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NAVIGATION AND VESSEL INSPECTION CIRCULAR NO. 5-93

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Subj: GUIDANCE FOR CERTIFICATION OF PASSENGER CARRYING SUBMERSIBLES

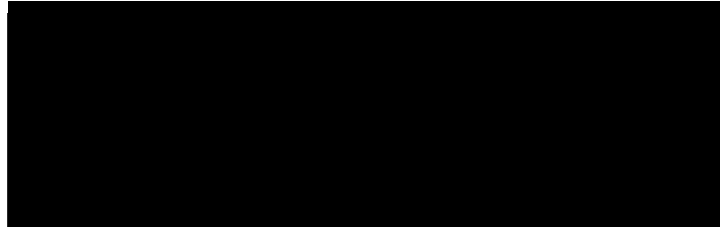
1. PURPOSE. This circular provides guidance for certification of passenger carrying submersibles under Title 46, Code of Federal Regulations, Subchapter T - Small Passenger Vessels (under 100 gross tons) (46 CFR Parts 175-187).
2. DIRECTIVES AFFECTED. None.
3. DISCUSSION.
  - a. Nonmilitary submersibles have been used for several decades in the industrial, experimental and research fields. The first successful commercial passenger carrying submersible was the AUGUSTE PICCARD (Switzerland, 1964-65). The first passenger carrying submersible operation in waters subject to Coast Guard jurisdiction commenced in 1987 at St. Thomas, U.S. Virgin Islands.
  - b. For operations under U.S. jurisdiction, the inspection statutes of U.S. Code Title 46 - Shipping (46 U.S.C.) 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.
  - 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). Design, construction and operation must be accomplished in a safety-conscious manner due to the significantly greater inherent risk to passengers (compared to surface vessels) and the unique nature of the vessels. 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. Note; At the time of writing of this publication, Bill H.R. 1159 was before Congress to require certification of all submersibles carrying one or more passengers for hire.

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- 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, in addition, recreational vessels must carry a Hull Identification Number (HIN). When a submersible is involved in a collision, accident, or casualty, the operator is required to report such occurrences to the appropriate Officer in Charge, Marine Inspection (OCMI) or state authorities, and to render all possible assistance to others involved in such incidents. The regulations contained in 33 CFR 155 (Oil Pollution Prevention Regulations for Vessels) and 33 CFR 159 (Marine Sanitation Devices) also apply to recreational submersibles. Voluntary reports of recreational submersible operations in or near U.S. waters may be made to the nearest Coast Guard Operations Center. These reports are intended for informative use in search and rescue (SAR) activities only. 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.
- e. Enclosure (1) to this circular provides general guidance relative to the inspection and certification requirements for submersibles, primarily those carrying more than six passengers. Enclosure (2) to this circular provides general guidance relative to the stability of the vessel, and enclosures (3) through (5) provide reference information. 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. The Coast Guard has used the results of two recent studies on passenger submersible safety as well as in-house research in developing these guidelines. Together with other recognized standards described or mentioned in enclosure (1), and until new regulations become necessary, this document is considered to be the best available guidance to facilitate this industry while ensuring passenger safety.
- g. For the purposes of this document; submersible, submarine, and sub have no difference in meaning. All three terms are used interchangeably to describe any self-propelled vessel carrying passengers and crew which is designed to operate on the surface, submerge, operate submerged, surface and remain afloat. Internal pressure is normally maintained at or near one atmosphere.

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4. IMPLEMENTATION. Coast Guard plan review, inspection, and certification will 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 to closely follow the guidelines of enclosures (1) through (6).



Rear Admiral, U.S. Coast Guard  
Chief, Office of Marine Safety  
Security and Environmental Protection

- End: (1) Guidance for Certification of Passenger Carrying Submersibles  
(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  
(6) Failure Modes and Effects Analysis (FMEA)

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## GUIDANCE FOR CERTIFICATION OF PASSENGER CARRYING SUBMERSIBLES

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## CHAPTER 1. GENERAL

### A. Background.

1. Introduction. Considerable research and development has 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 (SNAME). The safety of industrial and research submersible operations has been the primary concern of most 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 a few major accidents, resulting in the loss of one life. However, in the early seventies, two separate accidents claimed three more lives, the more well-known being the Johnson Sea-Link entrapment. Therefore, to ensure that an acceptable level of safety was maintained, the Coast Guard proposed legislation to obtain authorization for regulation of nonmilitary 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 questioned. 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, ABS, the Navy, and the Coast Guard gained extensive experience relative to small submersibles, primarily those for research, industrial, and experimental service. Subsequently, 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. In 1990, ABS published the "Rules for Building and Classing Underwater Vehicles, Systems, and Hyperbaric Facilities" which include specific requirements for passenger carrying submersibles.

5. Passenger Submersible History.

- a. In 1964 and 1965, the AUGUSTE PICCARD, a forty passenger submersible, took some 32,000 tourists on over 1100 dives to 300 meters 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 45 meters. 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. MARIEA I, a Panamanian flag submersible, operates in Saipan under Control Verification. More passenger submersible designers, fabricators and operators are moving into this emerging segment of the tourist industry.

B. Applicability.

1. Subchapter T - Small Passenger Vessels.

- 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. Subchapter T is divided into two subcategories: "S" and "L." "S" vessels are not more than 19.8 meters in length. "L" vessels are more than 19.8 meters in length. The length of the pressure hull, not the LOA, is used in determining the applicability of Subchapter S and Subchapter T requirements. To date, all Certificated submersibles have been considered "S" vessels. It is this group of submersibles on which this NVIC focuses. Submersibles to which Subchapter T(L) applies, and all submersibles designed to carry in excess of 49 passengers, will be considered novel and will be reviewed on a case-by-case basis by Commandant (G-MTH-4, see enclosure (4)). Compliance with applicable sections of 46 CFR Subchapter S -Subdivision and Stability, 46 CFR 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 the authority of the Ports and Waterways Safety Act (33 U.S.C. 1221, et. seq.) (PWSA) for port, waterway or vessel safety concerns, or under the Magnuson Act (50 U.S.C. 191, et. seq.) for security concerns. 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 U.S.C. 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 the PWSA or the Magnuson Act described above. 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.

[Note: At the time of writing of this publication, Bill H.R. 1159 was before Congress to require certification of all submersibles carrying one or more passengers for hire.]

3. Subchapter H - 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 U.S.C. 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 be 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. A written operations manual detailing normal and emergency operational procedures should be prepared early in the planning stage and submitted to Commanding Officer, Marine Safety Center (MSC; see enclosure (4)) for review. 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. Definitions.

1. Design Depth - maximum depth for which a system or vehicle is designed.
2. 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. The rated depth may not exceed the design depth
3. Operating Depth - Depth at which the vessel normally operates. The operating depth may not exceed the rated depth of the vessel.

E. 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, see enclosure (4)).

## CHAPTER 2. INSPECTION AND CERTIFICATION

- A. Concept Review. Concept review of submersibles will not be required for vessels which generally comply with the guidelines in this circular. All operations manuals and vessel designs must be approved by the Commanding Officer, MSC (see enclosure (4)). If the vessel incorporates novel features outside the scope of the guidance herein (i.e., if the vessel is in excess of 19.8 meters in length, has a pressure hull of a design other than that permitted by the American Society of Mechanical Engineers (ASME), carries in excess of 49 passengers, engages in operations other than that described in this circular, etc.), the proposal, or portions thereof, will be forwarded by the MSC to Commandant (G-MTH-4) for concept review.
- 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. See enclosure (4).
- C. Plan Review.
1. Detailed plan review will be done by the MSC (see enclosure (4)). 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. If the vessel incorporates novel features, conceptual plan review, as noted in Section 2.A above, may be performed by Commandant (G-MTH4, see enclosure (4)), 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. Both a surface and a submerged inclining experiment will be required. A proposed procedure for these two inclinings must be submitted to G-MSC (see enclosure (4)).
- 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. Therefore, 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 ABS rule 3.19.1 will normally satisfy this requirement.
- i. Power system and battery charging plans.
- j. Control systems plans and layout, including maneuvering, navigation, life support, and communication systems.
- k. Detection systems for hydrogen and chlorine gas generation.
- l. Quality control and testing procedures.
- m. Material identification.
- n. Failure modes and effects analysis. See enclosure (6) for guidance.

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. Coast Guard inspections during construction must be scheduled with the OCMI. Sea trials will be required as part of the initial certification in order to prove all of the vessel's systems. Construction of the vessel should not begin until all required plans have been approved. Owners who choose to build on speculation, prior to plan approval, do so at their own risk.
- 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 in 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. The requirements in 46 CFR Part 176 concerning periodic inspection for certification and reinspection apply. Except as may be allowed by the OCMI, a Coast Guard inspector must 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 Sections 7, 12 and 13 (Surveys after Construction) of the ABS Rules, in particular rule 13.17 through 13.21;
  2. Normally witness a test dive (see ABS rule 3.13) to the design depth (maximum depth for which a system or vehicle is designed) during which all systems are to be operationally tested [Note: If the sub is tested to a depth less than the design depth, the rated depth of the sub will be limited accordingly.];
  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; and
  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 manual. The requirements of section 12 of the ABS Rules shall also be considered.
- G. Reinspection. Reinspections will be conducted annually as required by 46 CFR Subchapter T and guided by ABS rule 13.17 through 13.21. 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. (The maximum depth reached during a manned test dive witnessed by an inspector or an ABS surveyor, as may be accepted by the OCMI. The rated depth may not exceed the design depth.)
5. Pilot evaluation.

