gain some insights that may impact on these guidelines, the regulations and the referenced industry standards. Eventually, we plan to establish specific regulations for this class of vessels. In the meantime, enclosure (1) is considered to be the best available approach to facilitating this industry while ensuring passenger safety.

3. IMPLEMENTATION. Coast Guard plan review, inspection, and certification viii be based on the guidance contained in this circular. Owners, operators, designers and builders of passenger carrying submersibles must become familiar with the applicable regulations and standards. To facilitate a timely Inspection for certification, they are also urged co follow the guidelines of enclosure (1) closely.

Encl:
(1) Small Passenger Submersible Guidance
(2) Guidelines for Stability of Shall Passenger Submersibles*
(3) References
(4) Addresses
(5) Urban Mass Transportation Administration (UMTA) Recommended Fire Safety Practices for Rail Transit Materials Selection (deleted)

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* Sample spreadsheet calculations (Figure 4) have been deleted from Enclosure 2.

Encl. (1) to NVIC

GUIDANCE FOR CERTIFICATION OF PASSENGER CARRYING SUBMERSIBLES

TABLE OF CONTENTS

Encl: (2) Guidelines for Stability of Small Passenger Submersibles

(3) References

(4) Addresses

(5) Urban Mass Transportation Administration (UMTA) Recommended Fire Safety Practices for Rail Transit Materials Selection

CHAPTER 1. GENERAL

A. Background

1. Introduction

Considerable research and development bas been conducted relative to the safe design, construction, and operation of small manned submersibles. Participation in such efforts has included the Navy, the Coast Guard, the submersible industry, the American Bureau of Shipping (ABS), and technical societies such as the Marine Technology Society (MTS) and the Society of Naval Architects and Marine Engineers (SNAKE). The safety Of industrial and research submersible operations has been the primary concern of moat work accomplished until recently. The advent of the passenger carrying submersible has created the need to look at manned submersibles in a different light. Since 1986 the Coast Guard has worked closely with the developers of this new industry to establish a sound safety policy for the design, construction, and operation of these new submersibles.

2. The Underwater Safety Project (USP)

a. The Coast Guard Headquarters USP was established in 1968 in reaction to what appeared at the time to be a strong near-term need for Coast Guard regulation of underwater vehicles and stations. At the time there were about 50 civilian submersibles in existence in the U.S. In a decade of submersible operations there had only been three major accidents, resulting in the loss of one life. Nevertheless, to ensure at least a minimum standard of safety was maintained, the Coast Guard proposed legislation to obtain authorization for regulation of non-military submersibles regardless of size, service, or number of passengers.
b. Research and development efforts were initiated to determine the basic requirements for submersible regulations. Liaison with industry and standards organizations was established in order to develop policy, codes, and guidelines for submersibles. MTS conducted three studies and published three sets of guidelines for submersible safety during the period from 1968 to 1979. These guidelines address design, operations, personnel, maintenance, procedures, and equipment. The Coast Guard actively participated in the development of the MTS guidelines and assisted with funding.
c. Not long after the USP was formed, the priority of the project was in question. The proposed legislation attempts regarding the regulation of nonmilitary submersibles had been unsuccessful. Also, the anticipated demand for submersibles and interest in the activity had not materialized. Although there had been steady advancement of submersible technology, the maritime industry had experienced an economic recession. The use of submersibles for other than limited industrial, experimental, or research applications did not appear likely. Coast Guard regulatory efforts on this subject ended with the termination of the USP in the late seventies.

3. U.S. Navy

The Navy has always been concerned with the safety of military submersibles. The loss of THRESHER in 1963 caused Navy efforts to intensify and resulted in special safety programs. With the advent of the deep research vehicles such as TRIESTE and ALVIN, the Navy took action to ensure the safety of Naval personnel when embarked on manned noncombatant submersibles. Military certification requirements were applied as appropriate, and additional safety requirements were dictated by the submersible's specialized design and use. ALVIN was the first such submersible certificated by the Navy. The Navy's certification requirements are now published in "Systems Certification Procedures and Criteria Manual for Deep Submergence Systems, NAVMAT P-9290."

4. American Bureau of Shipping (ABS)

a. During the mid-sixties, ABS was approached by industry representatives and by the U.S. Navy regarding the practicality of preparing standards for the design and construction of commercial submersibles. Because of the limited information and experience available in the area of commercial submersibles, ABS began a lengthy effort of collecting, evaluating and developing technical data, safety criteria, operational aspects, etc. which led to the 1968 publication of the "Guide for the Classification of Manned Submersibles."

b. During the seventies, builders, operators, and ABS (the Navy and Coast Guard as well) gained extensive experience relative to small submersibles, primarily those for research, industrial, and experimental service. Consequently, ABS published "Rules for Underwater Systems and Vehicles" in 1979 (ABS Rules). The Coast Guard participated in the development of these Rules. While not originally intended to encompass passenger submersibles, these Rules have served as a foundation for ABS to class a number of tourist submersibles to date.

5. Passenger Submersible History

a. In 1964 and 1965, the AUGUSTE PICCARD, a forty passenger carrying submersible, took some 32,000 tourists on over 1100 dives to 1000 feet in Lake Geneva at the Swiss National Exposition. Operation of the AUGUSTE PICCARD in the United States in passenger carrying service was proposed; however, the Coast Guard would not accept the vessel because it was not built under Coast Guard inspection. The AUGUSTE PICCARD was then converted and operated as a research and industrial submersible.

b. In 1984, a Canadian commercial submersible operating firm, Sub Aquatics Development Corporation, built two passenger carrying submersibles. The vessels, ATLANTIS I and II, were designed to carry 28 passengers and two crewmen on short voyages to a depth of 150 feet. These two vessels are now operating in the Cayman Islands and Barbados. With the success of these vessels, Sub Aquatics approached the Coast Guard with a proposal for a 47 passenger submersible to be operated within U.S Jurisdiction in the U.S. Virgin Islands (USVI). The Coast Guard worked closely with Sub Aquatics to define basic safety requirements. Acceptable design and operational features were established to ensure the safety of passengers and crew at a level equivalent to that of a small passenger vessel of similar capacity. This submersible, ATLANTIS III, was certificated in July 1987 and has been operating successfully in St. Thomas, USVI. In June 1988, another company successfully certificated a similar sized submersible, LOOKING GLASS, in St. Thomas. ATLANTIS IV and ATLANTIS V have been certificated for operations in Kona, Hawaii and Guam, respectively. MARIEA I, a Panamanian flag submersible, operates in Saipan under control verification.

B. Applicability

1. Subchapter T — Small Passenger Vessels (Under 100 Gross Tons)

a. Vessels less than 100 gross tons which carry more than six passengers are subject to the applicable sections of Title 46 of the Code of Federal Regulations (CFR), Subchapter T (Parts 175 through 187)-Small Passenger Vessels. It is this group of submersibles on which this NVIC focuses. Compliance with applicable sections of 46 CFR Subchapter S-Subdivision and Stability, 46 CFR Subchapter Subchapter B-Merchant Marine Officers and Seaman, 33 CFR Part 155-Oil Pollution Prevention Regulations for Vessels, and 33 CFR Part 159-Marine Sanitation Devices is also required.

b. In addition, due to the hazardous nature of operating a submersible vessel, the Captain of the Port (COTP) may impose special operational requirements under authority of Title 33, U.S. Code (33 USC), Chapter 25 (Sections 1221 through 1226)-Ports and Waterways Safety Program, and 33 CFR Part 160-Ports and Waterways Safety-General. Special concerns for the COTP would include navigation safety, port safety and security, available rescue resources, and vessel traffic safety. The cognizant COTP must be contacted well in advance of any intended operations.

2. Subchapter C — Uninspected Vessels

a. Submersibles carrying six or less passengers, are "uninspected vessels" as defined by 46 USC 2101 (42). Although not subject to inspection, these vessels must meet the requirements of 46 CFR Subchapter C-Uninspected Vessels. They must also meet the applicable requirements of 33 CFR Part 155-Oil Pollution Prevention Regulations for Vessels, 33 CFR Part 159-Marine Sanitation Devices, 33 CFR Subchapter S-Boating Safety, and 46 CFR Part 15-Manning Requirements.

b. Because of the unique design and operating characteristics, as well as the inherent hazards of underwater operation, an uninspected submersible may be permitted in U.S. passenger operations only if it is designed and constructed to a recognized industry standard. Additionally, the COTP may establish special local operating restrictions under the authority of 33 USC Chapter 25-Ports and Waterways Safety Program, and 33 CFR Part 160

Ports and Waterways Safety, General. These restrictions will address local navigation safety, port safety and security, and vessel traffic considerations. To avoid delayed operations due to safety concerns that may be raised about the design and construction of the vessel or its intended operating area, an operator should contact the cognizant COTP well in advance of any intended operations.

3. Subchapter R — Passenger Vessels

Any passenger carrying submersible that is 100 gross tons or more would be subject to inspection under 46 CFR Subchapter H. Although submersibles of this size are not envisioned for the near future, the guidelines of this circular could be used subject to application of Subchapter H instead of Subchapter T.

4. Recreational Submersibles

Recreational vessels, as defined in 46 USC 2101(25), are vessels manufactured or operated primarily for pleasure, or leased, rented, or chartered to another for the latter's pleasure. Submersibles within this category are subject to the requirements of 33 CFR Subchapter S-Boating Safety, Parts 173-183. The guidelines in this circular generally do not apply; however, depending on the area of operation, COTP operating restrictions may be appropriate. This will be evaluated on a case by case basis. These guidelines may be of assistance to a manufacturer or owner of a recreational submersible.

5. Foreign Flag Submersibles

See Chapter 11.

C. Equivalency

This NVIC is intended to outline a basis for determining equivalency of passenger carrying submersibles to conventional small passenger vessels. Since the applicable regulations were developed primarily with surface craft in mind, many specific features cannot he applied to or may otherwise be inappropriate for a submersible. The Coast Guard's approach to the novel design and unique operational hazards of passenger submersibles is to require a level of safety equivalent to that required for a surface craft of similar size and service. This is established in part through a combination of design requirements and operational restrictions. I written operations manual and safety plan detailing normal and emergency operational procedures should be prepared early in the planning stage for concept review and submitted to Commandant (G-MTH-4), see Appendix C for addresses. It will be evaluated in conjunction with the proposed design to ensure the project addresses crew training, operational parameters, surface vessel control, and safety features.

D. Regulation Development

As more experience is gained with passenger carrying submersibles, regulations specific to them and to their operations will be promulgated. Therefore comments to Improve this NVIC are solicited. Comments should be submitted to Commandant (G-MTH-4).

CHAPTER 2. INSPECTION AND CERTIFICATION

A. Concept Review

Passenger carrying submersibles are novel vessels and as such require special consideration. All new submersible vessel designs and all operations must be conceptually approved by Commandant. For concept review, an owner or builder should submit a proposal to Commandant (G-MTH-4). The proposal should cover, to the maximum extent possible, the aspects of design and operation raised in this NVIC and should include the draft operations/safety plan. This is an important first step that will facilitate the certification process, especially plan review and inspection.

B. Application for Inspection

An Application for Inspection (CG-3752) should be submitted to the Officer in Charge, Marine Inspection (OCMI) having responsibility for the location where the vessel will be built. Contact should also be made with the OCMI having Jurisdiction in the proposed operating area.

C. Plan Review

1. Plan review for most Subchapter T vessels is normally done by the cognizant OCMI. However, passenger submersibles are a unique class of vessels of very novel designs and operations, therefore detailed plan review will be done by the Marine Safety Center (G-MSC). Plan submittal procedures should be discussed with the cognizant OCMI(s) as well. Detailed plan review will not normally be performed before Jurisdiction (evidence that Coast Guard inspection is required) has been established and substantial evidence (e.g., a contract) is provided that the submersible will in fact be constructed. Conceptual plan review, as noted in Section 2.A. above, may be performed by Commandant (G-MTH) prior to substantiating intent to construct.
2. In addition to the plans noted in Subchapter T, the following will be required for detailed plan review:

a. Pressure hull strength calculations and construction tolerances including those for: viewports, hatches, Joint details, penetrations, attachments, and methods of attachment.
b. Life support systems/equipment, material specifications (as appropriate), and supporting calculations for:

(1) Carbon dioxide removal
(2) Oxygen supply
(3) Emergency breathing
(4) Sensors and monitoring equipment

c. Fire protection systems/equipment.
d. Bilge system.
e. Ballast system plans and calculations.

f. Weight, stability and buoyancy data and calculations. A surface and submerged inclining will be required for which a proposed procedure is to be submitted (see enclosure (2)).
g. Calculations which demonstrate adequate buoyancy and stability to permit the vessel to surface In a timely manner, while maintaining an upright attitude, after receiving damage to any ballast/ buoyancy tanks. Underwater escape and rescue from a submerged submersible is not likely to be successful and in any event it will be difficult and hazardous, so all means for returning the submersible to the surface in both the normal and emergency modes, should be detailed.
h. Intact and damage freeboard and limits of heel/trim calculations. Access to lifesaving equipment and means of exiting the submersible once on the surface may be difficult. Adequate freeboard and stability must be available on the surface to permit the safe disembarkation of passengers under the worst expected surface conditions in the designated operating area. Compliance with ASS rule 2.19.1 will normally satisfy this requirement.
i. Power system and battery charging plans.
j. Control systems plans and layout, including manuevering, navigation, life support, and communication systems.
k. Detection systems for hydrogen and chlorine gas generation.
l. Quality control and testing procedures.
m. Material identification.

D. Inspection for Initial Certification

1. The basic inspection and certification requirements are contained in Subchapter T. Inspection for certification is normally conducted only on U.S. flag vessels; however, exceptions to this are discussed below. Generally, construction and inspection will begin only after the required plans have been approved unless specific alternative arrangements are made with Commandant (G-MVI). In any case, when construction and inspection proceed without approved plans, there is no guarantee that modifications won't be required later as a result of deficiencies noted in plan review. The scheduling of inspections is to be worked out with the OCMI. Sea trials will be required as part of the initial certification in order to prove all of the vessel's systems.
2. For a U.S. flag vessel built overseas, the ultimate aim will be a degree of inspection during construction equivalent to that which would be attained if the vessel were built in the U.S. The Coast Guard maintains only a limited number of inspectors overseas, hence overseas inspections may be complicated by delays la communications and inspector availability. Additionally, the travel and subsistence costs associated with overseas inspections are reimbursable from the

owner to the Coast Guard. See NVIC 11-84 for further guidance on foreign construction requirements relative to the construction of U.S. vessels overseas.

3. Although the ABS Rules have been recognized in part, the presence of an ABS surveyor does not substitute for the presence of a Coast Guard inspector. A Coast Guard inspector will be present during various phases of construction and will witness all tests, except as the OCMI may allow otherwise.

E. Inspection for Certification

Certificates will normally be issued and be valid for three years. A periodic inspection for certification will be required at least every three years for renewal of the Certificate of Inspection. Except as Bay be allowed by the OCMI, a Coast Guard inspector will be present to inspect the vessel and witness all required tests. During periodic inspections for certification, in addition to the inspections required under Subchapter T, the inspector will:

1. be guided by 46 CFR 197.462 Pressure vessels and pressure piping (Commercial Diving Operations) and Section 10 (Surveys after Construction) of the ABS Rules, in particular Rule 10.11.
2. normally witness a test dive (see ABS Rule 2.13) to the design depth (maximum depth for which a system or vehicle is designed) during which all systems are to be operationally tested.
3. review maintenance records to ascertain the nature and extent of routine maintenance.
4. ensure that all monitoring instruments and gauges, particularly those in the life support systems, are calibrated.
5. examine the internal surface of the pressure hull in select locations to ensure the absence of corrosion or internal damage; review the results of dimensional checks to verify the geometric integrity of the pressure hull. These checks should be performed triennially.

F. Certificate of Inspection (COI)

A submersible will be certificated for a specific operation and a specific dive site. The dive site must be specified on the COI. If support vessels are integral to the safe operation of the submersible they should also be referenced on the COI with any operating restrictions regarding the support vessel's duties with respect to the submersible's safety. The maximum duration of an operational dive will be specified on the COI. The COI should also reference the operations/safety manual.

G. Reinspection

Reinspections will be conducted annually as required by 46 CFR Subchapter T and guided by ABS Rule 10.9. Except as may be allowed by the OCMI, a Coast Guard inspector will be present to inspect the vessel and witness all required tests. Emphasis will be given to emergency equipment, and the operation of all vessel control and life support systems.

1. A visual examination of the hull, both internally and externally, should be conducted Insofar as it is practicable.

2. Maintenance records should be reviewed by the inspector to ascertain the nature and extent of routine maintenance.
3. All monitoring instruments and gauges, particularly those in the life support systems, should be calibrated and proven functional.
4. An operational dive, which need not be to the rated depth, should be conducted and all systems operationally tested.
5. Pilot evaluation.

H. Drydocking or Hauling out

1. Submersibles shall be drydocked or hauled-out at intervals <u>not to exceed</u> 18 months. The periodic examination requirements specified in 46 CFR 197.462 for commercial diving equipment and Section 10 of the ABS Rules, Surveys after Construction, should be used as a guide during drydock examinations. Underwater surveys in lieu of an actual drydocking or haul-out are not considered an acceptable alternative for submersibles. The condition of externally mounted ballast tanks, high pressure air tanks and O_2 bottles, hydraulic and electrical systems must be given special attention. Additionally, care should be taken to determine if the pressure hull bas sustained any damage which will require repair. Generally, the Coast Guard will adopt a very conservative approach regarding repairs to the hull, life support systems, and buoyancy/ballast systems. Full restoration will be required. Approved welding procedures and non-destructive testing will be required on all pressure hull repairs.
2. Viewing ports have a limited number of dive cycles before fatigue failure becomes a concern. The estimated number of dives completed since installation should be compared to the manufacturer's data to determine when the viewports should be replaced. Should the operator present evidence that the viewports are still in serviceable condition, such as when actual dive pressures have been significantly less than the rated pressure, destructive testing and analysis of at least one viewport may provide a basis for retaining the remaining viewports until the next drydocking period. In any case, viewports will be replaced 10 years after their date of manufacture. See Section 2.I. below regarding replacement of damaged viewports.

I. Notification of Repairs and Alterations

1. Notification must be given to the OCMI before any repair or modification is made to the vessel. Additionally, no modifications or alterations shall be made to the pressure hull or any life support systems without consulting the Commandant (G-MTH-4).
2. Until evidence is presented to the contrary, any damage to a viewport, no matter how minor, will be cause for its immediate replacement.
3. Notification must be given to the OCMI of any unintentional grounding/stranding, loss of power, increase in CO, C02, or H_2 beyond limits, or any emergency surfacing evolution for any reason.

CHAPTER 3. CONSTRUCTION AND ARRANGEMENT

A. General Design

1. The basic requirement for passenger submersible design is that in the event of any single casualty the vessel can be returned to the surface under its own ability. Redundancy of systems and equipment is essential in order to meet this general design requirement. Vital systems, such as those necessary for the vessel to surface, to deploy lifesaving equipment, to disembark personnel, or for life support must be shown to have an acceptable level of reliability, a manual override control, or redundancy. A single casualty in most failure scenarios is assumed; however, some safety equipment and measures are required on the basis that more than one failure may occur in a single incident or in case the submersible is unable to return to the surface.
2. Positive buoyancy in all operating modes is highly recommended so that if power or some other critical system is lost the vessel will return to the surface naturally (automatically). Vertical thrusters can be used for maintaining the desired depth when operating with positive buoyancy. In the event the vessel cannot return to the surface on its own and sinks to the bottom, the depth of water at the dive site cannot exceed the rated depth (the maximum depth reached during a manned test dive witnessed by an inspector or an ABS surveyor, as may be accepted by the OCMI) of the submersible. Certification of the submersible is based on the safety of the overall operation including the dive site, support vessels, proximity of rescue/salvage services, crewing, and documented operational and safety planning.

B. Hull Structure

1. Structural Standards

The hull structure should be designed, fabricated, and inspected to the standards of the American Society of Mechanical Engineers (ASME) Code for Pressure Vessels for Human Occupancy (PVHO-1) or the standards of the American Bureau of Shipping (ABS) Rules for Building and Classing Underwater Systems and Vehicles. A proposal to use other established standards for underwater vehicles may be submitted to Commandant (G-MTH-4) for consideration. The standard used and the pertinent design parameters, such as maximum operating depth and structural safety factor, must be identified in the plan submittal.

2. Hull Penetrations

Requirements for hull penetrations for hatches, viewports, fluid piping, and electrical cable are found in the ABS rules and the ASME PVHO-1 standards. Details of such penetrations should be carefully designed because their failure could be catastrophic. Special attention should be given to clusters of penetrations to ensure adequate ligament strength and stress relief are provided. The potential "zipper effect" due to placing viewports or other penetrations in line should be investigated and appropriate reinforcement should be provided.

3. Viewports

The only recognized standard for acrylic viewports is ASME PVHO-1. The viewports should be adequately protected, e.g., protective covers or guards over the exterior and interior, to protect them from impact, scratching or chemical cleaning agents, keeping in mind that damaged viewports must be replaced.

4. Exostructure

An exostructure complying with ADS rule 9.17 should be provided to protect the pressure hull and viewports from damage due to collision, grounding, mooring, waves, or other hull impact forces. The exostructure should incorporate features to heighten the vessel's visibility while on the surface to reduce the possibility of collision.

C. Subdivision and Stability

1. Subdivision

Subdivision is not normally required for vessels that carry 49 passengers or less and that are less than 65 feet in length when operating in protected waters with sufficient surface support to prevent collisions.

2. Stability

See enclosure (2) for further guidance on stability.

D. Means of Escape

Two means of escape from the pressure hull are required by 46 CFR 177.15-1. Practically, this means that two hatches are required and must be arranged so that if one is not accessible due to fire or excessive trim the other is. Ladders may be collapsible but must be easily restored to the exiting position.

