Technical Report

R 749

NEMO, A NEW CONCEPT IN SUBMERSIBLES

November 1971

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Transparent hull						
Navy certification						
Life support system						
Power supply system						
Electrical distribution system						
Hydraulic system						
Winch/anchor system						
Air ballast system						
Thrusters						
Rotation						
Horizontal excursions						

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INTRODUCTION

The Naval Civil Engineering Laboratory (NCEL) and the Pacific Missile Range (PMR) began in 1965 a research and development program on spherical acrylic plastic pressure hulls for hydrospace application. From the 6-year project a unique submersible with an acrylic plastic pressure hull has been developed.

This report provides a basic technical description of the NCEL research submersible NEMO (Naval Experimental Manned Observatory). All of the NEMO systems are described, with the functional characteristics, components, and the interrelation of components and systems being emphasized. Also discussed are the intended operational characteristics and safety aspects of the submersible. An engineering and operational evaluation, currently being performed on NEMO by NCEL, will be presented in a future report.

Background

In attempting to explore hydrospace, man has encountered many problems, not the least of which has been obtaining an adequate visual capability. To better employ manned submersibles in such missions as observation, salvage, and work, the submersible operator must be provided with greater visibility. The approach to this problem to date has been to outfit metal pressure hulls with more numerous and larger diameter viewports. Ultimately, however, the greatest visibility is gained by providing a vehicle with a completely transparent pressure hull, such as glass or acrylic plastic.

NCEL and Southwest Research Institute (SWRI) have jointly produced a submersible with an acrylic plastic hull, called NEMO. NCEL developed the acrylic plastic pressure hull technology initially in cooperation with the Naval Missile Center (NMC) at Point Mugu, California. This development program was completed by NCEL and resulted in the design, construction, and test of the NEMO sphere. SWRI, under contract to NCEL, designed and built the remaining subsystems for integration with the acrylic plastic hull.

NEMO was completed in May 1970 and underwent initial sea trials in the Bahamas in May 1970. NCEL received NEMO in July 1970, and a material certification dive was performed on 19 July 1970 to 612 feet off Port Hueneme, California. Material certification of NEMO was obtained on

15 December 1970. The certification limits are for 1 year or 60,000 dive-feet (with a 600-foot maximum dive depth), whichever occurs first. NCEL has also obtained certification for six submersible operators—three in July 1970 and three in January 1971. The materials certification procedures and requirements are described in Appendix A. A summary of NEMO development is shown in Table 1.

Table 1. Summary of NEMO Development

Event	Date	Organization
Contract specifications	July 1968	NCEL
Request for material certification	September 1968	Chief of Naval Material
Contract let for pressure hull	February 1969	Swedlow, Inc.
Contract let for subsystems	April 1969	Southwest Research Institute
Request for operator certification	December 1969	Chief of Naval Operations
Operator certification interviews	April 1970	Submarine Development Group One
Material certification survey	April 1970	Naval Ship Systems Command
First manned dive	May 1970	Southwest Research Institute
Operator certification dives	July 1970	Submarine Development Group One
Material certification dive	July 1970	Naval Ship Systems Command
Material certification of NEMO	December 1970	Naval Ship Systems Command

During May, July, and December 1970, three cruises were made which served to check out and certify NEMO, to develop over-the-side launch and retrieval procedures from the NCEL warping tug, and to determine operating characteristics of NEMO. In January 1971 a cruise was made to obtain visibility data at a depth of 50 feet in order to evaluate the visual discrepancies perceived through the acrylic plastic hull. The results of this evaluation operation will be discussed in a later report.

Characteristics of Acrylic Plastic

The significant advantages of utilizing acrylic plastic as a pressure hull material are:

1. Transparency
2. Improved payload
3. Low cost
4. Observer comfort
5. Maintainability
6. Reparability
7. Suitability for cold environments

The most obvious asset of the acrylic plastic hull is its transparency. A transparent hull provides true color rendition and good depth perception for the observers.[1] The Navy,[2] after thorough operations with five manned submersibles in various undersea research and surveying tasks, found that simultaneous viewing by the operator and observer was a necessity. A transparent hull provides essentially omnidirectional viewing which, in addition to improving mission observation, also reduces the possibility of becoming entangled in submerged cables, fouling on overhanging cliffs, or striking vessels when surfacing.