H. Drydocking or Hauling Out.

1. Submersibles shall be drydocked or hauled-out at intervals not to exceed 18 months. The periodic examination requirements specified in 46 CFR 197.462 for commercial diving equipment and Section 13 of the ABS Rules, Surveys after Construction, should be used as a guide during drydock examinations. Attention is called to the need to check dimensional tolerances and is described in further detail in ABS rules 13.19.2.f. and section 5. 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<sub>2</sub> bottles, hydraulic and electrical systems must be given special attention. Additionally, care should be taken to determine if the pressure hull has sustained any damage which will require repair. External stiffeners and hull penetrations shall be checked carefully for evidence of fatigue cracking. 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. Viewports have a limited number of dive cycles before fatigue failure becomes a concern. The ASME PVHO-1 Code limits viewports to 10,000 pressure cycles or a design life of 10 or 20 years (depending on the type of loading) after the date of manufacture, whichever comes first. Alternatively, the operator may implement a testing program in accordance with the PVHO-1 code to empirically prove the cycle life of the viewport design over 101000 cycles. Each dive imparts some deformation to the hull and viewports. Therefore, each dive must be recorded as one pressure cycle, or 10,000 dives are equal to 10,000 pressure cycles. Operators wishing to extend the cycle life of their viewports through testing must contact Commandant (G-MTH-2, see enclosure (4)) for approval of the testing procedures. In any case, viewports must be replaced at the end of their design life. The design life is the lesser of the PVHO-1 Code requirement or the manufacturer's recommendation. Viewports should be visually inspected by the operator daily for evidence of failure. The window (the acrylic inside the viewport frame) supplier must identify the window in accordance with the PVHO Code. The owner is responsible for tracking each viewport's pressure cycles and time in service. See section 2.1 below regarding replacement or repair 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 MSC (see enclosure (4)).

2. Until evidence is presented to the contrary, viewports exhibiting crazing, cracking, or permanent visible deformation are considered failed, and will be cause for their immediate replacement. All viewport failures must be reported to the local OCMI and Commandant (G-MTH-4, see enclosure (4)).
3. Notification of any casualty must be given to the nearest OCMI, in accordance with 46 CFR 4.05. Because of the unique nature of submersibles, the definition of seaworthiness includes, but is not limited to: increase in CO, CO<sub>2</sub> or H<sub>2</sub> beyond the design 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 without external assistance. Backups of systems and equipment are 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. On surface vessels we consider that most failure scenarios occur with a single casualty. However, because of the unique operating conditions under which a submersible operates, some safety equipment and measures have been required based on the assumption that more than one failure may occur in a single incident. Similarly, other equipment has been required to preserve habitability in the event the submersible cannot surface.
2. Positive buoyancy in all operating modes is required 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. This may not exceed the design depth.) 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 operations manual.

### 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). A hull structure designed, fabricated, and inspected to the standards of the ABS Rules for Underwater Vehicles Systems, and Hyperbaric Facilities, is considered to provide an equivalent level of safety to ASME PVHO-1. A proposal to use other established standards for underwater vehicles may be submitted to Commandant (G-MTH-4, see enclosure (4)) for consideration. The standard used and the pertinent design parameters, such as design depth (maximum depth equivalent to the maximum pressure to which the vessel is designed) and structural safety factor, must be identified in the plan submittal. If the design deviates from the written standards in any manner, this must be approved by the Commandant prior to sending the plans to the MSC for plan review.
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 must be carefully designed as 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 provided.

3. Viewports. The only recognized standard for acrylic viewports is ASME PVHO-1. The viewports must be adequately protected, e.g., protective covers or guards on 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 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.
  5. Material. If material other than that specified in PVHO1 will be used in construction of the pressure vessel, early discussions with Commandant (G-MTH-4, see enclosure (4)) will be necessary. Fatigue testing will be required. Additional testing, the extent of which will be dependent on the material to be used, may also be required.
- C. Subdivision and Stability.
1. Subdivision. Subdivision is not normally required for vessels that carry 49 passengers or less and whose pressure hulls are less than 19.8 meters in length when operating in protected waters with sufficient surface support to prevent collisions. Vessels that will carry more than 49 passengers will be addressed by Commandant (G-MTH-4, see enclosure (4)) on a case-by-case basis.
  2. Stability. See enclosure (2) for 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)), except that for the ASTM E662 the value of  $D_s$  must not exceed 100, and that the critical radiant flux (CRF) for floor coverings must not be less than  $0.8 \text{ W/cm}^2$

- 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) Flammable 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 Underwriters Laboratory (UL) 67, panelboards, and UL 50, cabinets and boxes. Glass reinforced and thermoformed plastics will not meet these requirements. However, the use of these 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. Sufficient means of separation (e.g., a partition) between the control area and the passenger area to prevent passengers from interfering with operator performance should be provided. Arrangements must be satisfactory to the cognizant OCMI.
- 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 noncombustible material.

- c. Access to escape hatches must be unimpeded.
- d. Aisle width and headroom should be adequate for average sized persons standing upright, subject to the OCMI's approval.

F. Rails and Guards.

- 1. Studies have indicated that the most dangerous activity during normal operations of the submersible is the transfer of passengers between the submarine and the ferry boat. Rails as required by 46 CFR 177.35-1(h) must be installed on the deck perimeter for passenger and crew safety. Alternate arrangements must be to the satisfaction of the cognizant OCMI.
- 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. The arrangement must be to the satisfaction of the cognizant OCMI.

## CHAPTER 4. LIFESAVING EQUIPMENT

- A. Life Preservers. Coast Guard approved personal flotation devices, PFDs, will be required for everyone on board, including appropriate sizes for children. Type I PFDs may not be appropriate when the only escape routes are through small vertical hatches. Therefore, their use shall be subject to the approval of the cognizant OCMI. Use of approved inflatable PFDs is appropriate and encouraged on submersibles. PFDs must be stowed on board. However, due to the apparent lack of a significant supply of Coast Guard approved inflatable PFDs and subject to the OCMI's acceptance, similar FAA approved (meeting TSO-C13) inflatable PFDs may be used until adequate supplies of Coast Guard approved devices are available. Use of the FAA approved devices requires they be serviced at least annually and be maintained to the satisfaction of the OCMI.
- 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 liferafts, lifefloats and buoyant apparatus. Alternatives to on-board stowage, such as stowage on the surface support craft, must be addressed in the operations manual and are subject to the OCMI's approval.
- 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, unless the operations manual requires that PFDs be worn during these situations. Stowage arrangements must be addressed in the operations manual and are subject to the OCMI's approval.
- 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 signaling the surface support craft; the signaling method must not be incapacitated by loss of primary power. The surface craft must have VHF capability to relay distress information to search and rescue (SAR) stations and other rescue resources. If the submersible is capable of performing night dives, the means of signaling the surface craft must be visible at night.
- E. Emergency Position Indicating Radio Beacons (EPIRBs). Since 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 same contents as the approved kits will also be satisfactory.
- G. Individual Emergency Breathing Apparatus.
  - 1. Emergency life support shall be provided in the case of failure of primary systems. Compliance with ABS rule 8.21 or an equivalent arrangement will be accepted such as redundant breathing gas supply and CO<sub>2</sub> 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.

2. Gas masks, self contained breathing apparatuses (SCBAs), and supplied-air respirators for use on Coast Guard certificated vessels must meet the standards of the Mine Safety and Health Administration (30 CFR Part 11). The equipment's performance must be certified by the National Institute of Occupational Safety and Health, Department of Health and Human Services, or a Nationally Recognized Testing Laboratory such as Underwriters Laboratories, the Canadian Standards Association, or Factory Mutual Research Corporation. The Coast Guard will accept SCBAs that are properly certified for a service time (as defined in 30 CFR 11) of at least 1 hour, provided that:
  - a. All passengers can be sufficiently indoctrinated in the use of the equipment with a simple oral briefing (i.e., actual donning of the apparatus is not necessary for familiarization).
  - b. The device can be used by all passengers and crew on board (i.e., adults, children, those with facial hair, etc.) without presenting the face-fit problems inherent with full face masks.

## CHAPTER 5. FIRE PROTECTION EQUIPMENT

### A. General.

1. The operations manual should contain procedures for fire fighting. Fires will most likely 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 prohibited in the submersible. Flammable materials, particularly lighters and similar items, are not permitted. Passengers must be informed of such restrictions.
3. All certificated submersibles thus far have fixed Halon 1301 systems. While not specifically required by Subchapter T, the presence of such Coast Guard-approved fixed systems is encouraged. The presence of acceptable portable extinguishers is still required.
4. Due to environmental concerns, the International Maritime organization (IMO) has made the determination that there is no use of halon that is considered essential. Effective October 1, 1994, new halon installations aboard SOLAS certificated vessels will be prohibited. Since the production of halons is scheduled to be reduced to 50% of the 1990 level by 1994 and stopped prior to 2000, commercial conditions would most likely govern the phasing out of existing halon installations, thereby possibly making the purchase of halon extremely expensive. IMO is also considering setting a target date for the removal of all existing halon installations from ships. Future domestic requirements could result in prohibition of the use of halon aboard U.S. vessels not engaged in international trade.

### B. Fire Pump/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 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. Fixed Halon systems must be designed using the guidance provided in NVIC 6-72 change 1.

### D. Portable Fire Extinguishers. At least two approved portable extinguishers must be provided and be easily accessible. Halon 1301 and 1211 portable units are acceptable. If halon portable units are installed, they shall be Coast Guard approved and meet the minimum confined space criteria on the device's label (see UL 1093). The size of the units must be based on the requirements for Subchapter T. However, in the accommodation areas, consideration may be made to replace a B-II extinguisher with two B-I extinguishers if the configuration of the space is such that larger units would not be appropriate. The smaller units are not as effective as the larger ones, but the maneuverability for actually fighting the fire will outweigh this. If a fixed fire suppression system is installed, only two B-I extinguishers need be installed, one forward and one aft, which are easily accessible by a crew member. Consideration should be given to the concentration of halon inside the submersible should both the portable extinguishers and fixed halon system be discharged. CO<sub>2</sub> is not acceptable because it is asphyxiating in enclosed spaces. Dry chemical extinguishers may not be the best choice of portable units if a substantial portion of the vessel's electrical installation is behind interior panels.