E. Interior Construction

1. Fire Protection

a. 46 CFR 177.10-5 states that the ". . . general construction of the vessel shall be such as to minimize fire hazards insofar as reasonable and practicable." This means that a designer or builder should minimize the amount of flame, smoke, and toxic gas producing materials within the submersible to reduce the risk to passengers and crew. This is critical in a confined area, where return to the surface may take time. The following materials have been identified as meeting the intent of the regulation:

(1) Materials approved by the Coast Guard under 46 CFR Part 164 — Materials.
(2) Materials meeting the Urban Mass Transportation Administration (UMTA) Recommended Fire Safety Practices for Rail Transit Materials Selection (see enclosure (5)).

b. The following materials have been identified as meeting the intent of the regulation if they also meet the applicable UMTA recommended smoke density criteria (see enclosure (5)):

(1) Fire retardant polyester resins and gel coats meeting Military Specification MIL-R-21607.

(2) Polyester resins with a flame spread of 25 or less when tested to ASTM Standard E-84.
(3) Nonfire retardant gel coats not exceeding .035" in thickness.
(4) Materials approved by the Federal Aviation Administration (FAA) for the interiors of commuter or transport aircraft in accordance with Federal Aviation Regulations (FARs) 14 CFR Part 23, Appendix F, and Part 25, Appendix F, respectively.

c. Many test specifications including those referenced above have been promulgated by various organizations for the purpose of determining the properties of materials in response to heat and flame. Such tests are performed under controlled laboratory conditions and may not adequately indicate how a material or product will behave in an actual fire. Toxic gas production of plastic material in fires is of great concern to fire protection engineers in all fields of public transportation. Ideally, fire risk assessments should be performed in the selection of passenger compartment materials, but practical methods have not been adequately evaluated to allow the Coast Guard to prescribe a particular method for use by designers of submersibles. However, the Coast Guard does not want to discourage the use and development of fire risk assessments and will consider such assessments for meeting the intent of 46 CFR 177.10-5(a) if carried out in a professional and competent manner.
d. Material for the construction of panels and enclosures that contain electrical equipment must be noncombustible and meet UL 67, Panelboards, and UL 50, Cabinets and Boxes. It is doubtful that glass reinforced or thermoformed plastics can meet these requirements. The use of such materials in the pilot's control station is subject to the guidelines for interior construction materials outlined above. They should not be used in the machinery space which is the most likely source of fire on the vessel.

2. Arrangements

a. Separation (e.g., a partition) between the control area and the passenger area to prevent passengers from interfering with operator performance should be provided.
b. Machinery spaces must be separated from the passenger space by solid partitions and access doors must be closed during passenger operations. Machinery space partitions must be of an approved non-combustible material.
c. Access to escape hatches must be unimpeded.
d. Aisle width and headroom should be adequate for average sized persons standing upright.

F. Rails and Guards

1. Rails as required by 46 CFR 177.35-1(h) must be installed on the deck perimeter to prevent passengers and crew from falling overboard.
2. The means of boarding from a passenger transfer vessel must be substantial and incorporate side rails. The transfer of passengers should take into account the relative deck heights of the submersible and surface craft, differing roll periods, wave effects, and protection of submersible appurtenances and the hull of the transfer craft.

CHAPTER 4. LIFESAVING EQUIPMENT

A. Life Preservers

Coast Guard approved personal flotation devices, PFDs, will be required for everyone on board, including children. Type I PFDs may not be appropriate when the only escape routes are through small horizontal hatches. The use of approved inflatable PFDs is encouraged on submersibles. At least one manufacturer has obtained Coast Guard approval for an inflatable PFD. PFDs must be stowed on board.

B. Primary Lifesaving Equipment

Generally, primary lifesaving equipment must be provided as required by subchapter "T." However, there are obvious problems with on board stowage of life rafts, lifefloats and bouyant apparatus. Alternatives to on board stowage, such as stowage on the surface support craft, must be addressed in the operations manual.

C. Ring Buoys

Although permanent stowage of ring buoys on the deck of the submersible may be impractical, they must be readily available during passenger boarding or whenever personnel are on deck. Stowage arrangements must be addressed in the operations manual.

D. Distress Signals

Pyrotechnics are not to be stowed inside the submersible. Means of alerting surface craft to underwater distress situations must be addressed in the operations manual. Consideration should be given to any reliable means of signalling the surface support craft; the signalling method must not be incapacitated by loss of primary power. The surface craft must have VHF capability to relay distress information to SAR stations and other rescue resources. If the submersible is capable of performing night dives, the means of signalling the surface craft must be visible at night.

E. Emergency Position Indicating

Since most submersible operations are limited to specific dive sites, and they are required to have a surface support craft in attendance at all times, EPIRBs will not normally be necessary. However, the OCMI may require an EPIRB if in his opinion one is necessary for the safety of the operation. In any case, surface craft must be capable of rapidly determining the exact location of the submersible in an emergency. Water depth and clarity are obvious factors. Nighttime operations would require a more positive means, e.g., marker buoys.

F. First Aid Kit

A first aid kit should be provided. Since on-board injuries to passengers would most likely be minor, a kit approved under 46 CFR 160.041 is considered adequate. Other kits having essentially the sane contents as the Approved kits viii also be satisfactory.

G. Individual Emergency Breathing Apparatus

Emergency life support shall be provided in the case of failure of primary systems. Compliance with ABS Rule 5.11 or an equivalent arrangement will be accepted such as redundant breathing gas supply and CO_2 removal systems with individual protection from the contaminants of a fire for each person on board. The operator should be provided with an individual breathing gas mask.

CHAPTER 5. FIRE PROTECTION EQUIPMENT

A. General

1. The operations safety plan should contain procedures for fire-fighting. Fires may result from electrical system failures. The first step in combating fires of this nature should be to secure the electrical power to the affected equipment.
2. Smoking is strictly prohibited in the submersible and passengers must be informed of such restrictions.

B. Fire Pumps/Fire Main System

If a fire pump/fire main is provided the source of water and its conductivity should be considered in light of the fact that the fire is likely to be electrical in nature.

C. Fixed Fire Extinguishers

Fixed systems, if provided, must be nontoxic and nonasphyxiating. CO_2 is considered to be asphyxiating in an enclosed space and is not permitted. Halon 1301 is acceptable, but the system must be Coast Guard approved.

D. Portable Fire Extinguishers

At least two approved portable extinguishers must be provided and be easily accessible. Halon 1211 and CO_2 are not acceptable because they are considered toxic in enclosed spaces.

E. Fire Detection System

Detectors should be installed for normally closed spaces containing electrical equipment or machinery. If fire detectors are installed they must be listed. If a detection system is installed, the components must be listed and the system arrangement plan must be approved. To be considered listed, detectors and system components must be listed with a nationally recognized testing laboratory acceptable to the Commandant. Secondary power for fire detection systems should be supplied by the emergency power source or by batteries that have the capacity to operate the detectors for at least twice the maximum intended duration of an operational dive, or two hours, whichever, is longer.

CHAPTER 6. MACHINERY INSTALLATION

A. General

Marine engineering systems are subject to the requirements of 46 CFR Subchapter T and Subchapter F as appropriate. The following are certain specific items which must be considered and addressed in the design; however, this list is not all inclusive.

1. Pressure vessels (other than the main hull) which are permanently installed on board the vessel are subject to 46 CFR 54.01-5. Portable pressure vessels for use on board, but serviced/refilled ashore and remaining in commerce, are considered ship's stores and must he Department of Transportation (DOT) approved (46 CFR 147.04). DOT cylinders which are modified in any way are no longer considered DOT approved and must be shown to be equivalent to the appropriate pressure vessel standards.
2. Hydraulic and pneumatic systems must meet 46 CFR 58.30.
3. Air conditioning systems must meet 46 CFR 58.20.

B. Lifesupport Systems

1. General

The standards discussed in Section 5 of ABS Rules regarding oxygen supply, CO_2 removal, and emergency life support are generally acceptable. Provisions for personnel protection from hazards such as smoke or toxic vapors during the time it takes to surface and evacuate should be made. Life support systems should be capable of sustaining a full passenger and crew load for 72 hours beyond normal operations. Supporting calculations demonstrating compliance with these or similar standards must be submitted. If other standards are proposed, they must be submitted to Commandant (C-MTH) for evaluation.

2. Oxygen

The O_2 system should be designed to maintain the O_2 content at about 22 percent by volume. The O_2 content should not exceed 25 percent by volume, nor should it fall below 20 percent. The system must be adequately monitored.

3. CO2 Removal

The CO_2 removal system must be capable of maintaining the CO_2 concentration at or below 0.5 percent by volume. This system must be adequately monitored.

4. Tests

An initial test of the CO_2 removal system and the oxygen system should be conducted with the full passenger and crew load on board. The equilibrium point of CO_2 concentration, once achieved, should be maintained for a period equal to the longest anticipated dive or one hour, whichever is longer. If the CO_2 concentration exceeds 0.5 percent by volume or equilibrium cannot be maintained during this period, the system fails. The O_2 supply and CO_2 removal systems are among the operational systems that should be tested annually (see Section H of Chapter 2).

C. Bilge Systems

A bilge system is normally required. An acceptable alternative is a bilge water level sensing system provided an ample capability to quickly return to the surface is available upon activation of the sensing system alarm. A de-watering capability is required when the vessel is on the surface. A hand operated pump may be sufficient for this purpose.

CHAPTER 7. ELECTRICAL INSTALLATION

A. General

The electrical system must meet the requirements of 46 CFR Subchapter T Part 183 and Subchapter J Electrical Engineering Parts 110-113 as appropriate. System redundancy must be considered and addressed.

B. Cable

Low smoke cables are recommended for use. The low smoke cables provide a degree of safety surpassing that provided by the standard shipboard cables due to the closed environment of the submersible.

C. Emergency Power

1. An emergency power source and controls must be provided for emergency lighting, emergency recovery systems, emergency life support systems, and underwater communications systems. It must be independent of the main power source and must be sized to supply all connected loads for at least twice the maximum intended duration of an operational dive. At the end of this period the voltage of the battery must not be less than 88 per cent of the nominal battery voltage.
2. Emergency lighting must be automatically activated upon loss of the main power source. Pilot controls should be illuminated by the emergency lighting system. Emergency lights may have a means to turn them off to conserve power, but such means should not be accessible to the passengers.
3. There must be a means to indicate a low charge on the emergency batteries.

D. Batteries and Battery Charging

1. Ail batteries must be protected from salt water contamination, yet remain accessible for regular servicing.
2. Batteries may be installed within the vessel hull if suitable precautions are made to protect the passenger compartment from outgassing and other associated hazards. Battery compartment Isolation and sealing, monitoring of hydrogen and chlorine gas levels, catalytic conversion of gas emissions, and automatic bilge pumping are precautions that should be considered. Battery compartments must be sealed during normal passenger operations.

3. Battery charging procedures and equipment must be addressed from the standpoint of hydrogen generation and sources of ignition. Battery charging should be accomplished only while the submersible is at the surface. Adequate ventilation must be provided during charging operations. The ventilation system must exhaust outside the submersible to the weather. Portable venting arrangements would be adequate.

CHAPTER 8. VESSEL CONTROL

A. Ballast Systems

Ballast systems must be designed to enable the vessel to be sufficiently stable on the surface and have adequate freeboard for the safe transfer of passengers to and from the vessel in the worst expected operational sea state. Adequate capability of maintaining heel, trim and depth control while submerged must be provided. Positive buoyancy should be maintained at all times with depth maintained by vertical thrusters. "Hard ballast" or pressurized water ballast tanks must comply with the regulations for pressure vessels, 46 CFR Part 54. "Soft ballast" or free-flooding water ballast tanks must be constructed of material suitable for the intended use.

B. Emergency Ballast Systems

Sufficient Jettison ballast (i.e. drop weight) must be provided so that the vessel may return to the surface in the event the largest single floodable compartment or tank other than the main passenger compartment becomes flooded. The drop weight should be tested at each inspection for certification and more frequently if there is reason to believe the system may not be functioning properly. When practicable, this system should be tested in the water; otherwise a test in drydock may be accepted.

C. Auto-pilot

Auto-pilot control may be provided but may not be employed without constant pilot monitoring and a manual over-ride.

D. Communications

Communications systems for both submerged and surface modes must be provided. The system for submersed operation must be adequate for the rated depth of the vessel. Loss of submerged communications shall be cause for returning to the surface.

E. Alarms

All alarms must be independent of remote or automatic controls.

F. Remotely Controlled Valves

Remotely controlled valves in the air, oxygen, and ballast systems should be arranged for manual operation in an emergency.

CHAPTER 9. OPERATIONS

A. General

1. Since a submersible is usually not as self sufficient as a surface vessel, special consideration will be given to the overall system of operations, support and maintenance in view of the environment in which the submersible will operate. Depending on the location of operation, certain conditions such as strong tidal currents or hazards presented by other vessels or underwater obstructions may be cause for certain operating restrictions, additional design features, or possibly prohibiting operations altogether.
2. Submersibles will be restricted to operations in waters no deeper than the designed and certified maximum operating depth of the vessel. The OCMI will take into account the slope of the bottom in proximity to deep water.
3. Certification will be for a particular operating location, and operations in other locations will not be permitted without specific Coast Guard approval. All aspects of the intended operations must be discussed with the cognizant OCMI and Captain of the Port (COTP) for the proposed operating area early in the planning stage. The written operational safety plan would be useful as a basis for that discussion.
4. <u>Vital systems</u>. All vital systems should be identified and addressed in the operations manual. The failure of any vital system is reason to terminate dive operations until the system is repaired and tested. The OCMI should be notified any time a viral system fails during operations.

B. Dive Site

The OCMI will specifically approve the dive site. Since passenger transfer from a surface craft to the submersible will normally occur at the site, an evaluation of prevailing weather and sea conditions, and the availability of natural shelter, must be considered. Additionally, vessel traffic density, bottom contours, current strength, and the presence of wrecks or other potential entanglements in the proposed diving area should be evaluated to see if they pose any risk to the submersible. The dive site will be clearly identified on the COI, as will the maximum depth to which the vessel may descend; the dive site may not be any deeper than the maximum depth for which the vessel is approved.

C. Operations Manual/Safety Plan

1. A document containing operating and emergency plans and procedures must be prepared for approval by the local OCMI. It should be clear and comprehensive. Emergency procedures should be easily found in the document and should provide clear instructions for dealing with emergencies such as fire, system failures) loss of communications, medical problems or injuries, life support system malfunctions, atmospheric contamination from battery gases or other gas system leaks, support vessel casualties, etc. Reference to the Association of Offshore Diving Contractors Code of Practice for Operation of Manned Submersible Craft may be of assistance in developing an operations manual/safety plan.

2. In the planning stages and during review, a draft manual/plan is acceptable. Ultimately, the manual/plan must be finalized and adhered to. Changes may be made subject to approval of the OCMI and COTP. The operations manual/safety plan should address at least the following aspects of the operation:

a. support craft functions and capabilities. These should address: submersible shadowing, diver availability and capabilities, and emergency lift capability. The support craft should also be equipped with VHF radio and underwater telephone to permit ready communications with the submersible, shore stations, SAR facilities, and other vessels in the submersible's operating area.
b. normal operational procedures for: submerging and surfacing, surface operations, underwater operations (visibility, currents, communications, surface traffic, etc.), and ferrying and transferring passengers (surface vessels carrying more than six passengers to and from the submersible are also subject to Coast Guard inspection).
c. emergency procedures for scenarios such as: inability to surface, loss of power, controllable leakage of hull, collision, fire, evacuation out of and off the vessel.
d. mooring and operational area proposal.
e. the minimum amounts of air, oxygen, and battery power (amp-hours) which must be available before commencing any dive should be established and documented in the operations manual. The ABS rules should be used for guidance.

D. Rescue

1. Rescue capabilities should be identified as part of the original concept proposal and included in the operations manual. Regardless of all the precautions, there still exists a possibility that the submersible may not be able to surface on its own. Appropriate rescue facilities must be readily available in such a case. The depth of water for which the submersible will be certificated will in no case exceed the demonstrated capability of the available rescue equipment. Generally, divers should be immediately available on the surface support craft who can attach lifting cables or manipulate external ballast controls. Lifting capability on the surface must be available within a reasonable time, considering the amount of reserve life support on board the submersible.
2. Diver assistance at depths exceeding 150 feet requires special training and the use of mixed gas equipment. This obviously will take time to coordinate, if it is not already on-scene, and may be cause to limit the operating depth to no more than 150 feet. Remotely operated vehicles (ROVs) may be considered in lieu of divers. However, performance of all required functions must be demonstrated at the intended maximum operating depth to the satisfaction of the OCMI.

3. The operations manual should include: procedures for locating the submersible; steps necessary to raise it to the surface; a listing of available salvage facilities, including diver support; phone numbers; and estimated response times. Because of the potential for apparently minor situations to escalate, it is recommended that all emergencies be immediately reported by radio to the appropriate Coast Guard Rescue Coordination Center (RCC). It is also recommended that the rescue information contained in the operations manual be communicated to the Coast Guard station having Search and Rescue (SAR) responsibility for the operating area.
4. Although the Coast Guard has statuatory responsibility for SAR, it does not have an underwater SAR capability. In the event of an underwater SAR situation, the Coast Guard will coordinate the activities of external underwater rescue resources (e.g., Navy, commercial companies). These may not be immediately available. Therefore, the submersible operator must anticipate all likely casualty situations and provide for the ready availability of specific rescue resources.

E. Maintenance

Periodic maintenance is essential to continued safe operations. A schedule of regular periodic maintenance should be established and carefully followed. This schedule may be included in the operations manual/plan or developed as a separate maintenance manual/plan. Maintenance records, including test reports of life support, control and emergency systems, should be reviewed during inspections for certification and reinspections. Failure to maintain adequate records could result in operational delays when trying to substantiate proper maintenance and repairs of vital systems during periodic reinspections.

CHAPTER 10. MANNING AND LICENSING

A. General

The Coast Guard does not presently have regulations which specifically address licensing and manning of passenger carrying submersibles.

B. Submersibles not subject to inspection

Uninspected submersibles may be operated by individuals holding a license as operator of uninspected passenger vessels or other license which is authorized by regulation to serve as operator of uninspected passenger vessels. The operator must have familiarized himself/herself with the operation of the vessel and its equipment.

C. Submersibles subject to inspection

For inspected submersibles, a manning and licensing proposal must be submitted to Commandant (G-MVP) via the cognizant OCMI. This proposal must address levels of personnel training and qualifications as well as the number of personnel considered necessary for safe operation of the vessel.

1. Normally two licensed individuals will be required so as to ensure the vessel can be safely operated under all conditions, including incapacitation of the master.
2. The number of unlicensed deckhands required, if any, will be determined after evaluation of the manning proposal and operational safety plan.
3. Individuals serving as master or mate on inspected submersibles will be required to possess the appropriate license.

a. That license must authorize service on inspected passenger-carrying vessels of similar gross tonnage and route.
b. The license must contain an endorsement for the submersible or class of submersibles to be operated.
c. To obtain endorsement, an individual will be required to successfully complete a company training program that has been reviewed and approved by the local OCMI having a Regional Examination Center. Such a program would include, but not be limited to: vessel systems, vessel operations, emergency procedures, and "hands on" qualification dives. Reference to the Deep Submersible Pilots Association's "Guidelines for the Selection, Training and Qualification of Deep Submersible Pilots" may be helpful in this regard.
d. Applicants will be required to pass a specially prepared submersible operations examination module. The submersible operations module is vessel specific, and is prepared by the Coast Guard after studying the vessel's operations and technical manuals.

CHAPTER 11. FOREIGN PASSENGER SUBMERSIBLES OPERATING IN THE U.S.

A. Coastwise Trade

Vessels engaging in coastwise trade must be documented under the laws of the U.S. with a coastwise license. Foreign built and/or foreign flag submersibles may not engage in U.S. coastwise trade. With very few exceptions, all waters under the Jurisdiction of the U.S., for which the inspection statutes apply, are subject to the coastwise laws (Jones Act).

1. The U.S. Virgin Islands, the Commonwealth of the Marianas Islands, and American Samoa are not currently covered by the coastwise laws. There may be other U.S. territorial areas where the coastwise laws do not apply.
2. There are also specific operations such as qualified "voyages to nowhere" which have been determined by the U.S. Customs not to be coastwise voyages, i.e., vessels carrying passengers or cargo from a U.S. port to a point beyond the territorial waters and back to the same port.
3. Specific guidance on characterizations of trade should be sought from the Department of the Treasury, U.S. Customs Service, Carriers, Drawbacks, and Bonds Division, Carrier Rulings Branch.

B. Inspection Standards

All foreign passenger vessels operating in the U.S., are subject to the inspection laws of 46 USC. Due to the unique hazards associated with submersible operations, and the extraordinary application of the existing regulations, requests to operate foreign flag submersibles in the U.S. will be very closely scrutinized.

1. Reciprocity. U.S. law [46 USC 3303(a)] provides that a foreign vessel inspected and certificated under laws and standards that are similar to those of the U.S., are generally subject only to an inspection to ensure that the condition of the vessel's propulsion equipment and lifesaving equipment are as stated in its current certificate of inspection. A foreign country that is party to the International Convention for the Safety of Life at Sea, 1974, (SOLAS) is considered to have inspection laws and standards similar to those of the U.S. and certificates issued by that country may be accepted as evidence of lawful inspection provided that vessels of the U.S. visiting that country are accorded the same privileges.
2. The SOLAS regulations, like U.S. regulations, were written primarily with surface craft in mind. Given the unique nature of these vessels, flag administration exemptions from specific SOLAS regulations can be anticipated. Any exemptions issued by the flag administration must be discussed with and be acceptable to the Coast Guard in accordance with SOLAS (Chapter I, Regulation 4) prior to the vessel's operation in the U.S. to ensure the standards to which the vessel was inspected are in fact similar to those of the U.S. Requests for consideration of exemptions are to be addressed to Commandant (G-MVI).

