~~Report~~ 3825

DEEP SEA SIMULATION FACILITIES - PRESENT STATUS 1972

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20034

DEEP SEA SIMULATION FACILITIES

PRESENT STATUS

1972

by

Ralph B. Allnutt

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STRUCTURES DEPARTMENT

RESEARCH AND DEVELOPMENT REPORT

September 1972

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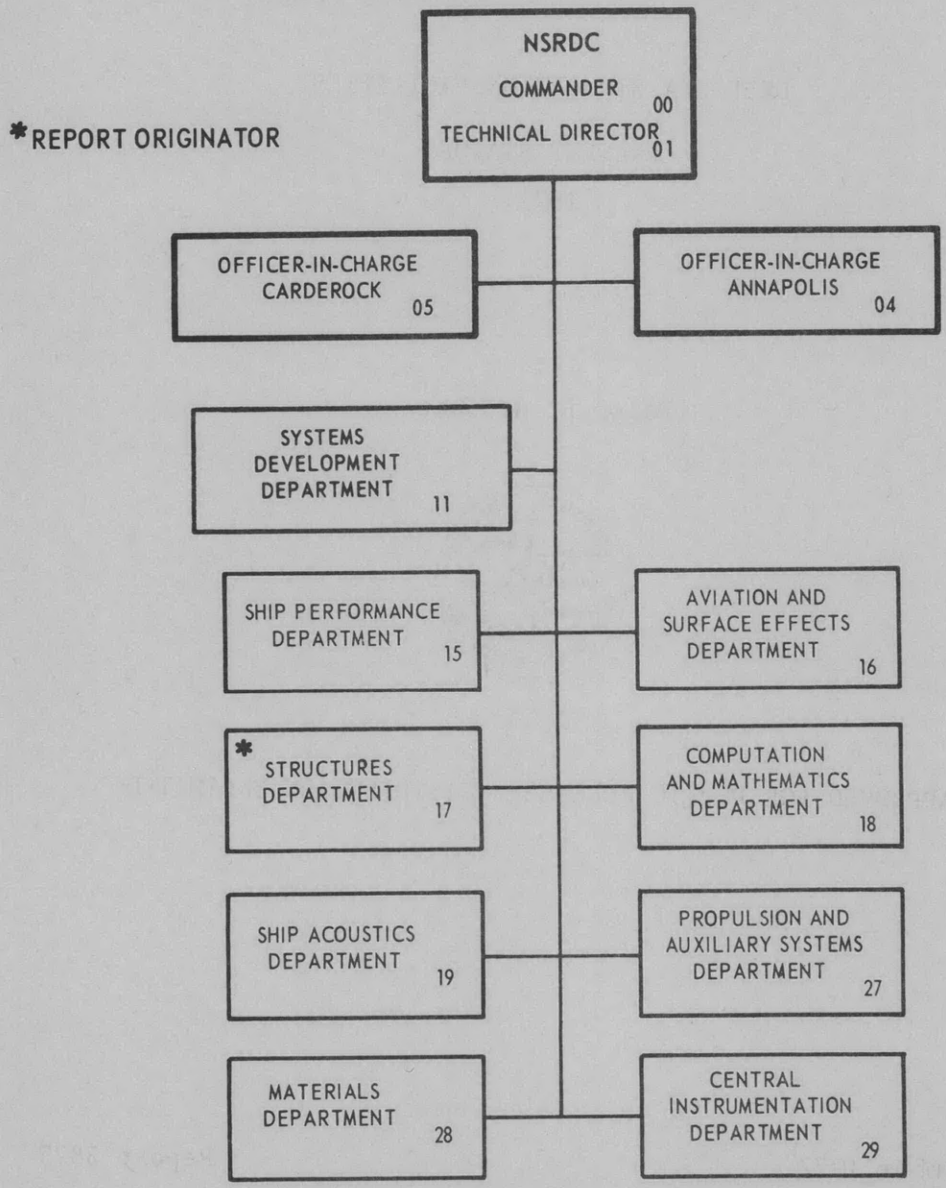
The Naval Ship Research and Development Center is a U. S. Navy center for laboratory effort directed at achieving improved sea and air vehicles. It was formed in March 1967 by merging the David Taylor Model Basin at Carderock, Maryland with the Marine Engineering Laboratory at Annapolis, Maryland.

Naval Ship Research and Development Center
Bethesda, Md. 20034

MAJOR NSRDC ORGANIZATIONAL COMPONENTS



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DEPARTMENT OF THE NAVY
NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER
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ABSTRACT

This brief overview lists the deep sea simulation facilities presently available in the United States. It indicates the possible needs for additional facilities and gives some insight into the conditions that require updating of existing facilities. Background material on types and frequencies of failures will be helpful to those concerned with design and certification.

ADMINISTRATIVE INFORMATION

The work was initiated and completed under Naval Ship Research and Development Center (NSRDC) in-house technical planning in support of Navy (DNL/NAVSHIPS/NAVFAC) interest in such facilities.

This report has, substantially, the same content as a paper presented at the Fourth Underwater Technology Conference of the American Society of Mechanical Engineers held at Houston, Texas, 19-23 September 1971.

INTRODUCTION

PURPOSE

This discussion of existing deep ocean simulation facilities in the United States is presented in terms of their primary purpose, their location, and some of their basic characteristics. It also provides some insight into their present material condition.

Data were obtained from two recent studies. An NSRDC study[1] recently updated by Heller[2] gives data on the location and operational capabilities of 360 separate test units. The major facilities include 164 separate units located at 37 private and government facilities located in 14 different states or geographic locations. The second study was made for NSRDC as part

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[1] Allnutt, R. B. et al., "Deep Sea Simulation Facilities," Part III AUTODOTS of Automated Deep Ocean Tank Simulation, U. S. Resources, NSRDC Report 2515-3 (Dec 1967). (A complete listing of references is given on page 47.

[2] Heller, S. R. Jr., "Deep Ocean Simulation Facilities of the United States," Catholic University of America (1969).

of a safety review by MPR Associates.[3] It documents information on pressure tank and piping system failure incidents and accidently related to 53 different facilities.

These studies are intended to serve those who have an interest in the development of hardware for use in the sea, those who have the responsibility for locating and using such facilities, those who are interested in acquiring new facilities, and those who are concerned with the specification design and certification of deep sea simulation facilities.

SCOPE

For purposes of this discussion, a deep ocean simulation facility is defined as a land site wherein prototype equipment or models are exposed to environments such as pressure, temperature, sea water corrosion, contamination, or combinations thereof which they may well encounter in the ocean.

Basically, deep sea simulation facilities of the type described herein provide a means of verifying the reliability and safety of hardware systems and subsystems prior to their use under actual service conditions. Failures can be corrected and better engineering designs can be developed prior to service at sea. This is particularly important for deep sea systems since failures at sea attended by possible loss of life or the necessity of aborting expensive operations at sea can result in postponement or curtailment of important programs.

This paper does not include the specialized deep sea simulation facility termed a hyperbaric facility whose purpose and requirements are quite different. A hyperbaric facility is used to study the medical and physiological effects of the ocean environment on animals, humans, and man-operated equipment. The primary concern in its design and operation is the provision of elaborate systems to support life, and its use has been exclusively for diver-related work. Hyperbaric facilities have maximum operating pressures of only about 1000 psi whereas the deep sea simulation facilities of concern here have operating pressures ranging from a few hundred to 50,000 psi.

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[3] "Survey of Pressure Vessels and System Failure," MPR Associates Report 247 (Oct 1970).

APPLICATION

The Navy submarine designer and the structural research engineer have found deep sea simulation facilities an indispensable tool in attaining their design goals with a high degree of confidence. As shown schematically by Figure 1 the designer's baseline experience and knowledge from prior designs is supplemented by new theory and verified by model experiments ranging from small-scale models employed to study the effects of varying geometric parameters to large-scale models employed to validate designs. The latter serve to verify the design strength (collapse pressure), to provide response data (strains, deflections), and to determine the critical mode of collapse for the specified geometry, material, and fabrication of the pressure hull for a new class of submarine prior to its construction.[4]

Since a submarine may fail in many different ways (or modes), some of which are shown by Figure 2, it is very important to identify the critical mode of collapse for a given geometry and to make certain that collapse does not occur prematurely. As shown by Figure 2, the collapse mode is easily discernable in a deep sea simulation facility because at the failure pressure, the collapse of the model causes a decrease of pressure to occur in the fluid inside the tank. Thus, the energy available to cause unlimited distortion of the model is reduced and controlled. In the sea this is not the case. A model lowered in the sea to its collapse pressure will fail catastrophically (Figure 3) due to the unlimited energy. Accordingly, it is virtually impossible to identify the mode of failure that triggered the collapse. For the particular model shown in Figure 3, the effect of collapse in the sea was simulated in a pressure tank by providing a pressurized head of nitrogen in the tank so that the pressure did not drop at collapse and the full energy at collapse was transmitted to the model.

The above application illustrates a specialized use of a deep sea simulation facility. There are many others, e.g., in the development of

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[4] Allnutt, R. B., "Relation between Testing and Performance of Structures for Deep Sea Vehicles," American Society for Testing Materials STP (1966).

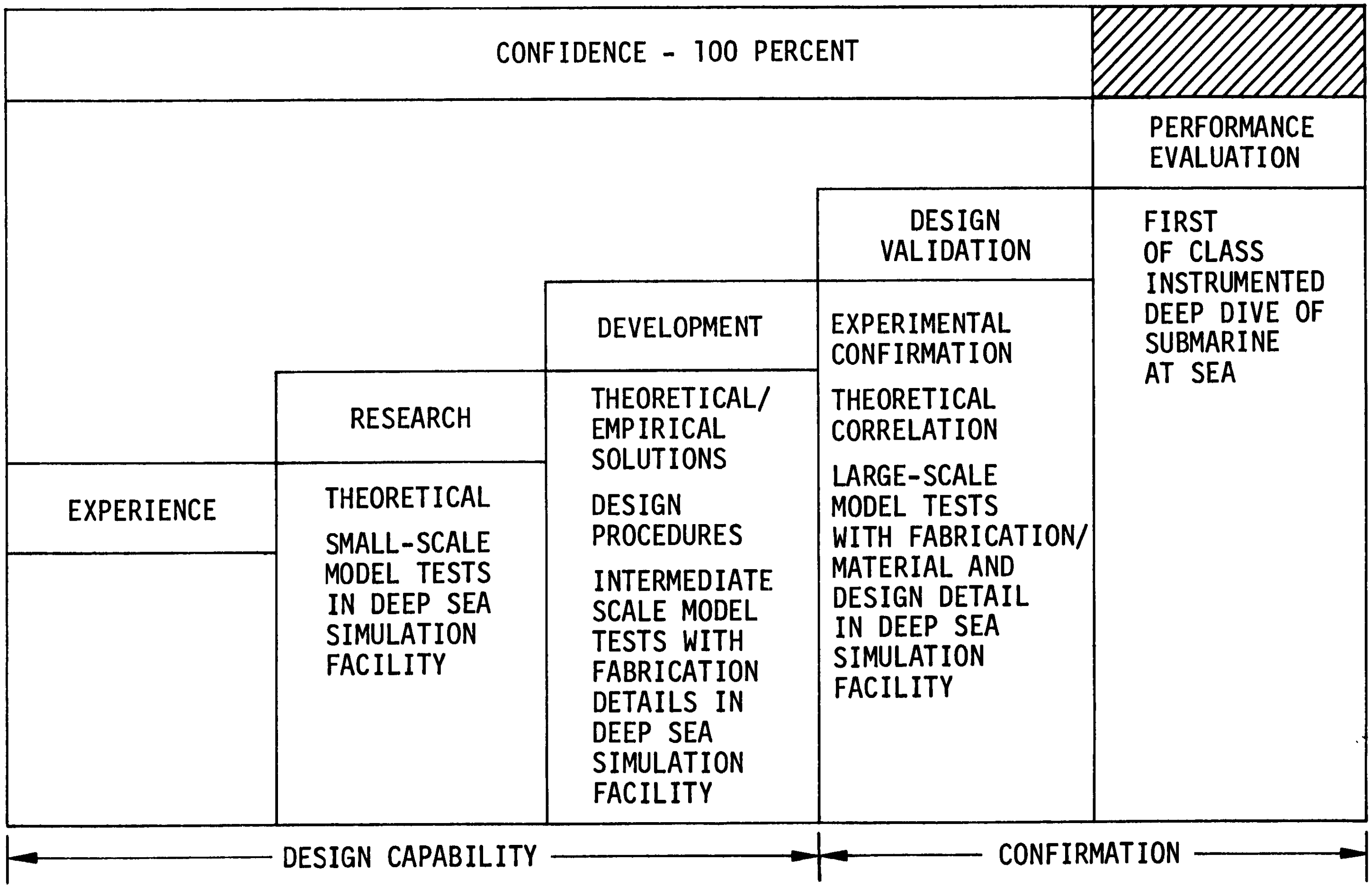
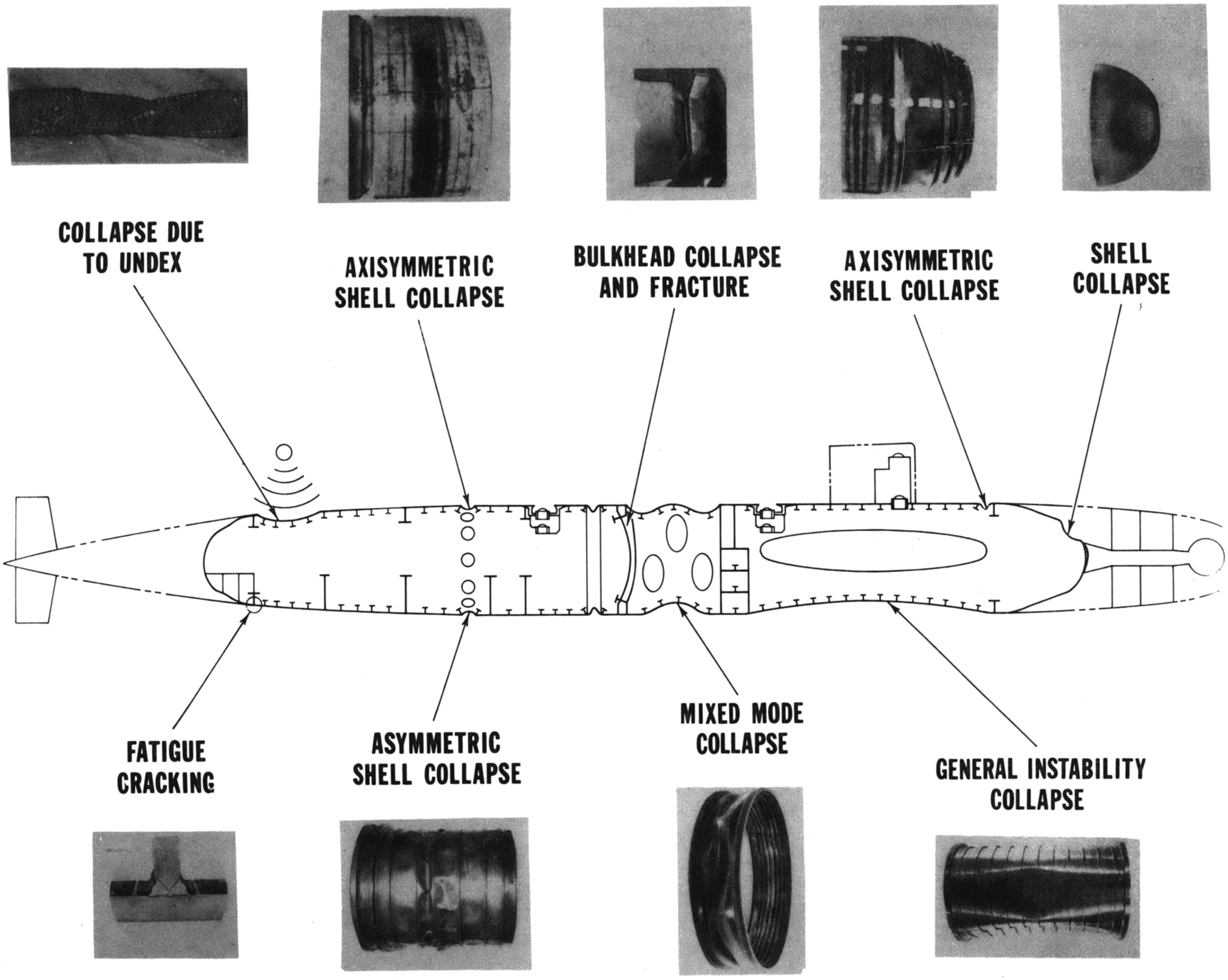