### 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 by a nationally

recognized testing laboratory (NRTL) acceptable to the Commandant. If a detection system is installed, the components must be so listed and the system arrangement plan must be approved by the Coast Guard's Marine Safety Center. For testing laboratories acceptable to the Coast Guard see NVIC 2-89, Guide for Electrical Installations On Merchant Vessels and Mobile Offshore Drilling Units. 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 be Department of Transportation (DOT) approved (46 CFR 147.04). DOT cylinders that have been modified 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. Life Support Systems.
1. General. The standards discussed in section 8 of ABS Rules regarding oxygen supply CO 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. Proposals for use of standards other than those in the ABS Rules must be submitted to Commandant (G-MTH) for evaluation.
  2. Oxygen. The O<sub>2</sub> system should be designed to maintain the O<sub>2</sub> content at about 21 percent by volume. The O<sub>2</sub> content should not exceed 22 percent by volume, nor should it fall below 19.8 percent. The system must be adequately monitored.
  3. CO<sub>2</sub> Removal. The CO removal system must be capable of maintaining the CO<sub>2</sub> concentration at or below 0.5 percent by volume. This system must be adequately monitored.
  4. Tests. An initial test of the CO removal system and the oxygen system should be conducted with the full passenger and crew load on board. The equilibrium point of CO<sub>2</sub> concentration, once achieved, should be maintained for a period equal to the longest anticipated dive or one hour, whichever is longer. If the CO<sub>2</sub> concentration exceeds 0.5 percent by volume or equilibrium cannot be maintained during this period, the system is not acceptable. The O<sub>2</sub> supply and CO<sub>2</sub> 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. In general, the electrical systems must meet the requirements of 46 CFR Subchapter T, Part 183 and Subchapter J - Electrical Engineering, Parts 110 - 113 as appropriate depending on whether the vessel will be certificated as a Subchapter T or Subchapter H vessel. System redundancy must be considered and addressed.
- B. Cable. All cable, on the low pressure side, of the hull, must meet one of the following fire test standards: IEEE VW-1, IEEE 1202, or IEC 332-3 Category A. The fire test standard used to qualify the cable must be identified. In addition, because of the confined area of the submersible, any amount of smoke may be extremely asphyxiating, irritating to the eyes, and could cause panic or disorientation among the passengers. For this reason, all power and lighting cable must be low smoke, low/zero halogen cables. Types LSX or LSE cable manufactured to IEEE Standard 45 (Draft, October 20, 1992), meeting the appropriate flame tests are acceptable. All enclosures of cable, on the high pressure side, must be Nation Electrical Manufacturers Association (NEMA) rated 70 or greater, or equivalent. Signal and communication cables must meet the requirements of 46 CFR 111.60.

[Note: Limited runs of water-blocked submarine cable connecting external electrical equipment to internal junction boxes or power supplies may be acceptable, and will be reviewed on a case by case basis by the Marine Safety Center.]

- 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 low potential on the emergency batteries
- D. Batteries and Battery Charging.
1. All 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 made gas tight 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, and no passengers are on board. 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. There should be a manual means of operating this system, and there must be a means of externally bringing the sub to the surface. 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. The drop weights should be released with the submersible at several angles of inclination, both forward aft, and athwartship. 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 override.
- D. Communications. Communications systems for both submerged and surface modes must be provided. The system for submerged 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. A surface support craft is required to be in the vicinity of the submersible at all times. 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. The requirements of ABS Rules, section 12, shall also be considered.
2. Submersibles will be restricted to operations in waters no deeper than the rated depth of the vessel. When approving the dive site, the OCMI should take into account the slope of the bottom in proximity to deep water to ensure that if the vessel veers off course in an emergency situation, it will not be stranded on the bottom in water deeper than its rated depth, or depth to which its rescue assistance is effective (45 meters in the case of no-decompression diving).
3. Certification will be for a specified dive location. Operations in other locations will not be permitted without specific Coast Guard approval. Early in the planning stage, all aspects of the intended operations must be discussed with the cognizant OCMI and Captain of the Port (COTP) for the proposed operating area. The written operations manual would be useful as a basis for that discussion.

### B. Failure of Vital Systems. 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 vital system fails during operations.

### C. Dive Site. The OCMI must 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 (rated depth); the dive site may not be any deeper than the maximum depth for which the vessel is certificated.

### D. Operations Manual.

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. The operations manual should also 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. 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. In the planning stages and during review, a draft operations manual is acceptable. Ultimately, the manual must be finalized and approved by the cognizant OCMI. Changes may be made, subject to approval of the OCMI.

2. The operations manual 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 of passengers (surface vessels carrying more than six passengers to and from the submersible are also subject to Coast Guard inspection) and embarkation and debarkation of passengers;
  - 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; and
  - e. The minimum amounts of air, oxygen, and battery power (coulombs) 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.

E. 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, salvage bags, 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 may require decompression treatment, special training and/or the use of special equipment, particularly when provided at depths exceeding 40 meters. If the operation depends at least in part on the availability of SCUBA diver assistance, it must be done within normal, no-decompression limits unless appropriate personnel and equipment are immediately available on scene (see 46 CFR 197 for guidance in this regard). The no-decompression limits used by the U.S. Navy are the recommended standard and they limit the maximum depth to 58 meters, and further limit bottom time at depths of 45 meters or greater to a maximum of five minutes (bottom time commences with the diver entering the water and stops when the ascent begins; repetitive dives within the preceding 12 hours will

further limit an individual's tolerance within these limits). Remotely operated vehicles (ROVs) may be considered in lieu of divers. However, performance of all required functions must be demonstrated at the intended rated depth to the satisfaction of the OCMI.

3. Because of the potential for apparently minor situations to escalate, all emergencies must be immediately reported by radio to the appropriate Coast Guard Rescue Coordination Center (RCC). The rescue information contained in the operations manual must also be communicated to the Coast Guard station having Search and Rescue (SAR) responsibility for the operating area.
  4. Although the Coast Guard has statutory 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.
- F. 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 or developed as a separate maintenance manual. 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.
- G. Navigation Rules. The navigation rules in Commandant Instruction (COMDTINST) M16672.2B (Rules of the Road) apply to all the submersible's support vessels and to the submersible when on the surface. However, the use of the intermittent flashing amber (yellow) light allowed for use on submarines is not applicable to the vessels discussed in this document.

## CHAPTER 10. MANNING AND LICENSING

- A. General. Coast Guard regulations do not currently address licensing and manning requirements for submersibles.
- B. Submersible Personnel Training and qualification Requirements. A manning and licensing proposal must be submitted to Commandant (G-MVP), via the cognizant OCMI (see enclosure (4)). 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, the total marine system supporting the vessel, and passenger management. The licensed individuals as well as any unlicensed crew would be required to complete a comprehensive course prescribed by the vessel manufacturer. This proposal should also include any certification, training, and operational requirements which were imposed by the flag-state administration if the vessel is registered in another country.
1. The Coast Guard does not currently provide formal approval of training courses for submersible operators. The OCMI's prior review and acceptance of a training course's level of proficiency is appropriate; an inspector may be assigned to participate in or monitor such a course to evaluate its effectiveness. The following instruction schedule has been found acceptable (although the OCMI's discretion in this regard is not limited):
    - a. Classroom Instruction. 40 hours;
    - b. Supervised Vessel Operation. 15 hours;
    - c. Unsupervised Vessel Operation. 5 hours; and
    - d. Route Training. 5 hours.
  2. Individuals serving as master or mate on inspected submersibles, or as operator of uninspected passenger vessels (OUPV) will be required to possess the appropriate license.
    - a. The license must authorize service on passenger-carrying vessels of similar gross tonnage and route.
    - b. The license must contain an endorsement for the particular 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 accepted 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, embarkation and debarkation of passengers, passenger management, 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 review of the vessel's operations and technical manuals.

3. Sample Scales.

a. Crew General Operation.

\*1-Master, or OUPV

\*1-Mate

\*Additional Deckhands based on the number of passengers aboard or service requirements.

\* **Denotes Variables**

- b. Variables. At least two licensed individuals should be provided to ensure the vessel can be safely operated under all conditions. This ensures that at least one other person is capable of taking control of the vessel's navigation should the pilot become incapacitated, and also provides another individual for assisting and directing the passengers and required crew in the event of an emergency.

## 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 U.S.C. 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 U.S.C. 3303(a)] provides that foreign vessels 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 vessels' propulsion equipment and lifesaving equipment are as stated in their current certificates 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. SOLAS Regulations. The SOLAS regulations, like U.S. regulations, were written primarily with surface craft in mind. Given that these vessels embody features of a novel kind, flag administration exemptions from specific SOLAS regulations can be anticipated. Any exemptions issued by the flag administration must be acceptable to the Coast Guard prior to the vessel's operation in the U.S. Plan review and examination of the vessel will be conducted to verify that the certificate issued is valid. 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 SOLAS, and have a 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 the MSC (see enclosure (4)) when addressing the standards applied (section B.2 above) and the exemptions for which approval is being sought. Control verification examinations 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 conduct overseas inspection of foreign flag vessels in accordance with 3317(b) of Title 46 U.S. Code which requires the owner or operator of a foreign vessel, who requests an examination at a foreign port, to reimburse the Coast Guard for travel and subsistence expenses incurred.
- D. Operations Manual. An operations manual, 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. In addition, the submersible should be manned according to the guidance provided in the Marine Safety Manual Volume III, Marine Industry Personnel (COMDTINST M16000.8).

## Guidelines for the Stability of Small Passenger Submersibles

1. Introduction. 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.
2. Basic Principles of Submersible Stability
  - a. 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.
  - b. 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>B</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.
<b>G</b>	The center of gravity of the vessel's weight, as loaded.
<b>K</b>	The baseline.
<b>M</b>	The metacenter. It is the point about which <b>B</b> rotates for very small angles of inclination.
<b>Z</b>	For a vessel on the surface; the intersection of the vertical line through <b>M</b> , and the horizontal line through <b>G</b> . For a submerged craft, the intersection of the vertical line through <b>B</b> and the horizontal line through <b>G</b> .
<b>KB</b>	The distance between <b>K</b> and <b>B</b> . Positive when <b>B</b> is above <b>K</b> .
<b>KG</b>	The distance between <b>K</b> and <b>G</b> . Positive when <b>G</b> is above <b>K</b> .
<b>KM</b>	The distance between <b>K</b> and <b>M</b> . Positive when <b>N</b> is above <b>K</b> .
<b>GB</b>	The distance between <b>G</b> and <b>B</b> . Positive when <b>B</b> is above <b>G</b> .
<b>GM</b>	The distance between <b>G</b> and <b>N</b> . Positive when <b>N</b> is above <b>G</b> .