3. Vessels which are not registered in a nation party to SOLAS, or otherwise not inspected by their flag administrations, are subject to the regulations of the applicable Subchapter of 46 CFR as if they were U.S. flag vessels.

C. Inspection and Certification

A foreign flag passenger submersible will not be allowed to operate in the U.S. until it has either a Coast Guard issued COI or a SOLAS Passenger Ship Safety Certificate (PSSC).

1. Submersibles with SOLAS certificates.

Foreign passenger submersibles that are inspected by their flag administrations under the SOLAS, and have valid PSSC, will be allowed to operate in U.S. waters subject to section B.2. above. Additionally, the OCMI will perform a control verification examination to determine if the vessel is substantially in compliance with its Certificate and that it complies with any special requirements associated with specific exemptions that may have been granted. In order to verify the standards which have been applied, certain plan review may be required. Plans should be submitted to Commandant (G-MVI) when addressing the standards applied (section B.2. above) and the exemptions for which approval is being sought. Control verification examination will be conducted annually with quarterly reinspections to ensure a vessel is maintained in compliance with the applied standards and the conditions of its certificates.

2. Submersibles without SOLAS certificates

Any foreign passenger submersible that does not hold a valid PSSC must undergo full Coast Guard plan review and inspection for certification in accordance with the guidelines of this NVIC. These will be handled on a case by case basis. The Coast Guard will not normally conduct overseas inspection of foreign flag vessels. Because many of the most critical aspects of submersible construction must be witnessed as the vessel is being built, our criteria for issuing a COI to a foreign submersible will be extremely stringent and may make this alternative unfeasible.

D. Operations Manual

An operations manual/safety plan, which includes the information described in Chapter 9 of this NVIC, must be submitted to the OCMI for approval. The dive site must be approved, and operating conditions stipulated, just as for U.S. submersibles, before operations will be permitted.

GUIDELINES FOR STABILITY OF SMALL PASSENGER SUBMERSIBLES

3 March 1989

The stability of submersibles is different in many ways from that of surface craft, but evaluating it is not any more difficult. These pages contain a short discussion of the principles of submersible stability, a list of the hazards to be guarded against, a list of the assumptions made in writing these guidelines, a procedure for conducting a stability review including evaluation criteria, and a sample stability letter.

Discussion

Submersible vessels operate both on the sea surface and submerged beneath it. These are two very different realms, with different forces at work in each. Surface craft are subject to the strong overturning moments of surface waves and wind. The stability criteria for surface craft are intended to guard against these. Submersibles are subject to the same forces and moments while they are surfaced, so they must meet criteria for surface craft. Beneath the surface, however, wind and wave effects are greatly reduced, and the mechanism of stability is entirely different. The criteria for submerged stability are correspondingly different.

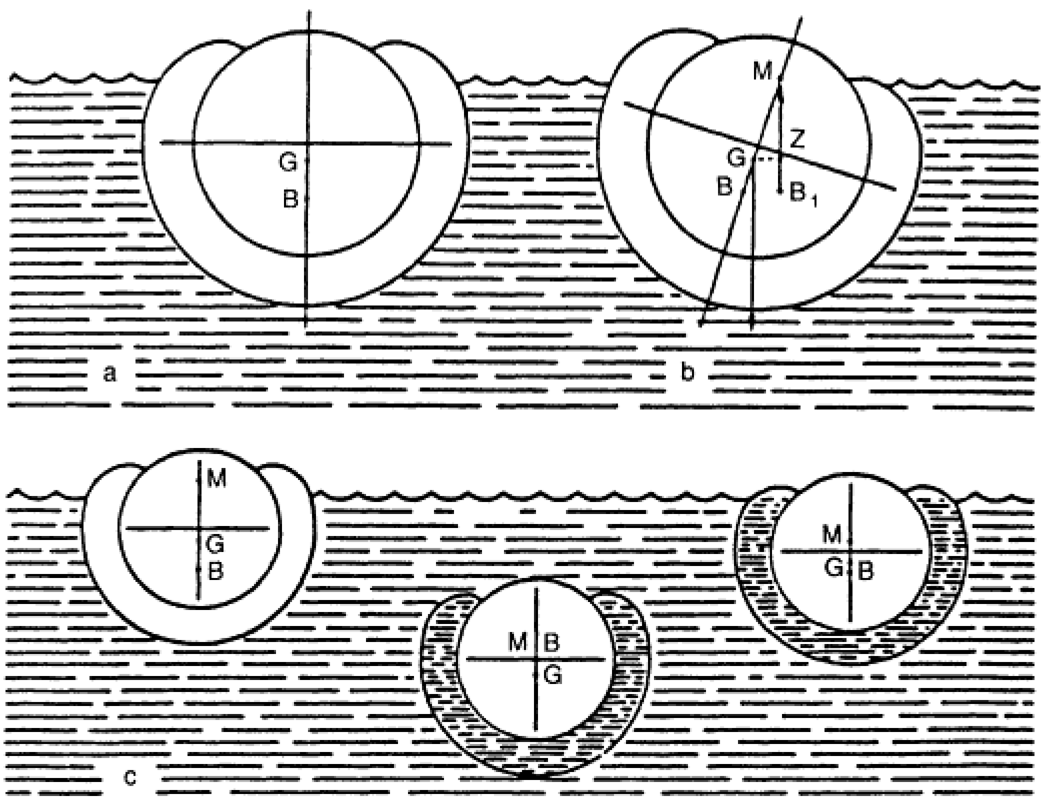

Figure 1 Basic Geometry

These guidelines assume some knowledge of basic naval architecture. It will be useful nevertheless to review the definitions of the most important variables. Refer to Figure 1.

B	The center of buoyancy. It is the geometric center of the submerged volume and remains stationary while the vessel is completely submerged, even if in a trimmed condition.
G	The center of gravity of the vessel's weight, as loaded.
K	The baseline.
M	The metacenter. It is the point about which **B** rotates for very small angles of inclination.
Z	For a vessel on the surface; the intersection of the vertical line through M, and the horizontal line through **G**. For a submerged craft, the intersection of the vertical line through **B** and the horizontal line through **G**.
KB	The distance between **K** and **B**. Positive when **B** is above **K**.
KG	The distance between **K** and **G**. Positive when **G** is above **K**.
KM	The distance between **K** and **M**. Positive when **M** is above **K**.
GB	The distance between **G** and **B**. Positive when **B** is above **G**.
GM	The distance between **G** and **M**. Positive when **M** is above **G**.
GZ	The distance between **G** and **Z**. This is the righting arm. It is positive if the vessel tends to right itself when it is inclined.
BM	The distance between **B** and **M**. Positive when **M** is above **B**.
In addition to these, there are several variables not shown in Figure 1:	
I	The moment of inertia of the waterplane. I depends on the orientation of an arbitrary axis. I is generally much larger in the longitudinal direction than in the transverse direction.
V	The submerged volume.
W	The weight of the submersible.
Δ	The displacement. This is the weight of water displaced by an object.

The geometric relation between **B** and **M** is; **BM = I/V**.

For a submerged object, there is no waterplane, so **I = 0**. This makes **BM =** 0 as well. Put another way, the center of buoyancy of a submerged object is zero distance from the metacenter: they are the same point. That is why it is convenient to refer only to **B** and not to **M** when discussing submerged stability.

The stability of a floating object depends on the fact that **B** shifts off the centerline when the object heels. This shift defines **GZ**, the lever arm upon which the weight and buoyancy act to right the object. For a submerged object, this shift in **B** does not occur. (Remember that **B** is the center of submerged volume, which does not move once the object is completely submerged.) If all weights associated with the object remain in place, **G** cannot move either.

Buoyancy forces act vertically upward through B, and weight acts vertically downward through **G**. In the absence of outside forces, the object will rotate until **G** is vertically below **B**. See Figure 2. The weight at **G** is in effect hanging from the buoyancy at **B**. For a submerged object in stable equilibrium, **G** is always vertically below B.

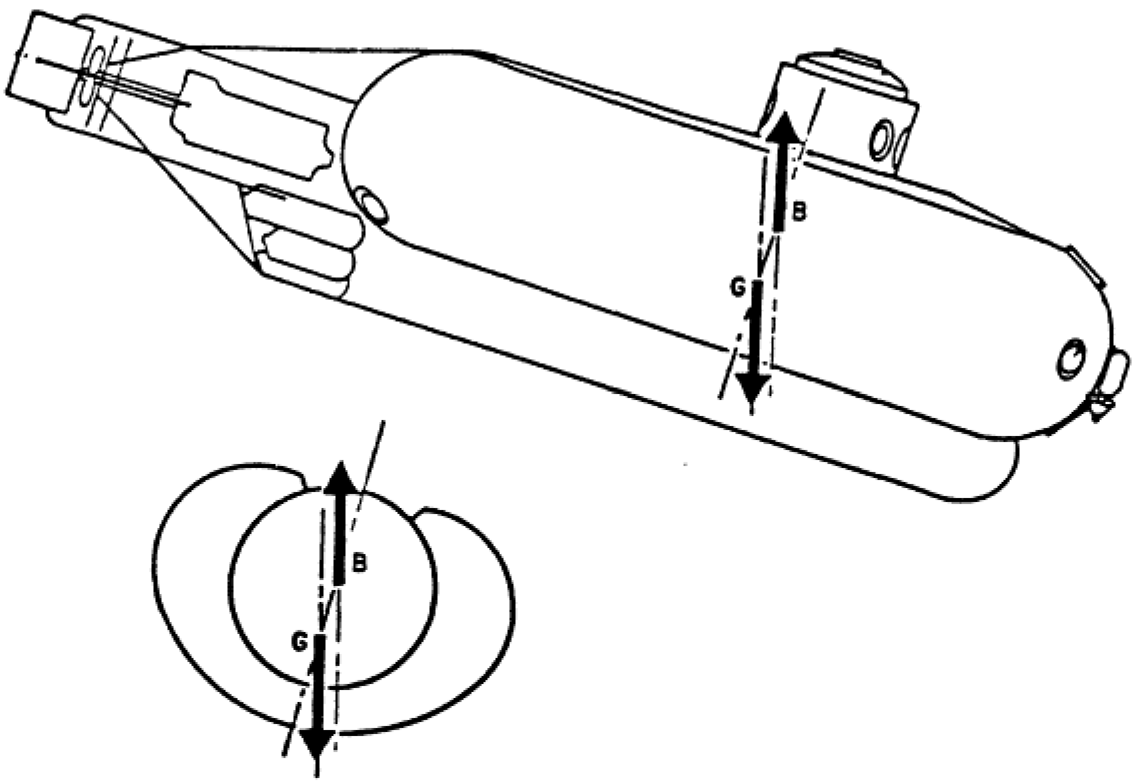

Figure 2 Restoring Moment

Recall that on the surface, I is very different in the transverse and longitudinal directions, so roll stability and trim stability are two very different cases on the surface. Submerged, however, B and G are fixed points that do not depend on I. So submerged stability is not dependent on direction: it is exactly the same in roll and trim. If some outside force acts to heel or trim the body, the restoring moment will be the weight of the object times **GZ**. Here, **GZ = GB sin** θ, where $\boldsymbol{\theta}$ is the heel or trim angle about any horizontal axis. This means that the restoring moment is the same no matter whether the submersible is inclined in the longitudinal or transverse direction.

In the parlance of naval architecture, "weight" and "displacement" are often interchanged. More correctly, however, "weight" refers to the weight of an object, while "displacement" is the weight of water displaced by the object. It is natural to interchange the two for an object floating on the surface, because the weight of the object always equals its displacement. This is not so for a submerged object. This distinction is extremely important, because the naval architecture of submersibles involves considerable effort to balance weight and displacement. If weight exceeds displacement, the submersible will sink. When displacement exceeds weight, the submersible rises. When its weight equals displacement, the submersible is neutrally buoyant, and its depth can be controlled.

Hazards

While surfaced, the stability of a submersible must be sufficient to safely withstand heeling moments caused by wind, waves, and passenger movement. The passenger submersibles built to date have been quite stable on the surface. For these, a simplified stability test is a conservative, but easy way of confirming surface stability. The assumptions below ensure that · simplified stability test is appropriate.

The significant stability hazard while submerged is the large trimming moment that can be generated by passenger movement. This can be guarded against by requiring a minimum **GB**. A submerged inclining experiment measures the **GB**. The vessel's stability is also influenced by the weight of the submersible.

Also while on the surface, the hatch or hatch coaming must be high enough to prevent being overtopped by 4 ft. waves, and the embarkation deck must be high enough to be reasonably dry for embarking passengers. Vessel hull and appendage configurations/shapes are important in helping keep the deck dry by deflecting waves. This can be observed during operational tests.

Assumptions

The submersible shown in Figure 1 is a military submarine. This is useful for discussing the principles of stability but there are some important differences between it and a passenger submersible. All passenger submersibles built so far are configured similar to the cross sections shown in Figure 3. These guidelines and criteria assume such a configuration and are therefore much simpler than earlier guidelines on the subject. Specifically, these guidelines have been developed for submersibles having the following parameters:

—the submersible is less than 100 gross tons;
—it is less than 65 feet LPH (Length of Pressure Hull);
—it carries 49 or fewer passengers;
—the submersible will be operating on a route for which the surface test was performed;

—the access hatches are on the top centerline, with a diameter not greater than one-half the main hull diameter;
—there is no diver lockout; and
—**GB** is positive at <u>all</u> times. This may be assumed to be the case if:

a. the main pressure hull is a circular cylinder;
b. the soft and hard ballast tanks are above the mid-height of the main pressure hull; and
c. the batteries are installed below the mid-height of the main pressure hull.

"Hard" ballast tanks are pressurized water ballast tanks, while "soft" ballast tanks are free-flooding water ballast tanks. It should be noted that the hard ballast tanks can cause considerable reduction in **GB** due to their weight and position above the hull centerline. In some scenarios, the positioning of these hard ballast tanks above the mid height of the main pressure hull could render the **GB** negative. There is also a possibility that the vessel could be unstable on the surface unless the waterplane intersects the soft ballast tanks.

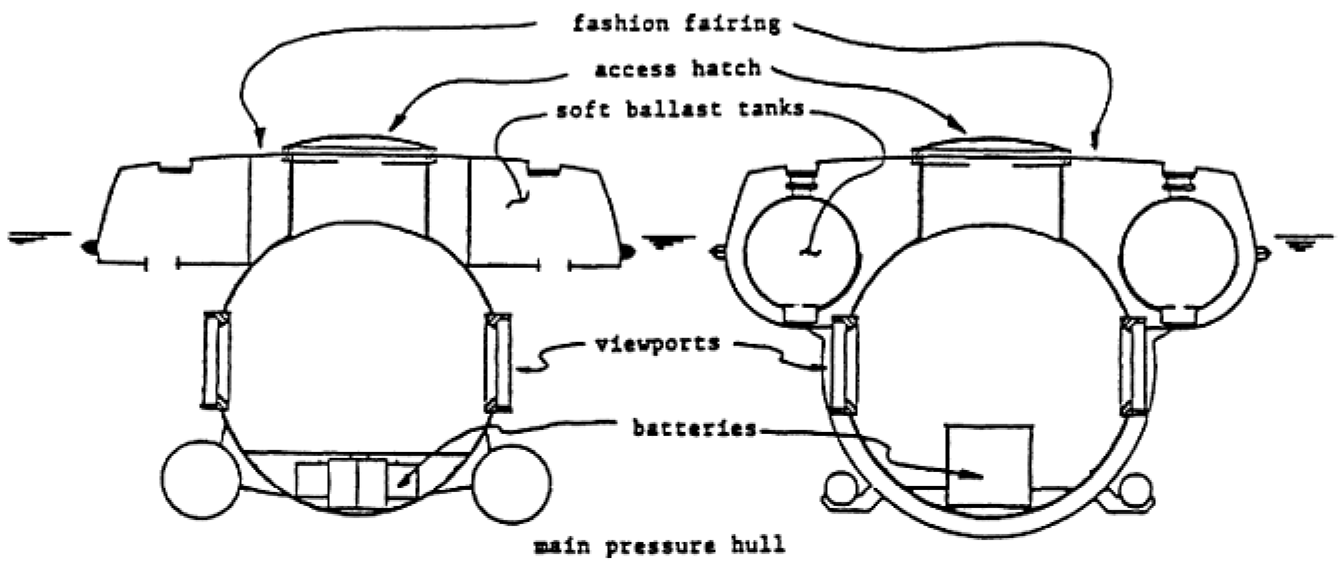

Figure 3 Midship Sections

A submersible that meets these assumptions will be very stable on the surface and while transiting through the surface. This can easily be confirmed with a simplified stability test, which frees the designer and the Coast Guard plan reviewer from developing a detailed computer model for calculating hydrostatic properties. Such a model is very difficult to develop for a passenger submersible because of its complex shape, so the simplified stability test saves a lot of effort without compromising safety. If a design is proposed that does not meet these assumptions, it may still be acceptable. But the stability review will have to address new questions and set new policy in that case.

Stability Review Procedure

There are several elements to a stability review for a submersible:

—A spreadsheet calculation of weight and displacement;
—A spreadsheet calculation of loading during emergency ascent verifying positive GB;
—A deadweight survey;
—A submerged inclining experiment;
—A simplified stability test on the surface; and
—Some operational tests.

Each of these are discussed below in detail.

Spreadsheet Calculation

The weight and displacement must be exactly equal if a submersible is to passively maintain its depth submerged. If the weight and displacement are not equal, the vessel have to take on extra ballast or use propulsors to mantain neutral buoyancy. To ensure that the weight and displacement are equal, submersible designers keep very detailed spreadsheets (See Figure 4) showing the weight, displacement, and location of every component of the submersible and its equipment. These spreadsheets, if well kept, are the most accurate calculations of **B**, **G**, **W**, and **Δ** available. Since they are the foundation of all subsequent calculations, the designer's spreadsheets must be constructed and reviewed with care.

The coordinate system for spreadsheet calculations should be clear and should be referenced to a drawing. The weight, displacement, and the locations of **G** and **B** should be calculated for a number of loading cases representing the complete range of operating conditions. By conducting the inclining experiment, the locations of **G** and **B** will later be confirmed (or not) for the "as inclined" condition. The spreadsheet should be detailed enough to use as a checklist during the deadweight survey.

The handling of variable ballast water on the spreadsheet can be a point of confusion. The internal volume of "soft" tanks should be considered to have no buoyancy and the ballast water in them should be considered to have no weight (This is a lost buoyancy approach). "Hard" tanks, on the other hand, should be calculated as buoyant volume, and the weight of the ballast water in them should be accounted for (Added weight). The weight and displacement of the ballast water in the soft tanks can have a significant effect on any calculations that involve **W** or **Δ**. **W** should not include the weight of water in soft tanks, and **Δ** should <u>not</u> include the volume of soft tanks. An error here can change the calculated value of **GB** by 10% or more. It is particularly important for this reason to understand Just how the spreadsheet calculates variable ballast water.

The spreadsheet should be submitted several weeks before the inclining experiment along with the inclining procedure. It should be well understood before the deadweight survey so that any questions can be cleared up at that time.

Deadweight Survey

The deadweight survey is really the first step in the inclining experiment, so they should be conducted In conjunction with each other. The submersible must be complete in all respects before the deadweight survey. All systems must be working, and all equipment must be aboard. The master should have made a recent trim dive to finalize the amount and arrangement of solid ballast.

The deadweight survey should be conducted with the spreadsheet calculation in hand. Each item on the spreadsheet should be verified as being aboard or be listed as a weight to complete. Also, each item aboard should appear on the spreadsheet or be noted as a weight to remove. The locations of all items should agree with those given on the spreadsheet.

Most submersibles will be designed to carry some fixed, solid ballast as a hedge against manufacturing inaccuracies and to ensure that a full payload can be carried. This has a significant effect on the stability of the submersible, so it is important to verify the amount and location of fixed ballast. This ballast should be well secured to prevent inadvertent shifting. Likewise, if the design includes a moveable trim control weight, its weight and location should be verified and compared to the position located at the operator's station.

It is reasonable that there be provisions for both truly fixed ballast and moveable, variable solid ballast. For example, if the submersible needs 2500 pounds of ballast to submerge with minimum payload, it can be expected that something like 2000 pounds will be bolted to the skids. This is truly fixed and is expected to stay there forever. The other 500 pounds might be placed in the battery compartment. It will normally stay there, but may be relocated, removed, or increased in small amounts to compensate for routine alterations to machinery and equipment. The operator needs this flexibility, and it can be accommodated by noting the amount, type, and location of ballast on the stability letter.

At least a half-day should be scheduled for the deadweight survey, but it will take longer than that if the submersible has not been prepared. To facilitate the survey, bilge plates and access panels should be loose so that battery compartments and machinery spaces can be inspected. The spreadsheet should itemize each piece of equipment, eg; "10 batteries @ 200 pounds = 2000 pounds." This is much easier to account for than; "Batteries — 2000 pounds."

The deadweight survey is also a good opportunity to check that all equipment is securely stowed in lockers or racks. Large trim angles are normal in submerged operation.

Submerged Inclining Experiment

Navigation and Inspection Circular (NVIC) 15-81 has been published as "Guidelines for Conducting Stability Tests." It is the basis for this section, and it must be well understood. This section does not replace NVIC 15-81, but adds information that was not contemplated when NVIC 15-81 was written.

In the intact condition, the only significant inclining moment submerged is due to passenger movement. If the distance **GB** is sufficiently large, the trim angle can be kept to some safe maximum, even if a percentage of the passengers were to move the entire length of the submersible. The following criterion addresses this passenger movement hazard, but passenger movement should nevertheless be restricted as much as possible.

The submersible must be inclined while submerged to determine the actual GB. Under full load conditions the distance, $\mathbf{GB}_{actual}$, determined by the inclining experiment must be not less than the minimum GB determined by the following formula:

$\mathbf{GB}_{min} = nwNd / W \tan \theta$

where	**n =**	0.1 (This represents 10% of the passengers all moving at one time.)
	w =	160 pounds (72.5 kg) per person
	N =	the total number of passengers aboard
	d =	the interior length of the main cabin accessible to passengers. This should not include machinery compartments if they are separated from the main cabin with a bulkhead.
	W =	the total weight (in units consistent with w) of the fully loaded submersible, not including soft ballast.
	$\boldsymbol{\theta}$ =	25º (representing the maximum safe trim angle. This assumes that each passenger has an individual seat that is contoured or upholstered so that a person can remain in it at this angle.)