Figure 1 - The Relation of Deep Sea Simulation Tests to Submarine Design


COLLAPSE DUE TO UNDEX
AXISYMMETRIC SHELL COLLAPSE
BULKHEAD COLLAPSE AND FRACTURE
AXISYMMETRIC SHELL COLLAPSE
SHELL COLLAPSE
FATIGUE CRACKING
ASYMMETRIC SHELL COLLAPSE
MIXED MODE COLLAPSE
GENERAL INSTABILITY COLLAPSE

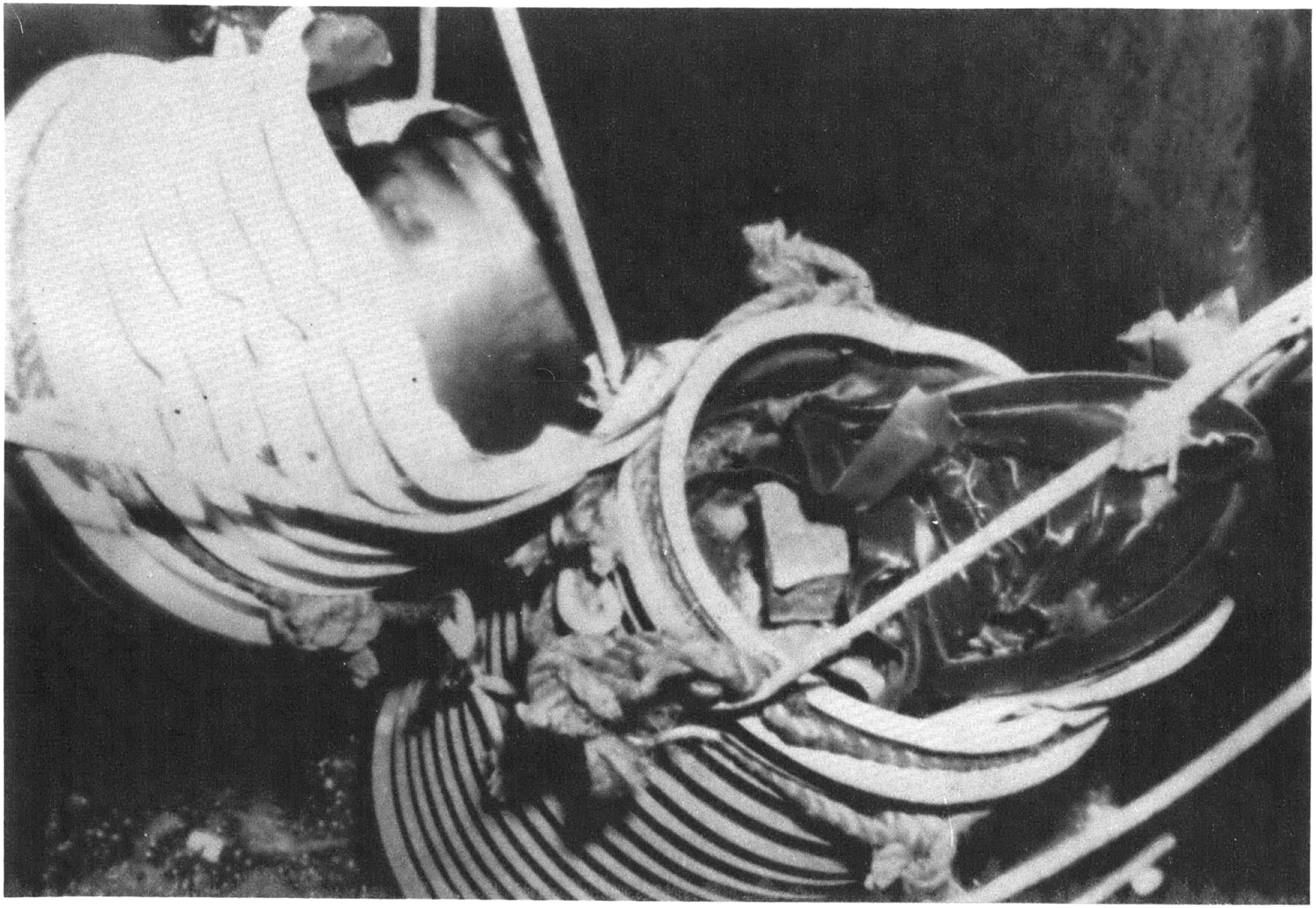


Figure 3 - Typical Catastrophic Collapse Mode of a Submarine Structure
(Tank simulation of the effect when the structure
is lowered in the sea to its collapse pressure.)

underseas engineering, machinery, power systems, and communications systems. Most facilities studied in the survey (both private and government) were procured to satisfy a particular or specialized need. However, the survey shows that most of them are available for additional work and that some may be adapted to other uses, particularly when scheduled well in advance. The various additional uses to which these facilities can be placed is illustrated by Table 1 which lists a few of the more recent tests made in the NSRDC facilities for other activities. These range all the way from tests of small submersible vehicles such as the deep sea rescue vehicle (DSRV), the ALVIN, the Johnson-Sea Link, and the Deep Star 20,000-ft vehicle, to tests of underwater electric motors, thermonuclear devices, and hydroacoustic systems, to tests of baled municipal garbage.

CHARACTERISTICS

The heart of a deep sea simulation facility is a pressure tank which is usually cylindrical or spherical in shape.[5] Pressure tanks used for deep ocean simulation studies have design operation pressures ranging from several hundred pounds per square inch (psi) to 50,000 psi and are capable of simulating ocean depths as deep as are found in the ocean with an additional margin to provide greater pressures for over-pressurization. Their diameters range from 1 in. to 30 ft and their lengths can be as much as 75 ft. Hydrostatic pressures are developed in the tanks by pumping with sea water, fresh water, or oil. The NSRDC study[1] shows that various tank configurations, materials, closures, and construction concepts are used for high pressure tanks. These range from conversion of 16-in. gun shells and gun barrels, simple cylinders closed with flat plates held together with tie rods, thick cylindrical forgings with several layers shrunk over one another to form the desired wall thickness, to thin

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[5] Allnutt, R. B., "The Use and Design of Pressure Tanks for Deep Sea Simulation Facilities," American Society of Mechanical Engineers 68-WA/UNT-4 (Dec 1968).

TABLE 1 - VARIOUS TYPES OF TESTS CONDUCTED IN NSRDC DEEP SEA SIMULATION FACILITIES FOR OTHER ACTIVITIES

Customer	Items Tested
U. S. Navy	DSRV - ALVIN Buoys, Anchor Housings, Torpedoes, Cable Cutters, Hydroacoustic Systems, Hydrophones, Thermoelectric Generator
Westinghouse	20,000-ft Deep Star, Heavy Lift, Buoyancy Bags
Sun Ship	Motor
Alcoa	Johnson-Sea Link
Lear Siegler	Stabilized Platform
Honeywell	Large Sphere
General Electric	Ceramic Sphere
Environmental Control Administration	Baled Municipal Refuse
General Dynamics	Hydroacoustic Transducer
Hydrospace Research	Vehicle System

multilayer all-welded construction. The state-of-the-art of some of these are discussed by Keller[6] and by Stachiw.[7]

Most facilities also have ancillary equipment to provide the special features needed to accommodate the particular type of test for which the facility is primarily used. For example, a test of submerged machinery requires some method of running machinery under load and no-load conditions and a method for removing the heat generated by machinery. A structural test requires the provision of equipment for sustaining impact loads due to implosions and for monitoring strains and deflections of the structures under test. If a cyclic test is required, the facility must be designed to simulate realistic conditions without unnecessarily shortening its fatigue life. A test of acoustic transducers requires the use of anechoic coatings on the tank walls. These are but a few examples to illustrate the specialized aspect of these facilities.

The basic elements of a deep sea simulation facility are shown in Figures 4 and 5. They include a pressure tank (or a series of pressure tanks of various sizes and capacities); facilities for handling test items and for opening and closing pressure tank heads; storage tanks for the pressure medium(s); pumps, motors, and accumulators for applying pressure; heat exchangers or refrigeration equipment for varying and controlling temperature; mechanical, electrical, and electronic control mechanisms; instrumentation housing and tank vaults; shields; and remote-monitoring equipment and fire-suppression systems to provide safety for operating personnel. A list of some of the considerations which must be taken into account in determining the pressure tank requirements for such a facility is given in Table 2.

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[6] Keller, K. H., "High Pressure Test Chambers - State-of-the-Art," American Society of Mechanical Engineers 68-WA/UNT-8 (Dec 1968).

[7] Stachiw, J. D., "Pressure Vessel Concepts," Naval Civil Engineering Laboratory R666 (Mar 1970).

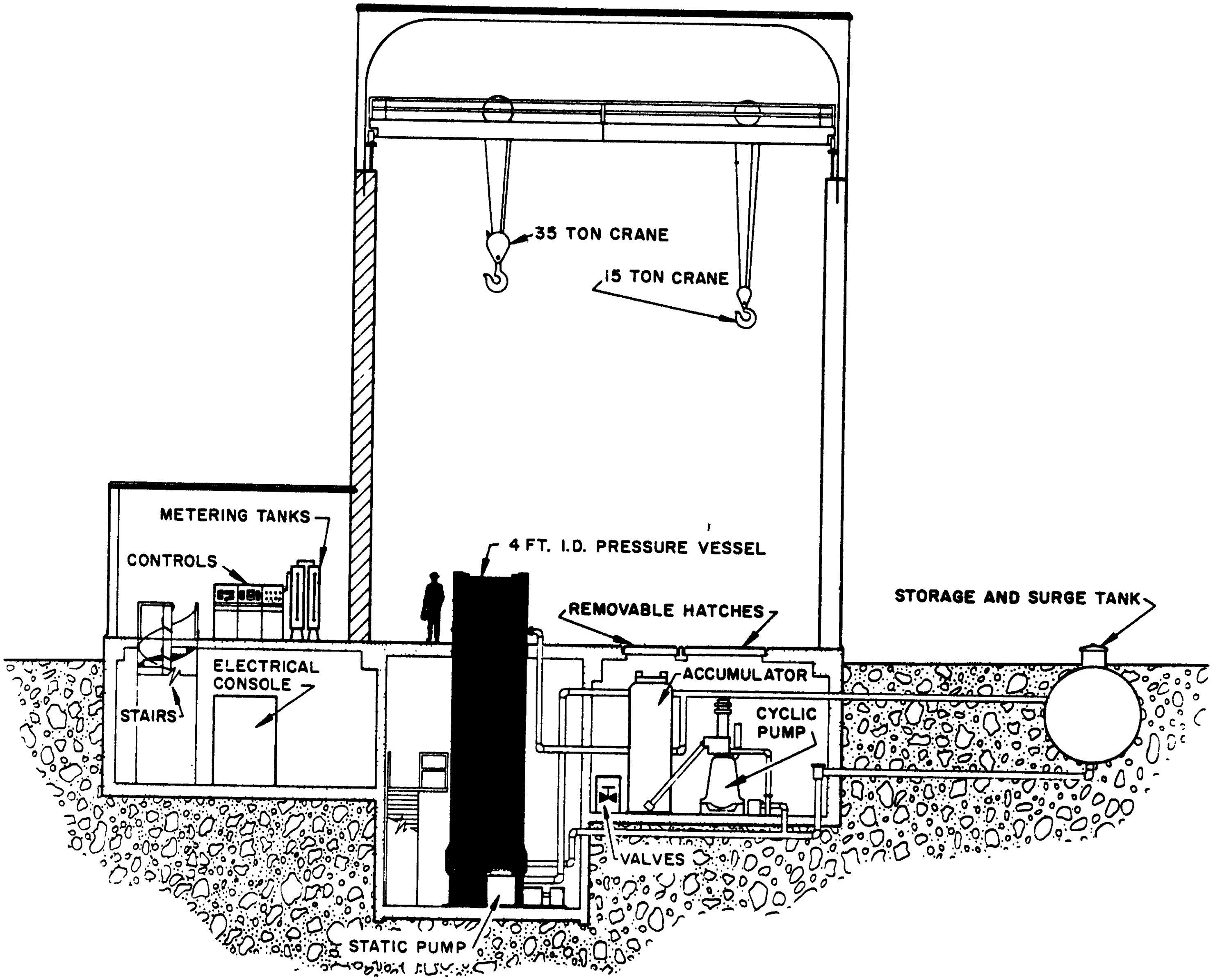
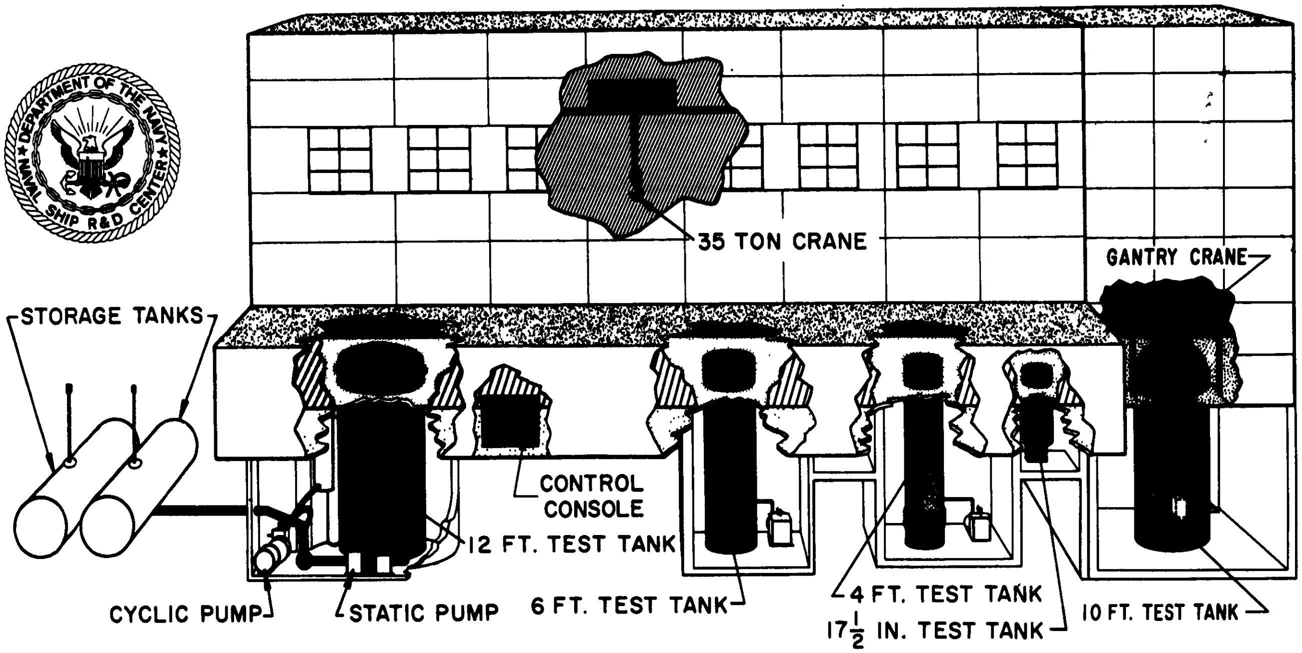


Figure 4 - Cross Section of a Deep Sea Simulation Facility at NSRDC



MAJOR PRESSURE VESSELS

DIAMETER FT	THICKNESS IN.	LENGTH FT	OPERATING PRESSURE PSI
12*	2	30	1,000
6*	6 5/8	21	6,000
4*	10	20	15,000
1 1/2	15 3/4	8	25,000
10	8 3/4	10	10,000
5		9	20,000

*AVAILABLE FOR BOTH STATIC AND CYCLIC TESTS

Figure 5 - Cross Section of an Array of Pressure Tanks Comprising a Deep Sea Simulation Facility

TABLE 2 - EXAMPLES OF CONSIDERATION IN DETERMINING PRESSURE TANK REQUIREMENTS

Considerations	Requirements
Use	Collapse tests, shock loadings, explosive loadings
Shape	Spherical or cylindrical (more efficient)
Size	Length, diameter
Material	Strength, toughness, fabricability, cost
Weight	Foundations, transportation of
Pressure	Maximum and minimum static, cyclic (rate) design and working
Pressure Medium	Water, oil, sea water, gas, etc.
Temperature	Static (max - min), cyclic (max - min), rate
Orientation	Vertical horizontal
Life	Fatigue life, anticipated usage and design life
Head Features	Size, time required to open and close tank
Seals	Zero leakage at all operating conditions
Penetrations	Size, locations
Feed-Thrus	For instrumentation, etc.
Coatings	Insulation and corrosion protection, clodding, painting, anechoic
Safety	Design and construction, operation standards

Figures 6 and 7 are photographs of the NSRDC deep sea simulation facilities at Carderock. Appendix A gives the detailed characteristics of these facilities and illustrates some of the various tests conducted in them.