Spherical acrylic plastic hulls provide greater payloads than equivalent metal hulls for continental shelf depths (that is, 1,000 feet) where most undersea activity will take place in the future. The major reason for the payload improvement is that steel hulls with a wall thickness less than 0.5 inch are impractical to fabricate due to the difficulty in maintaining tolerances on thickness and sphericity. The properties of perfect acrylic plastic and steel spherical hulls for 600-foot depths are:

Property	Perfect Acrylic Plastic Hull	Perfect Steel Hull
Outside diameter (in.)	66	66
Inside diameter (in.)	61	65
Weight (lb)	1,363	1,914
Displacement (lb)	5,570	5,570
Weight/displacement ratio	0.24	0.34

The cost of an acrylic plastic hull is low because the material and fabrication costs are low. Hull segments are made from commercial off-the-shelf acrylic plastic sheeting. The fabrication process draws heavily from the data on machining, thermoforming, and bonding generated by the aircraft industry and requires minimum machining and special equipment (see Appendix B). Because of the modular concept, acrylic plastic sheets in an assembly line process are thermoformed, milled into pentagons, and annealed to form 12 identical spherical pentagons, which are bonded together to form a sphere. No additional expense is required to machine and weld numerous viewport flanges as in a steel hull.

Observer comfort is becoming a common requirement for extended mission length. Reference 2 concluded that in many instances, in a steel hull with viewports, the efficiency of the observer is degraded quickly due to the variety of unnatural positions which must be assumed. The acrylic plastic hull, however, allows the observer to sit in a comfortable and natural position and move around while viewing.

The internal temperature of steel hulls varies greatly with ambient water temperature. It often becomes unbearably hot in tropical waters, and quite cold in colder waters. Also, cold ocean temperatures may affect steel hulled submersibles by lowering the impact strength to the nil-ductility range. In spherical acrylic plastic hulls, the impact strength is independent of temperature, and the strength of acrylic plastic is an inverse linear function of temperature (see Appendix C). The good insulation characteristics of acrylic plastic, as shown below, keep the interior of the hull warm in cold waters.

Material	Thermal Conductivity (Btu/hr ft ^{o}F)
Steel	25
Acrylic plastic	0.11

High temperature and humidity have been controlled rather effectively in NEMO for operation in tropical waters. The improved comfort achieved with the NEMO hull minimizes the need for crew changes, thus increasing operational efficiency.

Ease in maintainability is an intrinsic quality of the acrylic plastic pressure hull. Because the hull is transparent, all damage is visible to the naked eye. Techniques, such as X-ray and magnaflux, are not necessary for inspecting the hull for possible flaws or cracks. Painting or cathodic protection is unnecessary, since acrylic plastic exhibits little deterioration in a seawater environment.

If damage should occur to the hull, the reparability characteristics are excellent. For example, if the damage is corrosion of the top hatch ring, the modular design allows the ring to be unbolted, removed, and replaced with a new one. If the acrylic plastic hull is damaged or small cracks appear, the damaged area can be routed out and then filled with adhesive.

GENERAL CHARACTERISTICS

Description

The NEMO system (Figure 1) provides a panoramic view of hydrospace and functions as a comfortable in-situ center for observation, documentation, communication, and control. NEMO is an untethered submersible, completely self-contained, that provides a one-atmosphere environment for the operators. The vehicle characteristics are:

Operating depth	600 feet
Dimensions	78 inches wide; 110 inches high
Weight	8,300 pounds (in air)
Crew	one operator, one observer
Payload	crew plus 450 pounds
Mission duration	
Normal	8 hours
Emergency	24 hours, additional
Pressure hull	
Material	acrylic plastic
Shape	sphere
Outside diameter	66 inches
Wall thickness	2.5 inches

Figure 1. NEMO (Naval Experimental Manned Observatory).

Life support	oxygen bleed system
Power	
Main battery	lead–acid, 150 amp-hr, tapped at 120 VDC and 24 VDC
Emergency battery	24-VDC silver–zinc, 20 amp-hr
Mobility	
Vertical	
Method	2-hp winch; 400-pound anchor, 1,200 feet of 1/4-inch nonrotating wire rope
Speed	60 or 100 fpm, surface adjustable
Horizontal	
Method	two hydraulic motors, 1-1/2 hp at 3,000 rpm
Speed	0 to 3/4 knot
Lighting	two 500-watt lights; one wide angle 750-watt light; one 750-watt articulated spotlight
Buoyancy control	open air ballast tanks, 10-ft^3 volume, 371 scf of air available
Communications	
Surface	HF radio
Submerged	acoustic transceiver (8.1 kHz)
Work capability	underwater hydraulic supply (2.8 gpm at 3,000 psi)
	underwater electrical connectors (120 VDC)
Support facilities	28-foot trailer with 8-foot support van

The spherical acrylic plastic pressure hull is surrounded by a structural cage (Figure 2) that carries the entire weight of the NEMO system during lifting and protects the acrylic plastic hull from impact loads. Directly beneath the hull is the unit which contains the main ballast tank, service module, winch, and the main battery pack. The lower unit and structural cage are constructed of mild steel covered with an epoxy-based paint.

Design Parameters

Following is a list of factors governing the design of the NEMO system. Also included are stability figures and weights of the system components.