**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**.

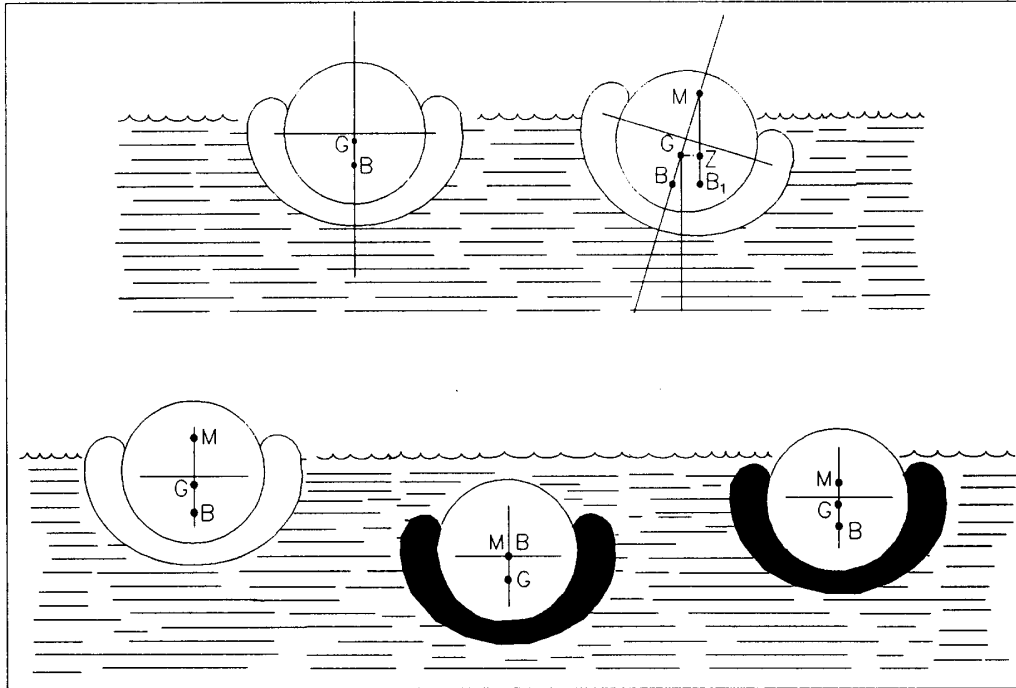


Figure 1 - Basic Geometry

- c. 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.
  - \*** The displacement. This is the weight of water displaced by an object.
- d. 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.
- e. 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.

- f. 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**.
- g. 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,  $GZ = GB \sin\theta$ , where  $\theta$  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.

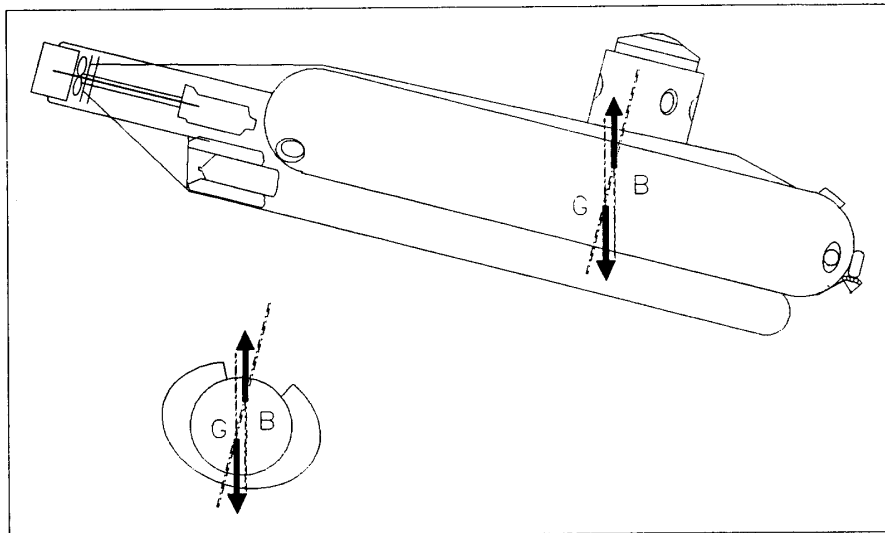


Figure 2 - Restoring Moment

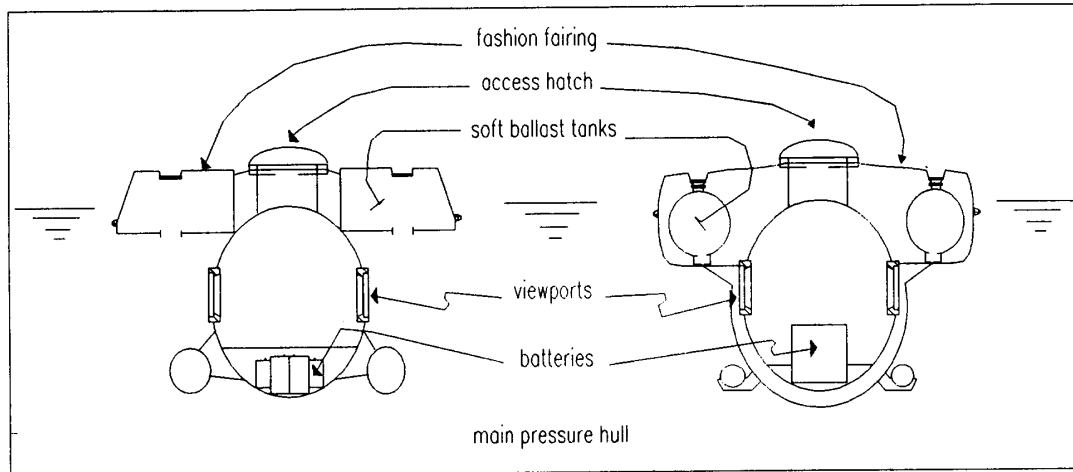
- h. In the parlance of naval architecture, "weight" and "displacement" are often interchanged. More correctly, however, "weight" refers to the weight of an object, while "displacement" is the weight of water displaced by the object. It is natural to interchange the two for an object floating on the 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.
3. Hazards.

- a. 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 a simplified stability test is appropriate.
- b. 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 test measures the GB. The vessel's stability is also influenced by the weight of the submersible.
- c. Also while on the surface, the hatch or hatch coming must be high enough to prevent being overtopped by 1.2 meter waves, and the embarkation deck must be high enough to be reasonably dry for embarking passengers. Vessel hull and appendage configurations or shapes are important in helping keep the deck dry by deflecting waves. This can be observed during operational tests.

4. Assumptions.

- a. The submersible shown in Figure 2 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:
  - (1) the submersible is less than 100 gross tons;
  - (2) it is less than 19.8 meters LPH (Length of Pressure Hull);
  - (3) it carries 49 or fewer passengers;
  - (4) the submersible will be operating on a route for which the surface test was performed;
  - (5) the access hatches are on the top centerline, with a diameter not greater than one-half the main hull diameter;
  - (6) there is no diver lockout; and
  - (7) GB is positive at all 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.
- b. "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.
- c. 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.



**Figure 3 - Midship Sections**

5. Stability Review Procedure. There are several elements to a stability review for a submersible:
- a. A spreadsheet calculation of weight and displacement;
  - b. A spreadsheet calculation of loading during emergency ascent verifying GB actual is greater than  $GB_{min}$ ;
  - c. A deadweight survey;
  - d. A submerged inclining test;
  - e. A simplified stability test on the surface; and
  - f. Some operational tests.

Each of these are discussed below in detail.

6. Spreadsheet Calculations

- a. 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 has to take on extra ballast or use propulsors to maintain neutral buoyancy. All certificated passenger submersibles are required to maintain a condition of positive buoyancy and use their propulsors to maintain their depth during operations. Thus, submersible designers must keep very detailed spreadsheets (see Figures 4a and 4b) 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 I

available. Since they are the foundation of all subsequent calculations, the designer's spreadsheets must be constructed and reviewed with care.

- b. 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 test, 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.
- c. 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 method). The weight and displacement of the ballast water in the soft tanks can have a significant effect on any calculations that involve W or  $\Delta$ . W should not include the weight of water in soft tanks, and  $\Delta$  should not 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.
- d. The spreadsheet should be submitted several weeks before the inclining test 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.

## 7. Deadweight Survey.

- a. The deadweight survey is really the first step in the inclining test, 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.
- b. 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.
- c. 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.

WEIGHTS							
Description	Weight  W (kg)	Position			Moment		
		X (m)	Y (m)	Z (m)	W * X (kg-m)	W * Y (kg-m)	W * Z (kg-m)
MAIN HULL							
Main Hull - Less Cutouts	26848.00	49.72	10.00	10.00	1334882.56	268480.00	268480.00
Fwd Sphere - Less Cutouts	1688.00	27.50	10.00	10.00	46420.00	16880.00	16880.00
Aft Sphere - Less Cutouts	1609.00	73.00	10.00	10.00	117457.00	16090.00	16090.00
HATCHES							
Fwd Hatch Nozzle	845.00	33.75	14.20	10.00	28518.75	11999.00	8450.00
Fwd Hatch	355.00	33.75	15.25	10.00	11981.25	5413.75	3550.00
Fwd Hatch Dogging Assy	64.00	33.75	14.70	10.00	2160.00	940.80	640.00
Fwd Hatch Hinge Assy	90.00	36.00	14.75	10.00	3240.00	1327.50	900.00
Main Hatch Nozzle	845.00	63.25	14.20	10.00	53466.00	11999.00	8450.00
Main Hatch	355.00	63.25	15.25	10.00	22453.75	5413.75	3550.00
Main Hatch Dogging Assy	64.00	63.25	14.70	10.00	4048.00	940.80	640.00
Main Hatch Hinge Assy	90.00	65.50	14.75	10.00	5895.00	1327.50	900.00
HULL STIFFENING RINGS							
Ring #1 (Lift & Skid)	1107.43	28.52	9.87	10.00	31583.90	10930.33	11074.30
Ring #2 (Lift & Skid)	703.20	30.17	11.19	10.00	21215.54	7868.81	7032.00
Ring #3	263.28	33.00	10.61	10.00	8688.24	2793.40	2632.80
Ring #4	640.66	35.83	8.69	10.00	22954.85	5567.34	6406.60
Ring #5	309.72	38.67	10.77	10.00	11976.87	3335.68	3097.20
Ring #6 (Skid)	292.21	41.50	10.64	10.00	12126.72	3109.11	2922.10
Ring #7	640.66	44.33	8.69	10.00	28400.46	5567.34	6406.60
Ring #8	309.72	47.17	10.77	10.00	14609.49	3335.68	3097.20
Ring #9 (Center)	267.04	50.00	10.78	10.00	13352.00	2878.69	2670.40
Ring #10	640.66	52.83	8.69	10.00	33846.07	5567.34	6406.60
Ring #11 (Skid)	309.72	55.66	10.77	10.00	17239.02	3335.68	3097.20
Ring #12	309.72	58.50	10.77	10.00	18118.62	3335.68	3097.20
Ring #13	640.66	61.33	8.69	10.00	39291.68	5567.34	6406.20
Ring #14	263.28	64.17	10.00	10.00	16894.68	2632.80	2632.80
Ring #15 (Lift & Skid)	703.20	67.00	10.61	10.00	47114.40	7460.95	7032.00
Ring #16 (Lift & Skid)	1107.43	69.83	9.87	10.00	77331.84	10930.33	11074.30
PAGE TOTAL	41361.59				2045246.93	425028.61	413615.90
CENTER OF BUOY. / DISP.		49.45	10.28	10.00			