An object in submerged equilibrium acts exactly as if its center of gravity at **G** were hanging from its center of buoyancy, B. This is true, regardless of the hydrostatic properties of the object, and regardless of the direction of inclining. This means that inclining in the longitudinal direction yields exactly the same result as inclining in the transverse direction. This is fortunate, because the extra distance available for moving inclining weights makes a longitudinal inclining much easier.

Recall from NVIC 15-81 that an inclining experiment measures the relationship,

wd / tan θ	where	**w** is the inclining weight, and
		d is the distance the inclining weight moves.
		$\boldsymbol{\theta}$ is the inclined angle (trim angle, here)

Since the weight of the submersible, **W**, and its center of gravity have been calculated precisely on the spreadsheet, the results of the inclining experiment can be used to calculate the actual **GB** with the formula;

$\mathbf{GB}_{actual} = wd / W \tan \theta$

Remember that **W**; should be the weight of the submersible, not including the weight of free flooding water ballast (soft ballast).

Below are some special procedures that will help obtain valid results from the inclining experiment.

In order to maintain its depth during the inclining experiment, the submersible should be suspended from a small buoy. See Figure 5. The buoy should displace 60 to 100 pounds. It should be attached near the submersible's longitudinal center of buoyancy by a line 30-50 feet long. The submersible should be trimmed to be 30-50 pounds "heavy" so that the buoy will be about 1/2 submerged. This should be observed throughout the experiment by the surface boat in attendance. The suspension buoy should be fairly rigid. Pneumatic fenders tend to compress as they submerge, and this can make it difficult to achieve neutral buoyancy.

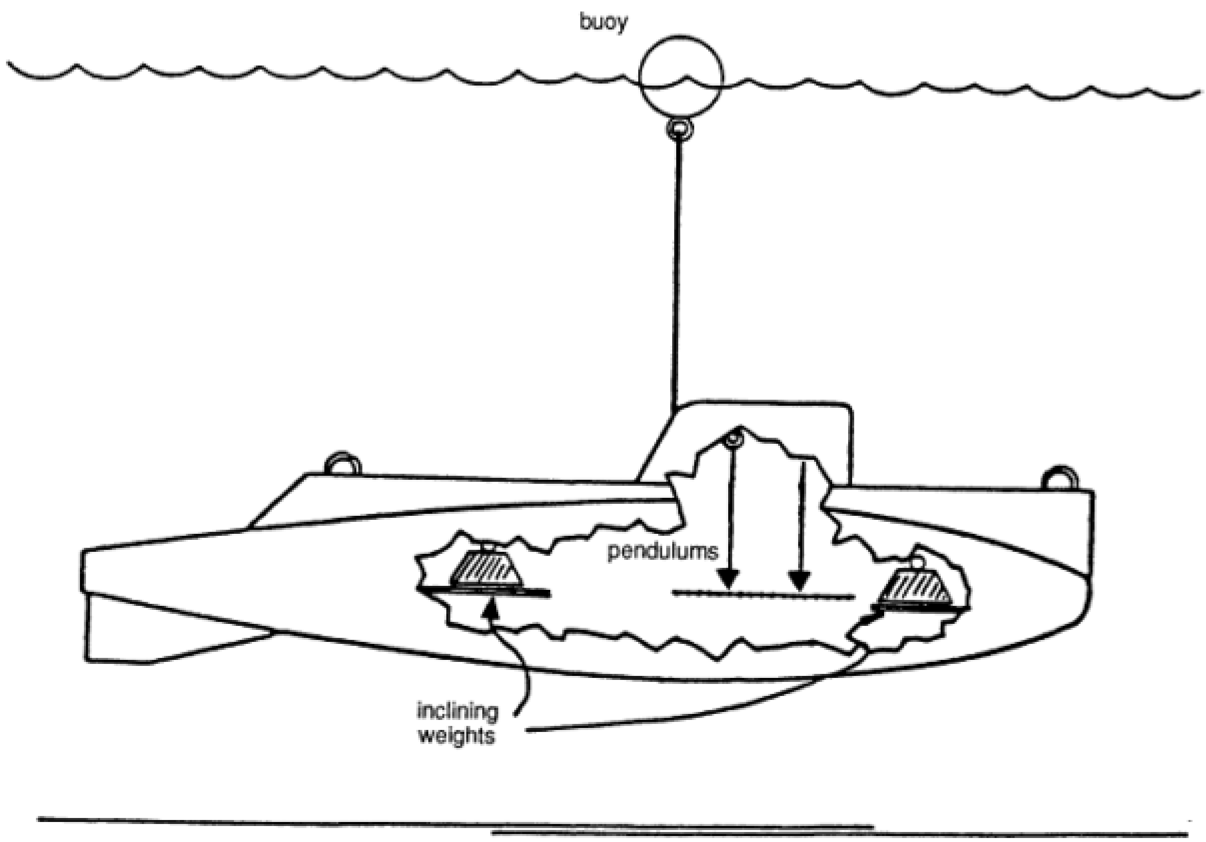

Figure 5 Inclining Experiment

Pendulums should be rigged to swing in the longitudinal direction. They should be as long as possible inside the pressure hull, but even a short pendulum can give good results. Since the distance **GB** is constant and does not depend on a small angle approximation (like **GM** does), the inclining will be valid at whatever angle is necessary to get readable deflections of the pendulums. Trim angles of 10 degrees or even more must be considered normal during diving and ascent, and the results of the inclining will be Just as valid at these angles as at small ones. Take this into account when planning for damping baths and water tubes, since spilled oil or water can be slippery and hazardous on the decks at these angles.

There will probably be no need for pendulum damping if the inclining can be conducted in relatively deep, calm water. If the surface is rough, the surge near the bottom will sweep the submersible back and forth, making it very difficult to get good pendulum readings in any case. It is best to choose a sheltered spot without any swell.

The submerged inclining experiment will require a number of people to be aboard. There should be one person for each pendulum, a pilot, and enough people to move weights or to act as inclining weights. The experiment can take several hours submerged, so life support and air conditioning systems must be functioning properly before the inclining begins.

Air entrained by the structure and under the fashion fairing can shift during the inclining and invalidate the experiment. There should be provisions for venting entrained air such as vent holes in the fashion fairing. Once the sub is submerged, it should be rocked or trimmed to large enough angles to ensure that all air has been vented before starting the submerged inclining.

Simplified Stability Test

The submersible must pass a simplified stability test to confirm that it is adequately stable on the surface. This should be as outlined in 46 CFR 171.030 with the following modifications:

A trim dive, the deadweight survey, and the inclining experiment should be done before the simplified stability test. This will ensure that the submersible is in diving trim.

The hard ballast tanks should be about half full and the soft ballast tanks should be blown as dry as possible.

In calculating the weight of personnel, **W**, the weight of each person should be taken as 160 pounds.

The beam, **b**, should be taken as the transverse distance between the embarkation deck railings. See Figure 6.

The passenger weight should be placed on the embarkation deck at a height equal to the center of gravity of the personnel aboard.

The submersible passes the test if no more than one half the freeboard is immersed. For this purpose, the freeboard is measured from the waterline to the horizontal line through the outboard limit of **b** at the embarkation deck level. See Figure 6.

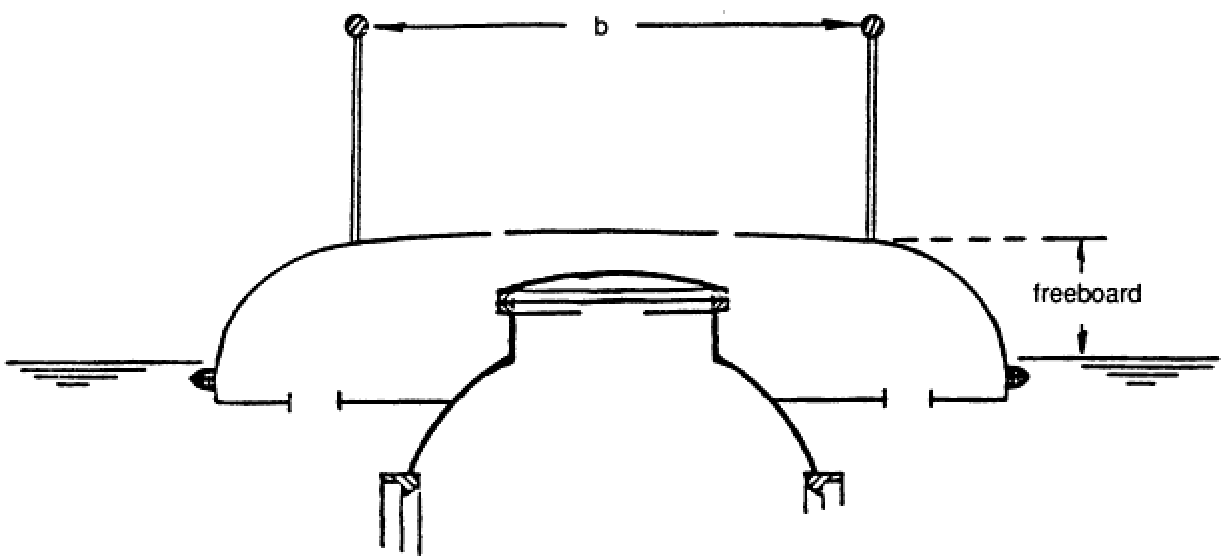

Figure 6 Simplified Stability Test

Operational Tests

Certain operational tests relate closely to stability. These can conveniently be done in conjunction with the inclining experiments.

Emergency ascents: From several depths, including the certified test depth, all ballast tanks should be blown simultaneously. The time from the beginning of the procedure until the submersible breaks the surface should be recorded. A Coast Guard witness should be aboard to make an evaluation of the motion and attitude during ascent and especially upon breaking the surface. One ascent should be performed by dropping the external drop weights. These tests should verify that the vessel does not attain a list such that the hatch becomes a downflooding point once it is opened on the surface for disembarkation.

Hatch Height: The submersible must be capable of remaining surfaced under a sea state having average wave heights up to 4 feet and average winds up to 16 knots. This requirement is similar to ABS procedures which are not necessarily required or performed except to verify intent of the submersible's operations. ABS has a formula for calculating hatch height, which requires a hydrostatic model and which assumes that the critical motion for wave overtopping will be in roll. Observations of existing submersibles suggest that wave overtopping is usually not a problem, and that any minor deck wetness comes from heave/pitch motions. As a check, the motion of the submersible on the surface should be observed and any tendency for deck wetness should be noted.

Damaged ballast tanks: From Just below the surface, all possible combinations of ballast tanks should Be blown and the equilibrium waterline observed. In each case it should Be noted whether the hatches are clear to open. A photographic record of these tests should Be kept and included in the vessel file.

Trim weight effect: If the pilot controls a moveable trim weight or can control trim with liquid ballast, this should be shifted as far as possible, both fore and aft. Record the trim angles experienced due to these ballast shifts.

Effect of passenger movement: With the submersible on an even trim, shift 10% of the intended number of passengers all the way forward and aft. Record the maximum and equilibrium trim angles achieved. The trim angle should not exceed the maximum safe angle for batteries or machinery, and all items of furnishing should remain secure. The maximum trim angle is not expected to be comfortable, but it should still be possible to move about the cabin.

Stability Letter

The end product of the stability review is a stability letter similar to the example below. Note that the stability letter should specifically limit the route to waters not deeper than the certified test depth and to waters consistent with the route assumed in performing the simplified stability test.

Name
Master

Subj: Submersible ________, O.N._______ Small Passenger Vessel Stability Letter

Dear Sir:

You are responsible for maintaining this vessel in a satisfactory stability condition at all times and for following the instructions and precautions listed below. A stability test witnessed by the U.S. Coast Guard was conducted on the Submersible ________, O.N. ______, at __________ on ________. On the basis of this test, and a deadweight survey performed on the subject vessel at __________ on ________, stability calculations have been performed. Results indicate that the stability of _________ as presently outfitted and equipped is satisfactory for operation both surfaced and submerged on protected/partially protected waters as indicated on the Certificate of Inspection, provided that the following restrictions are strictly observed:

Operating Restrictions

1. Route

Partially protected waters not more than ___ feet deep.

2. Passengers

A maximum of __ passengers may be carried. A maximum of __ persons (passengers and crew) may be carried. In no case shall the number of persons exceed that allowed by the Certificate of Inspection. All passengers are to remain seated, in the individual seats provided, for the entire duration of each voyage.

3. Freeboard and Draft

When surfaced to embark or disembark passengers, all air ballast tanks are to be blown dry so that maximum freeboard is maintained. Trim on the surface should be minimized. A load line is not authorized.

4. Watertight Openings

Hatches are to be secured closed and checked before commencing each dive. They are to remain secured until the surface craft has verified that they are clear of obstructions after resurfacing. Due to the danger of downflooding, hatches are not to be opened in seas having average wave heights exceeding 4 feet.

5. Cargo

No cargo is to be carried.

6. Weight Changes

No solid ballast or other such weights shall be added, removed, altered, or relocated without the authorization and supervision of the cognizant OCMI. All such ballast shall conform to ballast drawing No. _____. The vessel is fitted with ___ pounds of permanent lead ballast in the skids as well as ___ pounds of moveable lead ballast in the drop weight tray between the skids and ____ pounds of lead pigs secured in the battery compartment.

7. Bilges

The vessel's bilges shall be kept dry at all times consistent with pollution prevention requirements.

8. Freeing Ports

Deck freeing ports shall be maintained operable and completely unobstructed at all times.

This stability letter shall be posted under suitable transparent material inside the submersible so that all pages are visible. It supersedes the temporary stability letter dated _________.

Sincerely,

____

____

(Authorized Coast Guard Official)

bc: CCGD_(m)

REFERENCES

American Bureau of Shipping Rules for Building and Classing Underwater Systems and Vehicles 1979, American Bureau of Shipping, P.O. Box 910, Paramus, NJ 07653-0910

"Safety Standard for Pressure Vessels for Human Occupancy," ANSI/AMSE PVHO 1, The American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, NY 10017

Code of Federal Regulations:

Title 46 — Shipping Chapter I — Coast Guard, Department of Transportation:

Subchapter T — Small Passenger Vessels (Under 100 Gross Tons), Parts 175 to 186

Subchapter C — Uninspected Vessels, Parts 24 to 26

Subchapter S — Subdivision and Stability, Parts 170 to 174

Subchapter V — Marine Occupational Safety and Health Standards, Part/197

Subchapter H — Passenger Vessels, Parts 70 to 89

Subchapter B — Merchant Marine Officers and Seamen, Parts 10 to 15

Subchapter F — Marine Engineering, Parts 50 to 64

Subchapter J — Electrical Engineering Parts 110 to 113

Title 33 — Navigation and Navigable Waters, Chapter I — Coast Guard, Department of Transportation

Subchapter S — Boating Safety, Parts 173 to 183

Subchapter P — Ports and Waterways Safety, Parts 160 to 167

Subchapter O — Pollution, Parts 151 to 159

Marine Technology Society, Washington, DC:

Safety and Operational Guidelines for Undersea Vehicles

Safety and Operational Guidelines for Undersea Vehicles Book II

International Safety Standard Guidelines for the Operation of Undersea Vehicles

Manned Submersibles by R. Frank Busby, Office of the Oceanographer of the Navy

"Systems Certification Procedures and Criteria Manual for Deep Submergence Systems, NAVMAT P-9290" June 1976, Department of the Navy, Washington, DC 20362

"Code of Practice for Operation of Manned Submersible Craft," Association of Offshore Diving Contractors, 28-20 Little Russel Street, London WC1A 2HN

"Guidelines for the Selection, Training and Qualification of Deep Submersible Pilots" by the Deep Submersible Pilots Association

ADDRESSES

Department of the Treasury, U.S. Customs Service, Carriers, Drawbacks, and Bonds Division, Carrier Rulings Branch, 1301 Constitution Avenue NW, Washington, D.C. 20229

Commandant (G-MTH), U.S. Coast Guard, 2100 2nd Street SW, Washington, DC 20593-0001

Commandant (G-MVI), U.S. Coast Guard, 2100 2nd Street SW, Washington, DC 20593-0001

Marine Safety Center (G-MSC), 400 7th Street SW, Washington, D.C. 20593-0100

Officer in Charge, Marine Inspection

The addresses for each OCMI are as follows. The zone of responsibility for each OCMI is described in 33 CFR 3.

Atlantic Coast

Commanding Officer, Marine Safety Office, PO Box 108, Portland, ME 04112-0108

Commanding Officer, Marine Safety Office, 447 Commercial St., Boston, MA 02109-1096

Commanding Officer, Marine Safety Office, John O'Pastore Federal Bldg., Providence, RI 02903-1790

Commanding Officer, Marine Inspection Office, Battery Park Bldg., New York, NY 10004-1466

Commanding Officer, Marine Inspection Office, 801 Custom House, Philadelphia, PA 19106-2974

Commanding Officer, Marine Safety Office, Customhouse, Baltimore, MD 21202-4022

Commanding Officer, Marine Safety Office, Norfolk Federal Bldg., 200 Granby Mall, Norfolk, VA 23510-1888

Commanding Officer, Marine Safety Office, Suite 500, 272 North Front St., Wilmington, NC 28401-3907

Commanding Officer, Marine Safety Office, P.O. Box 724, 196 Tradd Street, Charleston, SC 29401-1899

Commanding Officer, Marine Safety Office, PO Box 8191, Savannah, GA 31402-8191
Commanding Officer, Marine Safety Office, Room 213, 2831 Talleyrand Ave., Jacksonville, FL 32206-3497
Commanding Officer, Marine Safety Office, Justice Bldg., 155 South Miami Ave., Miami, FL 33130-1609
Commanding Officer, Marine Safety Office, PO Box S-3666, Old San Juan, PR 00904-3666

Gulf of Mexico

Commanding Officer, Marine Safety Office, 155 Columbia Drive, Tampa, FL 33606-3598
Commanding Officer, Marine Safety Office, 1900 First Nat'l Bank Bldg., PO Box 2924, Mobile, AL 36652-2924
Commanding Officer, Marine Safety Office, 1440 Canal Street, New Orleans, LA 70112-7116
Commanding Officer, Marine Safety Office, 800 David Dr.-Rm. 232, Morgan City, LA 70380-1304
Commanding Officer, Marine Safety Office, Federal Bldg., 2875 75th St. & Hwy. 69, Port Arthur, TX 77640-2099
Commanding Officer, Marine Safety Office, Post Office Bldg., 601 Rosenberg, Galveston, TX 77550-1705
Commanding Officer, Marine Inspection Office, 8876 Gulf Freeway, Suite 210, Houston, TX 77017-6595
Commanding Officer, Marine Safety Office, PO Box 1621, Corpus Christi, TX 78403-1621

Great Lakes

Commanding Officer, Marine Safety Office, Rm 1111, Federal Bldg., 111 W. Huron St., Buffalo, NY 14202-2395
Commanding Officer, Marine Safety Office, 1055 East Ninth St., Cleveland, OH 4414-1092

Commanding Officer, Marine Safety Office, Federal Bldg., Room 101, 234 Summit St., Toledo, OH 43604-1590

Commanding Officer, Marine Safety Office, 2660 East Atwater Street, Detroit, HI 48207-4418

Commanding Officer, Marine Inspection Office, Municipal Bldg., St. Ignace, MI 49781-1425

Commanding Officer, Marine Safety Office, Canal Park, Duluth, MN 55802-2352

Commanding Officer, Marine Inspection Office, 360 Louisiana St., Sturgeon Bay, WI 54235-2479

Commanding Officer, Marine Safety Office, 2420 S. Lincoln Memorial Dr., Milwaukee, WI 53207-1997

Commanding Officer, Marine Safety Office, 610 South Canal Street, Chicago, IL 60607-4573

Inland Rivers

Commanding Officer, Marine Safety Office, Suite 700/Kossman Bldg, Forbes Ave & Stanwix St, Pittsburgh, PA 15222-1371

Commanding Officer, Marine Safety Office, PO Box 2412, Huntington, WV 25725-2412

Commanding Officer, Marine Safety Office, 600 Federal Place, Room 360, Louisville, KY 40202-2230

Commanding Officer, Marine Safety Office, PO Box 7509, Paducah, KY 42002-7509

Commanding Officer, Marine Safety Office, PO Box D-17, St. Louis, MO 63188-0017

Commanding Officer, Marine Safety Office, Suite 1134, 100 N. Main Bldg., Memphis, TN 38103-5014

Pacific Coast

Commanding Officer, Marine Safety Office, 2710 Harbor Drive, North, San Diego, CA 92101-1064

Appendix B

Suggested Inspection Requirements

This appendix describes in some detail a suggested inspection plan developed by the committee. It is based on existing Coast Guard inspection procedures but augmented with experience from U.S. Navy and commercial research submersibles, which would address the particular requirements of the tourist submersible arena.

As a first step, the Coast Guard could require that the vessel designer, in conjunction with the intended operator, obtain Coast Guard approval of a certification scope definition as part of the initial approval process. This document would provide information on how the submersible's design meets the regulations. In addition, the initial approval effort might include the development of a periodic inspection plan that defines, in detail, program areas that will be reviewed at prescribed time intervals.

Such an inspection plan should provide local inspectors with information on both the scope of the inspections and the quality assurance documentation necessary for sustaining approval. It should address the four major certification concerns: design, construction, operation, and training—even though the majority of the design and construction effort will have been completed before periodic inspections begin. Ideally, such a plan should be the result of a joint effort by the designers, operators, and the Coast Guard, with an understanding that each program and hardware combination is likely to have unique characteristics. The plan should result from a careful review of the initial design approval requirements and an analysis of how these requirements have been met by the equipment in question. A hazard analysis in some form (see Chapter 4) is likely to be necessary in order to ensure that the plan assigns the appropriate significance to various design details. Care must be taken to ensure that the plan is realistic; the goal is to ensure safe operations to the greatest extent practical without unnecessarily burdening the operators and encouraging them to focus attention on the primary safety concern. Experienced engineering and operational judgment should play an important role in defining the requirements.