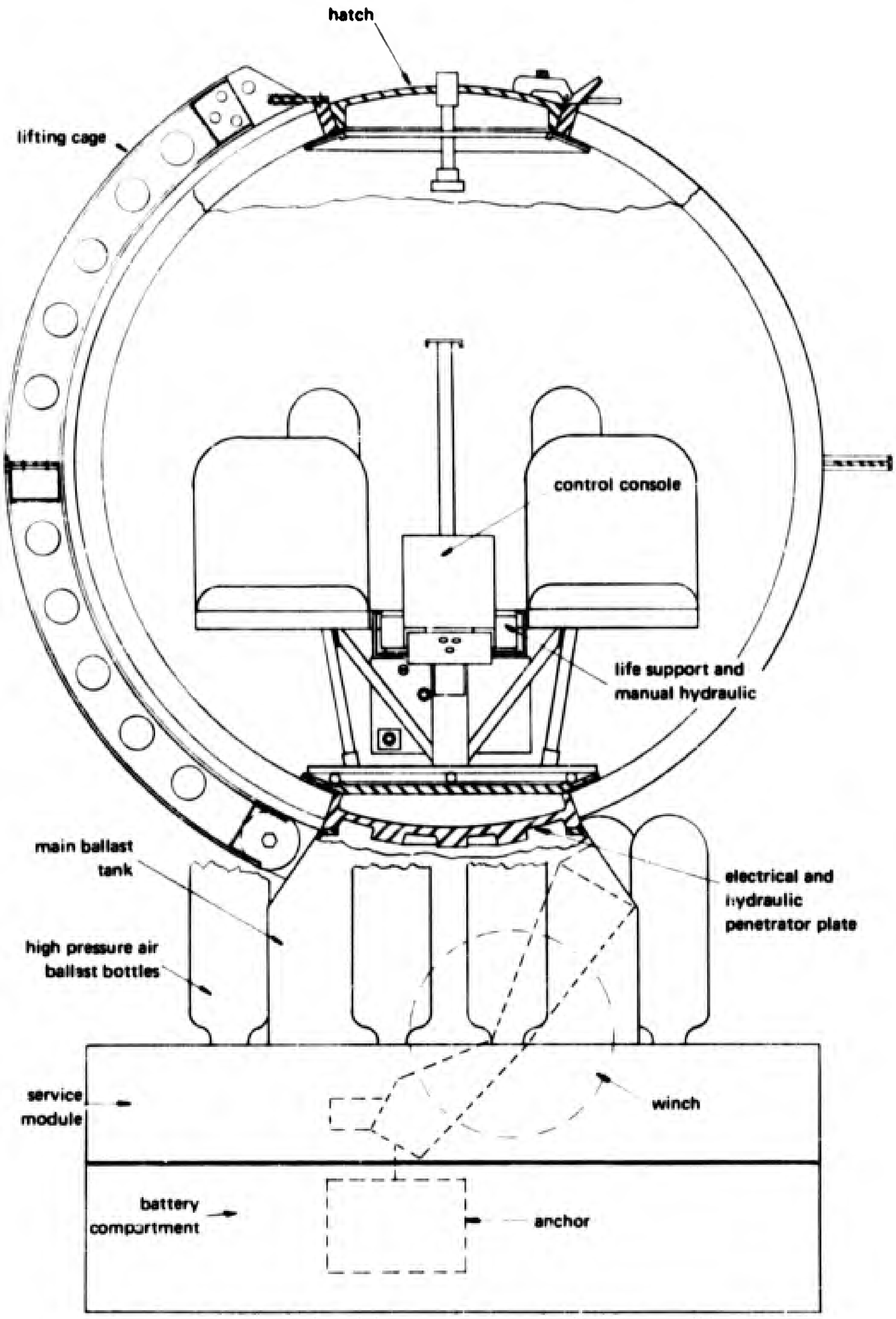


Figure 2. Schematic of the NEMO system.

I. Environmental

1. External

   a. Ocean temperature envelope . . . . . $34^{\circ}F$ to $70^{\circ}F$

   b. Horizontal current . . . . 2 knots maximum

   c. Pressure . . . . 267 psi

   d. Maximum sea state . . . . Beaufort 3; wind 7 to 10 knots; waves 2 feet

2. Internal

   a. Partial pressure of oxygen . . . . between 18 and 23% of one atmosphere

   b. Partial pressure of carbon dioxide . . . less than 1% of one atmosphere

   c. Internal temperature . . . . less than $75^{\circ}F$

   d. Internal humidity . . . . sufficient amount of moisture to be removed to prevent fogging and condensation on the inside hull walls

      . . . . internal equipment and materials to withstand and be operable under 90 to 100% humidity conditions

   e. Type of material . . . . nontoxic, nonflammable, and nonoutgassing materials to be used for internal subsystems