Figure 4a - Sample Spreadsheet Weight Calculations

DISPLACEMENTS								
Description	Displacm't D (kg)	Position			Moment			
		X (m)	Y (m)	Z (m)	D * X (kg-m)	D * Y (kg-m)	D * Z (kg-m)	
MAIN HULL Main Hull - Less Cutouts Fwd Sphere - Less Cutouts Aft Sphere - Less Cutouts	109727.00 5721.00 6070.00	47.92 27.25 73.00	10.00 10.00 10.00	10.00 10.00 10.00	5455626.44 155897.25 443110.00	1097270.00 57210.00 60700.00	1097270.00 57210.00 60700.00	
HATCHES Fwd Hatch Nozzle Fwd Hatch Fwd Hatch Dogging Assy Fwd Hatch Hinge Assy Main Hatch Nozzle Main Hatch Main Hatch Dogging Assy Main Hatch Hinge Assy	1108.00 206.00 0.00 11.50 1108.00 206.00 0.00 11.50	33.75 33.75 33.75 36.00 63.25 63.25 63.25 65.50	14.20 15.25 0.00 14.75 14.20 15.25 0.00 14.75	10.00 10.00 0.00 10.00 10.00 10.00 0.00 10.00	37395.00 6952.50 0.00 414.00 70081.00 13029.50 0.00 753.25	15733.60 3141.50 0.00 169.63 15733.60 3141.50 0.00 169.63	11080.00 2060.00 0.00 115.00 11080.00 2060.00 0.00 115.00	
HULL STIFFENING RINGS Ring #1 (Lift & Skid) Ring #2 (Lift & Skid) Ring #3 Ring #4 Ring #5 Ring #6 (Skid) Ring #7 Ring #8 Ring #9 (Center) Ring #10 Ring #11 (Skid) Ring #12 Ring #13 Ring #14 Ring #15 (Lift & Skid) Ring #16 (Lift & Skid)	143.97 91.42 34.23 83.29 40.26 37.99 83.29 40.26 34.72 83.29 40.26 40.26 83.29 34.23 91.42 143.97	28.52 30.17 33.00 35.83 38.67 41.50 44.33 47.17 50.00 52.83 55.66 58.50 61.33 64.17 67.00 69.83	9.87 11.19 10.61 8.69 10.77 10.64 8.69 10.77 10.78 8.69 10.77 10.77 8.69 10.00 9.87	10.00 10.00 10.00 10.00 10.00 10.00 10.00 10.00 10.00 10.00 10.00 10.00 10.00 10.00 10.00	4105.91 2758.02 1129.47 2984.13 1556.99 1576.47 3692.06 1899.23 1735.76 4399.99 2241.07 2355.42 5107.92 2196.31 6124.87 10053.14	1420.94 1022.95 363.14 723.75 433.64 404.18 723.75 433.64 374.23 723.75 433.64 433.64 723.75 342.26 969.92 1420.94	1439.66 914.16 342.26 832.86 402.64 379.87 832.86 402.64 347.15 832.86 402.64 402.64 832.86 342.26 914.16 1439.66	
PAGE TOTAL	125275.12				6237175.71	1264217.60	1252751.17	
CENTER OF BUOY. / DISP.		49.79	10.09	10.00				

Figure 4b - Sample Spreadsheet Displacement Calculations

- d. It is reasonable that there be provisions for both truly fixed ballast and moveable, variable solid ballast. For example, if the submersible needs 1000 kilograms of ballast to submerge with minimum payload, it can be expected that something like 800 kilograms will be bolted to the skids. This is truly fixed and is expected to stay there forever. The other 200 kilograms 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.
- e. 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; e.g., "10 batteries @ 100 kilograms = 1000 kilograms." This is much easier to account for than "Batteries --- 1000 kilograms."
- f. 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.

8. Submerged Inclining Test.

- a. American Society of Testing and Materials (ASTM) F 1321-90 has been published as a "Standard Guide for Conducting a Stability Test." It is the basis for this section, and it must be well understood. This section does not replace ASTM F 1321-90, but adds information that was not contemplated when ASTM F 1321-90 was written.
- b. 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.
- c. The submersible must be inclined while submerged to determine the actual GB. Under full load conditions the distance GB 1 determined by the inclining test must be not less than the minimum GB determined by the following formula:

$$GB_{\min} = nwNd I W \tan \theta$$

where **n** = 0.1 (This represents 10% of the passengers all moving at one time.)

**w** = 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.

$\theta = 250$  (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.)

- d. 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.

- e. Recall from ASTM F 1321-90 that an inclining test measures the relationship:

$$wd / \tan \theta$$

where **w** is the inclining weight

**d** is the distance the inclining weight moves

$\theta$  is the inclined angle (trim angle, here)

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

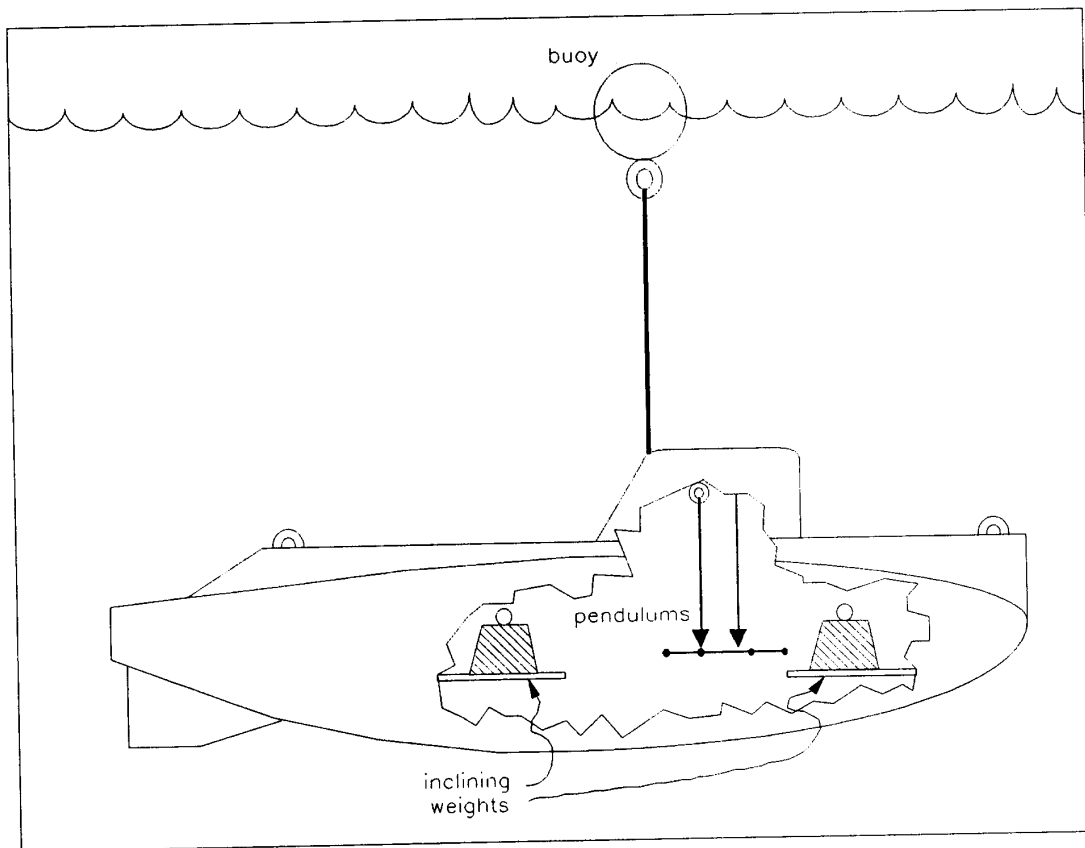
$$GB_{\text{actual}} = wd / W \tan \theta$$

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

- h. The following are some special procedures that will help obtain valid results from the inclining test.

- (1) In order to maintain its depth during the inclining test, the submersible should be suspended from a small buoy. See Figure 5. The buoy should displace 30-50 kilograms. It should be attached near the submersible's longitudinal center of buoyancy by a line 9-15 meters long. The submersible should be trimmed to be 15-25 kilograms "heavy" so that the buoy will be about 1/2 submerged. This should be observed throughout the test 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.
- (2) 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.



**Figure 5 - Inclining Test**

- (3) 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.
- (4) The submerged inclining test 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 test can take several hours submerged, so life support and air conditioning systems must be functioning properly before the inclining begins.
- (5) Air entrained by the structure and under the fashion fairing can shift during the inclining and invalidate the test. 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.

9. 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. A trim dive, the deadweight survey, and the inclining test should be done before the simplified stability test. This will ensure that the submersible is in diving trim.
  - b. The hard ballast tanks should be about half full and the soft ballast tanks should be blown as dry as possible.
  - c. In calculating the weight of personnel,  $W$ , the weight of each person should be taken as 72.5 kilograms.
  - d. The beam,  $B$ , should be taken as the transverse distance between the embarkation deck railings. See Figure 6.