AVAILABILITY/LOCATION

For simplicity, this discussion will be limited to deep sea simulation facilities with pressure tanks whose diameters are 1 ft or greater. The results of the survey indicate that over one-half of the pressure tank units reported were very small, i.e., less than 1 ft in diameter. The remaining 164 pressure tank units represent the more significant available capability. A detailed listing is given in Appendix B.

The survey shows that most of the facilities are available for additional work provided it is scheduled well in advance. This applies particularly to those at privately owned laboratory or research institutes and laboratories of the U. S. Navy.

As shown by Table 3, about one-half of these are owned by private laboratories or research institutes, oceanographic, instrument, and equipment companies and private shipyards and submarine builders and the remaining half are government owned and located mostly in the naval laboratories and shipyards. Geographically, the owners of these deep sea simulation facilities are in 37 separate locations along the Atlantic and Pacific coasts and the Gulf and Great Lakes areas as shown by Figure 8.

Figure 9 is a plot of tank diameter versus pressure for all available tanks with diameters of 1 ft or greater. The ten largest size tanks with the highest rated static pressure for a given diameter are shown in Figure 10 as a plot of length versus diameter. Generally speaking, for diameters up to and including 10 ft, tanks are available at pressures high enough to accommodate most deep sea simulation needs although for some specific applications the numbers of tanks available may be limited. Only two tanks are available with diameters greater than 10 ft and both of these are old and have an inadequate pressure and size capability. The lack of larger size tanks is a reflection of the high initial cost and the high cost of operating larger facilities. The greatest expense is for the pressure tank itself. On the basis of present materials and construction techniques, acquisition costs

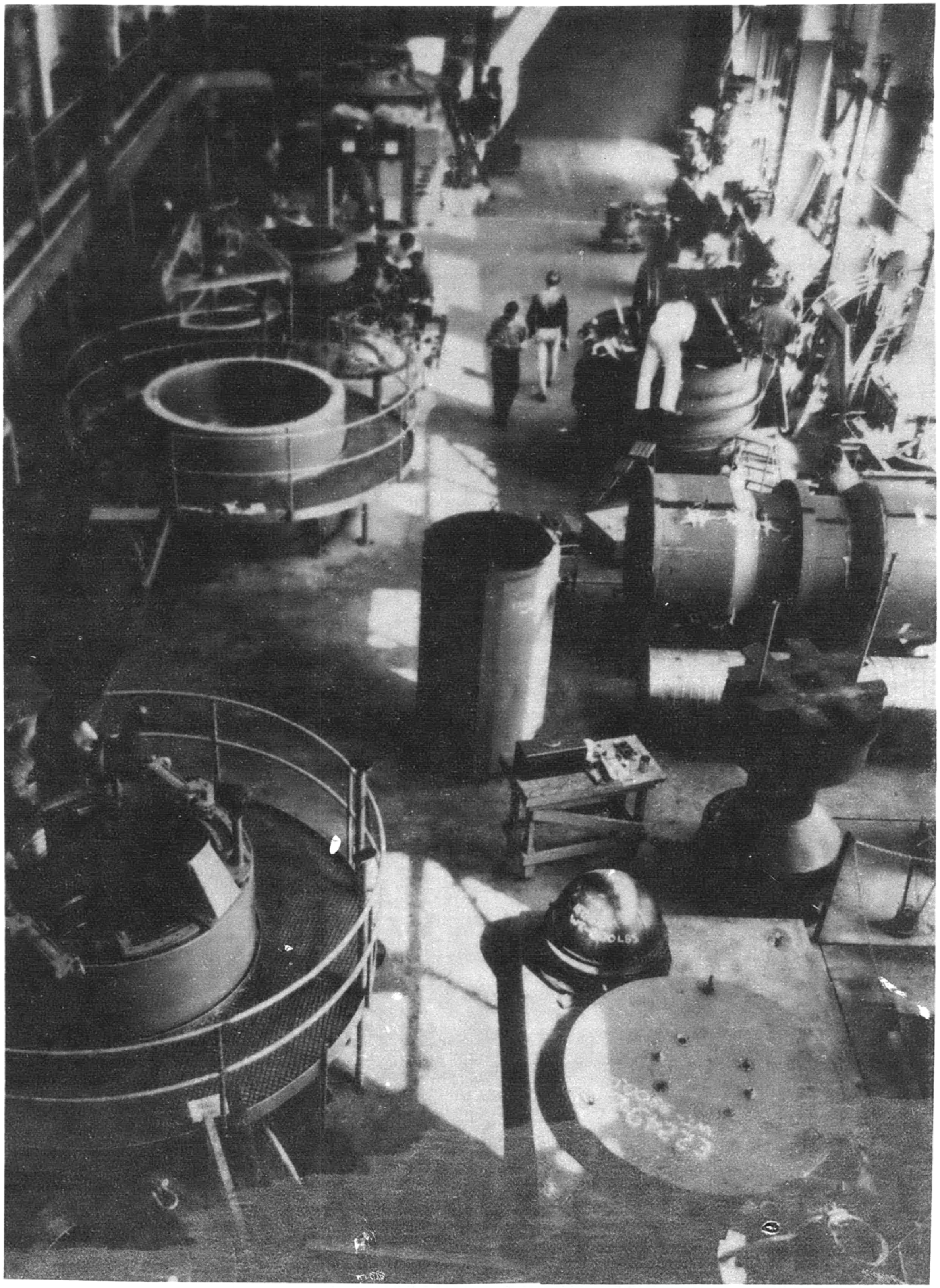


Figure 6 - Large Pressure Tanks at the NSRDC Facility

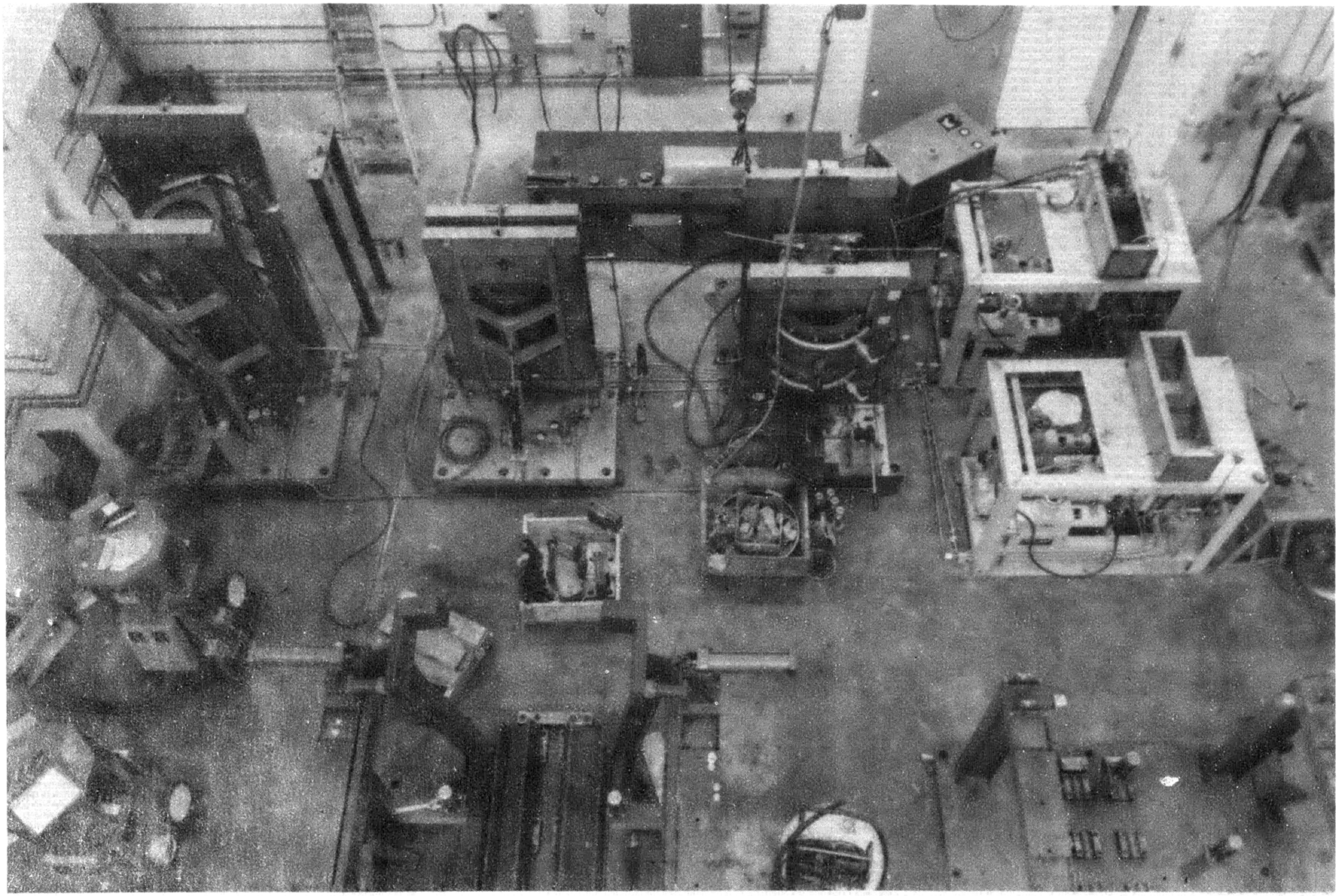


Figure 7 - Small Tanks at the NSRDC Facility

TABLE 3 - OWNERS OF MAJOR DEEP SEA SIMULATION FACILITIES

(Listing restricted to pressure tanks with diameters of 1 ft or greater. Additional details are available in Appendixes B and C.)

Privately Owned	Government Owned
Laboratories and Research Institutes: Southwest Research Institute Sandia Laboratory Wyle Laboratories Bell Telephone Laboratories IIT Research Institute Ordnance Research Laboratory	Navy Laboratories: NSRDC - Ship R&D Center, Carderock, Annapolis NURDC - Undersea R&D Center, San Diego, Pasadena NUSC - Underwater Systems Center, Newport, New London NWC - Weapon Center, China Lake NADC - Air Development Center, Warminister NCEL - Civil Engineering Laboratories, Port Hueneme NOL - Ordnance Laboratory, White Oak NRL - Research Laboratory, D. C., Orlando NCSL - Naval Coastal Systems Laboratory Panama City Naval Mine Engineering Facility, Yorktown, Pa. Naval Ordnance Station, Forest Park, Ill.
Oceanographic, Instrument, and Equipment Companies: Ocean Research North American Rockwell Sanders Association Submarine Signal Division of Raytheon A. C. Electronics Division of General Motors Benthos, Inc. Chesapeake Instrument Corporation Hazeltine Corporation	Oceanographic Laboratory: National Oceanographic Instrumentation Center
Shipyards and Submarine Builders: Perry Submarine Builders Electric Boat Division of General Dynamics Newport News Shipbuilding and Drydock Company Lockheed Missiles and Space Company	Naval Shipyards: Pearl Harbor Philadelphia Portsmouth Puget Sound Boston Charleston Mare Island

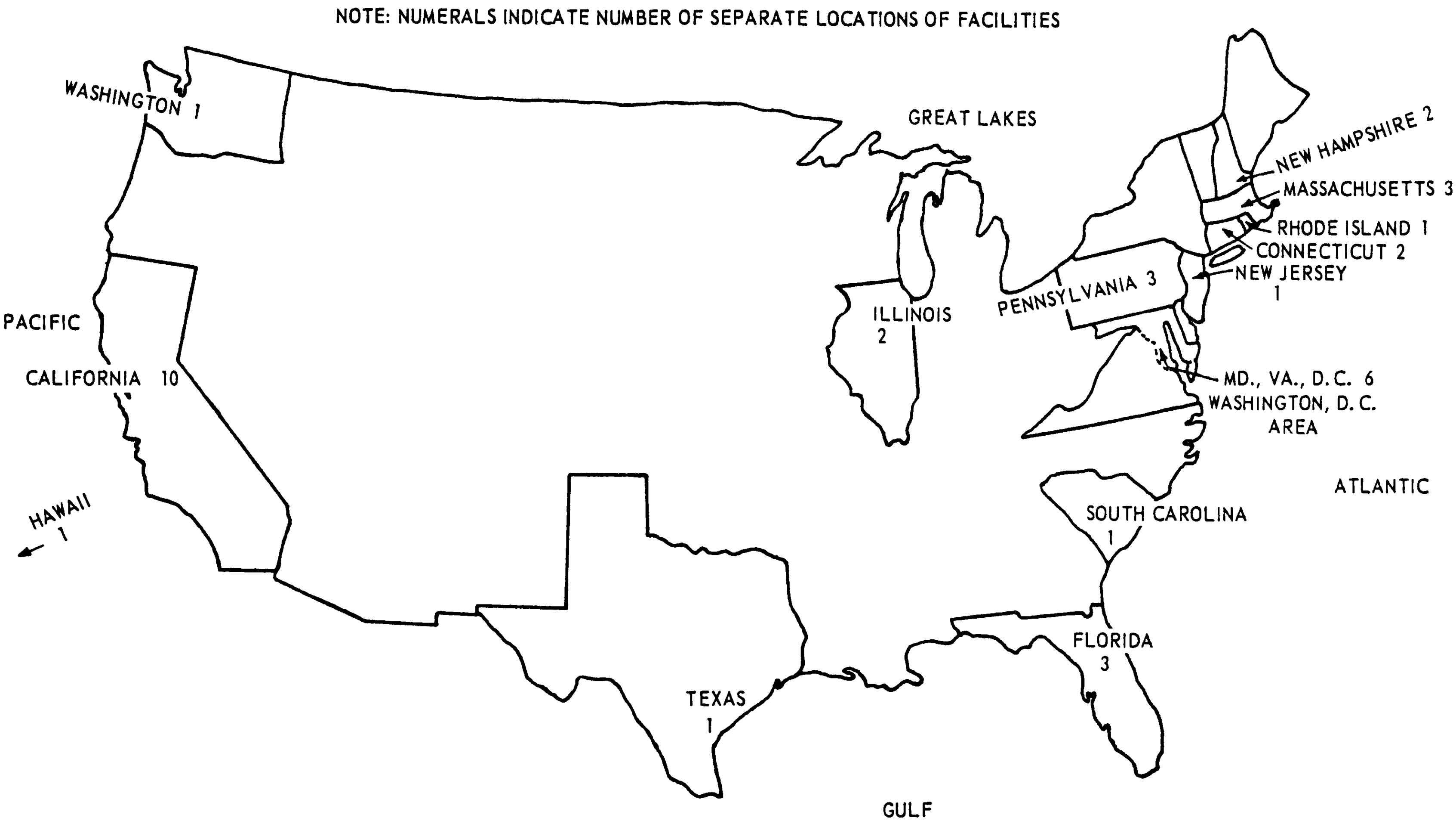


Figure 8 - Geographic Location of Deep Sea Simulation Facilities within the United States

(Limited to facilities with pressure tank diameters of 1 ft or greater.)

