SIMPLIFIED GUIDANCE FOR ENGINEERS ASSOCIATED WITH DESIGN, CONSTRUCTION, AND CERTIFICATION OF HYPERBARIC RESEARCH FACILITIES

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ABSTRACT

Because of potential hazards associated with diving in deep ocean research facilities, a procedure has been developed by which these facilities can be certified for safe operation. One of the major steps involved in this procedure is the review of documentation associated with the design, fabrication, and construction of these facilities. The review process affords the certifying authority the opportunity to evaluate the adequacy of design rationale, the adequacy of fabrication techniques and the conformance of these items with existing codes and standards. This paper concerns itself with the philosophy of the certification process and the rationale employed during the documentation review and evaluation.

1. INTRODUCTION

Diving, whether in the open ocean or in research facilities, is dangerous. The U. S. Navy, being a fore-runner in ocean research, have sought means to minimize endangerment to life in developing a program by which its hyperbaric research facilities can be certified for safe operations. The program is intended to assure (1) that the operators of the facility are qualified, (2) that the procedures for operation are adequate, and (3) that the rationale, methods and processes employed during the design and construction of these facilities are the most effective. This paper will address the latter, and will concern itself with the review and evaluation of documentation associated with design, fabrication and construction.

2. BACKGROUND INFORMATION

To combat the restraints of time, cost, limited knowledge, endangerment to life, and also to provide a controlled means by which both man and machine can be tested in simulated ocean environment, hyperbaric research facilities have been developed. These facilities provide a technological complex which simulates ocean environments by precisely controlling the magnitude and rate of change of pressure, temperature, salinity, turbidity and other ocean characteristics. These research chambers also provide a means by which the composition and condition of the confined atmosphere can be varied. From tests and experiments conducted in these facilities, the physiological effects of the ocean environment on man, his behavior, his ability to perform useful work, and the durability of machines can be evaluated.

Diver's safety, when the facility is operational, is the primary objective of certification. While confined within the facility (see Figure 1), divers are subjected to such hazards as uncontrolled depressurization, fire, hypoxia, high noise levels, CO and CO2 poisoning, narcosis, electrocution, embolism and toxicity. Of these, the two most feared are uncontrolled depressurization and fire. To date, 90 percent of all reported hyperbaric chamber casualties have resulted from fire.

Figure 1 - Elevation of a Hyperbaric Research Facility
To ensure the safety of divers and operators of these complex facilities, the U. S. Navy has developed a safety certification program. Certification is defined as "The procedures, including application independent review, survey and approval, to insure the adequacy of the facility to perform safely over its operational/emergency spectrum" (1).

The Naval Facilities Engineering Command is the System Certification Authority (SCA) for all shore based, Navy owned or leased hyperbaric facilities. The Naval Sea Systems Command is the SCA for all sea going facilities. The U. S. Coast Guard has established a program for certifying commercial facilities.

3. MAJOR CERTIFICATION EVENTS

The evolution of events occurring during the certification process are illustrated in figure 2 and summarized below:

a. The applicant, owner or his agent, makes an application for certification of his facility. In his application, he defines objectives, summarizes descriptions, lists overall parameters and states the desired tenure period.

b. The applicant and the System Certification Authority (SCA) negotiate the certification scope, milestone event schedule, documentation requirements and cost.

c. The applicant collects and submits to the SCA documentation related to design, fabrication, construction and testing.

d. The SCA reviews and evaluates the documentation.

e. The SCA performs an on-site survey of the facilities and identifies any deficiencies which may exist.

f. The applicant performs an operational test for the SCA, during which any irregularities are identified.

g. The applicant or his agent corrects all deficiencies or irregularities.
h. The SCA issues a certificate of certification.
i. The applicant sustains certification throughout the effective tenure.

The entire process can not be discussed in this paper. However, one of the most important events is the documentation review, for it is here that useful design and fabrication information can be obtained.

4. DOCUMENTATION REVIEW

As previously stated, the applicant collects and submits to the SCA documentation related to design, fabrication, construction and testing. With regards to design, these documents usually consist of design drawings and specifications, design calculations, stress analyses, base material selection evaluation, failure modes and effects analyses, flexibility analyses, manufacturer's catalog sheets, manufacturer's certification statements and other documents or information necessary to substantiate the adequacy of the facility to perform safely within the design parameters.

With regards to fabrication, and testing during fabrication, these documents usually consists of welding or brazing procedures and procedure qualifications; welding or brazing operator qualification and qualification acceptance tests; welding or brazing equipment qualification; non destructive examination (NDE) equipment qualification; NDE procedures and results; qualification of NDE operators, interpreters and inspectors; methods of forming base metal; ductile
MAJOR CERTIFICATION EVENTS

- **APPLICANT/SPONSOR**
  - Request Certification

- **APPLICANT/SPONSOR & SCA**
  - Collect and Submit Certification Documentation
  - Negotiate Certification Scope

- **SCA**
  - Perform Onsite Survey and Test
  - Perform Documentation, Technical Review and Evaluation

- **SCA**
  - Issue Certification Certificate

**RECERTIFICATION**
brittle transition test; post fabrication treatment; material traceability records; and records of material and component evaluation.

Additional documents are submitted and are related to systems cleaning; operational, emergency and maintenance procedures; quality of breathing gases; flammability and toxicity of materials; electrical insulation and continuity test; and other documents attesting to the safety of the facility.

The SCA then reviews these documents for evidence of such things as adequacy of design practices, built in redundancies, validity of design assumption and design rationale, adequacy of fabrication techniques, adequacy of construction practices and conformance with the applicable codes and standards to ensure that the facility as designed and constructed will not imperil the safety of the divers and operators.

