U.S. Department of Transportation
United States Coast Guard

Marine Safety Center Technical Note

Date: 08 March 1996

SSIC: 16703/46 CFR 183.05-20
MTN: 1-96

Subj: HYDROGEN AND IGNITION ENERGY HAZARDS IN PASSENGER SUBMERSIBLES

Ref: (a) Navigation and Vessel Inspection Circular No. 5-93 (NVIC 5-93), "Guidance for Certification of Passenger Carrying Submersibles"
(b) American Bureau of Shipping (ABS) Rules for Building and Classing Underwater Vehicles, Systems, and Hyperbaric Facilities, 1990
(c) Title 29 Code of Federal Regulations (CFR) 1915.12
(d) National Fire Protection Association 306-1984, "Standards for the Control of Gas Hazards on Vessels"
(e) IEEE 45, Recommended Practice for Electrical Installations on Shipboard

1. PURPOSE: To assist passenger submersible designers and operators in reducing the potential for the hazardous buildup and ignition of hydrogen gas created by lead acid or alkaline storage batteries and their charging systems.

2. DISCUSSION:

a. Storage batteries and their charging systems sustain vital systems onboard passenger submersibles, including life support, during normal and emergency operations. It is therefore essential to ensure battery systems are safely, properly, and fully charged during daily maintenance. Where batteries are stored inside the pressure hull, special measures are necessary to ensure the safety of passengers, crew, and maintenance personnel.

b. Since the guidance in reference (a) was published, there have been incidents aboard passenger submersibles involving their battery storage and charging systems. In at least one case, an explosion occurred due to the accumulation of hydrogen gas during overnight battery charging and subsequent ignition during pre-dive checks. One contributing cause to this incident was inadequate ventilation of both the battery compartment and passenger compartment during charging. (For the purposes of this MTN, the "passenger compartment" is any space on the submersible outside the battery compartment.) Another contributing cause was inadequate determination of hydrogen concentration before energizing electrical systems, creating potential ignition sources. While the exact ignition source in this incident is unknown, analysis indicates that attention to certain design and operational issues greatly reduces the likelihood of such an incident.

c. Essentially, three conditions must exist for the battery storage and charging system to create an explosive hazard; hydrogen accumulation, failure of detection, and a source of ignition.

(1) Hydrogen Accumulation:

(a) Although systems vary greatly, all battery charging will result in the production of some amount of hydrogen gas. Even in batteries designed for low hydrogen output this may occur due to a bad power supply, overcharging, or residual off-gassing. If battery compartment ventilation is inadequate, hydrogen gas will accumulate. Even with a sealed battery compartment, hydrogen gas can leak into the passenger compartment due to equipment failure or the crew's failure to follow proper maintenance procedures.

(b) Current methods to prevent hydrogen accumulation in the battery box and interior spaces include portable blowers, installed blowers, or scrubber systems. The operational integrity of these systems relies entirely on the expertise and alertness of the maintenance crew. Equipment casualties such as blower malfunction, blower power supply failure, or loss of air flow may cause an accumulation of hydrogen. Poorly designed ventilation systems may also cause accumulation due to inadequate flow, obstructions, or pocketing. Both Chapter 7.D of enclosure (1) to reference (a) and Section 3.23 of reference (b) lack specific guidance on this matter. Accordingly, this note provides recommendations to assist the designer and operator.

(2) Ignition Sources: When properly designed and maintained, ignition sources within the battery compartment are unlikely. Section 11.11.7 of reference (b) provides that all electrical equipment within the battery compartment be explosion proof or intrinsically safe. However for practical considerations, ignition sources in the passenger compartment are unavoidable. Recommendations to minimize ignition potential in each area are included in this note.

(3) Hydrogen Detection: Because the two conditions above may occur despite the best efforts of designers and operators, detecting hazardous levels of hydrogen is critical both in the battery and passenger compartments. However, if these indicators are not properly calibrated, are ignored, or require energizing of potential ignition sources, there is a heightened risk of ignition. Recommendations for the design, use, and maintenance of a detection system are included in this note.

3. ACTION: The potential for hydrogen accumulation to create a hazardous condition cannot be overemphasized. This condition may occur on existing, as well as new passenger submersibles. Recognizing that the design and installation of a new system offers more flexibility, new and existing submersibles will be discussed separately.

a. Passenger submersibles certificated prior to the date of this MTN:

(1) Systems vary greatly and there are many appropriate design approaches to mitigate hydrogen gas hazards. Each system must be evaluated individually. In partnership with the cognizant Officer in Charge, Marine Inspection (OCMI), each passenger submersible operator should review the design, installation, operation, and maintenance of the battery storage and charging system. At the request of the designer, operator or OCMI, the Marine Safety

Center will provide technical assistance. The results of this study should be reflected in the vessel's training procedures and the Operations Manual.