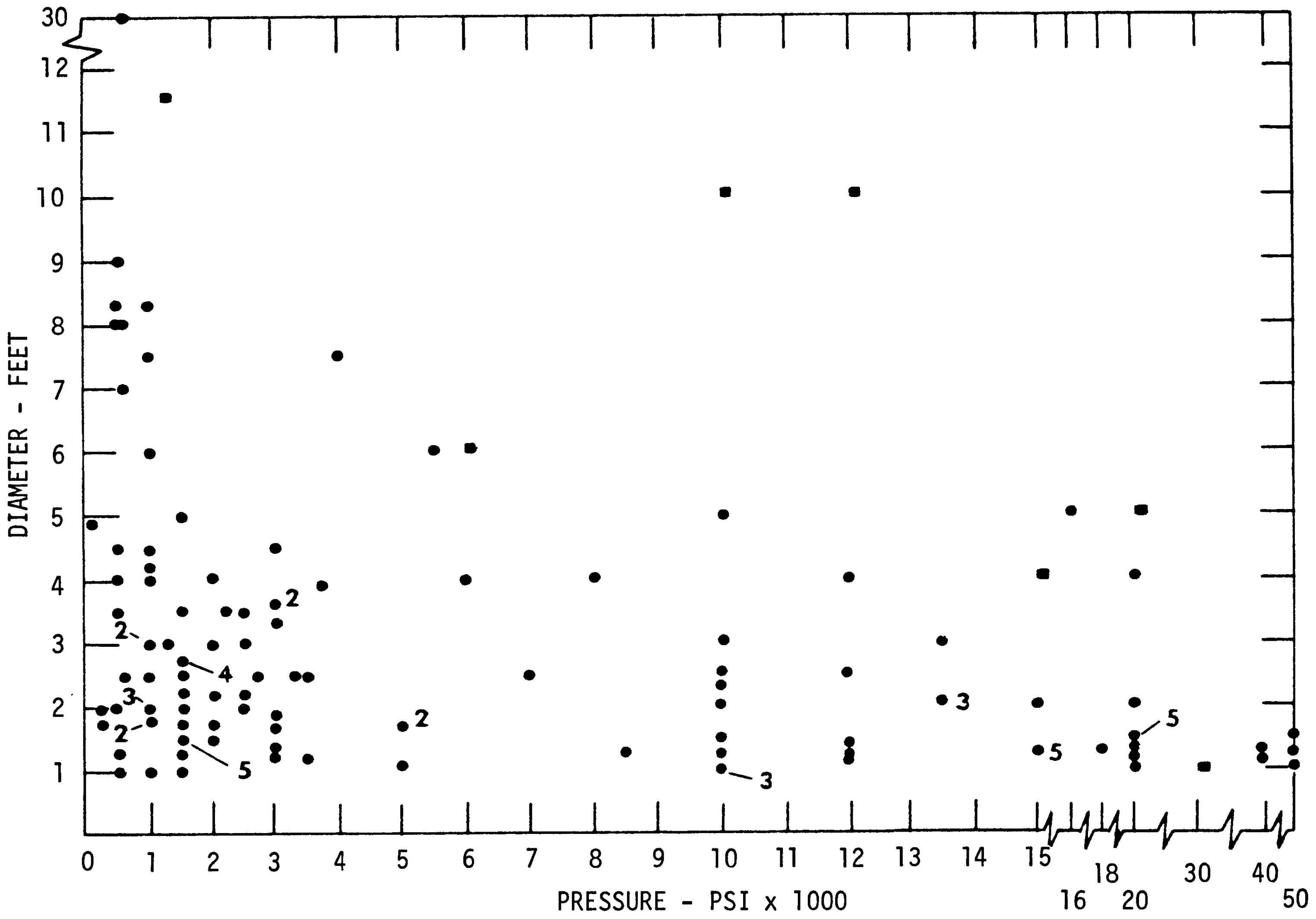


Figure 9 - Deep Sea Simulation Facilities (1972) - Pressure versus Diameter

(Limited to facilities with pressure tank diameters of 1 ft. or greater.)

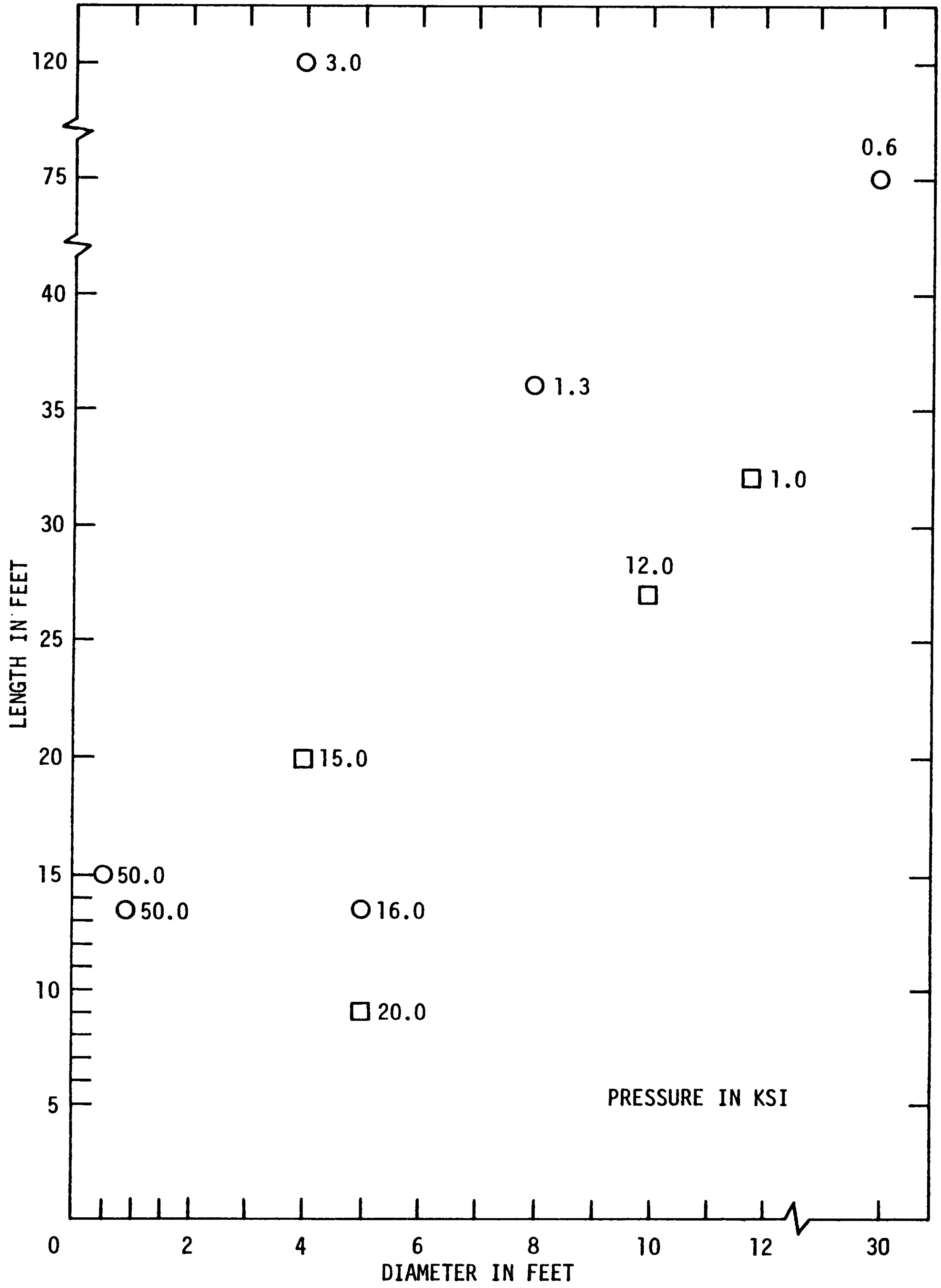


Figure 10 - Pressure versus Diameter for the Ten Largest Tanks with the Highest Rated Static Pressure

may run from $2 to $3 per pound or more. From time to time various studies and proposals have been made to determine the feasibility of larger facilities. Perhaps one of the more ambitious is shown by an artist's concept (Figure 11) of a facility to test full-scale submarines. None has been built in this country primarily because of the prohibitively high cost.

Aside from the basic considerations of tank size and hydrostatic pressure rating, other important features of these facilities include the pressure medium (fresh water, sea water, oil, or gas); cyclic pressure rating and rate; and temperature control. Obviously, a true deep sea simulation facility should be capable of employing sea water (real or artificially constituted) as the pressure medium and, preferably, should also permit the use of fresh water and oil. Oil is sometimes used to insulate instrumentation such as strain gages, etc., and thereby eliminate the added expense and effort needed to waterproof gages and instrumentation. The addition of cyclic capability and temperature control has become increasingly important since many devices and structures intended for use in the sea work very well under hydrostatic pressure but fail due to fatigue under cyclic loading; moreover many that work well at ambient temperatures do not work at all in the lower temperatures encountered in the sea.

The survey showed (Figure 12) that 164 of the 360 tanks have diameters of 1 ft or greater and that 85 of these permit the use of sea water for static testing only. Only 33 of these 85 are designed or equipped to permit static or cyclic pressure testing and only 21 of them include cyclic and temperature control. Only two tanks are available with diameters greater than 10 ft. Obviously, some of these can be updated to include the additional features of cyclic and temperature control. As shown later, however, many of the older tanks may be severely limited in this regard because of the materials from which they were made and because the original design does not meet present day standards.

MATERIAL CONDITION

One important consideration in the updating of an existing tank or building a new one for cyclic and/or low-temperature testing is the fracture-toughness of the material as measured by the nil-ductility-transition temperature (NDTT). This is generally determined by performing Charpy V-notch or

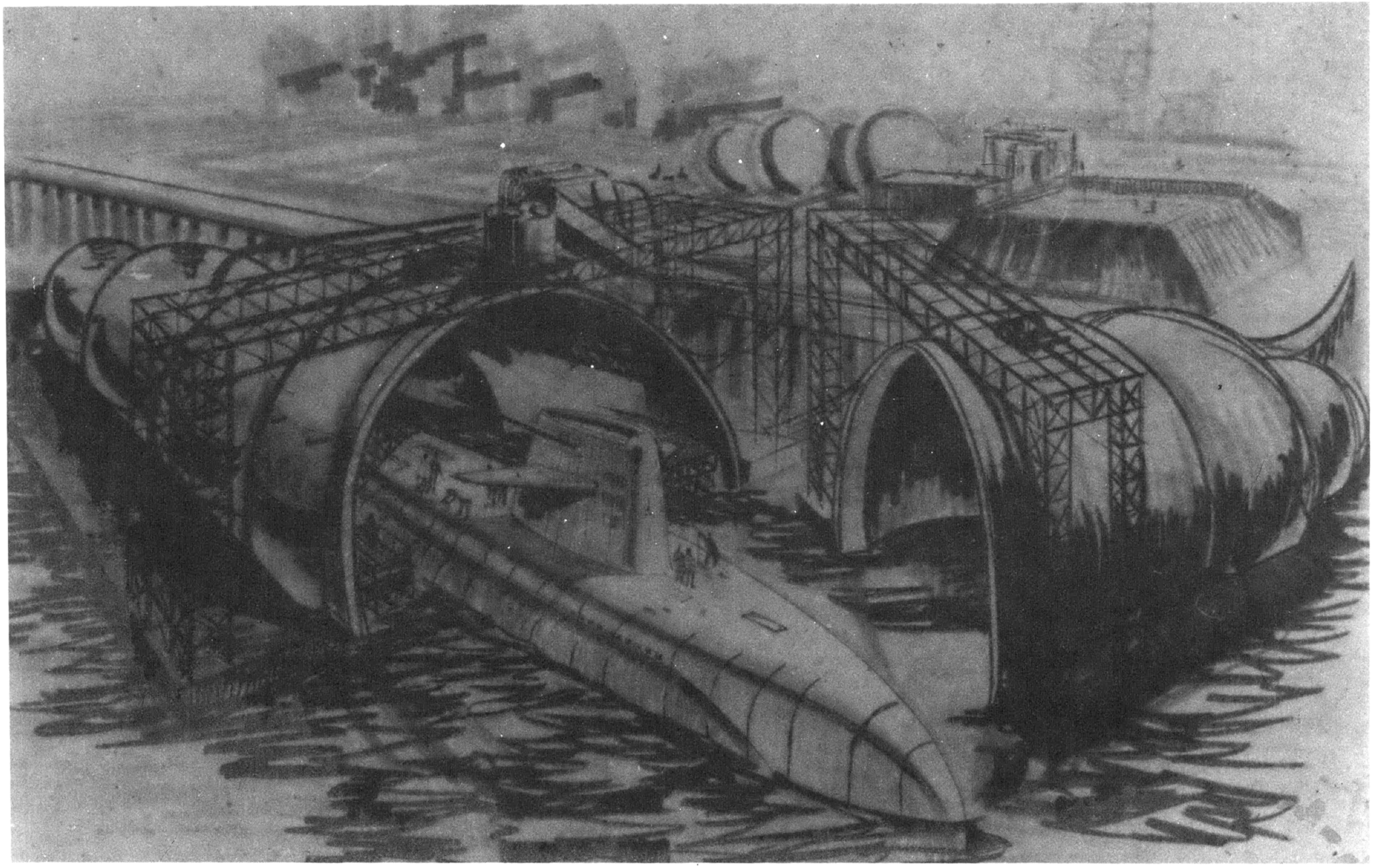


Figure 11. Artist's Concept of Tank for Testing Full Scale Submarines

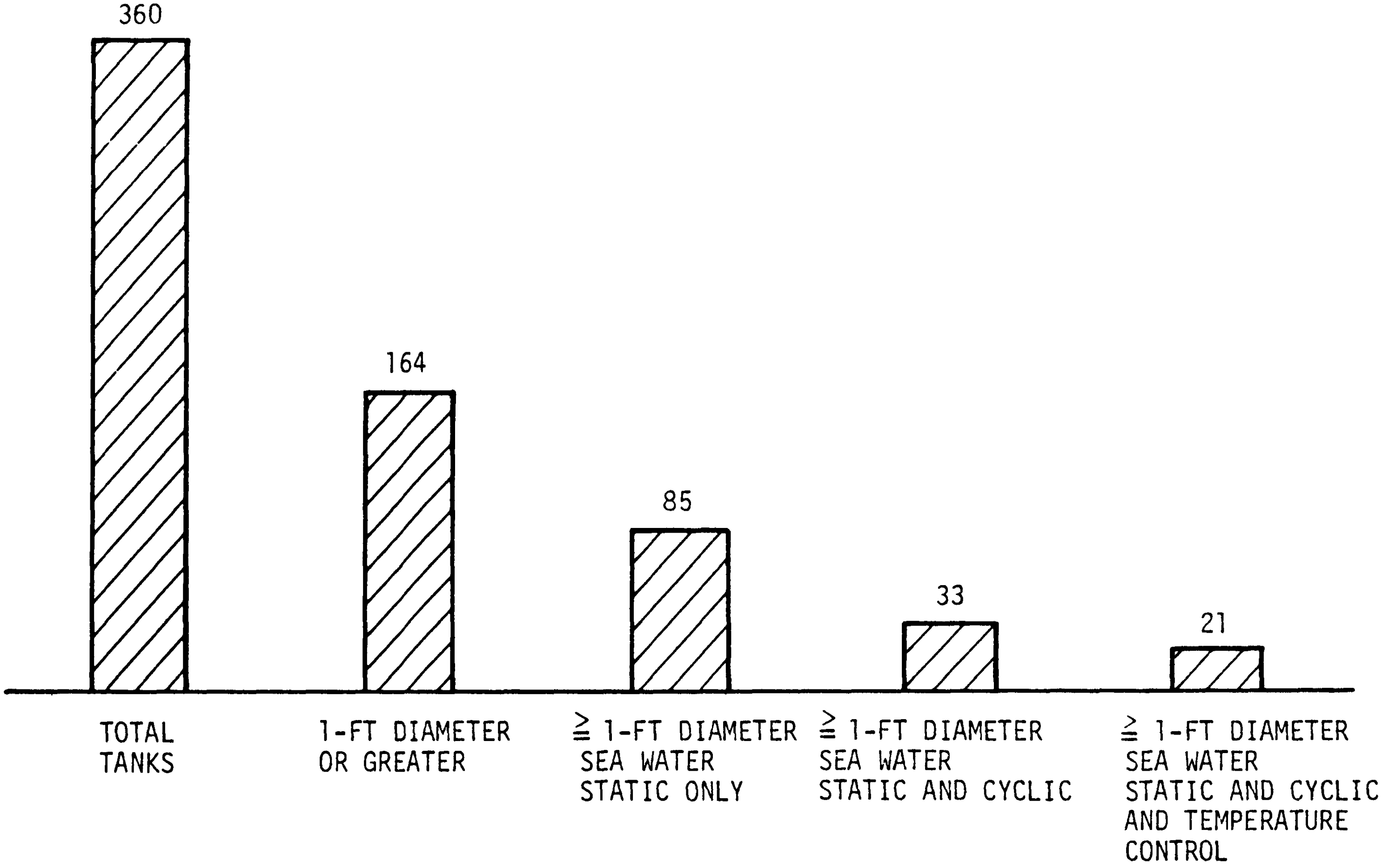


Figure 12 - Summary of Capabilities of Deep Sea Simulation Facilities

explosive bulge tests of the material.[8,9] In addition, any flaws or cracks in welds and components resulting from fabrication methods employed to construct pressure tanks and system components should be identified by appropriate nondestructive techniques such as ultrasonic, magnetic particle, liquid penetrant, and radiographic inspections, and the more recent stress wave emission methods. This information, together with an accurate finite element or similar stress analysis confirmed by strain measurements, constitutes a basis for conducting a fracture mechanics analysis to estimate the critical flaw size[10,11] and thereby determine whether or not the tank is susceptible to catastrophic brittle fracture or fatigue during its intended life cycle. Results of such an analysis determine requirements for periodic inspection, etc., during the service life of the tank and whether or not design specifications are met. The original design and fabrication should meet requirements of Section III ASME Pressure Vessel Code[12] or Section VIII, Division 2[13] or a suitable combination of these.