II. Operational

1. Operational depth capability . . . . . . 600 feet

2. Winch down speed . . . . 60 to 100 fpm

3. Mission duration . . . . life support capability for maintaining two men comfortably for an 8-hour mission. Emergency life support for an additional 24 hours

4. System life span . . . . 100 dives or 5 years, whichever comes first

III. Design and Test

1. Safety factors

   a. Hull design . . . . 7 on collapse (instaneous loading)

      . . . . 4.5 on collapse (50-hour load duration)

      . . . . 2.1 on yield (50-hour load duration)

b. Structural cage design 5

c. Support system design . . . . pressure compensated except for lights and air ballast supply tanks

d. System tests . . . . 1.5 times working pressure

2. Dynamic load (rough lifting, launching operations, and wave slap) 3g

3. Static stress . . . . calculations include weight of entrapped water during lifting

4. Stability

Condition	Distance Between Center of Buoyancy and Center of Gravity (in.)
a. Submerged, Main Ballast Tank (MBT) flooded	31.4
b. Submerged, MBT dry	24.2
c. Surface, MBT dry	21.6
d. Surface, MBT dry, anchor on the bottom	19.3
e. Surface, MBT dry, anchor and battery dropped	15.1

5. Weights and displacements (design)

Components	Weight in Air (lb)	Displacement (lb)
Compensators	60	0
Life support	160	65
Air ballast	530	600 variable 200 fixed
Battery (including oil)	2,170	1,030
Support	50	5
Cage	300	50
Electrical equipment	40	0

continued

5. Continued

Components	Weight in Air (lb)	Displacement (lb)
Internal equipment	240	0
Winch	450	65
Payload	500	0
Anchor	400	20
Miscellaneous	500	20
Hull	1,600	5,600
Motor, hydraulic/electrical distribution (including oil)	575	300
Total	7,575	7,955
Anchor dropped	7,145	
Ballast flooded		7,355

SUBSYSTEMS

Pressure Hull and Support Structure

The NEMO hull is the most important structural element of the vehicle in that it must withstand the hydrostatic pressure of the ocean. The development and fabrication of the acrylic plastic hull are described in Reference 3, while the structural analyses are contained in References 4, 5, and 6. The hull, fabricated under contract, incorporates 12 spherical pentagons of plexiglas G* acrylic plastic bonded together with SS-6217** clear adhesive. Off-the-shelf acrylic plastic sheets are used to fabricate the pentagonal sections. The sheets are cut into circular pieces, thermoformed into spherical sectors, and finally milled into pentagons. The two polar pieces are machined with conical cutouts for the two endplates. The individual pieces are placed in a jig and bonded together, one hemisphere at a time; then the two hemispheres are positioned together and bonded. A more detailed discussion of the fabrication of the hull is contained in Appendix B.

* Rohm and Haas tradename.
** Swedlow tradename.

The two 40-degree polar cutouts are fitted with conical steel endplates made of cadmium plated 4130 steel (Figures 3 and 4). The endplates are designed to have a rigidity about equal to that of the acrylic plastic hull. The personnel (top) hatch effects closure through an O-ring seal to the acrylic plastic hull, and is held to the hull with a retaining ring. The retaining ring has a neoprene gasket and is bolted to the stationary hatch ring. The hatch is held in the hatch ring during a dive by a "spider" retainer and clamping. screw (Figure 5). The design of the hatch allows it to be opened normally from the inside and from the outside in an emergency. The hatch has an open-lock position so that it cannot fall on the operators as they emerge from the sphere.

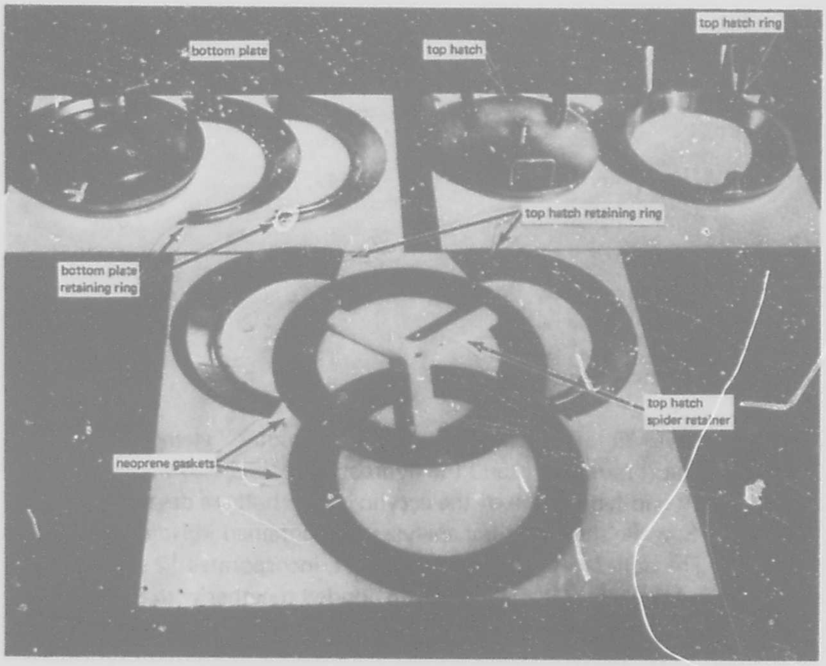


Figure 3. Components for the polar closures in NEMO.