(2) In conducting this review, use of a Failure Modes and Effects Analysis (FMEA), Fault Tree Analysis, or similar technique is advisable. Any evaluation of the battery storage and charging system should address at least:

(a) Hydrogen gas output during and after charging and during discharge.

(b) Adequacy of the charging power supply, maintenance of this power supply, and procedures for charging operations.

(c) Design of the ventilation system to prevent hydrogen accumulation within the battery box and passenger compartment, including required flow rate, the effects of pocketing and obstructions, reliability, sources of ignition from motors, hoses and fans, and interlocks within the charging system.

(d) Operation of the ventilation system before, during, and after charging, and after the submersible has been closed and secured for some period of time.

(e) Adequacy of other means to remove hydrogen during charging or discharging, as appropriate.

(f) Adequacy of hydrogen sensor system, including location, means of indication, calibration, continuous operation during and after charging, and ability to be read without creating a potential ignition source.

(g) Design, operation, and maintenance of seals between the battery compartment and passenger compartment.

(h) Maintenance of the batteries, charging, ventilation, and hydrogen detection system, including sequencing procedures to prevent arcing or sparking of electrical equipment, necessity to open battery box for maintenance, repair, replace fuses, etc.

(i) Interactions of vessel personnel with battery charging, ventilation, hydrogen detection, and other related equipment. Training and procedures necessary to prevent personnel from creating a hazardous condition.

b. Passenger submersibles coming into certification: Designers and operators should first consider the recommendations above. To further assist in dealing with specific issues, the following recommendations are offered:

(1) A means should be provided to determine the hydrogen level in both the battery and passenger compartments of the submersible. This indicator should be operable during charging, after charging, and after periods where the submarine has been closed and secured, and without energizing potential sources of ignition. Use of a portable hydrogen sensor is highly recommended.

(2) Hydrogen sensing equipment should be calibrated and maintained as recommended by the manufacturer.

(3) Consistent with the levels delineated in references (c) and (d), if a passenger compartment contains a concentration of flammable vapor or gas greater than 10 percent of the lower explosive limit (LEL), no person should be allowed to enter the submersible. The space should be ventilated to reduce the concentration below 10 percent of the LEL before persons are allowed to enter.

(4) No potential ignition sources within the submersible should be energized unless the concentration of flammable vapor and gas throughout the submersible is less than 10 percent of the LEL. A LEL above 10 percent may be acceptable within the battery box where the installation includes methods of hydrogen reduction (active or passive) and ignition source mitigation. The designer should perform a detailed analysis to validate that such a system manages hydrogen accumulation to safe levels. Otherwise, the affected space should be ventilated to reduce the concentration to below 10 percent of the LEL before energizing any potential ignition sources.

(5) Consistent with the requirements of Section 8.7.2 of reference (b), if the ventilation to the battery box becomes inoperable, then charging of the batteries is to be automatically discontinued.

(6) Consistent with the requirements of Section 11.11.6 of reference (b), overload and short circuit protection should be located in a separate space from the battery compartment, but lengths of cables between the battery and the protection should be kept as short as feasible.

(7) Consistent with the requirements of Section 11.11.7 of reference (b), electrical equipment within the battery compartment should be intrinsically safe or explosion proof.

(8) Consistent with the requirements of Section 16.4 of reference (e), the battery compartment ventilation should be designed to provide a complete air change every two minutes. The volume of air to be changed should be based on the unoccupied space within the battery compartment.

(9) Blower motors, fans, hoses, and other equipment as part of the battery charging system should be designed and installed to minimize potential ignition sources.

(10) Electrical cable runs within the submersible should be installed so as to protect against mechanical and chemical damage. An example would be the use of additional insulation in areas where the cable contacts the pressure hull.

(11) Preventive maintenance procedures should include monitoring of resistance level between terminals. The criteria of Section 11.11.2 of reference (b) is recommended.

c. Due to the number of possible arrangements and operational controls, each installation must be evaluated on a case-by-case basis, from the perspective of a system. This system extends beyond the equipment and design, to operation, maintenance, and training. The vessel operator should be vigilant in maintaining field procedures necessary to mitigate the hazards of hydrogen gas. The Marine Safety Center will, in partnership with designers, operators, and OCMI's, provide technical support to ensure safety on board passenger submersibles.

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