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[8] Masters, J. N. and C. F. Tiffanry, "Fracture Toughness Testing and Its Applications," Applied Fracture Mechanics, ASTM (1965).

[9] Pellini, W. S., "Advances in Fracture Toughness Characterizations Procedures and in Qualitative Interpretation to Fracture - Safe Design for Structural Steels," NRL Report 6713 (Apr 1968).

[10] Gifford, L. N., "Finite Element Analysis for Arbitrary Axisymmetric Structures," NSRDC Report 2641 (Mar 1968).

[11] Pellini, W. S. and F. J. Loss, "Interpretation of Metallurgical and Fracture Mechanics Concepts of Transition Temperature Factors Relating to Fracture - Safe Design for Structural Steel," NRL Report 6900 (Feb 1969).

[12] "Rules for Construction of Nuclear Vessels," ASME Boiler and Pressure Vessel Code Section III, New York (1968).

[13] "Pressure Vessel," ASME Boiler and Pressure Vessel Code Section VIII, Division 2 (1968).

As indicated by the tabulation given below, 50 to 60 percent of all existing tanks are made from materials whose properties are not known, and another 10 percent are made from materials not recommended for cyclic or low-temperature applications.

Tank Material	Percent
Properties unknown	50-60
Nonmetallic	2
Stainless steels	6
Quenched and tempered alloy steels	19
Normalized steels	2
Mild steels	6
Other (aluminum, cast iron)	1

The failure of a pressure tank made from brittle materials is quite catastrophic, as illustrated by Figure 13.

SAFETY

From a safety viewpoint, some insight into the importance of careful design, manufacture, operation and maintenance of these facilities is illustrated by the results of an NSRDC-sponsored survey which inquired into failures, mainly those of special-purpose high pressure test tanks and piping systems. The survey is limited since inquires were sent to only 50 government agencies and commercial organizations. Information resulting from this survey indicated the following reasons for failures or accidents involving high pressure test vessels and their systems:

1. Catastrophic brittle failures of vessels during hydrostatic tests, normal operation, or abnormal conditions.
2. Fatigue failures.
3. Failures due to faulty design.
4. Accidents caused by failure of auxiliary equipment (pressurizing system, cooling systems, pressure relief system, pipe whip, etc.).
5. Accidents caused by operator error.

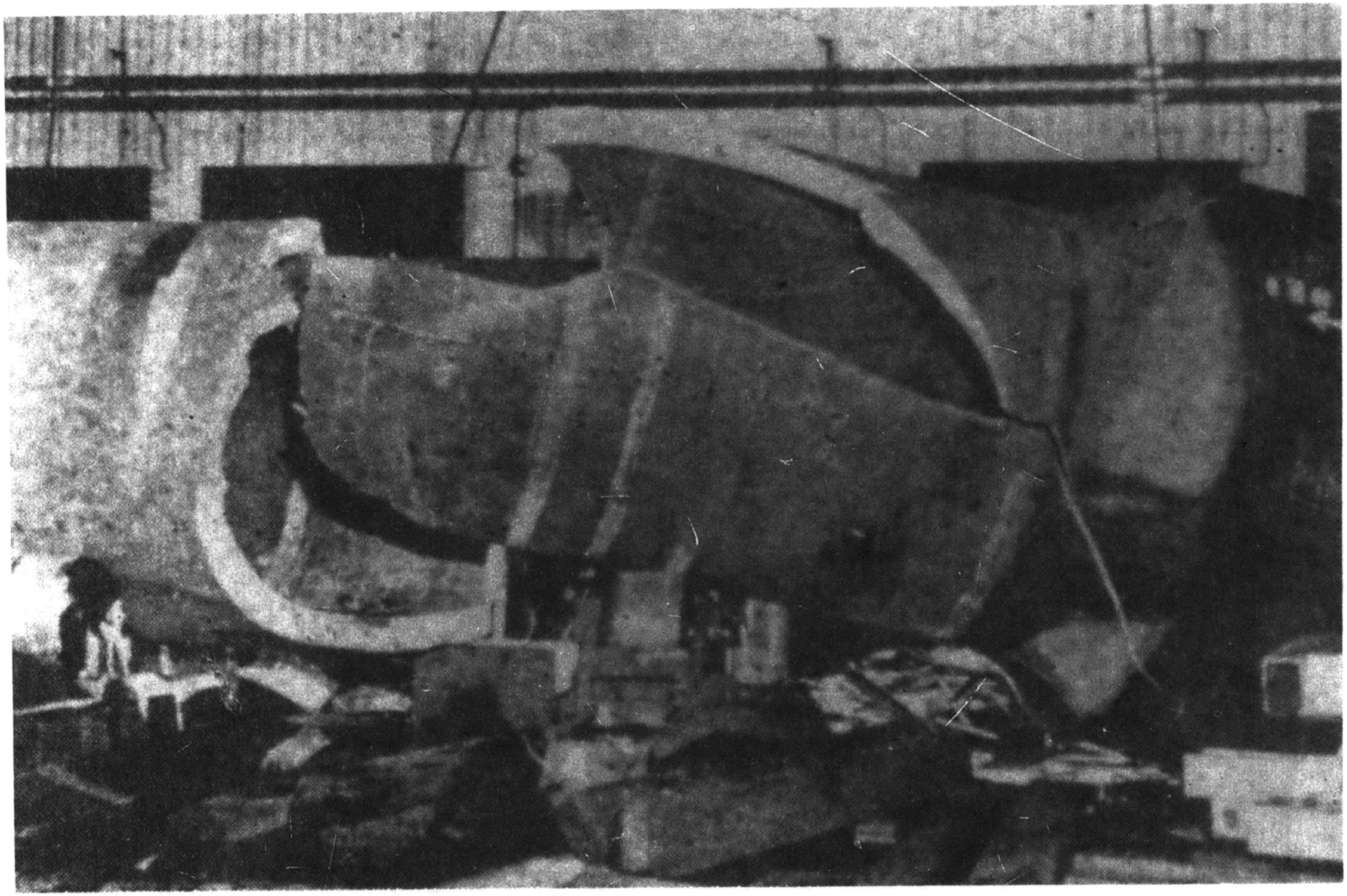


Figure 13 - Brittle Failure of Pressure Tank

6. Accidents caused by fire, vibration, explosions, earthquakes, etc.

7. Handling accidents.

8. Personnel accidents.

The causes of failure and the number of times they contributed to failures is shown in Table 4. Note that a large number of failures resulted from the use of materials with inadequate notch toughness, from inadequate designs that resulted in fatigue failure, from the presence of undetected flaws, and from improper welding and fabrication. Other important causes were attributed to ancillary systems failures such as missile and jet impingement due to failures at piping connection, inadequate piping restraints, control failures and malfunction, and fires.

TABLE 4 - TYPES AND FREQUENCY OF FAILURES
(Survey of 50 facilities)

Condition	Number of Times Condition Contributed to Failure
Inadequate Material Notch Toughness	18
Undetected Flaws Existing Prior to Installation	8
Lack of Appropriate Post-Weld Heat Treatment	8
Design Inadequacies and Fatigue Failures	14
Improper Material Selection	4
Inadequate or Improper Piping Restraints	4
Missiles and Jet Impingement	7
Poor Welds	2
Pressure-Gage Failures	2
Control System Malfunctions	3
Hydrogen Embrittlement	3
Failure of Converted Surplus Guns	2
Hydraulic Oil Fires	4
Laboratory Fires	2
Inadequate or Improper Maintenance Procedures	1
O-Ring Failures	2
Thermal Shock	2
Furnace-Sensitized Austenitic Stainless Steel	4
Use of Compressed Air Rather than Inert Gas	1

APPENDIX A

CHARACTERISTICS OF NSRDC DEEP SEA SIMULATION FACILITIES AT CARDEROCK

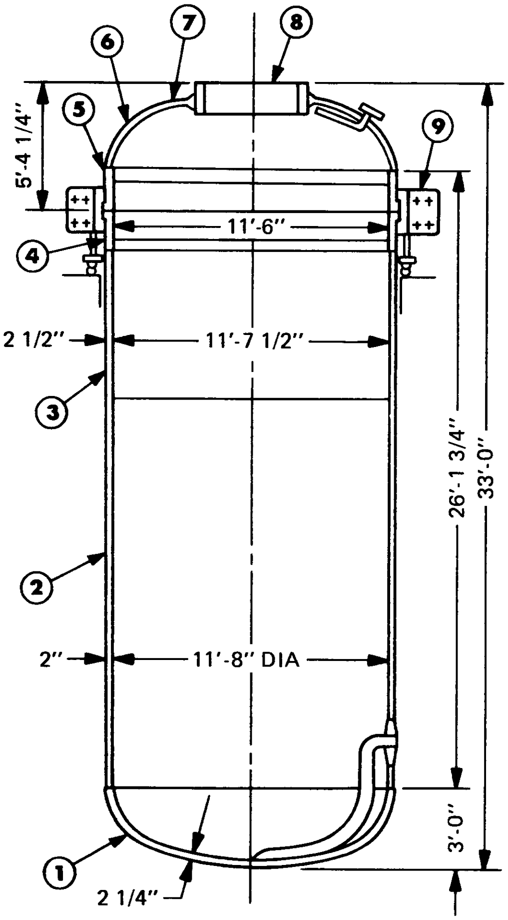
DEEP SUBMERGENCE SIMULATION FACILITIES

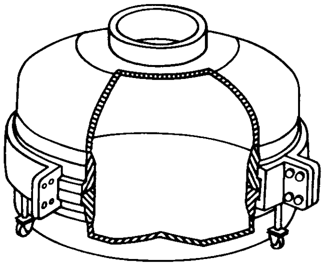
NSRDC, CARDEROCK

INSIDE DIAMETER	INSIDE LENGTH	MAXIMUM STATIC* OPERATING PRESSURE (PSI)	CLOSURE LOCKING SYSTEM
1.5 in.	2.25 in.	30,000	Bolts
2.25 in.	32 in.	40,000	Screw Ring
2.25 in.	32 in.	40,000	Screw Ring
3 in.	20 in.	47,500	Screw Ring
3 in.	22 in.	60,000	Pin
3 in.	22 in.	60,000	Pin
4 in.	3.3 ft	25,000	Screw Ring
5 in.	9 in.	30,000	Screw Ring
10 in.	23 in.	2,500	Bolts
11.5 in.	Spherical	30,000	Yoke Sleeve
12 in.	Spherical	30,000	Bolts
15 in.	22 in.	15,000	Yoke Plates
15 in.	22 in.	15,000	Yoke Plates
15 in.	3.5 ft	15,000	Yoke Plates
16 in.	4.6 ft	15,000	Yoke Plates
17.5 in.	8 ft	25,000	Breech Lock
20 in.	4 ft	2,500	Bolts
2 ft	4 ft	18,000	Yoke Plates
3 ft	Spherical	10,000	Radial Pins
4 ft	20 ft	15,000	Breech Lock
5 ft	9 ft	16,000	Yoke Plates
6 ft	21 ft	6,000	Screw Ring
10 ft	Spherical	10,000	Radial Pins
11.5 ft	30 ft	1,200	Ring Clamp

*Equipped for limited cyclic pressure testing in addition to static testing.

12 - FOOT DIAMETER TEST FACILITY





TEST TANK CHARACTERISTICS

Cylindrical

Maximum usable diameter is 11′ 6″

Inside length - 27 feet

Dished head lifts off

Locking Means - segmented clamping ring

OPERATING CHARACTERISTICS

Head is removable in 30 minutes

Average test set-up time 4 to 8 hours

TANK CONSTRUCTION

1. Dished Head, sts
2. Lower Cylinder, sts
3. Upper Cylinder, sts
4. Insert
5. Insert
6. Upper Head, sts
7. Collar
8. Port
9. Clamping Ring

TEST CAPABILITIES

Maximum pressure	1200 psi
Minimum soft cyclic pressure	100 psi
* Maximum soft cyclic pressure	1200 psi
Maximum cyclic rate	1 cpm
Tank cannot be cooled	

HANDLING FACILITIES

35 Ton Bridge Crane

15 Ton Auxiliary Hook

INSTRUMENTATION

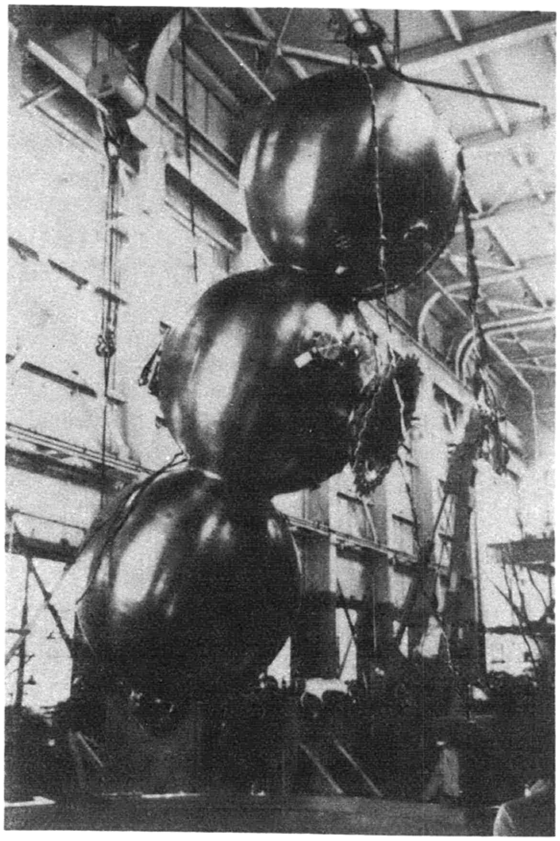
Recording equipment for up to 1900 strain gages

PRESSURE MEDIA

Fresh or salt water for static or cyclic testing

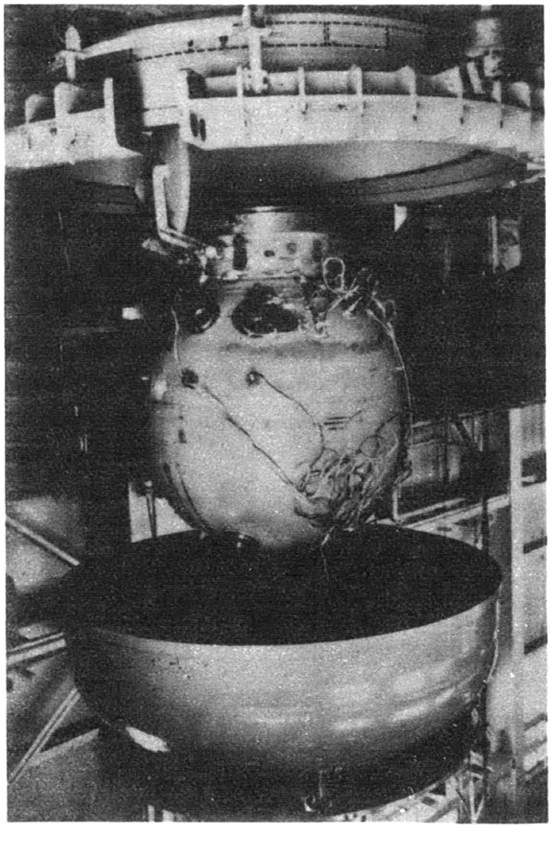
Oil (Shell Vitrea 21) for static tests only

*An NSRDC patented piping, valving and control system allows cyclic testing by varying the pressure within the model while keeping the tank pressure constant.