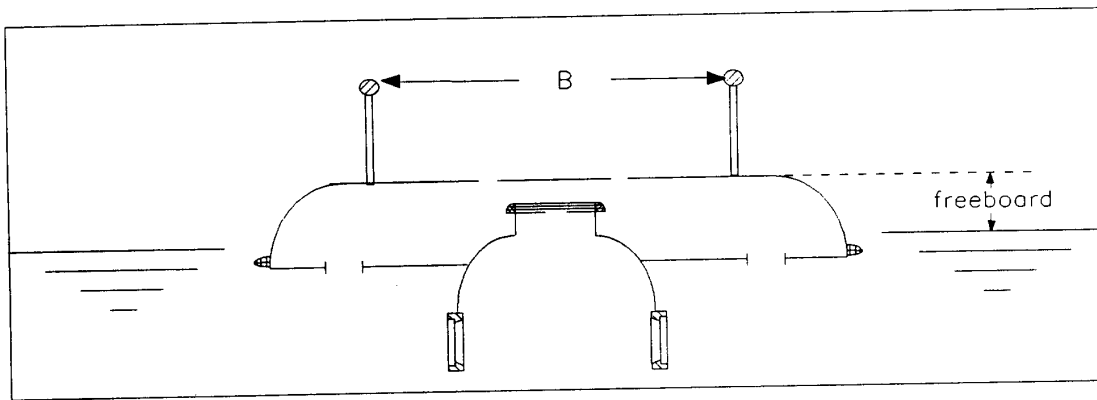


Figure 6 - Simplified Stability Test

- e. The passenger weight should be placed on the embarkation deck at a height equal to the center of gravity of the personnel aboard.
  - f. 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 the beam ( $B$ ) at the embarkation deck level. See Figure 6.
10. Operational Tests. Certain operational tests relate closely to stability. These can conveniently be done in conjunction with the inclining test.
- a. Emergency ascents: From several depths, including the rated 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.
  - b. Hatch Height: The submersible must be capable of remaining surfaced under a sea state having average wave heights up to 1.2 meters and average winds up to 16 knots. This

requirement is similar to American Bureau of Shipping (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.

- c. 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.
  - d. 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.
  - e. 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.
11. 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.

## SAMPLE STABILITY LETTER

---

Name  
Master

Subj: Submersible \_\_\_\_\_ O.N. \_\_\_\_\_  
Small Passenger Vessel  
Stability Letter

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 meters 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 1.5 meters.
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 \_\_\_\_\_ kilograms of permanent lead ballast in the skids as well as \_\_\_\_\_ kilograms of moveable lead ballast in the drop weight tray between the skids and \_\_\_\_\_ kilograms 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,

(Commanding Officer, Marine Safety Center)

bc: CCGD\_(m)

## References

American Bureau of Shipping Rules for Building and Classing Underwater Vehicles Systems and Hyperbaric Facilities. 1990, American Bureau of Shipping, ABS Americas, 16855 Northchase Drive, Houston, TX 77060

"Safety Standard for Pressure Vessels for Human Occupancy," ANSI/ASME 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

"Procedures for Performing Failure Mode, Effects and Criticality Analysis, MIL-STD-1629A," November 1980, Department of Defense, Washington, DC 20301

### 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

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

Marine Safety Center (G-MSC), 400 7th Street SW, Washington, D.C. 20593-0001

### 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, P0 Box 108, Portland, ME 04112-0108

Commanding Officer, Marine Safety Office, 455 Commercial St., Boston, MA 02109-1045

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 Safety Office, 1 Washington Ave., Philadelphia, PA 19147-4395

Commanding Officer, Marine Safety Office, Customhouse, 40 5. Gay St., 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, 196 Tradd Street, Charleston, SC 29401-1899

Commanding Officer, Marine Safety Office, P0 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, Claude Pepper Federal Building, 5th Floor, 51 SW 1st. Ave., Miami FL 33130-1609

Commanding Officer, Marine Safety Office, P0 Box 3666, San Juan, PR 00902-3666

### GULF OF MEXICO

Commanding Officer, Marine Safety Office, 155 Columbia Drive,

Tampa, FL 33606-3598

Commanding Officer, Marine Safety Office, 150 N. Royal St., PO Box 2924, Mobile, AL 36652-2924

Commanding Officer, Marine Safety Office, Tidewater Bldg., 1440 Canal Street, New Orleans, LA 70112-2711

Commanding Officer, Marine Safety Office, Rm. 232, 800 David Dr., 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., Room 313, 601 Rosenberg, Galveston, TX 77550-1705

Commanding Officer, Marine Safety Office, PO Box 446, Galena Park, TX 77547-0446

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 44114-1092

Commanding Officer, Marine Safety Office, Federal Bldg., Room 501, 234 Summit St., Toledo, OH 43604-1590

Commanding Officer, Marine Safety Office, 110 Mt. Elliot Ave., Detroit, MI 48207-4380

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, 57 N. 12th Ave., PO Box 446, Sturgeon Bay, WI 54235-0446

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

Commanding Officer, Marine Safety Office, (MSO Chicago) Suite D, 215 W. 83rd St., Burr Ridge, IL 60521-7059

### INLAND RIVERS

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

Commanding Officer, Marine Safety Office, 1415 6th Ave., Huntington, WV 25701-2420

Commanding Officer, Marine Safety Office, Room 360, 600 Martin Luther King Jr. Place, Louisville, KY 40202-2230

Commanding Officer, Marine Safety Office, 225 Tully St., Paducah, KY 42003-7509

Commanding Officer, Marine Safety Office, 1222 Spruce St., St. Louis, MO 63103-2835

Commanding Officer, Marine Safety Office, Suite 1301, 200 Jefferson Ave., Memphis, TN 38103-2300

#### PACIFIC COAST

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

Commanding Officer, Marine Safety Office, Los Angeles, Long Beach, 165 N. Pico Ave., Long Beach, CA 90802-1096

Commanding Officer, Marine Safety Office, Bldg. 14, Coast Guard Island, Alameda, CA 94501-5100 (MSO San Francisco Bay)

Commanding Officer, Marine Safety Office, 6767 N. Basin Ave., Portland, OR 97217-3929

Commanding Officer, Marine Safety Office, Bldg. 1/Pier 36, 1519 Alaskan Way S., Seattle, WA 98134-1192

Commanding Officer, Marine Safety Office, Suite 2A, 2760 Sherwood Ln., Juneau, AK 99801-8545

Commanding Officer, Marine Safety Office, PO Box 486, Valdez, AK 99686-0486

Commanding Officer, Marine Safety Office, 510 L St., Suite 100, Anchorage, AK 99501-1946

Commanding Officer, Marine Safety Office, 433 Ala Moana Blvd., Rm. 1, Honolulu, HI 96813-4909

Commanding Officer, Marine Safety Office, (MSO Guam) Box 176, FPO San Francisco, CA 96630-0176

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Federal Register / Vol. 49, No. 158 / Tuesday, August 14, 1984 / Notices



U.S. Department  
of Transportation

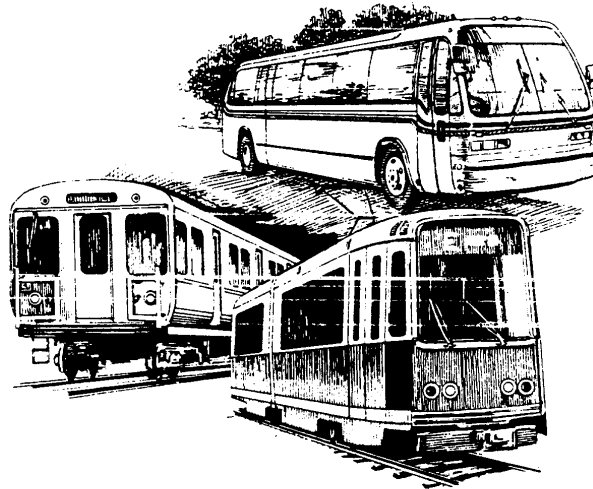
**Urban Mass  
Transportation  
Administration**

Office of Technical Assistance  
Safety and Security Office  
Washington DC 20590

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Cambridge, MA 02142

August 1984  
Reprint  
June 1988

## Recommended Fire Safety Practices for Rail Transit Materials Selection



**UMTA Technical Assistance Program**

Federal Register / Vol. 49, No. 158 / Tuesday, August 14, 1984 / Notices

**Urban Mass Transportation Administration**

**Recommended Fire Safety Practices for Rail Transit Materials Selection**

**AGENCY:** Urban Mass Transportation Administration, DOT

**ACTION:** Notice.

**SUMMARY:** The Urban Mass Transportation Administration is issuing recommendations for testing flammability and smoke emission characteristics of materials used in the construction of rapid rail transit and light rail transit vehicles. These recommendations are based on the Transportation Systems Center's "Proposed Guidelines for Flammability and Smoke Emission Specifications," which the transit industry, in general, uses on a voluntary basis.

**EFFECTIVE DATE:** August 14, 1984.

**FOR FURTHER INFORMATION CONTACT:** James A. O'Connor, U.S. Department of Transportation, Urban Mass Transportation Administration Director, Safety and Security Staff, (202) 426-2896.

**SUPPLEMENTARY INFORMATION:**

**Background**

On November 26, 1982, the Urban Mass Transportation Administration (UMTA) published a Notice and Request for Public Comment on "Recommended Fire Safety Practices for Rail Transit Materials Selection," Vol. 47 FR 53559. That Notice proposed recommendations for testing the flammability and smoke emission characteristics of materials used in the construction of rapid rail transit (RRT) and light rail transit (LRT) vehicles. Like the "Proposed Guidelines for Flammability and Smoke Emission Specifications" on

which they are based, these Recommended practices are not regulatory in nature. Rather, these Recommended Practices are intended to be used to assess the fire risk of materials used in RRT and LRT vehicles. They do not duplicate actual fire conditions. However, their use will result in the selection of more fire resistant materials, which will minimize the fire threat in RRT and LRT vehicles and thereby reduce the injuries and property damage resulting from transit vehicle fires. Moreover, issuance of the Notice at this time is consistent with the Department of Transportation's position on promoting safety in transportation.

In response to comments, UMTA has made one major substantive change to the Recommended Practices, as well as various editorial and minor substance revisions. The major change was to delete all references to National Fire Protection Association (NFPA) standards. This change is discussed more fully below.