The bottom plate, which is attached in the same manner as the stationary hatch ring, contains all the hull penetrations. The structural cage and the assembly below the hull are attached to the bottom plate. During lifting, the entire weight of NEMO is transmitted by the meridional cage members to the lifting sling, allowing no tensile loading of the hull.

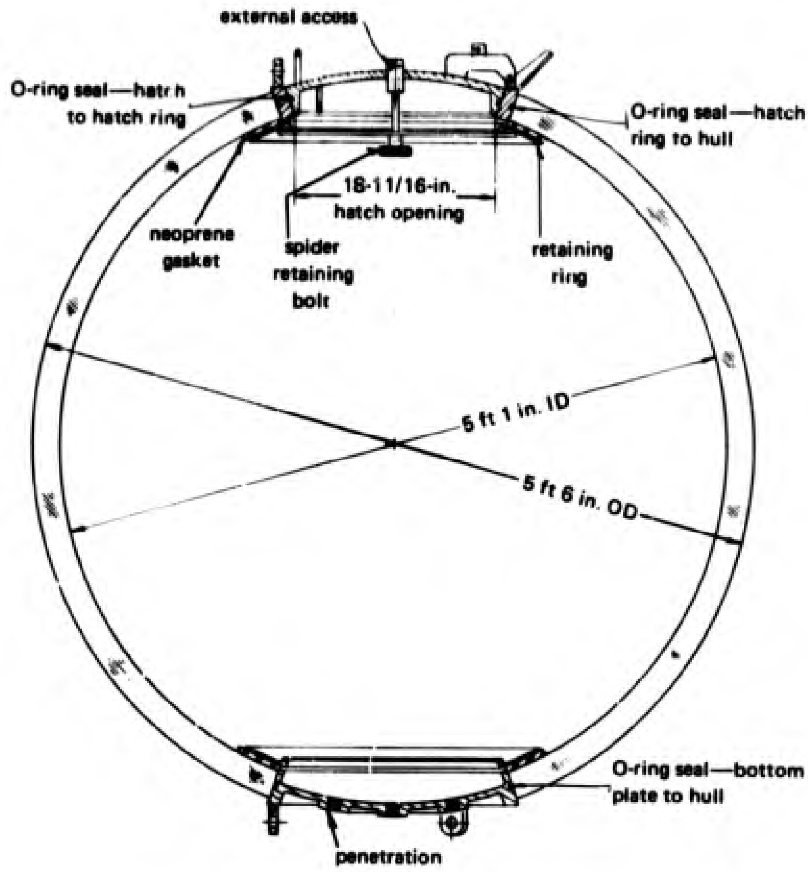


Figure 4. Hull and end plate attachment.

Since the NEMO hull diameter shrinks 0.08 inch in descending to 600 feet, a "floating" connection between the structural cage and the hatch support ring is provided to accommodate this motion. Rather than being bolted to the top hatch ring, the structural cage bolts to a circular ring. Three aligning studs, attached to the hatch ring, protrude through the circular ring. The aligning studs allow small vertical and horizontal relative motions between the NEMO sphere and the lifting/structural cage.

The main ballast tank, directly below the hull, transmits the weight of the service module and the battery pack to the structural cage (see Figure 2). It also serves as a housing for the electrical power cable, winch system, jettison systems, and the anchor. The diameter of the lower unit is less than that of the structural cage to reduce the possibility of fouling with submerged cables and to provide maximum unobstructed visibility from the acrylic plastic hull.

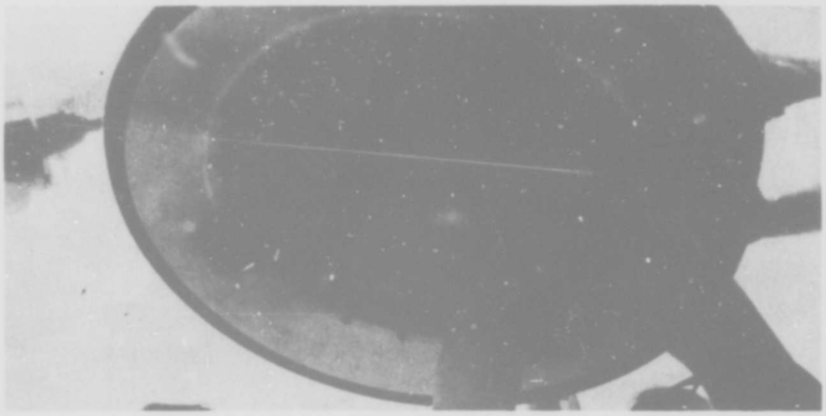


Figure 5. Spider and clamping screw.