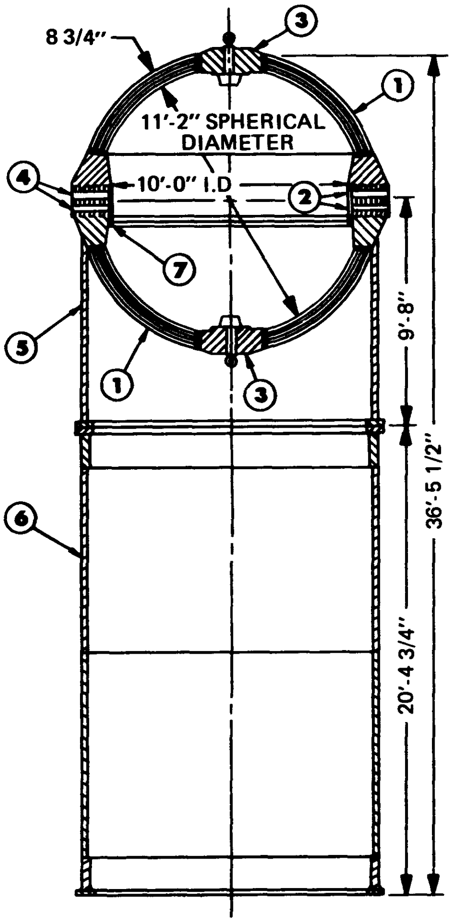


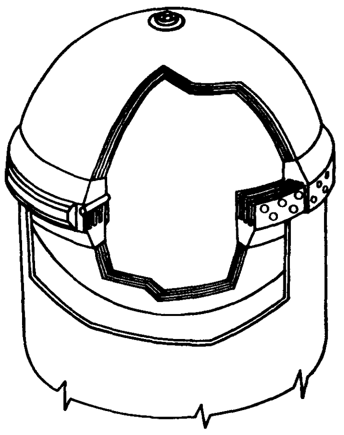
Pressure Hull of the Deep Submergence Rescue Vehicle instrumented for a static test being lowered into the 12-ft. diameter test tank.

Personnel transfer capsule is shown being tested in an operating position. The outside hatch at bottom is shown open so divers can be discharged at ocean depths. The capsule is also used to bring divers to the surface and discharge them directly into a decompression chamber.



10 - FOOT DIAMETER TEST FACILITY





TEST TANK CHARACTERISTICS

Spherical

Maximum usable diameter 10-Feet

Upper half sphere lifts off

Locking Means - Interleaved forgings and taper pins

OPERATING CHARACTERISTICS

Time required to open or close tank - - 1 hour

Average test set-up time - 4 to 8 hours

TANK CONSTRUCTION

1. Shell, Laminated Steel Plates
2. Interlocking Finger Forgings (Top & Bottom)
3. Penetration Forging (Top & Bottom) Accomodates leads for instrumentation
4. Radial Taper Pins (74 Required)
5. Support Skirt
6. Extension Skirt, Mild Steel
7. Seal, "O" Ring

TEST CAPABILITIES

Maximum Pressure	10,000 psi
Minimum Test Pressure	100 psi
* Soft Cyclic Maximum Pressure	10,000 psi
Maximum Cyclic Rate	1 cpm
Chilled Pressure Media to	+35° F

HANDLING FACILITIES

100 Ton Gantry Crane

35 Ton Bridge Crane

15 Ton Auxiliary Hook

INSTRUMENTATION

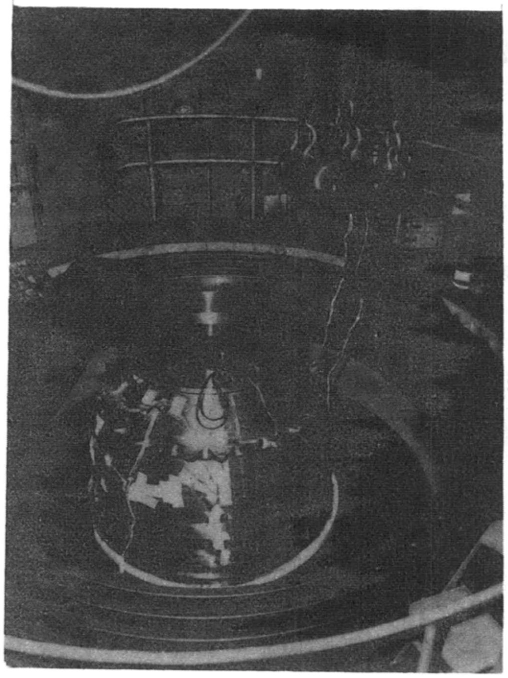
Recording equipment for up to 1900 strain gages

PRESSURE MEDIA

Fresh or salt water for static or cyclic testing

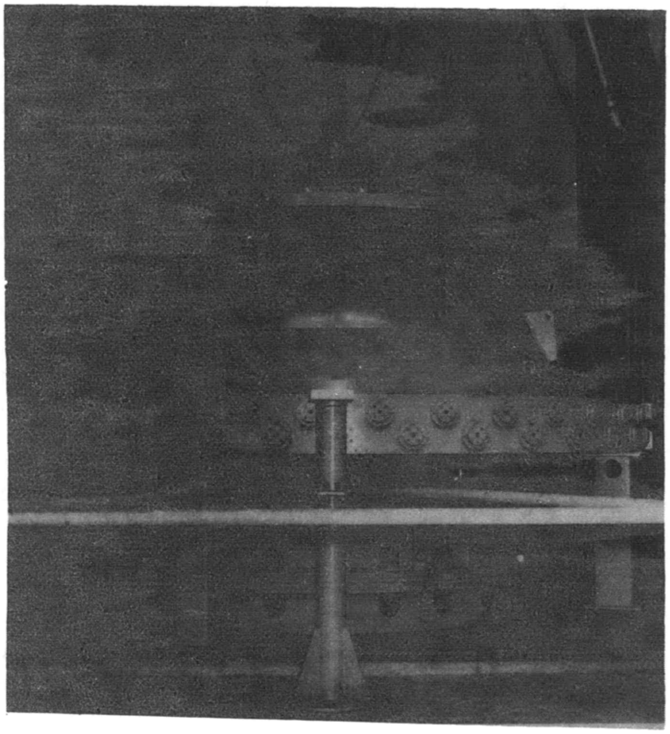
Oil (Shell Vitrea 21) for static tests only

*An NSRDC patented piping, valving and control system allows cyclic testing by varying the pressure within the model while keeping the tank pressure constant.

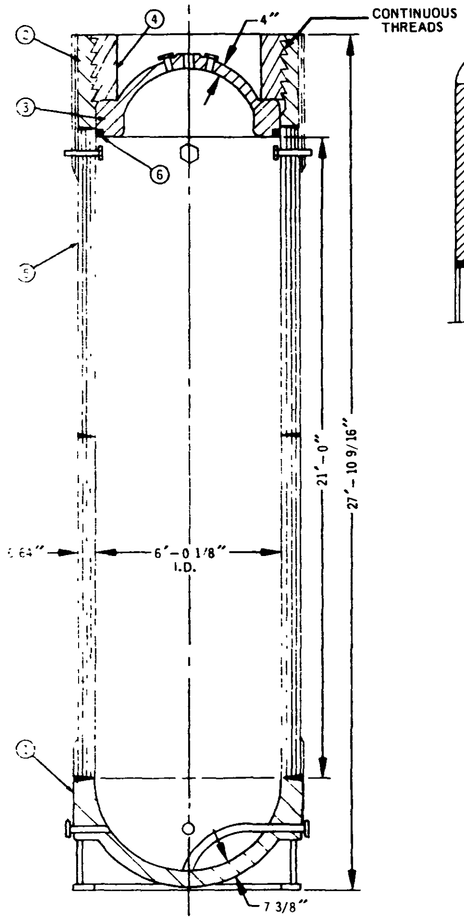


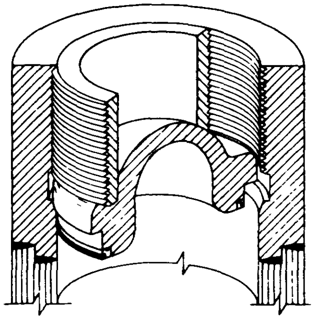
Upper half of tank removed. Model of Deep Submergence Rescue Vehicle Skirt instrumented and being readied for test.

View at right shows tank closed and nearly ready for test.



6 - FOOT DIAMETER TEST FACILITY





TEST TANK CHARACTERISTICS

Cylindrical

Maximum usable diameter is 6'-0"

Inside length - 23 feet

Hemi-head lifts off

Locking Means - threaded retaining ring

OPERATING CHARACTERISTICS

Head is removable in 15 minutes

Average test set-up time 4 to 8 hours

TANK CONSTRUCTION

1. Hemi-head, σ_y = 58 KSI forging
2. Ring, σ_y = 42 KSI forging
3. Hemi-head, HY-80 forging
4. Retainer, HY-80 forging
5. Cylinder, laminated σ_y = 70 KSI steel plate
6. Sealing ring

TEST CAPABILITIES

Maximum pressure	6,000 psi
Minimum soft cyclic pressure	100 psi
* Maximum soft cyclic pressure	5,600 psi
Maximum cyclic rate	1 cpm
Chilled pressure media to	+35° F

HANDLING FACILITIES

35 ton bridge crane

15 ton auxiliary hook

INSTRUMENTATION

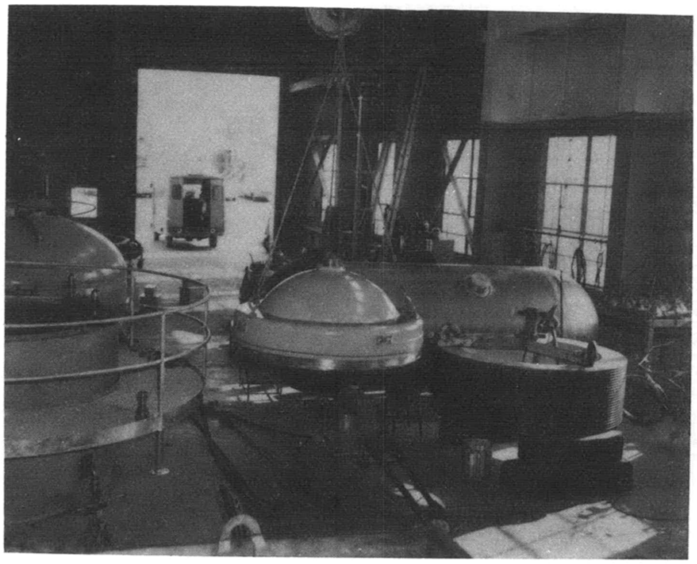
Recording equipment for up to 1900 strain gages

PRESSURE MEDIA

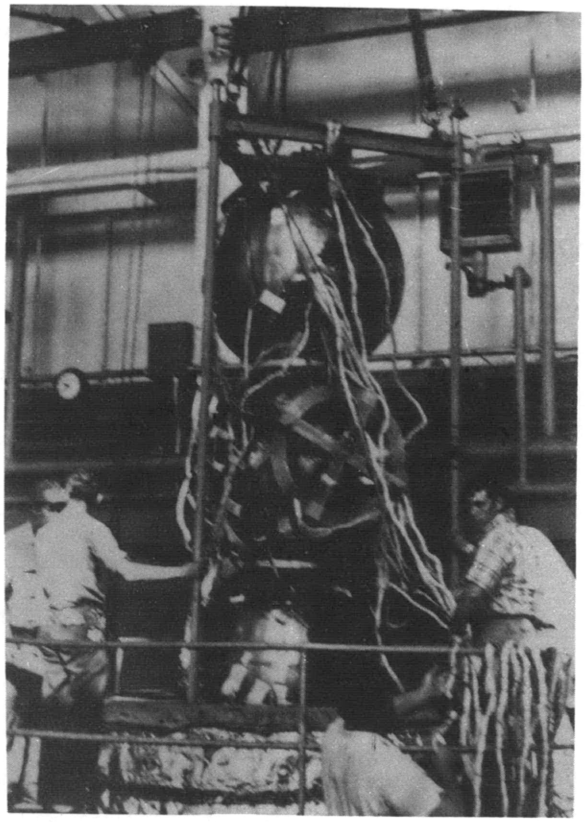
Fresh or salt water for static or cyclic testing

Oil (Shell Vitrea 21) for static tests only

***An NSRDC patented piping, valving and control system allows cyclic testing by varying the pressure within the model while keeping the tank pressure constant.**

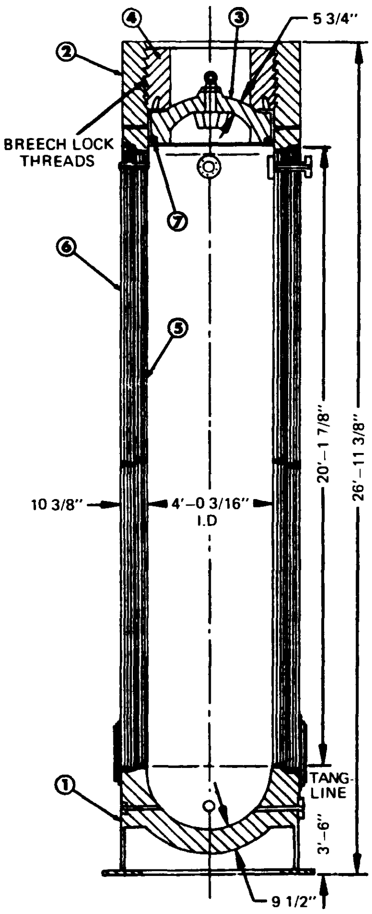


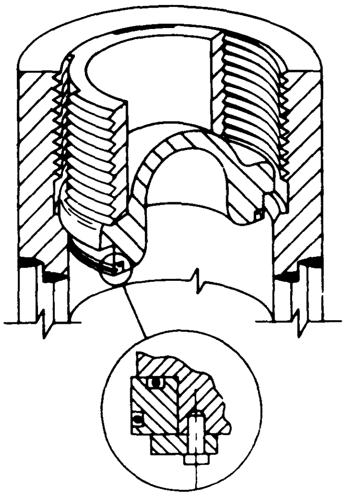
The 6-foot diameter test facility opened to show the closure head and the threaded retaining ring.



One-half scale model of the Deep Submergence Rescue Vehicle pressure hull, instrumented with 842 strain gages, being installed in the 6-ft. diameter test facility. The entire tank is covered with insulation for a chilled water test.