Approximately 25 organizations responded to the November 26, 1982 Notice. The majority of these, including all but one of the commenting transit agencies, generally supported the Recommended Practices. For the most part, these comments suggested only minor changes, such as correcting various typographical errors, and clarifying the list of referenced standards and the notes to Table 1. Most of these comments have been incorporated in this Notice. After careful review, UMTA has chosen not to adopt some comments. UMTA's goal in issuing the Recommended Practices is to suggest a means for providing the highest practical level of safety. It

is UMTA's opinion that the comments not adopted would not further this goal.

The major substantive comments that were not adopted concerned: using small scale tests, most notably the American Society for Testing Materials (ASTM) E-162 test method; modifying certain aspects of the performance criteria; substituting tests; addressing toxicity; and expanding the scope of the Recommended Practices.

In regard to using small scale tests, several commenters questioned whether such tests, which test component materials separately, can adequately simulate the synergistic effects of burning the various vehicle assemblies, as may occur in an actual fire. UMTA has determined that small scale tests are the best method to test for the most practical level of safety feasible. Small scale tests are especially useful as a screening device to select materials. As such, they have the advantage of allowing a transit authority to choose its own preferred combination of materials in making up specifications for RRT and LRT vehicles. The fact that there is sufficient correlation between the results of full scale tests and those in the Recommended Practices to support use of those small scale tests has been borne out by full scale tests conducted by the Bay Area Rapid Transit District. Furthermore, there are disadvantages to the use of full scale tests. There are 18 different categories of materials application that require individual testing in a vehicle. A full scale fire test that would determine the merits of combinations of materials would require a series of such tests that would be prohibitive in cost and

impossible to perform in a manner that would satisfy all parties. In addition, they would eliminate the small manufacturer who would be unable to compete in such testing. Moreover, one noted expert has stated that full scale tests do not provide basic information on individual components or allow extrapolation to conditions other than those reached in that test.

Also in connection with small scale tests, several commenters referred to the fact that the NFPA states that several of its standards are intended only for use as research and development tools, not for regulatory purposes. Although the Recommended Practices are not regulatory, UMTA recognizes that they will be used for more than research and development. Accordingly, NFPA standards have been deleted from the Recommended Practices. ASTM tests E-662 and E-648 have been substituted for these tests.

Another commenter suggested that a "disclaimer" for the use of the flame spread rating required under a Federal Trade Commission consent order be included in the Recommended Practices. When read in its entirety, however, the disclaimer would not affect the use of the flame spread test as suggested in the Recommended Practices. Given that fact, as well as the fact that the context differs from that of the FTC Consent order, repeating the disclaimer is considered unnecessary.

Several commenters suggested modifying the performance criteria of the tests. Most of these comments suggested relaxing various performance criteria. The most common argument for doing so was that materials are not available that will meet the performance criteria. However, a review of the UMTA materials data bank revealed that in all cases there are sufficient materials to

meet the criteria of the Recommended Practices. Moreover, a recent UMTA study, "Assessment of the Benefits and Costs associated with the Adoption of the Recommended Fire Safety Practices for Rail Transit Materials Selection," Transportation Systems Center, Report UMTA-MA-06-0098-81-3, December, 1982, found that the cost of implementing the Recommended Practices would be minimal for new vehicle construction. In addition, several transit agencies recently have used the Recommended Practices successfully in purchasing rail transit vehicles. Again, UMTA believes that relaxing any of the criteria as suggested by the commenters would result in an unacceptable decrease in safety.

Another comment concerning relaxing performance criteria was that the same criteria should not be used for both LRT and RRT vehicles. It is UMTA's position that there is not sufficient difference between the environments on LRT and RRT vehicles to warrant separate tests for their materials. An additional comment was that the restrictions on flammability are such that the restrictions on smoke emissions and, for carpets, critical radiant flux, are unnecessary. UMTA disagrees. There is not necessarily a relationship between flammability and smoke emission, so that the flammability test alone does not adequately test for those two characteristics. For example, some situations may result in very little flame spread, but a great deal of smoke. The low flammability will not indicate the smoke emission characteristics of such material.

Several commenters suggested making certain performance criteria more restrictive, for example by requiring additional vehicle materials categories to meet specific optical density requirements for smoke emission.

For the most part, these greater restrictions would eliminate otherwise useful materials without a corresponding increase in safety. In the case of electrical cable used for rail transit purposes, there is not at this time enough information available to develop Recommended Practices.

In regard to substituting tests, several commenters objected to the use of the ASTM E-162 test method. UMTA did not adopt these comments because the ASTM E-162 is widely accepted both in the United States and abroad as a means of determining the flame spread of materials that may be used in RRT and LRT vehicles. For example, it is used to test materials for commercial aircraft. On the other hand, although the ASTM E-84, the suggested substitute test, is widely used in the construction industry, it is not necessarily suitable for testing materials for use in LRT and RRT vehicles. For instance, many materials that melt and sag cannot adequately be measured using the ASTM E-84. In addition, the ASTM E-84 is a larger scale test than the ASTM E-162 and therefore more costly. A related issue is whether the Recommended Practices will exist in addition to NFPA Standard 130, or be adopted by the NFPA to replace NFPA Standard 130. One commenter expressed concern over the possible existence of two industry standards. There in fact will be two test protocols if the NFPA does not fully adopt the Recommended Practices, in which case users will choose the best method. UMTA believes that the Recommended Practices reflect the state of the art.

Commenters also requested that UMTA address the issue of toxicity of the products of combustion of these materials in the Recommended Practices. UMTA recognizes the need to address this issue, but because of

its complexity, is not able to do so in the Recommended Practices. Instead, in an effort to respond to transit industry needs UMTA has initiated a program to develop guidelines for assessing the combustion toxicity of materials. Recognizing the scope and extreme complexity of this issue. UMTA has requested the National Research Council's (NRC) Transportation Research Board and Materials Advisory Board of the Commission on Engineering and Technical Systems to assist in addressing this issue. In response to this request, the NRC has established a Committee on Toxicity Hazards of Materials Used in Rail Transit Vehicles. This committee, consisting of representatives of industry and academia, will review the present state of knowledge of combustion toxicity, identify specific toxicity hazards related to the use of polymeric materials in transit vehicles, and recommend a plan of action for developing guidelines for testing materials. A workshop will be convened to review the preliminary findings of the study group, with interested parties representing government, mass transit agencies, user groups, and industry in attendance.

Commenters also raised questions about the scope of the Recommended Practices, and their relation to the July, 1979, "Proposed Guidelines for Flammability and Smoke Emissions Specifications." The Recommended Practices supersede those 1979 proposed guidelines. The Recommended Practices are intended for use in selecting rail transit vehicle materials. UMTA does not have jurisdiction over such modes as trucks and mobile homes. Accordingly, it would be inappropriate for UMTA to recommend fire safety tests for selecting materials for those vehicles. Because buses operate in a different environment than RRT

and LRT vehicles, UMTA believes it would be inappropriate to use RRT and LRT safety tests for buses. However, UMTA intends to develop similar fire safety materials guidelines for transit bus vehicles in the future.

In addition to suggesting changes to the Recommended Practices, commenters raised several questions that require clarification. One commenter expressed concern that the cost of retrofitting RRT and LRT vehicles would be prohibitively expensive. The Recommended Practices are guidelines, not requirements or regulations. UMTA believes that maintenance of safety on transit systems is a local responsibility and that the application of the guidelines by individual transit systems is a local decision reflecting operating conditions and vehicles in each system. It is not UMTA's intention to direct when and how the guidelines are used, but rather to make them available for use as safety technical assistance to operating and planned rail transit systems.

Another commenter raised a series of technical questions. The first was whether the materials presented in Table 1 are the only components that require testing. They are. The tests usually prescribe the appropriate specimen geometry for testing the material specimens. If not, the tests should be to the most appropriate geometry. The second was whether Fed-Std. 191A and AATCC-86 are indicative of what will happen to fabrics over their predicted lives. These tests are merely meant to determine whether flame retardant is removed by cleaning the fabrics. The third question was why the Dmax value recommendation for NFPA 258 was deleted. This value was deleted because UMTA determined that measuring smoke obscuration by time was

preferable to measuring total maximum smoke obscuration. Therefore, the Dmax value was deemed unnecessary. The final question was when there is more than one material that can be used for a function, to which does the test apply. The answer is that the test applies to all materials that can be used for a particular function.

#### **Recommended Fire Safety Practices for Rail Transit Materials Selection**

##### **Scope**

The Recommended Fire Safety Practices for Rail Transit Materials Selection are directed at improving the vehicle interior materials selection practices for the procurement of new vehicles and the retrofit of existing RRT and LRT vehicles. Adoption of these recommended fire safety practices will help to minimize the fire threat in rail transit vehicles and, thereby, reduce the injuries and damage resulting from vehicle fires.

##### **Recommended Fire Safety Practices for Rail Transit Materials Selection Application**

This document provides recommended fire safety practices for testing the flammability and smoke emission characteristics of materials used in the construction of RRT and LRT vehicles.

##### **Referenced Fire Standards**

The source of test procedures listed in Table 1 are as follows:

(1) Leaching Resistance of Cloth, FED-STD-191A-Textile Test Method 5830.

*Available from:* General Services Administration Specifications Division, Building 197 Washington Navy Yard, Washington, DC 20407.