Any inspection plan should be specific to the design in question and list those items subject to periodic review along with a justification for their inclusion as required to clarify the conditions necessary for approval. As an example, it is reasonable to expect two independent means for determining submarine depth to be a regulation requirement. The submersible might have more than two depth-indicating devices installed but, for maintenance reasons, the operators may wish that only two simple, reliable mechanical pressure gauges be considered mandatory. This is likely to be acceptable only if at least one of these gauges is the primary device used by the pilot for determining depth. Therefore, their mounting location and the wording of the operator's manual must be considered as part of their approval process. Also, for safety purposes, it may be possible to show that the accuracy of these gauges is not critical except at maximum allowable depth and, therefore, the acceptance criteria may involve only a single point calibration. The inspection plan might therefore specify a requirement for review of two external pressure gauges mounted within plain sight of the pilot, marked with a calibrated point indicating maximum operational depth and specified for use by the pilot in the operator's manual.

The original approval process is likely to include the requirement for operational definitions such as those that might be included in a management plan, operations manual, or maintenance manual. The existence of these manuals may be required and their contents subject to approval. Periodic inspections would therefore need to determine if the required, approved manuals are in use. The obvious method is via direct observation of operations, but this is rarely possible during scheduled inspection periods and often is not adequately quantitative. A better alternative is to ensure that the approved procedures generate qualitative documentation that can be reviewed by inspectors or auditors. Daily check sheets, work logs, personnel training records, failure reports, inspection/test reports, receipt inspection records, and records of replacement or repair are examples of this type of documentation. The review of records of this type should be specifically required by the periodic inspection plan. Their existence provides a significant indication to the inspectors that proper procedures are being followed and their content provides objective information on machinery and personnel histories.

An approved operations procedure will undoubtedly specify a submersible pilot training program and pilot qualification maintenance procedures. Here also, there should be a requirement to generate defined documents that can be reviewed by the inspectors. Examples of such documents are the results of suitable medical examinations, records indicating successful completion of training milestones and a pilot's log book. This latter item should record diving experience as well as participation in required safety and emergency drills.

The inspection plan must also specify the documentation necessary to provide objective quality evidence of acceptable conformity to approved specifications. Specifications are the standards to which equipment and components are purchased, installed, tested, and maintained. They are a primary line of defense against equipment failures. An inspector may be presented with a detailed piping pressure test report generated as the result of a maintenance manual requirement. The validity and, therefore, usefulness of this report depend upon the test specifications, and the test documentation must include evidence that the specifications were met. The fact that required maintenance was performed and a pressure test conducted is useful information but it is equally important to know that the test pressure was correct for the application and that the gauges were calibrated in the way that the specifications are likely to require.

A typical periodic inspection will follow the procedures agreed upon during the generation of the inspection plan and involve both observational inspection and auditing functions. The inspections allow verification of equipment condition and witnessing of prescribed tests in a manner similar to that done during the construction and trials phase. Auditing involves review of the documentation generated in accordance with the prescribed operational procedures. As an example, an inspector may visually survey the pressure hull and witness a prescribed test designed to demonstrate acceptable hatch operation. He may then ask to see the hatch maintenance records required as part of the necessary hatch maintenance procedures in the approved maintenance manual. These records are likely to document timely replacement of the primary hatch O-ring using a record-of-repair form. It must include evidence of adherence to the proper procurement and handling specifications as well as a receipt inspection report for the O-ring itself. A hatch fit test may have been required, and if so, the test procedures and results must be documented on a suitable test form, including the pass/fail criteria and an analysis of the results by qualified persons.

This is similar to present Coast Guard inspection procedures, except that the inspection plan provides the local inspector with considerably more information on how the design is intended to meet the regulations and how its condition and method of operation can be evaluated. At no place in the above example is the inspector likely to be required to make a critical technical judgment. The hatch requirements have been documented and approved in advance, including pass/fail criteria for the general inspection, which are determined at the time of design. The inspector is simply reviewing the objective evidence available as a result of the requirements. For the most part, this evidence will be generated in advance of the inspection, so there should be no question about the outcome. If a problem is discovered, it is likely to indicate two deficiencies: a defective piece of hardware and a poorly designed or implemented procedure that allowed the defect to go undetected prior to the inspection. Both need to be corrected.

As is the case with the Coast Guard's present method of operation, inspection timing should be fixed at agreed-upon intervals with unannounced inspections allowable. The length of the fixed intervals must be such that an inspection will occur before serious system degradation is likely to occur under probable maintenance conditions. This time interval should be determined by experience with systems of this type; it may vary with the particular hardware involved and the operational location. An initial period of between 3 and 6 months is recommended, with the proviso that, at the Coast Guard's discretion, it may be increased following some specified length of uninterrupted operational experience. This initial short time period accomplishes three things: (1) it allows a more controlled initial evaluation of the hardware and operating personnel on the part of the Coast Guard; (2) it forces the operators to maintain adequate awareness of the approval requirements during the operational startup period; (3) and it provides the operators with a reasonable time interval for their education in the area of maintaining the Coast Guard's approval. Once the operators have demonstrated an understanding of the requirements and established a history of acceptable performance, it should be possible to decrease the frequency of scheduled inspections.

The Coast Guard presently documents inspection/audit results in a prescribed manner along with the corrective action required and the allowed time period. Generally, deficiencies must be corrected by meeting the approved requirements. There will be instances where this is not possible in a timely manner or where good judgment indicates that another course of action may be more appropriate. These cases should require approval of a waiver requested through a process independent of the inspection. Again, the inspector should not be required to make technical judgments.

Organized, periodic inspections are an important aspect of ongoing operations. The designs of tourist submersibles and their method of operation can be sufficiently unique to require a high degree of detailed knowledge on the part of an inspector to ensure an adequate safety review. This requirement can be met by providing a detailed inspection plan generated as part of the initial approval process and encompassing the program's equipment, operational procedures, and training programs. The inspectors should rarely be required to make technical judgments; instead, the inspection plan should contain the necessary pass/fail criteria for each approved item or system. As with the initial system approval, periodic inspections represent a major effort on the part of both the Coast Guard and the operators. Great care must be taken to limit the inspection criteria to those items and procedures of real importance to the safety of the passengers and operational personnel.

Appendix C

Operational Safety

Chapter 4 of the report focused primarily on safety in the design and operation of the tourist submersible vessel itself. However, this system includes many interrelated elements of the entire operation. Professional societies and classification societies recognized by the Coast Guard have assisted in establishing system safety criteria for the submersible itself. This section, prepared for the committee, addresses facilities not ordinarily under the purview of these societies and authorities. Many of the comments in this appendix deal with fundamental—even common sense—facility and operational considerations, which can be useful as a preliminary checklist in operational planning and hazard assessments.

All facilities in the system should be reviewed as part of the safety certification process. They include: the check-in or ticket office (with or without souvenir shop); the route from there to embarkation/debarkation site to ferry; embark/debark site; the ferry itself; the ferry route to and from the submersible; the transfer site between the ferry and submersible; transfer equipment; the submersible itself; the dive site; the surface support safety boat; the shore logistics site; the tow boat used to move the submersible from shore logistics site to dive site; any major maintenance activity; and available standby rescue equipment.

CHECK-IN OR TICKET OFFICE

Safety begins in this office. Passenger safety orientation, using either a brief lecture or a video, could easily start here. Passengers should be informed about what can be carried onto the submersible and the number and size of carry-ons permitted. Excess carry-ons should be checked in the office for pickup on return. During the orientation, employees should carefully observe passengers to detect any nervousness or unusual activity. Employees should be coached on coping with these situations and advised to pass unusual observations on to those in charge of tourists as they move forward in the system.

ROUTE FROM TICKET OFFICE TO EMBARKATION/DEBARKATION SITE

This route should be as short and direct as possible, with a system guide directing tourists along it and warning of any safety hazards along the way.

EMBARKATION/DEBARKATION SITE

Adequate railings should be in place to prevent tourists from falling into the water. Life rings should be available for emergencies. A proper brow should be available for use of tourists in boarding the ferry. If necessary, employees should be positioned to assist tourists boarding.

FERRY

The ferry should comply with existing Coast Guard rules. The ferry capacity should be at least twice the submersible capacity plus crew. The seating and entry/exit positions on the ferry should be arranged to facilitate management of two groups of tourists as they simultaneously debark the ferry to the submersible and debark the submersible to the ferry. Safety orientation should continue on the ferry during the transit to the dive site. Repetition of safety information, without alarming the tourists, will permit the important safety information to be understood even in the predive excitement. The ferry should be equipped with both VHF (radio) and UQC (underwater telephone) capability.

TRANSFER SITE BETWEEN FERRY AND SUBMERSIBLE

The selection of this site will, in large part, establish the hazard level for the safety of the system. Movement between ferry and submersible can present a major hazard. A sheltered transfer site is preferred.

TRANSFER EQUIPMENT

Proper fenders should be used to dampen relative motion between ferry and submersible. If fenders are not used, and ferry and submersible get "out of step" in the seaway, damage can result to the ferry, submersible, or both. Undamped relative motion will exacerbate motion-related problems to passengers attempting to move about. A proper brow tended by crew member(s) will reduce the hazard and expedite transfer of passengers to and from the submersible. Separate brows should be used for incoming and outgoing passengers to enhance passenger control and expedite passenger flow.

THE DIVE SITE

This site should be thoroughly surveyed during site selection. Part of the survey should include determining that the area is clear of unexploded ordnance or pressure vessels, cables, or other types of entanglements. The bathymetry should be such that at no time, when passengers are aboard, should the submersible be in water deeper than the submersible design depth. The submersible should never operate beneath rock or coral outcropping or any other impediment to surfacing. Both the surface support safety boat and the ferry should remain well clear of the position overhead of the submersible while it is submerged. The direction and intensity of current in the dive area should be well known. Local unique weather phenomena should be well understood. Fetch, prevailing winds, and swell direction are factors in dive site selection. The submersible should be operated along a path so that, if power were lost, wind and current would not sweep it into nearby danger.

THE SURFACE SUPPORT SAFETY BOAT

This craft should be equipped with both VHF and UQC communications to communicate with the submersible. Should communications fail, the ferry should be summoned to perform this function until normal communications can be restored. Communications intervals with the submersible should not exceed 15 minutes. If communications with the submersible are lost for longer than 15 minutes, the submersible should be expected to surface. The surface support safety boat should linger nearby when the submersible is submerged but never directly overhead. This vessel should carry life jackets and life rafts sufficient to accommodate the occupants of the submersible and the safety boat crew.

At least two suited scuba divers (one an emergency supporter for "buddy" dives) should be available in the vicinity of the surface support safety boat to assist in the event of an emergency. These divers can also participate in other scheduled activities in the vicinity of the submersible.

THE SHORE LOGISTICS SITE

This site serves as an intermediate maintenance activity and replenishment base for the submersible. The site must be in a sheltered area with a proper pier or alongside space to provide safe berths for the submersible and, if possible, the ferry, surface support safety boat, and tow boat (if a separate boat other than the ferry or surface support safety boat is used for this purpose). Electrical, electronic, and mechanical repair or maintenance shops should be nearby. Air changing, battery charging, and possibly oxygen charging equipment must be available. Proper battery charging, O_2 charging, and air charging procedures should be posted and adhered to. Proper housing, cleanliness, noise insulation, and other safety/protection features for these charging facilities should be provided. A proper preventive maintenance program indicating required preventive maintenance, frequency, and dates performed should be available for reference and inspection. A configuration management plan should be conspicuously posted and complied with. A contingency plan for both catastrophe and approach of extremely severe weather (e.g., hurricane) should be available. This site should be staffed with experienced, well-trained maintenance personnel. They should be well versed in quality assurance, pressure testing, and material identification procedures related to the submersible and other associated craft. Periodic verification inspections should be conducted on an unannounced basis to ensure that all inspection, charging, and maintenance procedures are followed diligently. Adequate spares for high usage items should be stocked at the site along with consumables. This site should be situated to be relatively near the dive site, and the route between the two sites should be well marked and take into account expected local prevailing wind, weather, swells, and current.

TOW BOAT

The boat used to tow the submersible to and from the dive site should be seaworthy and have sufficient power to adequately cope with all expected weather and current conditions while conducting a controlled safe tow of the submersible. If either the ferry or surface support safety boat is capable of fulfilling those conditions, it may be used as a tow boat. This boat should be VHF and UQC equipped.

MAJOR MAINTENANCE ACTIVITY

This activity should have the capability of removing the submersible and associated system craft from the water for periodic inspection and maintenance. A crane and marine railway or drydock should be available at the facility for this function. Appropriate shop facilities should be collocated. The adequacy of the preventive maintenance, system, and hull inspection programs will probably be directly proportional to the nearness of and costs at such a facility. During periods of approaching extremely severe weather, the submersible may be removed from the water at this facility to avoid unnecessary damage.

STANDBY RESCUE EQUIPMENT

The location, availability of, and means to obtain rescue equipment should be part of the contingency plan. This is addressed more completely in the emergency response planning section (see Chapter 5) of this report.

Appendix D

Commentary on Training

This discussion of training is based largely on Section D of *Safety and Operational Guidelines for Undersea Vehicles*, published by the Marine Technology Society in 1974. However, training should require the development of criteria or standards for an acceptable level of competence of crew members in all their responsibilities. This is usually referred to as "competency-based" training.

BASIC INDOCTRINATION

Indoctrination can be accomplished in a variety of ways ranging from a formal course to on-the-job training. The program would be dictated by the size of the class, the time and equipment available, and other related factors. Regardless of what type of program is used, the use and personal maintenance of a pilot's or crewman's notebook are strongly urged. This notebook should be initiated at the outset of training and be maintained as long as the individuals are engaged in submersible activities. The notebook should contain such things as lecture notes and handouts, system descriptions and sketches, design criteria, written examinations, ship characteristics, personal observations, etc.

Basic indoctrination must be designed and controlled to ensure that candidates possess as least a good working knowledge of the following as applied to their vehicle system:

- submersible principles, ballasting, thrust control, environmental control;
- submersible construction, mechanical systems, electrical systems, propulsion systems, life support systems, buoyancy emergency systems, hull and structural materials, buoyancy materials;
- control systems, communications, navigation systems, operational instrumentation;
- all operational and emergency procedures;
- physiological parameters and safety considerations required in the closed environment of the submersible cabin;
- all test principles and procedures;
- maintenance, overhaul, and documentation requirements and procedures;
- Coast Guard rules and regulations as they apply to passenger submersible operations;
- the ocean environment in and on which the submersible will operate; and
- first aid as taught by the American Red Cross or a branch of military service (this must include a current cardiopulmonary resuscitation certification).

In general the candidate should become completely familiar with the basic concepts, physical hardware, and principles of operation of every system and subsystem of the vessel. Written and oral examinations should be regularly given to determine the effectiveness of the training program.

OPERATIONAL TRAINING

Operational training should start with a maintenance apprenticeship on the actual vessel. This apprenticeship should probably be concurrent with classroom work and should track the normal work activities of the operating team. The candidate would be expected to understand and use checklists to conduct the routine inspections and required maintenance, under the direction and guidance of the maintenance chief. At the same time the candidates should be exposed to the work environment and the overall operation. They should be assigned tasks involving the observation of actual dives, communications, tracking, etc., during normal operation—always while under the guidance of qualified team members. In this manner, useful experience is gained and the trainee acquires confidence in the system and himself. Additionally, this period should be used to further evaluate the candidates and to provide any supplemental instruction that may be needed prior to advancing to the final apprenticeship phase under the chief pilot.

The final apprenticeship phase is intended to provide a candidate with the actual on-the-job training under real conditions that will provide sufficient knowledge of his vehicle, the environment, his support and handling equipment, and procedures to be able to accomplish his mission in a safe and competent manner. This phase begins with in water familiarization and training and extends through complete ocean training leading to solo operation.

As the candidate progresses he should be given increased responsibility including, in the case of pilot trainees, early hands-on control of the vessel under supervision. When the pilot candidate is considered ready for qualification he should be able to demonstrate his ability to:

- maneuver the vehicle on the surface, while diving, in mid-water, and on the bottom, while remaining in full control at all times, perform obstacle avoidance course changes, demonstrate the precision control required during the course of normal operations, and be able to surface under normal and real or synthesized casualty conditions;
- to operate all equipment normally installed on or associated with the submersible;
- supervise all support activities and functions such as communications, tracking, operational replenishment, and any other activities associated with operation of his particular organization;
- perform all emergency procedures including the solving of life support system emergencies that might occur in the cabin while submerged; and
- provide passenger management during both normal and emergency situations.

A similarly comprehensive training program is recommended for all submersible operational crewmen. The variables in vehicle design and specific job assignment make the itemization of skills impossible here; however, the owners or operators are responsible for ensuring that the candidates are sufficiently trained and have demonstrated their proficiencies in the assigned job.

QUALIFICATION

It should be noted that no attempt has been made to specify the number of hours that this training should require. It is believed that the variables involved make any such attempt presumptuous; however, the length of the training course or individual training activity should be long enough to provide confidence that the trainee has achieved the required skill level or established standard of performance or competency.

Satisfactory completion of a course as outlined above should be sufficient to qualify a person as a pilot or crewman of that submersible. The qualification should remain in force as long as the pilot is engaged continuously and actively in the piloting or crewing of the submersible and is able to meet the required physical criteria. Periodic retesting of skills is not thought to be required for those continuously engaged in piloting or crewing. Retraining and refresher checkouts are appropriate should any lapse of continuous submersible activity exceed six months.

Qualification as a submersible pilot or operating crewman should be for only that specific vehicle in which the qualification was demonstrated. The only possible exception to this policy would exist in the case of sister vessels. It should be noted, however, that an experienced pilot or crewman has an excellent background to call upon should training in another submersible become necessary. This background could be expected to result in significantly shorter training times than might otherwise be required.

SUPPORT TEAM

Thus far, only the selection and training of submersible operating crews have been addressed. It is in those roles that the physical requirements, psychological stresses, and individual training requirements are highest. However, the rest of the operating team—the submersible support group—must not be taken for granted or ignored. The satisfactory performance of the mission and the ultimate safety of the submersible depend in large measure on the performance of these people. The team leader is in charge of the overall operation. He need not be a qualified pilot but he must be intimately familiar with all aspects of the total submersible system. He must be a leader, dependable under stress, and capable of instilling confidence in the team.

The support crew must be a well-drilled and competent team. Each person should be a volunteer selected on the basis of expertise in a specific discipline related to the submersible and his ability to function as a team member. Where specific skills are required, such as welding, hydraulic system repair, and electronic servicing, the technician should be adequately trained and, where applicable, licensed (i.e., certified welder).

Appendix E

Contingency Planning and Preparation

Contingency plans for tourist submersibles should contain, as a minimum:

1. *Emergencies by category* (well indexed). This should come from the vulnerability or hazards analysis that goes through potential threats to establish which hazards ought to have the highest priority in developing a comprehensive disaster mitigation program.

   Having well-indexed plans that can be easily read and understood by personnel not fully trained is important. In addition, since there is always the possibility that key personnel will be either involved in the accident, or otherwise be unavailable, having trained backup personnel and adequate written instructions is important. Copies of the plans should be placed in advance and kept current at the locations of personnel expected to be called on for assistance.
2. *Actions to be taken for each emergency*. Should contain specifications for "Who Does What" (1) on scene, (2) by support craft, (3) ashore, and (4) other functions.
3. *Responsibility*. Responsibility should be clearly defined for each aspect and phase. There can be no doubt at every stage of a major disaster that failure to have clear lines of authority and responsibility nearly always contributes to making the disaster worse. Without clear definition of authority and responsibility, when an emergency comes, there will always be additional confusion in figuring out who is in charge. In addition, throughout the emergency, there is apt to be confusion as various individuals jockey for authority or try to duck responsibility. Unfortunately this situation is generally worse if there are several qualified and competent people involved. When there is a predetermined line of authority and responsibility it is much easier for everyone to work together to solve problems. If things go well, there will always be plenty of glory to go around. If they don't go well, there will, likewise, be plenty of blame for everyone.

   For example, with most emergencies, primary action must be taken immediately by the pilot of the submersible. In most cases he will resolve the emergency successfully, and no other person will be required to take charge. However, if the submersible is trapped on the bottom, does the operator of the surface support craft become the overall person in charge, or does the chief pilot, or the general manager, or some other individual? Obviously there are many choices, and in some circumstances each would be the correct choice. This needs to be thought out in advance, and spelled out in the plans.
4. *Personnel to be notified and how*. Prompt notification of the Coast Guard in the event of a casualty is important and should be high on the priority list of notifications to be made.

   The U.S. Navy has a SubMiss/SubSunk emergency alert and contingency plan (see Appendix F). If this is to be included, and it probably should be, then the means of rapid notification and the responsibility to do so must be planned. It was U.S. Navy assistance that provided the key assistance in the rescue of personnel from a trapped submersible in the North Sea some years ago. They have responded in several other submersible accidents. Flyaway deep-diving capability, remotely operated vehicles (ROVs), experienced search personnel and ships are some of the capabilities they may be able to provide. Both fleet submarine force commanders have submarine rescue plans and personnel. In the event of the loss of a U.S. commercial submersible these resources ought be brought into action at the earliest possible moment. The National Search and Rescue Plan requires that this be done through the Coast Guard.

5. *Equipment to be mobilized*. Should be broken down by: (1) own staff, (2) government agencies, and (3) contract. The discussion must include not only what equipment, but how it is to be moved, by whom, and where it is to be taken. The necessary means for this mobilization must be provided. When the equipment is not owned by the company involved, contracts need to be in place. If the equipment is not maintained and, where necessary, calibrated, it will generally prove to need this sort of attention at the most inopportune time.