The service module is an annular ring attached to the main ballast tank, with a 32-inch inside diameter and a 64-inch outside diameter (Figure 2). This module is divided into three pressure-compensated housings separated by free-flooding access areas. The housings contain the electrical distribution system, hydraulic distribution system, and the auxiliary air ballast tank. The access areas are covered with expanded metal grates; the housings are covered with removable covers and sealed with O-rings.

The battery pack is another annular ring attached approximately 2-1/2 inches below the service module. The pack contains the main batteries and is filled with mineral oil for pressure compensation. The battery pack is attached to the service module by three pins which protrude through "ears" attached to the battery pack. The spring-loaded pins can be retracted hydraulically to jettison the entire battery pack after the main power cable has been cut with a pyrotechnic cable cutter.

Life Support

The life support system consists of oxygen supply, CO_2 absorbent, and dessicant systems. The system is capable of sustaining two men for 8 hours with an additional 24-hour emergency backup.

Oxygen is supplied via a bleed system which consists of two 50-ft^3 oxygen bottles filled to 1,600 psi for an effective volume of 32 scf, an oxygen supply pressure gage, and primary and secondary flow control systems (Figure 6). The primary flow control system includes an on-off valve, a 50-to-80-psi regulator, and a flowmeter. The flow rate is selected by the

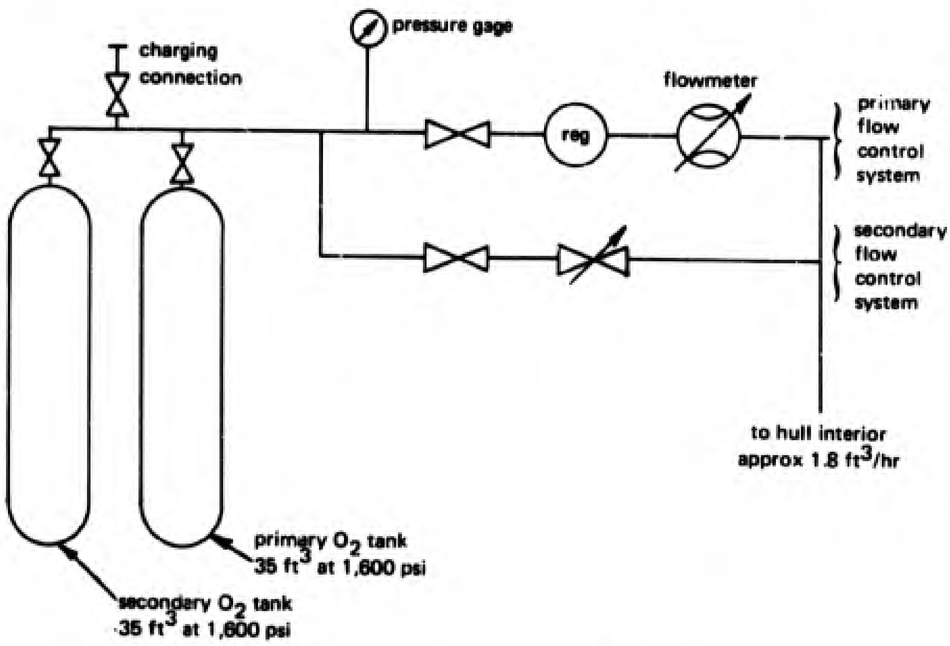


Figure 6. Schematic of oxygen system.

operator, and the partial pressure of oxygen is continuously monitored by a Beckman Minos pO_2 meter and a Kollsman cabin pressure gage. The oxygen content of the atmosphere is kept between 18 and 23%. Should the primary system fail, it can be isolated and the secondary system selected. The secondary flow control system includes an on-off valve and a micrometer flow control valve. A shut-off valve is supplied for filling the high-pressure oxygen tanks. All valves and piping in the high pressure oxygen system are monel.

The carbon dioxide content is controlled by an active Baralyme CO_2-removal system. An AC brushless motor powers the blower, which draws cabin air down through the Baralyme-filled canister at a rate of 12 cfm. The canister is fitted with baffles to eliminate channeling of air down the sides. One Baralyme-filled canister is sufficient for 4 hours of operation, and a spare canister is carried between the seats (Figure 7). In addition, sufficient Baralyme can be carried for 32 hours of operation. The carbon dioxide content is maintained at a partial pressure of less than 1% of one atmosphere and is continuously monitored by a Beckman Minos pCO_2 meter. A hand operated Drager kit is carried for backup determination of the cabin carbon dioxide and oxygen partial pressures. Two closed circuit oxygen rebreathers are carried in the event the atmosphere is contaminated.