(2) Federal Aviation Administration Vertical Burn Test,

**TABLE 1. RECOMMENDATIONS FOR TESTING THE FLAMMABILITY AND SMOKE EMISSION CHARACTERISTICS OF RAIL TRANSIT VEHICLE MATERIALS**

Category	Function of Material	Test Procedure	Performance Criteria
Seating	Cushion <sup>1,2,5,9*</sup>	ASTM D-3675	$I_s \leq 25$
		ASTM E-662	$D_s(1.5) \leq 100; D_s(4.0) \leq 200$
	Frame <sup>1,5,8</sup>	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100; D_s(4.0) \leq 200$
	Shroud <sup>1,5</sup>	ASTM E-162	$I_s \leq 35$
		ASTM E-622	$D_s(1.5) \leq 100; D_s(4.0) \leq 200$
	Upholstery <sup>1,2,3,5</sup>	FAR 25.853 (Vertical)	Flame Time $\leq 10$ sec; burn length $< 6$ inch
		ASTM E-662	$D_s(4.0) \leq 250$ coated $D_s(4.0) \leq 100$ uncoated
Panels	Wall <sup>1,5</sup>	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100; D_s(4.0) \leq 200$
	Ceiling <sup>1,5</sup>	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100; D_s(4.0) \leq 200$
	Partition <sup>1,5</sup>	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100; D_s(4.0) \leq 200$
	Windscreen <sup>1,5</sup>	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100; D_s(4.0) \leq 200$
	HVAC Ducting <sup>1,5</sup>	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(4.0) \leq 100$
	Window <sup>4,5</sup>	ASTM E-162	$I_s \leq 100$
		ASTM E-662	$D_s(1.5) \leq 100; D_s(4.0) \leq 200$
Flooring	Light Diffuser <sup>5</sup>	ASTM E-162	$I_s \leq 100$
		ASTM E-662	$D_s(1.5) \leq 100; D_s(4.0) \leq 200$
Flooring	Structural <sup>6</sup>	ASTM E-119	Pass
	Covering <sup>7</sup>	ASTM E-648	C.R.F. $\geq 0.5\text{w/cm}^2$
Insulation	Thermal <sup>1,2,5</sup>	ASTM E-162	$I_s \leq 25$
		ASTM E-662	$D_s(4.0) \leq 100$
	Acoustic <sup>1,2,5</sup>	ASTM E-162	$I_s \leq 25$
		ASTM E-662	$D_s(4.0) \leq 100$
Miscellaneous	Elastomers <sup>1</sup>	ASTM C-542	Pass
	Exterior Shell <sup>1,5</sup>	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100; D_s(4.0) \leq 200$
	Component Box covers <sup>1,5</sup>	ASTM E-162	$I_s \leq 35$
		ASTM E-662	$D_s(1.5) \leq 100; D_s(4.0) \leq 200$

\*Refers to Notes on Table 1.

**Available from:**  
Superintendent of Documents, U.S.  
Government Printing Office,  
Washington, DC 20402.

(3) American Society for  
Testing Materials (ASTM)

(a) Specification for  
Gaskets, ASTM C-542;

(b) Surface Flammability  
for Flexible Cellular Materials  
Using a Radiant Heat Energy  
Source, ASTM D-3675;

(c) Fire Tests of Building  
Construction and Materials, ASTM  
E-119;

(d) Surface Flammability of  
Materials Using a Radiant Heat  
Energy Source, ASTM E-162;

(e) Bonded and Laminated  
Apparel Fabrics, ASTM D-2724;

(f) Critical radiant flux of  
floor covering systems using a  
radiant heat energy source, ASTM  
E-648;

(g) Specific optical density  
of smoke generated by solid  
materials, ASTM E-662.

**Available from:** American  
Society for Testing and Materials,  
1916 Race Street, Philadelphia, PA  
19103.

In all instances, the most recent  
issue of the document or the  
revision in effect at the time of  
request should be employed in the  
evaluation of the material  
specified herein.

#### **Definition of Terms**

1. Critical radiant flux (CRF) as  
defined in ASTM E-648 is the level  
of incident radiant heat energy on  
the floor covering system at the  
most distant flame-out point. It is  
reported as  $W/cm^2$ .

2. Flame spread index ( $I_s$ ) as  
defined in ASTM E-162 is a factor  
derived from the rate of progress  
of the flame front ( $F_s$ ) and the rate  
of heat liberation by the material

under test (Q), such that  $I_s = F_s \times Q$ .

3. Specific optical density ( $D_s$ )  
is the optical density measured  
over unit path length within a  
chamber of unit volume produced  
from a specimen of unit surface  
area, that is irradiated by a heat  
flux of 2.5 watts/cm<sup>2</sup> for a specified  
period of time.

4. Surface flammability  
denotes the rate at which flames  
will travel along surfaces.

5. Flaming running denotes  
continuous flaming material  
leaving the site of material  
burning or material installation.

7. Light rail transit (LRT)  
vehicle means a streetcar-type  
transit vehicle operated on city  
streets, semi-private rights-of-way,  
or exclusive private rights-of-way.

8. Rapid rail transit (RRT)  
vehicle means a subway-type  
transit vehicle operated on  
exclusive-private rights-of-way  
with high-level platform stations.

#### **Recommended Test Procedures and Performance Criteria**

(a) The materials used in RRT  
and LRT vehicles should be tested  
according to the procedures and  
performance criteria set forth in  
Table 1.

(b) Transit agencies should  
require certification that  
combustible materials to be used  
in the construction of vehicles have  
been tested by a recognized  
testing laboratory, and that the  
results are within the  
recommended limits.

(c) Although, at present, there  
are no Recommended Fire Safety  
Practices for electrical insulation  
materials, information pertinent to  
the selection and specification of  
electrical insulation for use in the  
rail transit environment is  
contained in the following UMTA  
reports:

1. Electrical Insulation Fire  
Characteristics, Volume I,  
Flammability Tests, December,  
1978, UMTA-MA-06-0025-79-1,  
PB294 840/4GA

2. Electrical Insulation Fire  
Characteristics, Volume II, Toxicity,  
December, 1978, UMTA-MA-06-  
0025-79-2, PB294 841/2GA

3. Combustibility of Electrical  
Wire and Cable for Rail Transit  
Systems, Volume I, Flammability,  
May 1983, UMTA-MA-06-0025-83-  
7, PB83-233742

4. Combustibility of Electrical  
Wire and Cable for Rail Transit  
Systems, Volume II, Toxicity, May  
1983, UMTA-MA-06-0025-83-7,  
PB83 233759

**Available from:** The National  
Technical Information Service,  
Springfield, VA 22161

#### **Notes**

1. Materials tested for surface  
flammability should not exhibit  
any flaming running, or flaming  
dripping.

2. The surface flammability  
and smoke emission characteristics  
of a material should be demon-  
strated to be permanent by  
washing if appropriate, according  
to FED-STD-191A Textile Test  
Method 5830.

3. The surface flammability  
and smoke emission characteristics  
of a material should be demon-  
strated to be permanent by dry-  
cleaning, if appropriate, according  
to ASTM D-2724. Materials that  
cannot be washed or dry cleaned  
should be so labeled and should  
meet the applicable performance  
criteria after being cleaned as  
recommended by the  
manufacturer.

4. For double window glazing, only the interior glazing should meet the material requirements specified herein; the exterior need not meet those requirements.

5. ASTM E-662 maximum test limits for smoke emission (specific optical density) should be measured in either the flaming or non-flaming mode, depending on which mode generates the most smoke.

6. Structural flooring assemblies should meet the performance criteria during a nominal test period determined by the transit agency. The nominal test period should be twice the maximum expected period of time, under normal circumstances, for a vehicle to come to a complete, safe stop from maximum speed, plus the time necessary to evacuate all passengers from a vehicle to a safe area. The nominal test period should not be less than 15 minutes. Only one specimen need be tested. A proportional reduction may be made in dimensions of the specimen provided that it represents a true test of its ability to perform as a barrier against undercar fires. Penetrations (ducts, etc.) should be designed against acting as conduits for fire and smoke.

7. Carpeting should be tested in accordance with ASTM E-648 with its padding, if the padding is used in actual installation.

8. Arm rests, if foamed plastic, are tested as cushions.

9. Testing is performed without upholstery.

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Ralph L. Stanley,

*Administrator.*

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## FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

1. While the objective of an FMEA is to identify all modes of failure within a system design, its first purpose is the early identification of all catastrophic and critical failure possibilities so they can be eliminated or minimized through design correction at the earliest possible time. The analysis shall be used to assess high risk items and the activities underway to provide corrective actions. The FMEA shall also be used to define special test considerations, quality inspection points, preventive maintenance actions, operational constraints, and other pertinent information and activities necessary to minimize failure risk.
2. There are no specific Coast Guard requirements for the format of the FMEA. A number of publications are available that provide guidance on the preparation of an FMEA (see enclosure (3), last entry, for an example). In general, the following steps should be included in the analysis:
  - a. Conduct a study of all systems comprising the submersible. This should include a narrative description of each system and its functional requirements, including the following information:
    - (1) a general description of the operation of each system;
    - (2) the functional relationship among each of the system elements;
    - (3) acceptable functional performance limits of each system in each mode of operation of the vessel; and
    - (4) system constraints.
  - b. Develop system block diagrams which show the function, operation, interrelationships and interdependencies of the various systems. It may be necessary to provide different block diagrams for different operational modes. At minimum, the block diagrams should include:
    - (1) a breakdown of the submersible into its major systems, subsystems, and equipment; and
    - (2) all redundancies, and other engineering and operational features which provide "fail-safe" service.
  - c. Identify failure modes, causes, and effects, including all potential system and interface failure modes and their effect on the immediate function on the systems and on the overall safety of the vessel and its occupants.
    - (1) Each system should be considered in a top-down approach, starting from the system's functional output. Failure should be assumed by one possible cause at a time. A failure is defined as, but not limited to:
      - A. the inadvertent actuation of a component/system;
      - B. inaccurate sensors/gages; or
      - C. the failure of a component/system to operate as designed.

- (2) Since a failure mode can have more than one cause, all potential independent causes for each failure mode must be identified. If systems or subsystems can fail without any adverse effect, there is no need to consider them further unless the failure can go undetected by the crew.
  - (3) Identification of system redundancy alone is not sufficient to demonstrate that no adverse effect will occur. Redundancy must be shown to be immediately effective or brought on line with negligible time lag. In addition, if the sequence is, for instance: "Failure - alarm - operator action - start of backup - backup in service," the effects of delay must be considered.
- d. Evaluate the consequence of failure modes and their effects. These consequences should be classified as:
  - (1) Catastrophic - a failure which may cause death or system loss.
  - (2) Critical - a failure which may cause severe injury, or major property damage.
  - (3) Marginal - a failure which may cause minor injury, minor property damage, or minor system damage.
  - (4) Minor - a failure not serious enough to cause injury, property damage, or system damage, but which will result in unscheduled maintenance or repair.
- e. If the end effect of a failure is classified as critical or catastrophic, backup equipment or appropriate corrective action is normally required to prevent or minimize such effect. Single failure must not result in a catastrophic event, unless the likelihood is extremely remote.