A major problem often encountered by design engineers and fabricators is unfamiliarity with existing codes and standards applicable to the design and construction of hyperbaric research facilities. For some applications, codes and standards do not exist. However, there are many existing codes and standards which are applicable to the design and construction of these facilities.

The ones which most designers and fabricators are familiar are Section VIII, Divisions 1 and 2 of the American Society of Mechanical Engineers' (ASME) Boiler and Pressure Vessel Code (2,3). However, if one is referring to a man rated pressure vessel, these are not the governing codes. The American National Standard Institute (ANSI) and ASME standard ANSI/ASME PVHO-1(4) is the governing standard. As a supplement to Section VIII Divisions 1 and 2 this standard, establishes the rules governing the design, fabrication, and inspection during construction for man rated pressure vessels, their appurtenances and viewports. It should be emphasized however, that Section VIII Divisions (1) and (2) are the criteria and basis of PVHO-1.

It also must be understood and realized that a hyperbaric research facility is more than a pressure vessel. It is an intricate connection of the pressure vessel with its supporting systems. Systems typical of a hyperbaric research facility include the following:

1. The Pressure Vessel, its Appurtenances and Supports
2. The Atmospheric Conditioning System
3. The Potable Water System
4. The Waste Disposal and Sanitary System
5. The Gas Storage System
6. The Wet Chamber Water Conditioning System
7. The Oxygen Make-up System
8. The Gas Pressurization and Vent System
9. The Fire Extinguishing System
10. The Built-in Breathing (BIB) System
11. The Electrical System
12. The Communication System
13. The Gas Analysis System
14. The Panel System

Codes and standards applicable to the design and construction of these systems are summarized in Table (1). Abbreviations have been used to conserve space. Full titles are given in the references.
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**TABLE I**

CODES & STANDARDS APPLICABLE TO HYPERBARIC RESEARCH FACILITIES
The standards manuals and codes listed in Table (1) can not be considered to be all inclusive. There are many standards and codes governing the design and fabrication of the many components of these systems. Nevertheless, when these systems are designed with sound engineering judgement, fabricated and constructed with high quality workmanship, and when the design and fabrication techniques conform with the requirements of the codes and standards listed in Table (1), it can be assured that the facility will be safe for operation. A by-product of this effort would surely be an easier task for the System Certification Authority.

5. PHILOSOPHY OF HAZARD LEVELS

In determining the codes and standards applicable to the design and fabrication of the aforementioned systems, consideration has to be given to the different modes of failure of the components and the effect such failures would have on the safety of the divers. A method was needed which would allow an evaluation of the failure on the basis of its severity. MIL-STD-882 (5) was helpful in providing guidance. It offers a procedure for categorizing failures into hazard severity levels. Using this procedure, components of the system can be evaluated during the failure mode and effect analysis, and dependent upon the effect such failures would have on the safety of the divers, assigned a hazard severity number. The more severe the effect of the failure, the lower the severity number. The hazard severity evaluation criteria adopted for certification purposes are as follows:

a. Category I - Catastrophic - Diver fatality or injury is highly probable. Failure management or means to circumvent the failure or malfunction is not possible.

b. Category II - Critical - Diver injury is imminent. Failure management is possible and necessary to sustain life.


d. Category IV - Negligible - No diver injury. Failure management performed at the discretion and convenience of the owners.

In adopting this approach it can readily be seen that the lower the hazard severity category number, the more stringent the code governing the design, the fabrication methods and techniques and the construction practices.

6. CONCLUSIONS AND SUMMARY

The process of certification is viewed by some as being an unnecessary process. The question often asked is "Why should a double check be made of design practices and fabrication techniques?" To date, for every hyperbaric research facility that has been constructed and certified, the certification process has uncovered areas of potential hazards. This in no way implies incompetence on the part of designers and fabricators, for they are very much concerned with the safety of these facilities. It must be realized that these facilities are among the first generation of ocean facilities. Where there is room for error, mistakes will be made. Even with the process of certification, there is no guarantee that diving casualties will not result. Yet it is comforting to know that in the minds of the designers, fabricators, builders and certifiers, the facility will perform safely.

Man in the oceans will eventually be required for any meaningful exploitive purposes. His being there will require the use of some type of liveable facility. The reliability and safety of these facilities will in many ways be dependent upon the research being conducted today in hyperbaric
facilities. Designers and fabricators will have obtained valuable knowledge in the design and construction of these needed facilities, requirements will be better defined and new criteria will evolve. From these requirements and new criteria, safety standards and codes will be developed. With a continued conscious effort toward safety, reliability and operability, certification will have paved the way and proven its effectiveness.

7. REFERENCES

2. ASME Section VIII, Division 1, "Pressure Vessel Code".
3. ASME Section VIII, Division 2, "Pressure Vessel Code, Alternative Rules".
4. ANSI/ASME PVHO-1, "Safety Standard for Pressure Vessels for Human Occupancy".
7. ANSI B31.1, "Code for Pressure Piping, Power Piping".
11. NAVSEA 0994-LP-001-9010

12. NAVSHIPS-0900-006-9010, "Fabrication Welding and Inspection of HY-80 Submarine Hulls".
13. NAVSHIPS 0900-01-7000, "Fabrication and Inspection of Brazed Piping Systems".
14. MIL-STD 1693(YD), "Fabrication, Welding and Inspection of Hyperbaric Chambers and Other Critical Land-Based Structures."
15. NFPA-70, "National Electrical Code".
16. NAVSHIPS 9230.12A
17. NAVSHIPS 9230.15
20. MIL-STD-271E, "Non Destructive Testing Requirements for Metals".
22. ASME Section V, "Non Destructive Examination".
23. NAVFAC DM-24, "Land Operational Facilities".
24. NFPA 50-1, "Bulk Oxygen Systems".