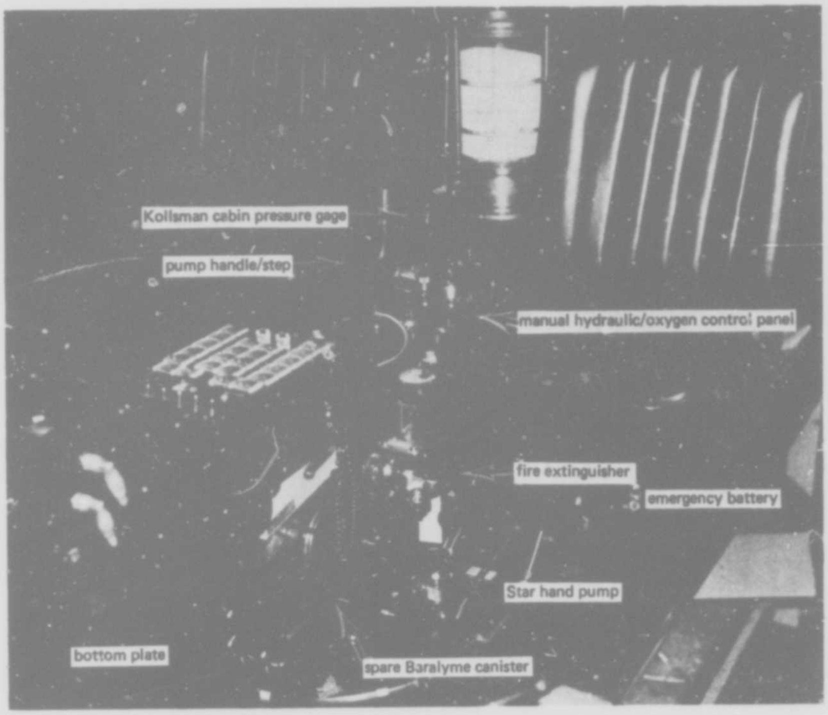


Figure 7. Internal framework and components (front view).

Humidity control is provided primarily by a dynamic silica gel bed and ice. The silica gel bed is located in the top third of the CO_2 removal canister, and the ice is contained in small metal cans placed near the air stream outlet of the scrubber blower. Moisture is absorbed by the silica gel and condensed on the ice. This combination will keep the humidity in the 70 to 80% range and, thus, will prevent fogging of the hull walls. Air is circulated over the personnel hatch by a small fan to provide additional condensation and to cool the cabin air. A drip ring attached to the spider retainer collects the water condensed on the hatch surface. A relief valve is provided in the hatch to equalize any internal overpressure that might occur. The relief valve, which includes a check valve to prevent flow from outside to inside, is normally left open so that as NEMO approaches the surface, the overpressure is relieved automatically, if the inside pressure becomes greater than atmospheric.

Internal Components

The internal components are supported by an anodized aluminum tubular framework attached to the bottom plate (Figures 7 and 8). A footrest is supplied for the crew's feet so they will not scratch the acrylic plastic hull. Slightly forward and between the operators is the control console. A hand-operated hydraulic pump is located beneath the operator seat. This pump powers the manual hydraulic system which can be used to jettison the battery pack, cut the anchor cable, or apply a mechanical lock to the winch. Between the seats are the manual hydraulic control board, the oxygen control board, and the pO_2 and pCO_2 meters (Figure 9).

A removable step is provided for personnel ingress and egress, and it can be used also as a pump handle for the manual hydraulic system. The CO_2 scrubber, cabin pressure gage, and hygrometer/thermometer are located at the back of the hydraulic/oxygen control board. The oxygen tanks are located behind the seats. Attached to the hatch retaining ring is an overhead fan to circulate air over the hatch for cooling. A fire extinguisher is located just forward of the hydraulic/oxygen control board. The underwater transceiver is attached beneath the observer's seat, and the HF radio is attached to the bottom of the control console. The 24-volt silver–zinc emergency battery is located beneath the operator's seat.

Power

Two independent power sources operate NEMO. The main battery (Figure 10) consists of 21 6-volt 150-amp-hr lead–acid batteries connected in series to supply 120 volts (nominal). Internal electrical component and control power (solenoid valves and pyrotechnic devices) is provided by a 24-VDC tap on the main battery. The battery pack is filled with mineral oil which is compensated to ambient pressure via a Bellofram rolled diaphragm cylindrical compensator. Three 1-1/2-psi pop-off valves located on domed sections of the acrylic plastic battery housing covers allow expulsion of hydrogen gas. The 1-1/2-psi overpressure in the battery housing insures that the compensator will reset after every dive. The acrylic plastic cover plates and 2-1/2-inch clearance between the battery housing and the service module allow inspection of the compensator and batteries and location of any unexpelled hydrogen gas.