4-FOOT DIAMETER TEST FACILITY





TEST TANK CHARACTERISTICS

Cylindrical

Maximum usable diameter is 4'-0"

Inside length - 21 feet

Hemi-head lifts off

Locking Means - Breech lock retaining ring

OPERATING CHARACTERISTICS

Head is removable in 10 minutes

Average test set-up time 4 to 8 hours

TANK CONSTRUCTION

1. Hemi-head, HY-80 forging
2. Ring, HY-80 forging
3. Hemi-head, HY-80 forging
4. Retainer, HY-80 forging
5. Liner, monel
6. Cylinder, laminated HY-100 thin plate
7. Sealing ring

HANDLING FACILITIES

35 ton bridge crane

15 ton auxiliary hook

TEST CAPABILITIES

Maximum pressure	15,000 psi
Minimum soft cyclic pressure	100 psi
* Maximum soft cyclic pressure	11,000 psi
Maximum cyclic rate	1 cpm
Chilled pressure media to	+35° F

INSTRUMENTATION

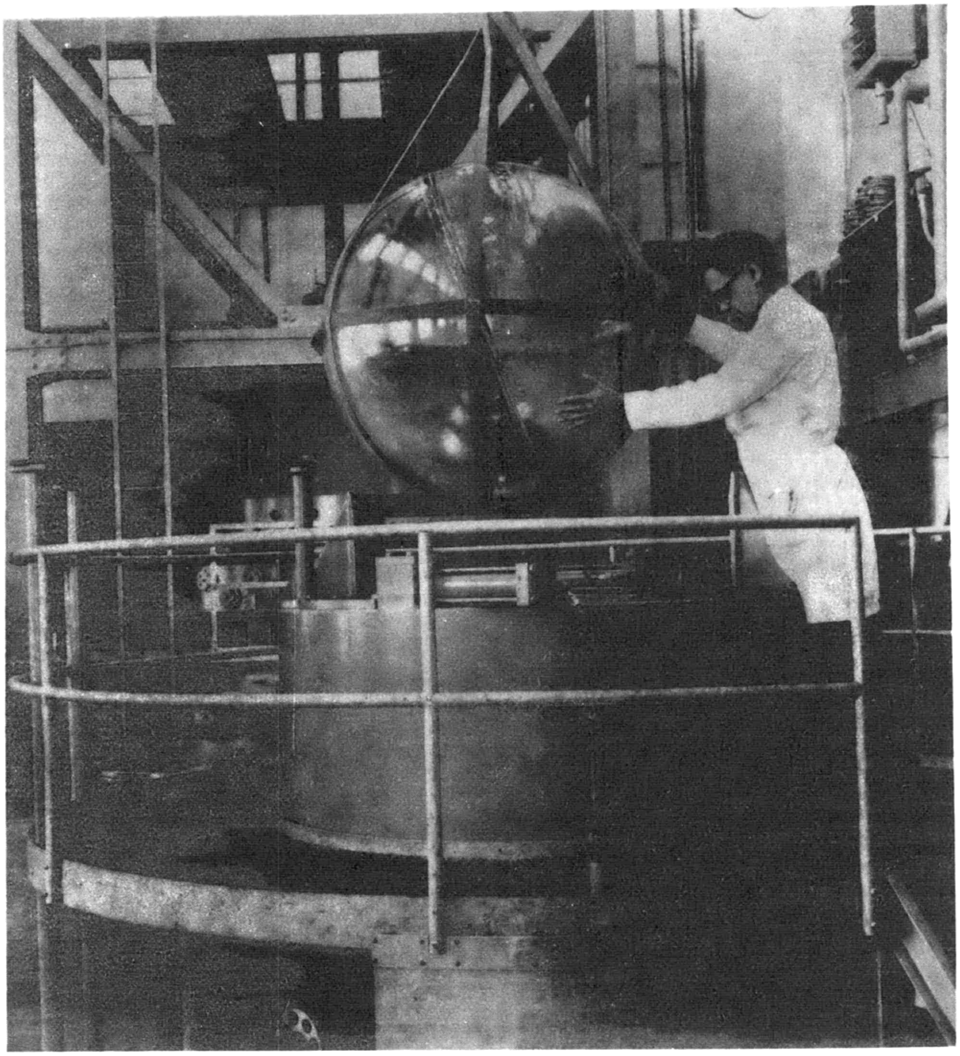
Recording equipment for up to 1900 strain gages

PRESSURE MEDIA

Fresh or salt water for static or cyclic testing

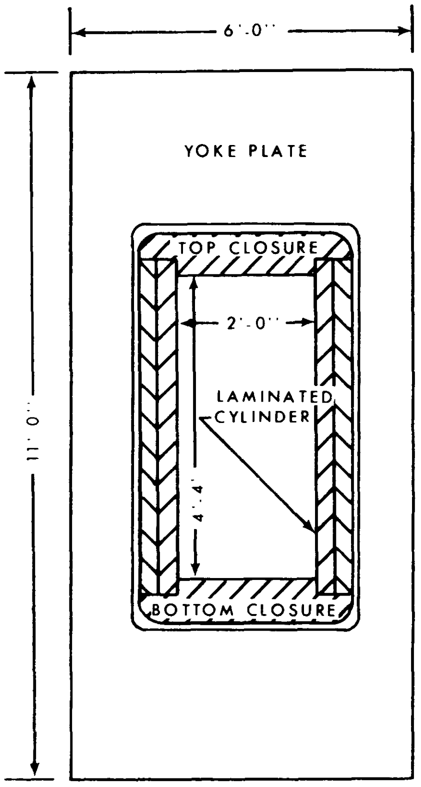
Oil (Shell Vitrea 21) for static tests only

*An NSRDC patented piping, valving and control system allows cyclic testing by varying the pressure within the model while keeping the tank pressure constant.



44-inch diameter fusion-welded massive glass sphere is lowered into the 4-Foot Diameter Tank to be tested for the Deep Ocean Technology Program

2 - FOOT DIAMETER TEST FACILITY



TEST TANK CHARACTERISTICS

Maximum usable diameter	23.5"
Maximum usable length	4' - 0"
End closure locking system	Yoke Plates

OPERATING CHARACTERISTICS

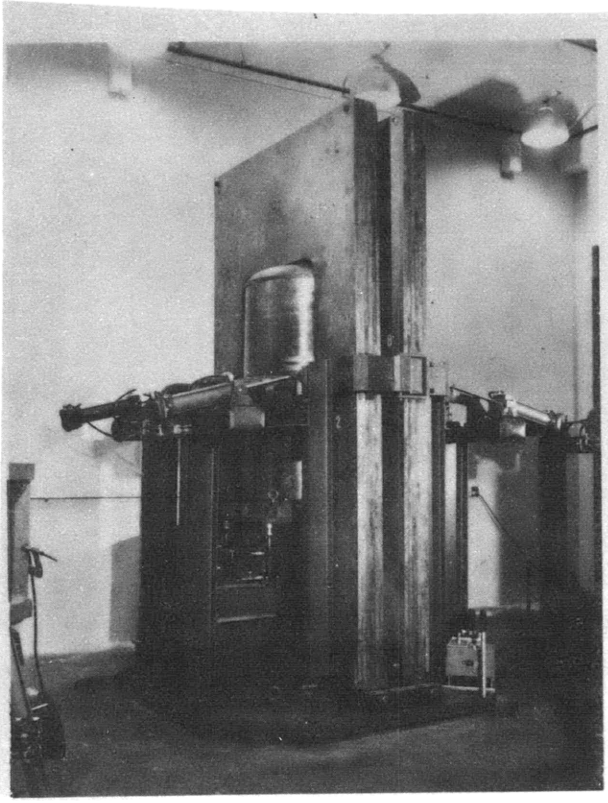
Time required to open or close tank	10 Min
Average test set-up time	2 - 4 hr
Electrical penetrator leads available for strain gages	500

STATIC TESTING

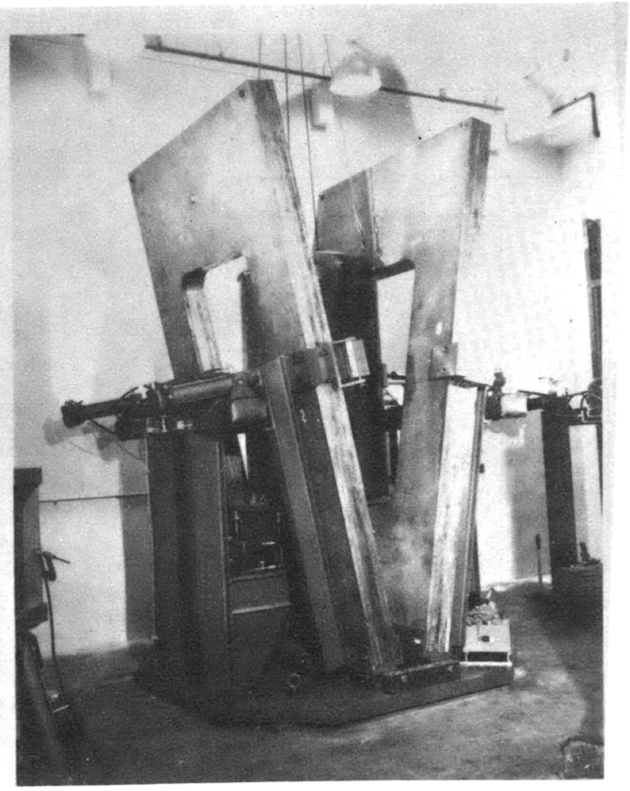
Maximum operating pressure (20,000 psi in present temporary location)	30,000 psi
Pressurization medium	Fresh water or Oil (Shell Vitrea 21)

CYCLIC TESTING

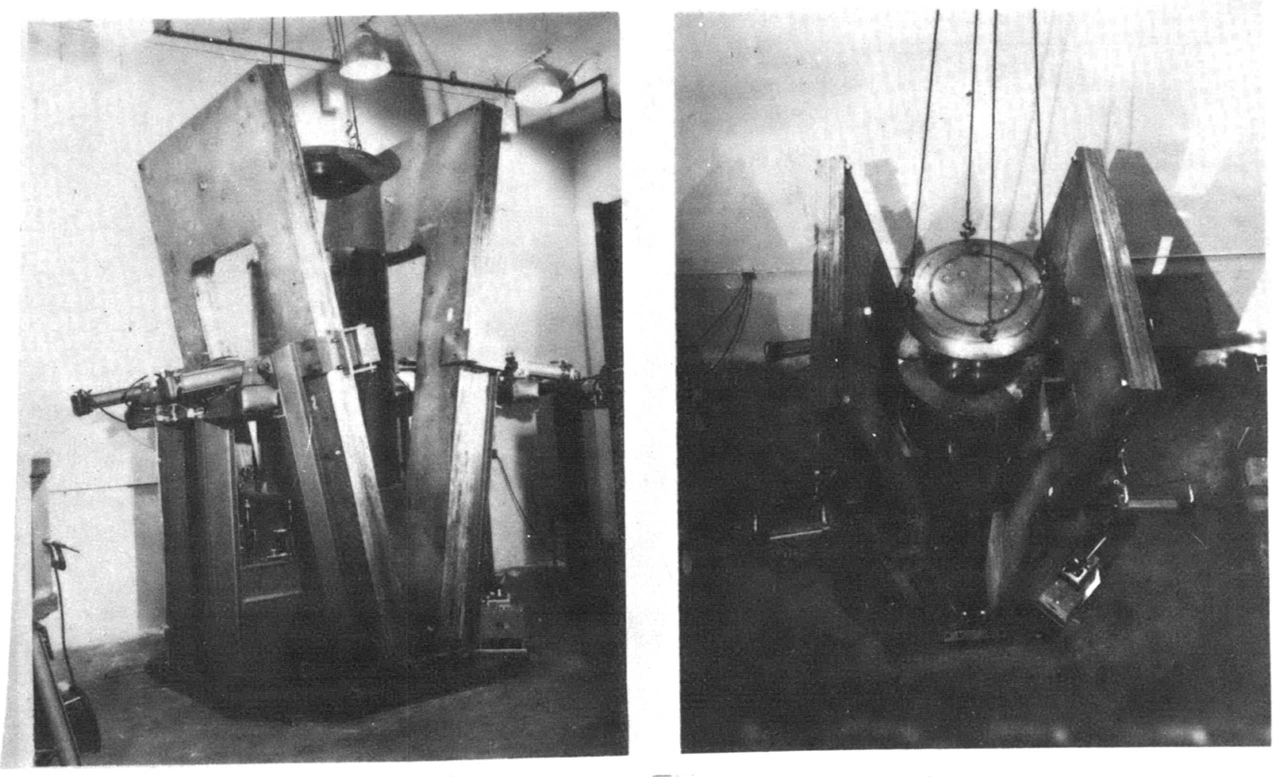
Maximum cycling pressure	10,000 psi
Maximum cycling rate	.1 cpm
Pressurization fluid	Fresh water



The 2-foot diameter test facility with the yoke plates closed and the tank ready to be pressurized.

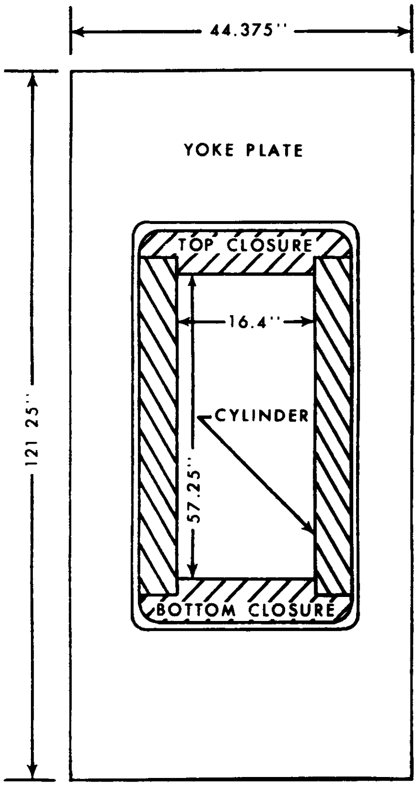


The tank is lifted off the yoke plates and supported on jacks while the yokes are opened.



The top closure is lifted by the crane to permit access into the cylinder.

16 - INCH DIAMETER TEST FACILITY



TEST TANK CHARACTERISTICS

Maximum usable diameter	15.5"
Maximum usable length	52"
End closure locking system	Yoke Plates

OPERATING CHARACTERISTICS

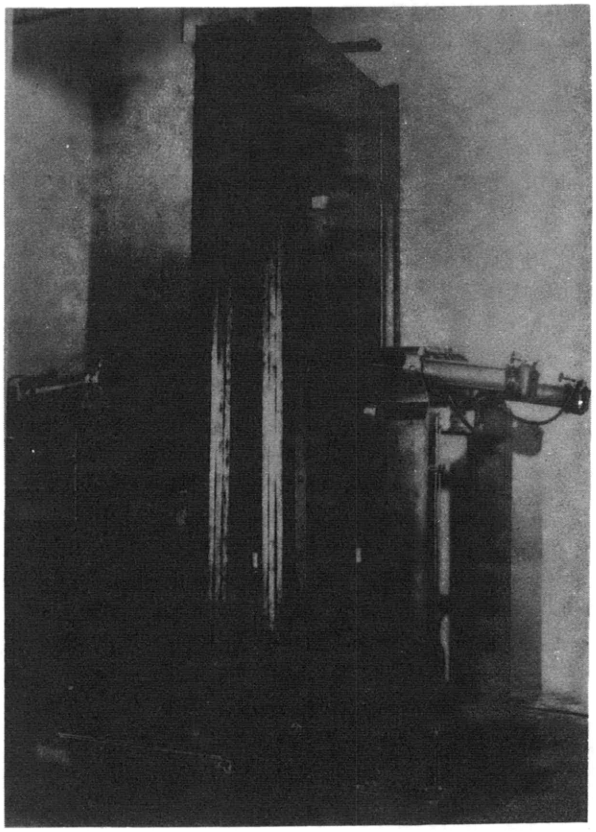
Time required to open or close tank	10 min
Average test set-up time	2 - 4 hr
Electrical penetrator leads available for strain gages	500

STATIC TESTING

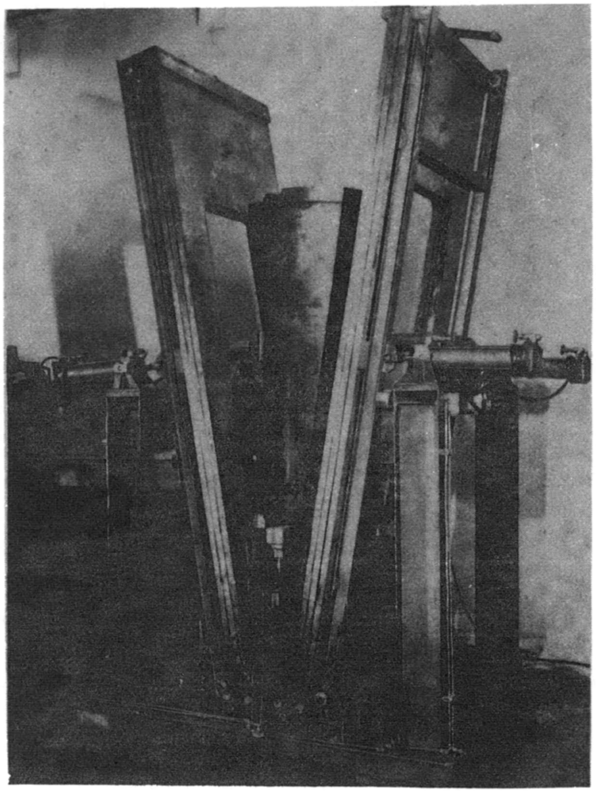
Maximum operating pressure	15,000 psi
Pressurization medium	Fresh water or Oil (Shell Vitrea 21)

CYCLIC TESTING

Maximum cycling pressure	6,000 psi
Maximum cycling rate	1 cpm
Pressurization fluid	Fresh water

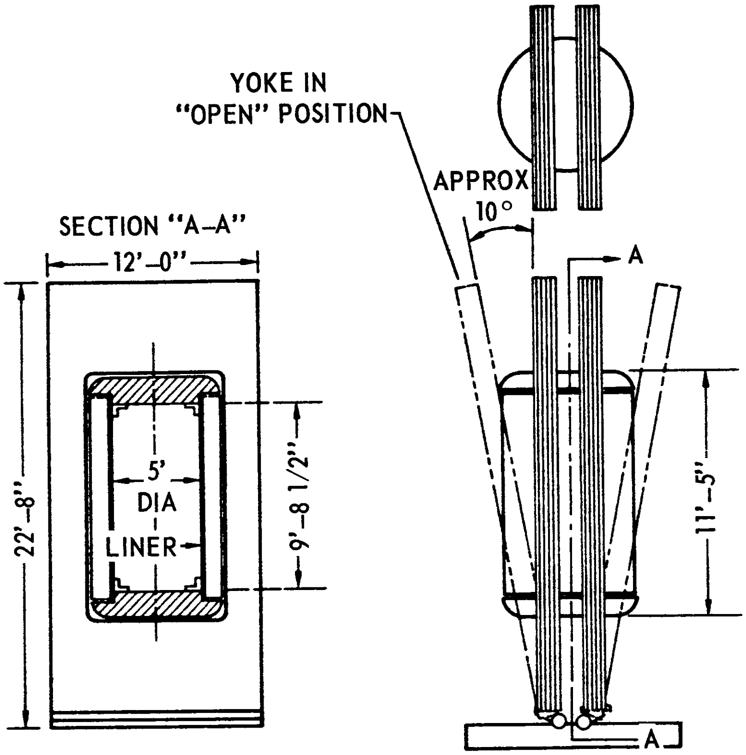


The 16 - inch diameter test facility with the yoke plates closed and the tank ready to be pressurized.