PREPARATIONS

This area deals with the drills and training to be conducted and how they are to be conducted. Specific areas to be included in the drills and training follow (the listing is not intended to be comprehensive). It is critical that each of these plans be exercised from time to time to ensure they work and are kept current. Communications equipment not exercised will invariably fail when most required. Medical personnel will change. Necessary fire and ambulance personnel will either be unable to respond, or will not know what is expected of them. Divers will either not be available, or their equipment will not function. Phone numbers have a way of changing.

Rescue/Salvage/Recovery Plan

This plan should cover responsibilities, personnel, and equipment. It is intended here that the salvage plan be one that is immediately available since this may be the only practical means of rescue of trapped personnel in a sunken submersible. However, in addition to the salvage plan, plans should be developed for the rescue of those stranded, if there is any practical means to accomplish this. Again, it is to be noted that in the past, salvage of the submersible has proven to be the means of rescue for those trapped.

Having the drawings of the vessel available both at the command center and with the salvage crew is a critical element that should not be overlooked. Frequently the ability to understand the systems and to improvise using them is critical to the operation.

Communications Plan

Communications equipment for an emergency is always inadequate. In addition, frequently much of it does not work. Frequently plans do not have sufficient additional communications for things like the press, for routine purposes, and for the emergency. When planning a real disaster type of operation, one should plan for additional telephone lines in large quantity, and both mobile phones and radios. The press can and will monitor radio transmissions, and they will use this information as the basis for stories, regardless of the clear law in this area. (The Navy's experience with the space shuttle *Challenger* disaster, as well as many other similar experiences, shows this to be the case.)

Emergency Medical Plan

Medical problems associated with the possible rescue of personnel from a lost submersible can be outside the normal understanding of the local medical community and require someone who understands submarine medicine. Specifically this may include the need for hyperbaric treatment of the passengers, including development of some sort of decompression protocol.

Fire and Ambulance Plan

The pumping ability of the local fire department can be valuable in an emergency, as is their medical training.

Diving Support Plan

Two divers should be available on the surface safety support vessel and in the vicinity of the submersible in the event that an emergency should arise. The diving plan should include plans for mobilization of additional divers. These divers should be familiar with the design and engineering aspects of the submersible, and should be able to perform emergency work on the vessel if required to free it from entrapment on the bottom or to exercise its external safety features. A source of additional diving air should be noted in the plan, and the location of spare diving equipment should be spelled out. An ROV should be available on short notice as a regular part of the plan.

Emergency Gas Support Plan

This item is intended to include both compressed air and other compressed gases that might be required to sustain the life support system in a sunken submersible and rescue or salvage the submersible.

Public Affairs Plan

This might seem a minor point, but in the event of a serious disaster, the lack of such a plan can and will detract from the ability of all responsible parties to work on the real problem, as they will be continually pulled away to brief the press.

FACTORS AFFECTING SALVAGE OTHER THAN CONTINGENCY

Submersible design factors such as the following must be taken into account:

- Salvage air fittings with standard connections and valves, for running air hoses from the surface to a vessel on the bottom. Both high and low fittings should be addressed.
- Standard mating rings for rescue (at least one hatch). This would permit mating of a decompression chamber to the submersible after salvage, in the unlikely event that it were pressurized. This can be accomplished by providing a transition or adaptor section, known as a "Dutchman," which will mate to the hatch of the submarine and the other face will mate to whatever is determined to be the industry standard.
- Standard lifting attachments to provide points for attachment in the event of an external lift requirement. These should be able to provide sufficient lift in the event of flooding of the hull. They must be designed so that they can be connected to an ROV if the submersible is to be operated in water depths beyond those accessible by divers.
- Standard emergency through-water telephone equipment compatible with rescue or potential rescue equipment. In addition, a transponder that can be interrogated by a search vehicle will greatly enhance the ability of a rescue effort to find a submersible lost on the bottom.
- Sufficient emergency hose and other equipment to permit mounting an initial salvage/rescue attempt should be prepositioned and available. (This might entail use of U.S. Government facilities and/or equipment positioned in the continental United States.)

Operational features which will facilitate rescue or salvage in an emergency are:

- mutual assistance plans among operators and others;
- prior planning with the U.S. Navy and Coast Guard elements who would be involved in any rescue attempt;
- exchange of plans with above in order to ensure optimum coordination; and
- coordinated communications plans, including radio frequency assignments, that include means for rapid contact with nearby Coast Guard and Navy facilities capable of rapid response help.

Appendix F

Other Relevant Contingency Plans

- COAST GUARD NATIONAL SEARCH AND RESCUE PLAN, CHAPTER 6, "PROCEDURES FOR UNDERWATER INCIDENTS" (pp. F2-F8)
- OPNAV SUBMISS/SUBSUNK BILL (pp. F9-F20)
- NAVSEA SUBMISS/SUBSUNK BILL FOR SUBMARINES AND MANNED NONCOMBATANT SUBMERSIBLES (NAVSEA INSTRUCTION 4740.1A) (pp. F21-F34)

CHAPTER 6. PROCEDURES FOR UNDERWATER INCIDENTS

Ref:
(a) CG Diving Policies & Procedures Manual, COMDTINST M10560.4 series (NOTAL)
(b) CG Navigation and Vessel Inspection Circular, COMDTPUB P16700.4 series (NOTAL)
(c) CG Helicopter Rescue Swimmer Operations Manual, COMDTINST M3710.4 series (NOTAL)
(d) CG Boat Crew Seamanship Manual, COMDTINST M16114.5 series (NOTAL)
(e) CG Cutter Swimmer Instruction, COMDTINST 16134.1 series (NOTAL)
(f) NAVSEA SUBMISS/SUBSUNK Bill for Submarines and Manned Noncombatant Submersibles, NAVSEAINST 4740.1 series (NOTAL)

A. Purpose

1. This chapter gives Coast Guard SAR response procedures for underwater incidents. It focuses on life-threatening incidents requiring assistance from military or civilian divers or dive resources.
2. Though not mandated to perform rescues, the Coast Guard is responsible for developing, maintaining and operating facilities for the promotion of safety under, as well as on and over the high seas and waters subject to the jurisdiction of the United States; and, traditionally, has assisted distressed persons wherever and whenever possible. The responsibility extends to civilian submersibles operating on scientific, industrial or other missions; capsized or sunken vessels; or crashed aircraft in which persons may be trapped.

B. Submersibles

1. Most SAR cases involving submersibles have occurred on the surface. The Coast Guard or local resources handle these. Rescues of persons trapped in sunken vessels will normally require assistance from outside resources.
2. Submersibles have good safety records, but a few accidents have demonstrated the difficulty of rescue and the potential for high public interest. The number of submersibles, especially for recreational and passenger-for-hire use, is increasing, and, therefore, increasing the probability of rescue incidences.
3. The Coast Guard has no special equipment to assist submerged vessels or persons trapped in underwater habitats. It must request suitable outside equipment and assistance.

4. The U.S. Navy is the primary source of expertise and resources for complex underwater SAR incidents. The Navy Department's point of contact is the Navy Command Center Duty Captain at the Pentagon. This Navy command center can provide fleet resources, specialized experimental equipment and civilian undersea salvage specialists. When the Navy responds, it normally assumes SAR mission coordination and the Coast Guard takes on a support role. Until then the Coast Guard must respond with its own or other available resources.
5. Reference (a), Coast Guard Diving Policies and Procedures, states that a Commanding Officer may use military divers, commercial divers or similarly highly trained diving resources, such as local police divers. If a commanding officer is faced with a life threatening situation and none of the military, commercial or other highly trained diving resources are reasonably available, he may consider using personnel with recreational diver qualifications who volunteer their services. Reference (a) states clearly that this discretion should be exercised most carefully after seriously considering the training, qualification, medical, physical, and psychological condition of the volunteer, the condition of the diver's equipment, and the hazards of the dive.
6. Submersible operators have no mutual assistance plans at this time. Plans are being developed to possibly create a mutual assistance program for research/construction deep submersible owners and operators. This initiative is being facilitated by NOAA and members of the deep diving submersible community.
7. Commandant (G-MTH) has described various safety procedures for passenger-carrying-submersibles in reference (b). Various requirements for safety of submersible vessels carrying more than six passengers include maximum depth of water for the submersible's operating area, means of escape from the pressure hull, predetermined route of the submersible, support vessel, lifesaving equipment, life support systems, etc. This publication also outlines the authority and recommended actions of the Captain of the Port (COTP) regarding recreational submersibles.

8. The Coast Guard operates a voluntary reporting system for civilian submersible operations for salvage, research, construction, etc. Submersible operators may provide the nearest Coast Guard district with details of a planned submersible operation.

C. Persons Trapped in Capsized Vessels

1. Incidents do occur where persons are trapped under capsized vessels or in compartments of vessels, aircraft, automobiles, etc. Coast Guard resources for rescue in these cases are severely limited. Immediate Coast Guard SAR response resources may include SRU's which may have rescue swimmers. Rescue of persons trapped below the surface of the water is an inherently dangerous exercise and therefore the long standing policy of the Coast Guard regarding placing of Coast Guard personnel in "unreasonable danger" applies.
2. Policy regarding the use of rescue swimmers is:

a. Helicopter Rescue Swimmers. Outlined in reference (c). The decision to deploy a helicopter rescue swimmer is initiated by the pilot-in-command, but the rescue swimmer has the authority to decline deployment if the rescue swimmer assesses the situation to be beyond his/her capabilities. A helicopter rescue swimmer shall not swim into nor under a capsized or submerged vessel, aircraft, or vehicle. The helicopter rescue swimmer may search visually and reach inside from the exterior of the object. If it is determined that someone is trapped under or in the object and cannot be reached from the exterior, alternative assistance must be used such as divers.
b. Small Boat Swimmers. Procedures for small boat swimmers are presented in reference (d). Swimmers from small boat SRUs are normally boat crewmembers without specialized rescue swimmer training and operate tethered to the small boat.
c. Cutter Swimmers. The training requirements and intent of the use of swimmers from cutters are outlined in reference (e). Cutter swimmers are not meant to act on their own and are to be tethered and serve as the means of transporting a victim back to the cutter or its small boat.

3. Procedures recommended for rescuing personnel trapped in a capsized vessel are:

a. Upon arrival on scene attempt to find out if anyone is trapped inside and where they might be. Question survivors, especially those who escaped from the hull. Communicate through the hull by tapping or shouting. If successful, keep trapped persons advised throughout the operation.
b. Stabilize the hull with other boats tied alongside or with a buoy tender. DO NOT ATTEMPT TO RIGHT THE BOAT at this stage.
c. Estimate the volume of air remaining in the compartment. This estimation need not be exact, but it is necessary in order to calculate the remaining survival time of the trapped persons. An approximation of the total minutes of breathable air remaining from the time of capsizing can be calculated by multiplying the volume of trapped air (in cubic feet) by three and then dividing by the number of persons trapped.
d. Rescue swimmers may dive beside the vessel and attempt to lead trapped persons out by reaching under or inside the vessel. The rescue swimmer shall not dive under or into the vessel or any of its compartments.
e. Inject clean air only from diving tanks or diving compressors so that it bubbles up inside. This will help keep the boat afloat and may provide more breathing air. Unless one end of the hose is connected to a source of air pressure or unless the hose has a check valve, do not put the air hose in the air pocket. This precaution is to prevent siphoning air out of the pocket through the hose. DO NOT puncture the hull to get air to victims—this can cause loss of the air they have.
f. Only if no rescue from the capsized vessel is possible, rerighting the craft may be considered. Refer to reference (d) for direction and procedures for rerighting a craft. If rerighting cannot be accomplished safely, very carefully tow the vessel close to shore and attempt beaching. Do not allow vessel to roll over because it may sink. Keep the trapped persons informed of your intentions. Do not use gas cutting torches on powered vessels to cut through the hull to remove trapped personnel.

D. Use of Underwater Acoustic Beacons (Pingers)

1. Many aircraft downed in moderate or shallow waters have not been found, or excessive time and funds have been expended in determining crash locations. Some of these aircraft could have been located if they had an installed Underwater Acoustic Beacon, commonly called a pinger. A pinger emits a sound in a submerged aircraft that may be detected by surface craft or divers using an underwater acoustic locator. All Coast Guard aircraft have been equipped with pingers.
2. Pingers may be attached to the hull of an overturned vessel that is in danger of sinking, when personnel are known or suspected to be trapped inside the hull. This action is not routine, and is not taken in all SAR cases involving overturned hulls. When such action is needed, the OSC should request a pinger from the SMC. Pingers are not readily available in all locations. They may be obtained from a Coast Guard or U. S. Navy air station or by calling the U. S. Navy Duty Captain desk at the Pentagon for supply by the Supervisor of Salvage.
3. Personnel trained to locate pingers using locator receivers are available through the U. S. Navy Supervisor of Salvage office. For emergencies, requests for service are to made with the U. S. Navy Duty Captain Desk in the Pentagon.

E. Action Required for Underwater SAR Preparation

1. Coast Guard Rescue Coordination Centers shall:

a. Monitor civilian submersible and underwater habitat activity within the district and advise the Commandant of developments which may affect procedures and policies of this directive.
b. Inform submersible manufacturers, owners and operators within the district of the voluntary reporting system for submersible operations.
c. When informed of a civilian submersible operation, send a message to Chief of Naval Operations and issue a Notice to Mariners giving the location(s) and time(s) of the operation. Tourist submersibles are approved for specific sites and have as many as 12 dives per day; therefore, notification for tourist submersibles should be as a permanent record.
d. Maintain files of copies of the Certificate of Inspection (COI) and a copy of the submersible operations manual as approved by the COTP in the RCC for reference in the event of a rescue incident.

e. Establish a resource file of local, state, commercial, military rescue and/or salvage divers and submersibles for use in underwater search and rescue.

f. When assistance is required for a civilian underwater SAR incident:

(1) Call the Navy Department Duty Captain at the Pentagon (On duty 24 hours: Commercial (202) 695-0231, Autovon 225-0231). If the incident involves a civilian submersible, request implementation of SUBMISS/SUBSUNK per reference (f). Send a follow-up message confirming the request.

(2) Respond with Coast Guard resources as appropriate (On-Scene Commander, rescue platform such as buoy tender, traffic control, aircraft, communications, and/or logistics.)

(3) Serve as SAR Mission Coordinator (SMC). If Navy resources are used, the Navy may assume SMC. If the Navy assumes SMC, continue to assist as requested.

(4) Inform the Area Commander and Commandant of the progress of the rescue before and after the Navy assumes SMC.

(5) Prepare a SAR Case Study in addition to the normal assistance report.

2. Commandant (G-NRS) shall:

a. Maintain liason with the Navy and other organizations to coordinate planning for civilian underwater SAR emergencies.

b. Distribute available reports on U.S. submersibles and other appropriate information to district commanders and to Rescue Coordination Centers.

3. Marine Inspection Offices/COTPs shall:

a. Forward copies of the Certificate of Inspection (COI) and the approved operations manual of passenger carrying submersibles to the appropriate RCC showing safety features and conditions, determined route, depth and any other applicable information necessary to prosecute a SAR case with the vessel.
b. Submit to the appropriate RCC information on any requirements developed for recreational submersibles. Authorizations for recreational submersible operations should be copied to the RCC.

Department of the Navy Office of the Chief of Naval Operations Washington, DC 20350-2000

IN REPLY REFER TO 3130 Ser 02/9U576280 12 September 1989

From: Chief of Naval Operations

Subj: OPNAV SUBMISS/SUBSUNK BILL

Encl:
(1) Information Regarding Action to be Taken in the Washington Area
(2) Washington Area Notification List
(3) Information Regarding Capabilities of Forces Afloat
(4) Information Regarding Manned Noncombatant Submersibles/Submarines
(5) Status of Rescue Agreements with Foreign Countries

1. Enclosures (1) through (5) provide information to assist the Navy Department Duty Captain (NDDC) and Navy Command Center (NCC) personnel in the event SUBMISS/SUBSUNK is declared for a submarine or manned noncombatant submersible.
2. This letter supersedes CNO 1tr 3130 Ser 02/8U576271 of 9 May 88.
3. Enclosures (1) through (5) are to be incorporated into the "Submarine Disaster Binder" maintained in the Navy Command Center and the OP-02 Duty Officer's safe. OP-231 will verify and update this binder on a semiannual basis. The OPNAV point of contact is OP-231 at 202-697-2069.

D. L. COOPER
By direction

Distribution: CNO (OP-00N, 09C, 092, 093, 21, 22, 23, 24, 29, 03, 04, 05, 06, 64, 07) COMNAVSEASYSCOM (SEA-00P2 for Duty Officer, PMS-393 TIC, PMS-395) COMNAVMILPERSCOM (Code N011 for Duty Officer)

INFORMATION REGARDING ACTION TO BE TAKEN IN THE WASHINGTON AREA

1. SUBMISS/SUBSUNK declaration is made as follows:

a. For a U.S. or friendly foreign submarine operating under U.S. control, SUBMISS/SUBSUNK will be declared by the Submarine Operating Authority under whose control the submarine is operating.
b. For a manned noncombatant submersible operated by the U.S. Navy or operating under a Navy lease, SUBMISS/SUBSUNK will be declared by the Submarine Operating Authority in whose area the submersible is operating.
c. For the loss of a civilian submersible not operated by or under lease to the U.S. Navy, the U.S. Coast Guard may request Navy assistance in accordance with the National Search and Rescue Plan, 1969. Under federal law, the Coast Guard is responsible for developing, establishing, maintaining and operating, with due regard to the requirements of national defense, rescue facilities for the promotion of safety on, under, and over the high seas and waters subject to the jurisdiction of the United States. The Navy is assigned no direct responsibility in the National SAR Plan for the rescue of personnel or salvage of civilian owned and operated submersibles. However, provision is made for the use of Navy facilities to meet civil needs on a not-to-interfere basis with higher priority military missions. If Navy assistance is requested by the Coast Guard, SUBMISS/SUBSUNK will be declared by the Navy Department Duty Captain (NDDC) after consultation with the cognizant fleet commander and the Assistant Chief of Naval Operations (Undersea Warfare) (OP-02). If SUBMISS/SUBSUNK is declared, the Navy will respond to the fullest extent possible within its existing capabilities. If Navy assistance is provided, the NDDC, when requested by OP-02, will designate a Naval Command as SAR Mission Coordinator (SMC) and will notify the cognizant Coast Guard Area or District Commander of this designation. The SMC will designate an appropriate naval officer on scene as the On Scene Commander (OSC). The OSC shall be qualified for succession to command at sea, and if practicable, be a submarine officer serving in a submarine billet.
d. OP-02 will evaluate any request for submarine or submersible rescue not addressed above and direct action as may be deemed appropriate by cognizant U.S. authority.

2. When SUBMISS/SUBSUNK is declared by a Submarine Operating Authority or when a manned civilian non-combatant submersible emergency arises, the following actions will be taken within OPNAV:

Enclosure (1)

a. The NDDC shall:

(1) Notify the persons and activities listed in the Washington Area Notification List, enclosure (2). Notification should be made in the order listed using the most expeditious means available.
(2) Coordinate with the OP-02 Crisis Action Team (CAT) leader.
(3) Upon receipt of a request for naval assistance from a cognizant Coast Guard area or district commander, declare SUBMISS/SUBSUNK for the loss of a manned civilian submersible not operated by or under Navy lease, after consultation with the Assistant Chief of Naval Operations (Undersea Warfare) (OP-02) and the cognizant fleet commander. Request that the fleet commander take appropriate action and authorize direct liaison with the cognizant U.S. Coast Guard commander.
(4) Inform the Chief of Naval Information (CHINFO) in order to coordinate preparation of a statement concerning the SUBMISS/SUBSUNK event. All information releases will be coordinated with the cognizant fleet commander and OPNAV staff offices. If a nuclear submarine is involved, the release must be cleared through the Nuclear Propulsion Directorate (SEA-08).

b. OP-02 shall determine the type of watch to be set in the CNO Crisis Action Center to coordinate follow-on actions. A Crisis Action Team (CAT) or a response cell will be formed to coordinate actions and remain stationed until the SUBMISS/SUBSUNK condition is terminated. In some instances, such as responding to a foreign country under a rescue agreement, a one-officer continuous watch in the CNO Crisis Action Center may be sufficient. For the loss of a U.S. submarine, the complete CAT would be required.

(1) The following are designated to report to the NCC to form the CAT or response cell.

CORE			
	I	II	III
Leader	OP-21	0P-22	0P-23
Asst Leader	OP-212C	OP-232	OP-223C
Member	OP-231	OP-223E	OP-212D
Clerical Support	OP-21W	OP-22W	OP-02S1

(2) The following shall be incorporated into the CAT as necessary:

OP-00N	Representative	MEMBER
OP-092	Representative	MEMBER
OP-093	Representative	MEMBER
OP-03	Representative	MEMBER
OP-04	Representative	MEMBER
OP-05	Representative	MEMBER
OP-07	Representative	MEMBER
OP-06	Representative	BRIEFER
OP-09C	Representative	LIAISON
NMPC	Representative	LIAISON
OP-64	Worldwide Military Command and Control System Intercomputer Network (WIN)	OPERATOR

c. The CAT leader shall:

(1) Coordinate, as necessary, follow-on actions and any assistance that may be required from assets not under the command of the Search and Rescue Mission Coordinator (SMC).
(2) Coordinate with COMSUBDEVGRU ONE to make search, recovery, and rescue assets ready and to provide staff assistance to the On Scene Commander (OSC).
(3) Keep OP-02, the NDDC and CHINFO informed of continuing developments.

3. When a foreign navy requests assistance for submarine rescue under an existing agreement, the NDDC shall determine and take appropriate action after consultation with OP-02, OP-06 and Navy JAG staff as to the terms of the agreement. Enclosure (5) provides the status of agreements.
4. The Naval Sea Systems Command Headquarters Duty Officer will alert appropriate NAVSEA personnel so that technical assistance may be provided expeditiously. He shall also alert the Nuclear Propulsion Directorate (SEA-08) in the event that a nuclear submarine is involved.