The tank is lifted off the yoke plates and supported on jacks while the yokes are opened. The top closure can now be lifted for access into the cylinder.

5-FOOT-DIAMETER TEST FACILITY



PRESSURE TANK 5 FT DIAMETER – 16,000 psi

TEST TANK CHARACTERISTICS

Maximum usable diameter is 5 ft 0 in.

Maximum usable length is 9 ft

End closure locking system – Yoke Plates

OPERATING CHARACTERISTICS

Time required to open or close tank is 1 hr

Average test setup time is 4 hr

Electrical penetrator leads available for strain gages – 1000

STATIC TESTING

Maximum operating pressure – 16,000

Pressurization medium – Fresh water with rust preventative or Oil (Shell Vitrea 21)

CYCLIC TESTING

Maximum cycling pressure – 10,000 psi

Maximum cycling rate – 1 cpm

Pressurization fluid – Fresh water with rust preventative

APPENDIX B

LISTING OF AVAILABLE FACILITIES WITH PRESSURE TANKS OF 1-FOOT DIAMETER OR GREATER

LOCATION	DIAMETER	LENGTH	MAXIMUM PRESSURE - PSI		FLUID	TEMP CONTROL
	FT	FT	STATIC	CYCLE		
A. C. Electronics Division of General Motors Goleta, California	2.33	5.0	10,000	0-10000 3 CPH	FW SW	35-75F
Bell Telephone Laboratories East Hanover, New Jersey	1.16	9.75	12,000	None	FW/SW Oil	25-70F
Benthos, Inc. N. Falmouth, Massachusetts	2.0	6.0	15,000	0-15000 6 CPH	FW/Oil	34-70F
Boston Naval Shipyard Boston, Massachusetts	5.0	5.0	1,500	None	FW/SW	None
	3.5	4.0	1,500	None	FW/SW	None
	1.5	12.5	1,500	None	FW/SW	None
	8.0	5.0	500	None	FW/SW	None
	1.75	3.83	250	None	FW/SW	None
Charleston Naval Shipyard Charleston, South Carolina	3.5	14.0	2,200	None	FW	None
	4.5	6.33	1,000	None	FW	None
	3.0	27.0	1,000	None	FW	None
Cheasapeake Instrument Corporation Shadyside, Maryland	1.0	5.0	10,000	0-10000	FW/SW Oil	None
	4.0	12.0	1,000	0-1000 12 CPH	FW	None
	2.0	3.0	1,000	0-1000	FW/Oil Gases	None
Electric Boat Division of General Dynamics Groton, Connecticut	1.33	13.58	40,000	0-40000	FW/SW Oil	None
	3.0	12.0	3,000	0-3000 12 CPH	FW/SW	28-200F
	1.08	2.0 (2)	3,000	None	FW/Oil SW/Gages	None
	2.7 (can be tilted 45°)	11.92	1,500	0-1500 24 CPH	FW/SW Oil	28-100F
	2.71	11.92	1,500	0-1500 20 CPH	FW/SW Oil	28-100F
	2.71	3.75	1,500	None	FW/Oil SW/Gases	None
	2.71	3.5 (2)	1,500	0.1500 20 CPH	FW/SW	28-100F
	2.5	10.0	1,500	None	FW/Oil SW/Gases	None
	2.0	10.0	1,500	None	FW/SW	None
	1.73	2.0	1,500	None	FW/Oil SW/Gases	None
	1.67	5.0	1,500	None	FW/Oil SW/Gases	None
	1.65	1.62	1,500	None	FW/Oil SW/Gases	None
	7.5	14.75	1,000	None	FW	None
	4.54	9.83	500	None	FW	None
	4.0	3.5	500	None	FW/Oil SW/Gases	None
Hazeltine Corporation Braintree, Massachusetts	2.0	14.0	2,500	None	FW	32-100F
	3.0	6.0	1,500	None	FW	32-100F
IIT Research Institute	4.0	8.17	20,000	0-14000 8 CPH	Oil, Gases Water-Oil Mix	32-125F
	1.33	3.0	20,000	0-20000 6 CPH	Oil, Gases Water-Oil Mix	32-125F
	1.17	5.0 (3)	20,000	0-20000 6 CPH	Oil, Gases Water-Oil Mix	32-125F
	1.0	1.17	20,000	0-20000 12 CPH	Oil, Gases Water-Oil Mix	32-125F
Lockheed Missiles and Space Company Sunnyvale, California	3.0	4.0	13,500	0-1000 1 CPM	FW/SW Oil	28-100F
	1.7	3.75	3,000	None	None	None
Mare Island Naval Shipyard Vallejo, California	4.0	5.0	6,000	None	FW/SW	None
	3.0	3.0	2,000	None	FW/SW	None
	1.0	20.0	1,500	None	FW/SW	0-60F
	6.0	12.0	1,000	None	FW/SW	None
	3.0	6.25	1,000	None	FW/SW	0-50F
	3.0	2.0	1,000	None	FW/SW	None
	4.33	3.0	600	None	FW/SW	None
	9.0	10.0	550	None	FW/SW	None

LOCATION	DIAMETER FT	LENGTH FT	MAXIMUM PRESSURE - PSI		FLUID	TEMP CONTROL
			STATIC	CYCLE		
National Oceanographic Instrumentation Center	2.0	8.0	20,000	0-20000 0.6 CPH	FW/SW	None
	2.04	2.3	18,000	0-18000	FW	-2-80C
	1.25	2.0	12,000	None	FW/SW	None
	2.0	2.16	10,000	0-10000	FW	-2-80C
	1.24	3.0	10,000	0-10000 2 CPH	FW/SW	-2-40C
Naval Air Development Center Warminister, Pennsylvania	1.33	12.0	18,000	500-18000	TW	None
Naval Civil Engineering Laboratory Port Hueneme, California	1.50	3.0	20,000	0-20000	FW/SW	25-70F
	6.0	15.0	5,500	0-2750	FW/SW	None
	1.53	3.50	1,500	0- 750	FW	None
	1.53	3.50	1,500	0- 500	FW	None
	1.33	2.50	1,500	0- 750	FW	None
	1.58	3.0	1,000	0- 500	FW	None
	1.33	2.50		0- 250	FW	None
	2.0	3.0	250	0- 125	FW/SW	None
Naval Mine Engineering Facility Yorktown, Pennsylvania	2.5	8.25	1,000	None	FW	None
	7.0	13.0	600	None	FW	None
Naval Ordnance Laboratory Silver Spring, Maryland	1.25	7.50	15,000	None	FW/SW	None
	1.25	1.0	3,000	None	FW/SW Air	None
	8.33	36.5	1,250	0-1250 0.2 CPH	FW Air	None
	2.5	9	1,250	None	FW/SW Air	None
Naval Ordnance Station Forest Park, Illinois	2.5	24.0	3,500	0-3500 2 CPM	FW	Yes (not specified)
Naval Research Laboratory (NRL) Washington, D. C.	1.0	2.0	50,000	0-50000 0.1 CPH	FW-Oil	None
	1.25	10.0	10,000	2000-10000 0.1 CPH	FW	None
	4.0	8.0	8,000	2000-8000	FW	None
	1.92	2.58	1,500	200-1500 0.2 CPH	FW	None
Naval Research Laboratory (NRL) Orlando, Florida	1.25	55.0	8,500	0-8500	FW	None
	8.30	26.0	1,000	0-1000 10 CPH	FW	12-40C
Naval Ship Research and Development Center (NSRDC) Carderock, Maryland	1.0-Sphere		30,000	0-10000 1 CPM*	FW-Oil	None
	5.0	9	20,000	0-10000 1 CPM*	FW-Oil	None
	2.0	4	20,000	0-10000 1 CPM*	FW	35-70F
	4.0	20	15,000	0-10000 1 CPM*	SW/FW Oil	35-70F
	1.33	4.6	15,000	0-6000 1 CPM*	FW-Oil	None
	1.25	3.5	15,000	0-6000 1 CPM*	FW-Oil	None
	1.25	1.5	15,000	0-6000 1 CPM*	FW-Oil	None
	1.25	1.5	15,000	0-6000 1 CPM*	FW-Oil	35-70F
	10.0-Sphere		10,000	0-10000 1/2 CPM*	Oil FW/SW	35-70F
	3 -Sphere		10,000	None	FW	None
	6.0	21	6,000	0-5600 1 CPM*	Oil FW/SW	35-70F
	3.5	6.2	2,500	None	FW	None
	11.5 *	30	1,000	0-1000 1 CPM*	Oil FW/SW	None
				*Above cycle section - water only		
Naval Ship Research and Development Center (NSRDC) Annapolis, Maryland	1.5	3.33	20,000	0-15000	FW	None
	1.5	5.0	20,000	None	FW	None
	10.0	27.0	12,000	0-4000	SW/FW	30-100F
	4.0	12.0	12,000	0-4000	SW/FW	30-100F
	2.5	6.3	7,000	0-7000	SW/FW	40-100F
	1.75	9.75	5,000	0-4000	SW	40-100F
	1.66	10.5	5,000	None	FW	None

*To be replaced by 13.0' dia 40' long, 3,000 psi tank.

LOCATION	DIAMETER FT	LENGTH FT	MAXIMUM PRESSURE - PSI		FLUID	TEMP CONTROL
			STATIC	CYCLE		
Naval Coastal Systems Laboratory (NCSL)** Panama City, Florida	2.0	7.5	1,000	0-1000	FW Gases	None
	1.0	4.75	445	None	FW Gases	None
Naval Undersea Research and Development Center (NURDC) San Diego, California	1.5	12.0	50,000	None	FW/SW	33-150F
	1.25	15.0	50,000	None	FW/SW	33-150F
	1.17	6.50	40,000	Manual	Ethylene Glycol	None
	5.0	10.0	10,000	None	FW/SW	28-75F
	1.0	2.5 (Acoustic)	10,000	None	FW	None
	3.0	4.0 (Acoustic)	2,000	None	FW	40-90F
	4.20	12.00	1,000	10-900 1/2 CPH	FW/SW	33-75F
	2.5	4.5 (Acoustic)	800	None	FW	40-90F
	4.90	11.50	125	None	Gases	None
Navy Underwater Sound Laboratory (NUSL) New London, Connecticut	1.08	5.50	5,000	None	FW	None
	4.0	9.5	2,000	None	FW	None
	1.0	20.0	1,000	None	FW	None
	3.5	3.75	500	None	FW	None
Naval Underwater Weapons Center (NUWC) Pasadena, California	1.5	5.0	10,000	None	FW	None
	2.25	17.0	1,500	None	FW	None
Naval Underwater Systems Research and Development Station Newport, Rhode Island	1.0	2.5	10,000	0-10000 (Oil)	FW/SW	None
	3.0	24.5	2,500	0-2500	FW/SW Oil, Gases	None
	2.2	7.0	2,000	0-2000	FW/SW Oil, Gases	None
	3.0	25.0	1,300	0-1300	FW/SW	None
	1.0	3.0	1,000	0-1000	FW/Oil	None
Naval Weapons Center (NWC) China Lake, California	1.46	10.0	20,000	None	Glycerine FW/Air	None
Newport News Shipbuilding and Dry Dock Co. Newport News, Virginia	5.0	23.0	1,000	None	FW/SW	None
	3.5	7.0	1,000	None	FW/SW	None
North American Rockwell Long Beach, California	2.5	5.42	10,000	0-10000	FW/Oil	None
	1.0	16.5	1,200	None	FW/Oil	None
Ocean Research Equipment, Inc. Falmouth, Massachusetts	1.43	3.0	12,000	0-12000	FW	34-70F
	4.0-Sphere		300	0-300	FW	34-70F
Ordnance Research Laboratory University Park, Pennsylvania	1.5	14.0	20,000	0-20000 3 CPH	FW	None
	5.0	13.75	16,000	0-16000 1/8 CPH	FW	None
	1.9	5.0	3,000	0-3000 5 CPH	FW	None
Pearl Harbor Naval Shipyard Pearl Harbor, Hawaii	1.5-Sphere		2,000	None	FW	None
	3.33	30.0	1,000	None	FW	None
	2.0	8.0	1,000	0-1000	FW	None
	8.33	7.0	500	None	FW	None
	2.0	5.0	450	None	FW	40-80F
Perry Submarine Builders Riviera Beach, Florida	8.0	29.0	1,300	None	FW	None
Philadelphia Naval Shipyard Philadelphia, Pennsylvania	1.75	13.0	2,000	None	FW/SW	None
	3.42	5.0	1,000	None	FW/SW	None
	2.75	25.0	1,000	None	FW/SW	None
	2.5	3.0	600	None	FW/SW	None
	1.33	12.5	500	None	FW/SW	None
Portsmouth Naval Shipyard Portsmouth, New Hampshire	3.30	6.41	3,500	0-3500 0.3 CPH	FW	None
	4.5	14.0	3,000	None	FW	None
	3.60	13.17	3,000	None	FW	None
	3.58	120.0	3,000	0-3000	FW	None
	2.54	4.08	2,700	None	FW	None
	3.50	6.75	1,000	None	FW	None
	3.50	4.40	1,000	None	FW	None
	1.67	4.33	1,000	None	FW	None
	1.5	4.0	1,000	None	FW	None
	1.5	3.0	1,000	None	FW	None
	30.0	75.0	600	0-600 1 CPM	SW	None
	8.0	14.0	600	None	FW/SW	None
Puget Sound Naval Shipyard Bremerton, Washington	1.4	5.0	3,000	None	FW	None
	6.0	12.0	1,500	None	FW	None
	3.0	23.75	1,000	None	FW	None
Sanders Assoc., Inc. Nashua, New Hampshire	1.83	6.17	1,095	55-75F	FW	None
Sandia Laboratories Livermore, California	2.17	6.125	2,500	0-2500 12 CPH	FW/Oil	None
	1.83	5.75	1,000	0-1000 30 CPH	FW/Oil	None
Southwest Research Institute San Antonio, Texas	2.04	9.92	13,500	0-13500	FW/SW	32-85F
	2.04	4.67	13,500	0-13500	FW/SW Oil	32-85F
	2.04	1.42	13,500	0-13500	FW/SW Oil	32-85F
	2.5	10.33	12,000	0-12000	FW/SW Oil	32-85F
	7.5	19.17	4,000	0-2000	FW/SW Oil	None
	3.93	8.75	3,750	0-3750	FW/SW	32-85F
	7.58-Sphere		1,200	0-1200	FW/SW	32-85F
Submarine Signal Division of Raytheon Company Portsmouth, Rhode Island	3.33	8.0	3,000	None	FW	None
	2.5	9.0 (Acoustic)	1,200	None	FW	None
	2.5	8.0	1,000	None	FW	None
Wyle Laboratories El Segundo, California	1.2	5.3	3,500	None	FW	None

**Also has a new 15' dia, 1000 psi hyperbaric facility.

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13. ABSTRACT

This brief overview lists the deep sea simulation facilities presently available in the United States. It indicates the possible needs for additional facilities and gives some insight into the conditions that require updating of existing facilities. Background material on types and frequencies of failures will be helpful to those concerned with design and certification.

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Submarines and Submersibles, verification of structural adequacy						
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