5. The Commander, Naval Military Personnel Command is responsible for the notification of next of kin of military personnel. The Naval Military Personnel Command (NMPC) Duty Officer will be notified and directed to alert the Director, Community and Personal Services Division, and the Casualty Assistance Branch for effecting notification of next of kin. In view of the squadron/group commander's access to current information contained in the submarine's sailing list or next of kin book, the submarine's squadron/group commander will work closely with NMPC in accomplishing notification of next of kin. The submarine's squadron/group commander will provide NMPC with a copy of the sailing list and next of kin information by the most expeditious means. In the case of a Navy operated or leased submersible, the commanding officer, commander, or director of the Navy organization operating the submersible will be tasked to provide NMPC with a copy of the sailing list and next of kin information by the most expeditious means. The NMPC Duty Officer will also alert the NMPC Public Affairs Officer for coordinating release of names of crew members with CHINFO. A representative of NMPC may be assigned to the CAT if the event involves the loss of a U.S. submarine.
6. The OP-05 Duty Officer is to be informed on the presumption that there will be personnel or material to be flown to the vicinity of the casualty.

Washington Area Notification List

(High Priority Calls)

________ OP-64

________ OP-641

________ OP-06A

________ OP-02A

________ OP-23

________ OP-02DutyOfficer(notifyallOP-23personnel)

________ OP-09A

________ OP-002

________ SECNAVEA

________ OP-00N(ifnuclearvesselinvolved)

________ OP-21B

________ OP-22B

________ OP-642

________ CHINFODutyOfficer

________ DDONMCC(note1)

________ COMSUBDEVGRUONEDutyOfficerAV553-7132/7094/7088/89COM (619)553-XXXX

________ OP-932/932C R

Notes:

1.Recommendthatthefollowingbenotified:

ASSTSECDEF(PublicAffairs)
ASSTSECDEF(AtomicEnergy) (ifnuclearweaponsornuclear vesselinvolved)

2.TelephonenumbersaremaintainedcurrentbytheNCCandOPNAV staffDutyOfficers.

Enclosure (2)

Washington Area Notification List

________	OP-03A	
________	OP-04A	
________	OP-05A	
________	OP-01A	
________	OP-092	
________	OP-981	
________	OP-094A	
________	OP-07A	
________	OP-096	
________	OP-24	
________	COMNAVSEASYSCOMDutyOfficer(note1)	
________	COMNAVMILPERSCOMDutyOfficer(note2)	
________	BUMEDDutyOfficer(notifyNUMI) (MEDCOM 21) (MEDCOM 21)	R
________	NAVPOLAROCEANCENDutyOfficer(763-1111)	
________	NOICSeniorWatchAnalyst(763-2255)	
________	OP-05DutyOfficer	
________	NavalMedicalResearchLab,NewLondon(AV241-4877ask for beeper #145)	A

Notes:
1.NAVSEADutyOfficertofurthernotifySEA92,SEA00,SEA08 (ifnuclearvessel),SEA09,PMS395,SEA00C,PMS350,PMS393, PMS396,andSEA00D.
R
2.TofurtheralertCOMNAVMILPERSCOM,ASTCOMNAVMILPERSCOMfor Distribution (NMPC-4),DirectorCommunityandPersonalService Department(NMPC-64)andCasualtyAssistanceDivision(NMPC-642), DirectorSubmarine/NuclearPowerDivision(NMPC-42)andthe AssistantforPublicAffairs(NMPC-050).
3.TelephonenumbersaremaintainedcurrentbytheNCCandOPNAVstaffDutyOfficers.

Information Regarding Capabilities of Forces Afloat

1.Submarineforcecommanderinstructionscallforplacing SUBMISS/ SUBSUNKplansineffectwhencertainconditionsexist withoperatingsubmarines.

2.Theprimarymissionuponexecutingtheplanistheprompt renderingofassistancetothesubmarineindistressthrough expeditioussearch,locationandrescue.Themethodusedto rescuepersonnelwilldependlargelyonthenatureofthe casualtyandwillbedeterminedatthescene.Ifthesubmarine cannotbesurfacedreadily,useoftheDeepSubmergenceRescue Vehicle(DSRV),theSubmarineRescueChamber(SRC),orescapeby buoyantorfreeascentmaybenecessary.Undermostconditions ofdamagetothesubmarine,salvageoftheshipwillbeaslow andprolongedoperationandisnotapartoftherescue operation.

3.Informationandproceduresconcerningrescueofadisabled submarinemaybefoundinNWP19-1(A) (NavySearchandRescue (SAR)Manual)andinS9594-AE-GTP-010/DISABLEDSUB(Disabled SubmarineManual).TransportationrequirementsfortheDSRVmay befoundinNAVSEASG400-AF-GIB-010/DSRV (DeepSubmergenceRescue Vehicle(DSRV)TransportationManual). R

4.TheNavy'stwoUSRVs,MYSTICandAVALON,arehomeportedin SanDiegoattheSubmarineRescueUnit(SRU) andareunderthe controlofCommander,SubmarineDevelopmentGroupONE.OneDSRV isalwaysinstandbystatusreadytorespondtoasubmarine disaster.TheDSRVsarecapableofbeingdeployedtoallareas oftheworldbyairorsea,andcanoperatefromeitherASR-21 ClassSubmarineRescueVessels(ASRs)oranyofthe20U.S.,4 U.K.andIFrenchnuclearsubmarinesconfiguredasMother Submarines.DSRVscanmatewithallU.S.submarinesandconduct rescuestocollapsedepthsofallcombatantsubmarines. Twenty-fourmenpertripcanbecarriedfromthedistressedsubmarine. R

5.SubmarineRescueVessels(ASRs)areassignedtoeachfleet. Thesevesselsarecapableoflayingafour-pointmoorovera sunkensubmarineindepthsupto850feetandoperatinga SubmarineRescueChamber(SRC)tosuchdepths.Theycarry divers,divingequipmentandahyperbaricchamber.

6.CommanderSubmarineForce,U.S.PacificFleetmaintainsa submarinepersonnelrescuefly-awaykitattheSubmarineRescue Unit(SRU)inSanDiego,California.Thiskithasbeen establishedtoproviderescuecoverageinareaswhereasubmarine rescueship(ASR)isnotimmediatelyavailable.Ithasan850 footSRC,independentmooringandrescuecapabilities,and requiresonlyavesselcapableoftransportingittothescene andtoserveastherescueplatform.Anyshipcapableofloading thekitisconsideredsuitable,althoughonewithrelativelylow freeboardaft,suchasanARSorATF,ispreferable.Therescue

ENCLOSURE (3)

chambercanberiggedfortowingintheeventtheshipisnot equippedwitha10-toncapacityboomcapableofhandlingthe chamber.PersonnelfromSubmarineDevelopmentGroupONEwill accompanythekittoassistinthemooringevolutionandwill operatetherescueequipment.

7.Eachsubmarineisequippedwithescapehatcheswhichwould allowthecrewtoexitthesubmarinebylockoutandfreeascent. Thismethodisonlyappropriateifthesubmarineisbottomedin shallowwater.

Enclosure (3)

INFORMATION REGARDING MANNED NONCOMBATANT SUBMERSIBLES/ SUBMARINES

1. Deep submersibles are generally designed to perform specific ocean engineering tasks. As a result, the size, hull form and equipment arrangements are usually unique. Some may have diver lockout capability.
2. Deep submersibles have the following common characteristics:

a. The capacity of life support systems varies but is generally less than 48 hours. Two exceptions are the Submarines NR-1 and USS DOLPHIN (AGSS-555).
b. The hatches on the deep submersibles are normally not compatible with the Deep Submergence Rescue Vehicles (DSRVs) and Submarine Rescue Chambers (SRCs) used for submarine rescue.
c. Deep submersibles are usually not designed for escape of operating crews using buoyant ascent; divers may escape from those with lockout capability. Submarines DOLPHIN and NR-1 are exceptions, since buoyant ascent escapes from these submarines are possible.
d. At the present time the only feasible method of saving all lives in an untethered, manned, noncombatant deep submersible crew would be to recover the vessel.
e. Commander, Submarine Development Group ONE has various resources available such as manned and unmanned submersibles, unmanned towed search devices, and other appropriate equipment which could be used in the search, location, and recovery of a manned, noncombatant deep submersible.
f. COMNAVSEASYSCOM (Code 00C) has various resources such as unmanned submersibles, unmanned towed search devices, and other appropriate equipment which could be used in the search, location and recovery of a manned noncombatant deep submersible.

Enclosure (4)

Status of Rescue Agreements with Foreign Countries

Submarine Rescue Agreements (established for use of the DSRV/SRC):

Canada		
Netherlands		
Peru		
RepublicofChina(Taiwan)		
UnitedKingdom		
Greece		
France		A
Brazil		
SubmersibleRescueAgreement:		
France	establishedformutualrescueservices betweenSEACLIFF(U.S.)andNAUTILE(France)	

Enclosure (5)

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
WASHINGTON, DC 20362-5101

IN REPLY REFER TO

NAVSEAINST 4740.1A CH-2
OPR PMS395
20 March 1990

NAVSEA INSTRUCTION 4740.1A CHANGE TRANSMITTAL 2

From: Commander, Naval Sea Systems Command

Subj: NAVSEA SUBMISS/SUBSUNK BILL FOR SUBMARINES AND MANNED NONCOMBATANT SUBMERSIBLES

Encl: (1) New Enclosure (1)

1. Purpose. To update the telephone numbers for the NAVSEA SUBMISS/SUBSUNK Bill.

2. Action. Replace current enclosure (1) with new enclosure (1).

W. H. Cantrell
W. H. CANTRELL
Deputy Commander
Submarine Directorate

Distribution:

SNDL	A1	ASSTSECNAV (RES,ENGR,SYS)
	A2A	CNR
	A3	CNO (OP-23)
	A5	Bureaus
	B5	COMDT COGARD
	21A	Fleet Commanders in Chief
	23	Force Commanders
	24G	Submarine Force Commanders
	26VV2	COMSUBGRU FIVE AND NINE
	28K	Submarine Group and Squadron
	C84B	NAVMATDATASYSGRU
	FB30	NAVSHIPREPFAC
	FD1	COMNAVOCEANCOM
	FF1	COMNAVDIST WASHINGTON DC
	FF5	NAVSAFECEN
	FKQ6B	NAVCOASTSYSCEN
	FKQ6C	NAVOCEANSYSCEN
	FKQ6D	NAVXDIVINGU
	FKQ6E	DTRC
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NAVSEAINST 4740.1A CH-2 20 March 1990

NAVSEA SUBMISS/SUBSUNK NOTIFICATION LIST

CODE	TITLE	OFFICE TEL NO.**
SEA 92	Deputy Commander for Submarines	(703) 602-1564
SEA 00	Commander, NAVSEA	(703) 602-3381
SEA 08	Deputy Commander for Nuclear Propulsion (If Nuclear sub)	(703) 602-3387
SEA 09	Vice Commander, NAVSEA	(703) 602-3681
PMS395*	Program Mgr, Deep Submergence Systems Program (See Note 1)	(703) 602-3421
SEA OOC	Director of Ocean Engineering, Supervisor of Salvage and Diving	(703) 697-7386
PMS350*	Program Mgr, SEA WOLF Class Sub	(703) 602-7200
PMS393*	Program Mgr, Attack Submarine Program (See Note 1)	(703) 602-3405
PMS396*	Program Mgr, Strategic Submarine Program	(703) 602-7207
SEA 08	Applicable SEA 08 Project Officer (as determined by applicable PMS)	
SEA OOD	Director, Congressional/Public Affairs Office	(703) 602-1556

* Applicable Program Manager for particular submarine.
** NAVSEA Duty Officer has access to all home phone numbers.
Note 1: PMS395 is the Program Manager for the following SSNs:

USS SAM HOUSTON (SSN 609)

USS JOHN MARSHALL (SSN 611)

USS PARCHE (SSN 683

USS RICHARD B. RUSSELL (SSN 687)

Enclosure (1)

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
WASHINGTON DC 20362 5101

IN REPLY REFER TO

NAVSEAINST 4740.1A CH-1
OPR PMS395
8 JAN 1988

NAVSEA INSTRUCTION 4740.1A CHANGE TRANSMITTAL 1

From: Commander, Naval Sea Systems Command

Subj: NAVSEA SUBMISS/SUBSUNK BILL FOR SUBMARINES AND MANNED NONCOMBATANT SUBMERSIBLES

Encl: (1) New Enclosure (1)

1. Purpose. To update the NAVSEA SUBMISS/SUBSUNK BILL.

2. Action

   a. Replace old enclosure (1) with new enclosure (1).

   b. Make the following pen and ink changes.

      (1) Change reference (a) to "CNO ltr Ser 02/6U385030 of 1 Apr 86, Subj: OPNAV SUBMISS/SUBSUNK Bill".

      (2) In para 2.d, third line, of enclosure (2) delete "SLM or SHAPM" and insert "Program Manager".

      (3) In para 5, first two lines, of enclosure (2) delete "PDS 350.... SHAPM" and insert "the applicable NAVSEA Program Manager".

      (4) In para 4, second line, of appendix A to enclosure (2) delete "921R" and insert "92Q".

W. H. Cantrell
W. H. Cantrell
Deputy Commander
Submarine Directorate

Distribution: (See next page)

S-003

NAVSEAINST 4740.1A CH-1 8 JAN 1988

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	24G	Submarine Force Commanders	
	26VV2	COMSUBGRU REP	
	28K	Submarine Group and Squadron	
	C84B	NAVMATDATASYSGRU	
	FB30	NAVSHIPREPFAC	
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	FKQ6C	NAVOCEANSYSCEN	
	FKQ6G	NUSC	
	KFQ6E	DTNSRDC	
	FKQ6B	NAVOASTSYSCEN	
	FKM22	NAVPUBFORMCEN (200)	
	FKP6D	NAVXDIVINGU	
	FKP7	NAVSHIPYD	
	FKP8	SUPSHIP	
	FT44	NAVDIVESALVTRACEN	
	FT88	EDOSCOL	
SEA	OOC	(10)	SEA 09B11 (5)
	00V	(2)	09B 38 (100)
	08	(5)	
	92	(5)	
	PMS 350	(5)	
	PMS393	(10)	
	PMS394	(5)	
	PMS395	(5)	
	PMS396	(5)	

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NAVSEAINST 4740.1A CH-1 8 JAN 1988

NAVSEA SUBMISS/SUBSUNK Notification List

Code	TITLE	OFFICE**
SEA 92	Deputy Commander for Submarines	692-1564
SEA 00	Commander, NAVSEA	692-3381
SEA 08	Deputy Commander for Nuclear Propulsion (IF NUCLEAR SUBMARINE)	692-3887
SEA 09	Vice Commander, NAVSEA	692-3681
* PMS395	Program Manager, Deep Submergence Systems Program (See Note 1)	692-3421
SEA 00C	Director of Ocean Engineering, Supervisor of Salvage and Diving	697-7386
* PMS 350	Program Manager, SEA WOLF Class Submarine Acquisition Program Management Office	692-5503
* PMS393	Program Manager, Attack Submarine Program (See Note 1)	692-3405
* PMS396	Program Manager, Strategic Submarine Program	692-7207
SEA 08	Applicable SEA 08 Project Officer (as determined by the applicable PMS)	
SEA 00D	Director, Congressional/Public Affairs Office	692-6928

* Applicable Program Manager for particular submarine.
** NAVSEA duty officer has access to all home phone numbers.
Note 1. PMS395 is the Program Manager for the following SSNs:

USS SAM HOUSTON (SSN 609)

USS JOHN MARSHALL (SSN 611)

USS PARCHE (SSN 683)

USS RICHARD B. RUSSELL (SSN 687)

Enclosure (1)

DEPARTMENT OF THE NAVY

NAVAL SEA SYSTEMS COMMAND
WASHINGTON, DC 20362-5101

IN REPLY REFER TO
NAVSEAINST 4740.1A
Ser 92/34
12 Sep 85

NAVSEA INSTRUCTION 4740.1A

From: Commander, Naval Sea Systems Command
To: All Offices Reporting Directly to COMNAVSEA

Subj: NAVSEA SUBMISS/SUBSUNK BILL FOR SUBMARINES AND MANNED NONCOMBATANT SUBMERSIBLES

Ref: (a) OPNAVINST 3130.2G of 3 Jul 84, Subj: OPNAV SUBMISS/SUBSUNK BILL

Encl: (1) NAVSEA SUBMISS/SUBSUNK Notification List
(2) NAVSEA Action To Be Taken In Support Of A SUBMISS/SUBSUNK Event

1. Purpose. To ensure that the Naval Sea Systems Command is alerted to provide assistance whenever a SUBMISS/SUBSUNK event is executed for submarines or manned noncombatant submersibles.

2. Cancellation. NAVSEAINST 4740.1 of 23 January 1975.

3. Background

a. Reference (a) outlines the actions to be taken by the Navy Department Duty Captain (OPNAV), Navy Command Center (NCC), in case of a SUBMISS/SUBSUNK event involving a U.S. submarine, a friendly foreign submarine operating under U.S. control, or a manned noncombatant submersible operated by the U.S. Navy or operating under Navy lease. "EVENT SUBMISS/SUBSUNK" will be placed in effect by the submarine operating authority under whose control the submarine is operating. A submarine may be reported missing (SUBMISS) if the crew fails to observe a scheduled contact (in accordance with its operational orders) within a prescribed time lapse. If a submarine is known to be lost through accident or has been listed SUBMISS for a prescribed period, a SUBSUNK report may be issued. In either case the report will be issued by the parent command of the missing submarine by naval message of FLASH precedence. The Navy Department Duty Captain is directed by reference (a) to notify the NAVSEA Headquarters Duty Officer of the situation.

b. "EVENT SUBMISS/SUBSUNK" will also be placed in effect by the Navy Department Duty Captain when U.S. Navy assistance is requested by the U.S. Coast Guard in the event of the loss of a submersible not operated by or under lease to the U.S. Navy. Under the terms of the National Search and Rescue Plan, a federal government interagency agreement, the Coast Guard has authority to call upon the facilities of other signatory agencies for assistance in Search and Rescue (SAR) cases. If so requested, the Navy will respond to the fullest extent possible within its capabilities. A SUBMISS/ SUBSUNK report will be issued by naval message of FLASH precedence. The Navy Department Duty Captain is directed by reference (a) to notify the NAVSEA Headquarters Duty Officer of the situation.

S-144

NAVSEAINST 4740.1A
12 Sep 85

4. Scope

a. This instruction serves to:

(1) Ensure NAVSEA codes who may receive notification of a SUBMISS/ SUBSUNK event alert appropriate personnel.
(2) Designate and assign responsibilities to NAVSEA codes for support of SUBMISS/SUBSUNK events.

b. The provisions of this instruction will cease to apply should the operation become one of a salvage nature. Appropriate salvage instructions will then apply. This could occur should:

(1) The personnel in the submarine escape or be rescued and the submarine or parts thereof remain on the bottom.
(2) The personnel entrapped have perished due to exhaustion of their life support or some other casualty and rescue is no longer possible.

5. Action

a. NAVSEA personnel who receive notification of a SUBMISS/SUBSUNK event shall immediately ensure that the NAVSEA Headquarters Duty Officer (during non-working hours) or the NAVSEA Deputy Commander for Submarines (SEA 92) (during working hours) is notified.
b. When notified that "EVENT SUBMISS/SUBSUNK" has been placed in effect, the NAVSEA Headquarters Duty Officer (during non-working hours) or the NAVSEA Deputy Commander for Submarines (during working hours) shall contact the personnel listed in enclosure (1) in the order listed, and inform them of the situation and any action(s) required of them by enclosure (2).
c. The Deputy Commander for Submarines (SEA 92) shall direct the NAVSEA response to SUBMISS/ SUBSUNK events. The Program Manager, Deep Submergence Systems Program, (PMS395) shall assist SEA 92 and shall act in his absence. Responsibilities are assigned by enclosure (2) to affected NAVSEA codes.
d. The Office of Military Personnel (SEA OOV) shall ensure that a copy to this instruction and reference (a) are readily available to the NAVSEA Headquarters Duty Officer in the standing instructions.

Copy to: (See page 3)

H. L. YOUNG
Vice Commander

NAVSEAINST 4740.1A 12 Sep 85

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SNDL	A1	ASSTSECNAV RES
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	B5	COMDT COGARD
	21A	Fleet Commanders in Chief
	23	Force Commanders
	24G	Submarine Force Commanders
	26VV2	COMSUBGRU REP
	28K1	Submarine Group and Squadron LANT
	28K2	Submarine Group and Squadron PAC
	C84B	NAVMATDATASYSGRU
	FB30	NAVSHIPREPFAC
	FD1	COMNAVOCEANCOM
	FF1	COMNAVDIST WASHINGTON DC
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	E3D3	NAVCOASTSYSCEN
	E3D4	NAVOCEANSYSCEN
	E3D6	DTNSRDC
	E3D9	NUSC
	FKM22	NAVPUBFORMCEN (200 and negatives)
	FKP6D	NAVXDIVINGU
	FKP7	NAVSHIPYD
	FKP8	SUPSHIP[D]
	FT44	NAVDIVESALVTRACEN
	FT88	EDOSCOL
	OOC	(10)
	OOV	(2)
	08	(5)
	92	(5)
	921	(10)
	PDS 350	(2)
	PMS393	(5)
	PMS394	(5)
	PMS395	(5)
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NAVSEAINST 4740.1A 12 Sep 85

NAVSEA SUBMISS/SUBSUNK Notification List

Code	TITLE	OFFICE**
SEA 92	Deputy Commander for Submarines	692-1565
SEA 00	Commander, NAVSEA	692-3381
SEA 08	Deputy Commander for Nuclear Propulsion (IF NUCLEAR SUBMARINE)	692-3887
SEA 09	Vice Commander, NAVSEA	692-3681
PMS395	Program Manager, Deep Submergence Systems Program	692-3421
SEA OOC	Director of Ocean Engineering, Supervisor of Salvage and Diving	697-7386
* PDS 350	Director, Attack Submarine Acquisition Program (SSN 21 Class)	692-7002
* SEA 921	Director, Submarine Logistic Division	692-3405
* PMS393	Program Manager, Attack Submarine Acquisition Program	692-7200
* PMS394	Program Manager, SSN 21 Acquisition Program	692-1888
* DMS396	Program Manager, TRIDENT Submarine Acquisition Program	692-7200
SEA 08	Applicable SEA 08 Project Officer (as determined by PDS 350, SEA 921 or the PMS, as applicable)	
SEA OOD	Director, Congressional/Public Affairs Office	692-6928

* Applicable Ship Logistics Manager (SLM), Program Director (PDS) or Ship Acquisition Project Manager (SHAPM) for particular submarine.

** NAVSEA duty officer has access to all home phone numbers.

Enclosure (1)

NAVSEAINST 4740.1A
12 Sep 85

NAVSEA ACTION TO BE TAKEN IN SUPPORT OF A SUBMISS/SUBSUNK EVENT

1. When notified that "EVENT SUBMISS/SUBSUNK" has been placed in effect, the Duty Officer (during non-working hours) or the Deputy Commander for Submarines (SEA 92) (during working hours) shall:

a. Contact the personnel listed in enclosure (1), in the order listed, either at work or home, using the most expeditious means available.
b. Inform them of the situation and the action(s) required of them as listed herein. (Appendix A hereto provides background information on noncombatant submarines and submersibles.)

2. Upon being notified of "EVENT SUBMISS/SUBSUNK", SEA 92 shall take the following action:

a. Assist the Deputy Chief of Naval Operations (Submarine Warfare)(OP-02) in coordinating CNO's action. A Crisis Action Team or a response cell will have been established in the CNO Crisis Action Center (697-6573, 4, 5) under OP-02 direction.
b. Contact the operational TYCOM to determine what technical assistance can be offered.
c. Establish a continuous watch in SEA 92.
d. Provide advice and direction to the Supervisor of Salvage, the Program Manager, Deep Submergence Systems Program, (PMS395) and the applicable SLM or SHAPM for the particular vessel.
e. Alert the Naval Shipyard Commander nearest the scene.
f. Alert the Supervisor of Shipbuilding, Conversion and Repair, USN nearest the scene.
g. If the submarine is nuclear-powered, coordinate information and action with the Deputy Commander for Nuclear Propulsion (SEA 08).
h. Establish liaison with the Commander, Submarine Development Group ONE.

Enclosure (2)

NAVSEAINST 4740.1A
12 Sep 85

3. Upon being notified of a SUBMISS/SUBSUNK event, PMS395 shall provide advice to SEA 92 on submersibles and rescue matters.
4. Upon being notified of a SUBMISS/SUBSUNK event, the Supervisor of Salvage (SUPSALV) (SEA OOC) shall take the following action:

a. Provide advice to SEA 92 on diving and salvage matters.
b. Make all preparations to deploy the Experimental Diving Unit's emergency diving team.
c. Alert the Navy Diving and Salvage School of the event and possible drawdown of its instructor personnel.
d. Alert SUPSALV Deep Drone contractor and CURV III personnel for possible deployment.
e. Alert the closest emergency ship salvage material base.
f. Alert the appropriate diving contractor.
g. Alert the appropriate salvage contractor.
h. When directed by SEA 92, execute a rescue by salvage.

5. Upon being notified of a SUBMISS/SUBSUNK event, PDS 350 (SSN 21) or the NAVSEA SLM or SHAPM for the particular submarine will take the following action:

a. Provide advice to SEA 92 and to SEA OOC on submarine matters.
b. Alert and coordinate with the SEA 08 Program Officer (if a nuclear submarine is involved).
c. Assemble the applicable following publications for the submarine or submersible as appropriate:

(1) Booklet of General Plans
(2) Training Aid Booklets
(3) Submarine Certification Boundary Book
(4) Damage Control Book

Enclosure (2)

NAVSEAINST 4740.1A
12 Sep 85

(5) Ship Salvage Drawings
(6) Ship Systems Manuals
(7) Steam and Electric Plant Manuals

6. Upon being notified of a SUBMISS/SUBSUNK event, the Public Affairs Office (SEA OOD) shall advise SEA 92 and prepare media notification (via the Navy's Office of Information) about the event, coordinating efforts with SEA 08 when a nuclear powered submarine is involved.

Enclosure (2)

NAVSEAINST 4740.1A
12 Sep 85

BACKGROUND INFORMATION REGARDING NONCOMBATANT SUBMARINES AND SUBMERSIBLES

1. Noncombatant submarines and submersibles are generally designed to perform specific ocean engineering tasks. As a result the size, hull form, and equipment arrangements of such vessels are usually quite different from those of combatant submarines.
2. Noncombatant submarines and Submersibles have the following common characteristics:

a. The life support is short term except for NR-1 and USS DOLPHIN.
b. Hatches are not compatible with the Submarine Rescue Chamber or the Deep Submergence Rescue Vehicle (DSRV) used for submarine rescue.
c. They are generally not designed for escape using buoyant ascent.
d. The most feasible method of saving the lives of the crew is to salvage the vessel.

3. The NAVSEA Deep Submergence Program Office (PMS395) is responsible for the technical and logistic support of noncombatant submarines and submersibles. These include NR-1, USS DOLPHIN, DSV TURTLE, DSV SEA CLIFF, DSRV MYSTIC and DSRV AVALON. PMS395 has detailed knowledge about these submarines/submersibles.
4. DSV ALVIN is operated for the Navy by Woods Hole Oceanographic Institute. SEA 921R has detailed knowledge about this submersible.

Appendix A
Enclosure (2)

Glossary

Buoyancy	The tendency for a vessel to float due to the pressure of the surrounding fluid acting in the opposite direction to the pull of gravity on the vessel's mass. If the weight of the displaced volume of fluid exceeds the weight of the vessel (positive buoyancy), it will float.
Captain of the Port (COTP)	A Coast Guard officer responsible for safety of facilities and operations in a given port under U.S. jurisdiction.
Center of buoyancy	The mathematical center of the volume displaced by a vessel. (Unlike the center of gravity, for center of buoyancy only intact volumes—i.e., the external outline—contribute to the calculation. Internal components such as batteries and motors do not contribute.)
Center of gravity	That point in an object around which its weight is evenly distributed or balanced (i.e., the mathematical summation of the center of weight of every component aboard a vessel).
Certificate of Inspection	(COI) A certificate issued by the U.S. Coast Guard that certifies a vessel has been inspected and satisfies safety requirements for the hull and required onboard operating and safety equipment. A COI for small passenger vessels less than 65 feet long is valid for 3 years. At least two reinspections must be made within the triennial inspection period in order for the COI to remain valid.
Certification	The action the U.S. Coast Guard takes in awarding a vessel a Certificate of Inspection (see COI). It is not a guarantee that the vessel is safe to operate, but simply a recognition that it has passed the Coast Guard's inspection on a given date.
Classification	Various classification agencies worldwide "class" specific vessel designs. Classification means the classification agency states that the vessel complies with its rules for design and construction (which underwriters, in turn, take to mean that the vessel is a good insurance risk).
CO_2 scrubber system	An onboard life support system component that removes ("scrubs") CO_2 to maintain the gas at a safe level in the onboard atmosphere.
Critical dimensional check	A test or inspection of safety-critical dimensions of the structure of a submersible, such as hull roundness or circularity.
Deep submergence rescue vehicle (DSRV)	One of a class of U.S. Navy minisubs (approximately 50 feet in length) whose primary mission is to rescue submariners trapped in their disabled submarine. The maximum diving depth of the DSRV is 5,000 fsw (feet of sea water, rated), or 1,524 meters.
Deep submergence vehicle (DSV)	A small, deep-diving submersible that typically carries a crew of three (no passengers) and is used in support of offshore gas and oil development or for oceanographic research. DSVs have made dives as deep as 35,800 feet, although most operate at depths of 1,200 feet or less.
Drop test (hydrostatic test)	A structural test of a newly constructed submersible, in which the vessel is lowered to its design depth in water to test its physical integrity.
Drop weight system	An onboard safety system that consists of several weights (usually lead or concrete) attached to the exoskeleton, which may be dropped to provide positive buoyancy and rapid ascent in the event of an emergency. They are designed to be released from the inside (and, sometimes, the outside) of the vessel.
Exostructure	The outer shell that surrounds a submersible's MPV and on which are mounted the diving control surfaces, lights, exterior decks, etc.
Factor of safety (f.o.s.)	Factors of safety are utilized by designers to provide safety margins. For submarines, the f.o.s. are usually fixed in terms of maximum operating depth and design depth (e.g., if the usual operating depth is 100 feet, the design depth may be 200 feet, for an f.o.s. of 2:1). In terms of materials, the f.o.s. relate the material's yield strength to the actual or anticipated stress it will bear at the typical operating depth (e.g., an f.o.s. of 2 means that the yield stress is twice the actual stress).
Fault tree analysis	An analytical technique whereby an undesired state of a subject system is specified (usually one that is critical to safety) and the system is then analyzed in the context of its environment and operation to find all credible ways in which the undesired event can occur. The technique relies on a symbolic logic diagram showing the cause-effect relationship between the undesired event and one or more contributing causes.

Ferry	This surface vessel is used to transfer passengers from the shore site to the submersible and from the submersible to the shore.
Hazard analysis	A systematic and comprehensive engineering analysis of the hardware, personnel, operational, and procedural elements of a system such as a submersible, which is intended to identify the sources of hazards, their mechanisms, and their effects.
Life support	A generic term for the functions and systems required to provide for the physical requirements and comfort of the passengers under normal and emergency conditions. On a tourist submersible, life support consists of the breathable air supply (including emergency air) and air filtration and regeneration system, CO_2 monitoring, the fire suppression system, and other emergency equipment such as life preservers.
Main pressure vessel (MPV)	This is the central structural component of a submersible that provides the primary barrier to external water pressure on the hull. Passenger safety depends critically on the integrity of the MPV.
Metacentric height (BG)	An index of intact stability, measured by the vertical separation between the center of gravity and the center of buoyance. For a submersible, positive stability occurs when the center of buoyance is located above the center of gravity. (A separation of [cm] 3-12 inches is the typical range of BG for DSVs and tourist submersibles.)
Officer in Charge of Marine Inspection (OCMI)	A U.S. Coast Guard officer who is responsible for onboard inspection of vessels under U.S. jurisdiction in and near a given port, in accordance with Coast Guard regulations.
Pressure vessels for human occupancy (PVHO)	In engineering terms, a class of tank that will be required to withstand external or internal pressure while manned.
Quarterly control verification exam	For foreign-built vessels only, quarterly control verification exams are conducted jointly by the Coast Guard and the classifying agency. The Coast Guard issues a certificate, CG-4504, "Control Verification for Foreign Vessels," to foreign vessels in compliance with SOLAS regulations.
Rebreather	A device designed for use by one person and intended to provide emergency air supply requirements for passengers aboard a submersible in the event of an emergency (such as fire or failure of the CO_2 scrubber system) that reduces the breathability of the onboard atmosphere.
Safety of Life at Sea (SOLAS) passenger ship safety certificate	An international certificate issued under the SOLAS convention by the government of the nation under whose flag a vessel is sailing. All signatory governments agree that vessels they certificate will be in compliance with the SOLAS regulations governing ship safety. The U.S. Coast Guard makes "control verification" inspections to verify that foreign flag vessels operating in U.S. ports comply with SOLAS regulations. (Only rarely does this apply to tourist submersibles.)

Safety review	A comprehensive review of a system's hardware and operations that is intended to improve the identification, analysis, and elimination or control of hazards. This review is broader in scope than the hazard analysis and includes that analysis as input. It brings the organizational experience to bear on the subject system.
Submersible	Any vessel that operates with its entire hull below the surface of the water. While most are free-swimming, submersibles may also be tethered or on tracks. They may be manned, or unmanned and remotely operated, and (if manned) may or may not require a self-contained air supply.
Surface support safety boat	A small surface craft, sometimes referred to as the "chase boat," which follows the tourist submersible during its dive in order to provide diver support and immediate assistance in the event of an emergency. This vessel also deploys divers, if required, as part of the underwater entertainment program.
Tourist submersible	A manned submarine employed by private companies to carry a crew and passengers on a commercial basis, primarily for recreational and educational purposes. Structurally, they are characterized by large viewing windows, large (relative to DSVs) passenger capacity, and shallow diving depths. Operationally, they are designed to make multiple dives and handle a large number of passengers daily.
Trim	Trim is an inclined attitude taken by a submersible's bow (or stern) when it moves above or below the even keel (level) attitude. A longitudinal separation between the center of gravity and center of buoyancy will cause a submersible to trim about the center of gravity. If the center of gravity is aft of the center of buoyancy, the vessel will trim aft (down by the stern). If the center of gravity is forward of the center of buoyancy, it will trim forward (down by the bow).
Yield stress (strength)	A material's yield stress or yield strength is the maximum stress that can be applied to the material without permanently deforming it or causing it to fail.

Biographies of Committee Members

William M. Nicholson, Chairman, retired as a Captain from the U.S. Navy, where his long career included positions as head of Ship Design Division at the Bureau of Ships, and projects manager for the Deep Submergence System Project, Deep Submergence Rescue Vessel, and Sea Lab. Captain Nicholson also served as Professor of Naval Construction at MIT for three years and was Associate Director of NOAA's National Ocean Survey for nine years upon retiring from active duty. A former Marine Board member (1981-84), Captain Nicholson has served on NRC committees (Committee on Assessment of Arctic Ocean Engineering Support Capability, Committee on Engineering Considerations for Continuation of Deep Sea Drilling for Scientific Purposes, Ocean Science Board study of the UNOLS fleet); is active in the Society of Naval Architects and Marine Engineers, American Society of Naval Engineers, and the Marine Technology Society; and is president of the Air-Sea Symposium, an annual meeting of leaders in ocean engineering. He is a graduate of the U.S. Naval Academy.

Donald L. Caldera is a consultant and former Chairman and Chief Executive Officer of Bermuda Star Line, Inc., a passenger cruise line. Prior to this position, he held senior executive positions with a number of companies, including Midland Enterprises, Inc. (marine transportation, primarily bulk commodities), Interocean Management Corporation (vessel management), Qualpeco Services, Inc. (common carrier trucking leasing firms), Transportation Techniques, Inc. (business consulting), and American Export Industries and Subsidiaries (worldwide shipping and freight forwarding). He received a BS degree from Webb Institute of Naval Architecture and graduated from Yale Law School. Mr. Caldera is a member of the New York and American Bar Associations, the Society of Naval Architects and Marine Engineers, and a number of other professional organizations.

Harry A. Jackson is senior lecturer in naval architecture at the Massachusetts Institute of Technology, and has also been in private practice since 1969 in submarine design. Mr. Jackson has held numerous positions in ship design and construction, including design and contract administration for the Electric Boat Division of General Dynamics Corporation; FBM submarines overhaul and prototype surface ships design for the Puget Sound Naval Shipyard; design of *Thresher* class nuclear, *Barbel* class diesel electric, and *Albacore* submarines for the Portsmouth Naval Shipyard; design for *Polaris* submarines for the Bureau of Ships; technical advisor for nuclear power for submarines and surface ships for the Office of Chief of Naval Operations; and development of *Seawolf* nuclear power plant for General Electric. Recipient of the H.E. Saunders award from the American Society of Naval Engineers, he received his BS in naval architecture and marine engineering from the University of Michigan, and attended the General Electric Company's advanced engineering course in nuclear power.

Colin M. Jones has been a private consulting engineer since his retirement as a Captain in the Navy. During his Navy career he served in various positions (production officer, repair superintendent, production engineer) at the Pearl Harbor Naval Shipyard, where submarine repair and modification are a major component of the yard's operation. Previously, he had been Supervisor of Salvage and Commanding Officer of the Navy Experimental Diving Unit. He was responsible for the Navy oil pollution control efforts in the Gulf of Mexico for the Bay of Campeche oil well blowout, and recently served on the Marine Board Committee on the Effectiveness of Oil Spill Dispersants. Captain Jones received degrees from Duke University (BSEE) and the U.S. Naval Postgraduate School (MSEE), and is a graduate of the Navy School of Diving and Salvage, Navy Saturation Diving and Salvage, and Underwater Swim School.

Joyce A. McDevitt is Executive Scientist at ORI, Inc., where she provides system safety services in the form of policy development, documentation review, reviews and surveys, and training in support of the Naval Air Systems Command, NASA Space Station Program Office, and the National Space Transportation System Safety Risk Assessment Ad Hoc Committee. Her background includes positions as Manager of System Safety at NASA (1979-1981), where her policy development responsibilities included flammability, fracture control, and structural verification issues—areas of interest to submersible safety; and at the Air Force Systems Command and the Naval Ordnance Station. A member of the System Safety Society and American Society of Safety Engineers, she has received several prestigious awards including the NASA Special Service and NASA Exceptional Performance awards. Ms. McDevitt received a B.S. degree in chemical engineering from the University of New Hampshire and an M.S. degree in engineering management from The Catholic University. She is a registered professional engineer in safety engineering in the state of California.

John Bradford Mooney, Jr., retired from the Navy as Rear Admiral in 1987 and is currently President of Harbor Branch Oceanographic Institution and a consultant to universities and industry in ocean engineering and research management. He also is a visiting professor at the University of New Hampshire and a research associate at Texas A&M University. Adm. Mooney's Navy career included six sea and shore commands and diverse assignments, including positions as Chief of Naval Research, Oceanographer of the Navy, Navy Deputy to NOAA, and director of the Navy Oceanography, Meteorology and Hydrographic Survey. Adm. Mooney has extensive experience with submarines and submersibles. He was the Navy's fifth Hydronaut (Deep Submergence Vehicle operation); he piloted the *Trieste II* when it located the sunken submarine *Thresher* on the Atlantic seafloor at 8,200 ft; he coordinated submersible and diving operations over 300 ft in the search and recovery of a hydrogen bomb lost off the coast of Spain in 1966; and he established the Navy's first deep submergence command. A graduate of the U.S. Naval Academy (BS), he has pursued postgraduate studies at George Washington University (management) and at Harvard University's National and International Security Program.

Harold E. Price is Vice President for the Human Factors & Training Group of the Essex Corporation. He has held senior executive positions for Serendipity, Inc., The Matrix Corporation, and Biotechnology, Inc. His career has encompassed the area of human factors and systems analysis in the study of safety, training, and automation issues in such areas as nuclear power plant operations, transportation, and military systems. He received a BSEE degree in electrical engineering from the University of Maryland and continued his postgraduate study in experimental psychology at American University. He is a fellow of the Human Factors Society, a member of the American Nuclear Society, has served on the NRC Committee on Demilitarizing Chemical Munitions and Agents, and participated in the International Joint Commission, Great Lakes Science Advisory Board workshop on man-machine interface.

John A. Renzo is a design specialist in naval architecture and marine engineering at Lockheed Advanced Marine Systems where his primary responsibility is conceptual design of manned submersibles, remotely controlled vehicles, and autonomous test beds. His purview includes launch and recovery systems, weight and balance, and inclining experiments for the U.S. Navy's Deep Submergence Rescue Vessel and *Sea Cliff*. This work builds on earlier experiences with Perry Oceanographics in the areas of hydrostatic and hydrodynamic calculations for manned submersibles and general system testing. His background also includes drydock and ship transfer systems design, stability and loading guidelines, ship conversion and basic hull design for commercial vessels. He has an M.S. degree in ocean engineering from the Stevens Institute of Technology, and a B.S. degree in mechanical engineering from the University of Bridgeport, Connecticut.

Lawrence A. Shumaker is program operations manager for General Offshore Corporation, where he is responsible for the U.S. sonobuoy quality assurance program in the U.S. Virgin Islands. Previously, he was director of the Ocean Sciences Department of Interstate Electronics Corporation where his responsibilities included support of the ocean survey vessel *Antelope*. He has also managed operations and maintenance of an experimental offshore oil production platform; served on the Navy bathyscaph *Trieste*; and supervised final construction of Lockheed's *Deep Quest* submersible (1966-1969), piloted the vessel, and trained other pilots and support crew. He also developed a training program for Lockheed pilots for the Deep Submergence Rescue Vehicle (DSRV) (1969-1973) and managed the Deep Submergence Engineering and Operations Section of Woods Hole Oceanographic Institution, including engineering and operational support of *Alvin/Lulu*. A founding member of the Deep Submersible Pilots Association, he served for two years as its president. He is a graduate of the U.S. Naval Academy (1954) and U.S. Navy Submarine School.

Barrie B. Walden is Manager of Submersible Engineering and Operations and Shipboard Scientific Services at Woods Hole Oceanographic Institution. His research interests are in the areas of manned and unmanned undersea research vehicles and support equipment, scientific saturation diving facilities, and specialized oceanographic research tools and instrumentation. He holds a patent for an underwater torpedo recovery device and has written or co-written numerous articles and reports, including operation manuals for the *Alvin* submersible program and two scientific saturation diving programs. Mr. Walden is a graduate of Florida Atlantic University where he received a BS in ocean engineering, which included extensive work at Rensselaer Polytechnic Institute.

Don Walsh is President and co-founder of International Maritime, Incorporated, a marine consulting company whose services include market analyses, systems design and engineering, resource use planning, environmental research and studies, and marine operations and activities. Prior to entering private practice, Dr. Walsh was Dean of the University of Southern California's Institute for Marine and Coastal Studies and served in the Navy for 23 years achieving the rank of Captain before retiring in 1975. He is a founding member of the Deep Submersible Pilots Association. Dr. Walsh holds a doctorate and master's degree in physical oceanography from Texas A&M University, a master's degree in political science from San Diego State University, and a bachelor's degree in engineering from the U.S. Naval Academy.