The second power source is a 25.5-VDC 20-amp-hr silver–zinc battery, carried inside the pressure hull for emergency use. It is capable of operating all 24-volt equipment necessary for emergency conditions, such as the life support and communications equipment, ballast system, and the pyrotechnic emergency cable cutters.

Electrical Distribution

The electrical distribution system, located in the electrical distribution housing on the port side of the service module, consists primarily of electric motor starting and protection systems, and relays to actuate solenoid valves. All the electrical systems are operated from the control console (Figure 11). The circuitry inside the hull is 24-VDC, except for the main battery voltmeter.

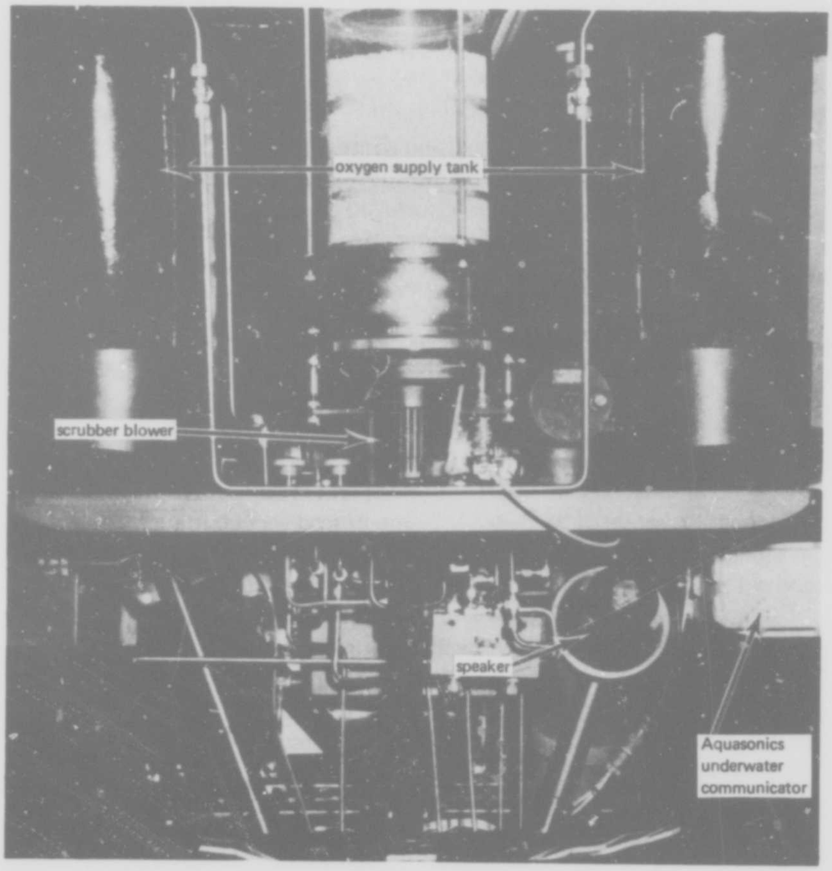


Figure 8. Internal framework and components (back view).

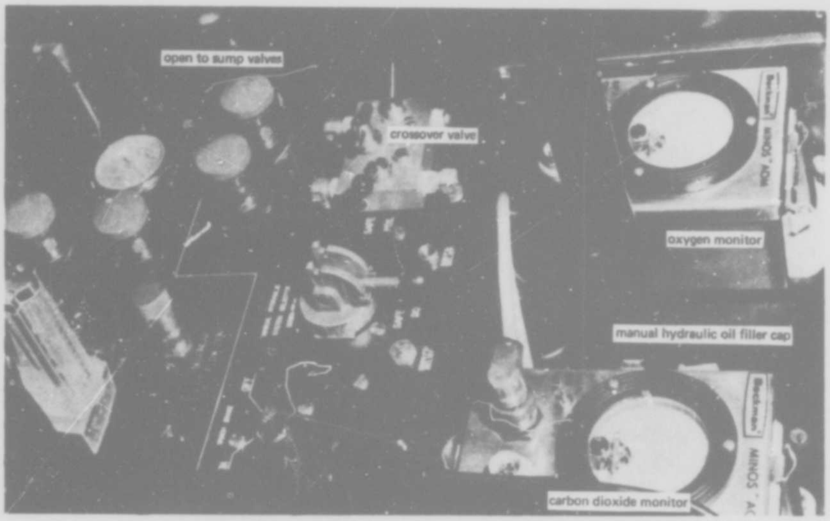


Figure 9. Manual hydraulic/oxygen control board.

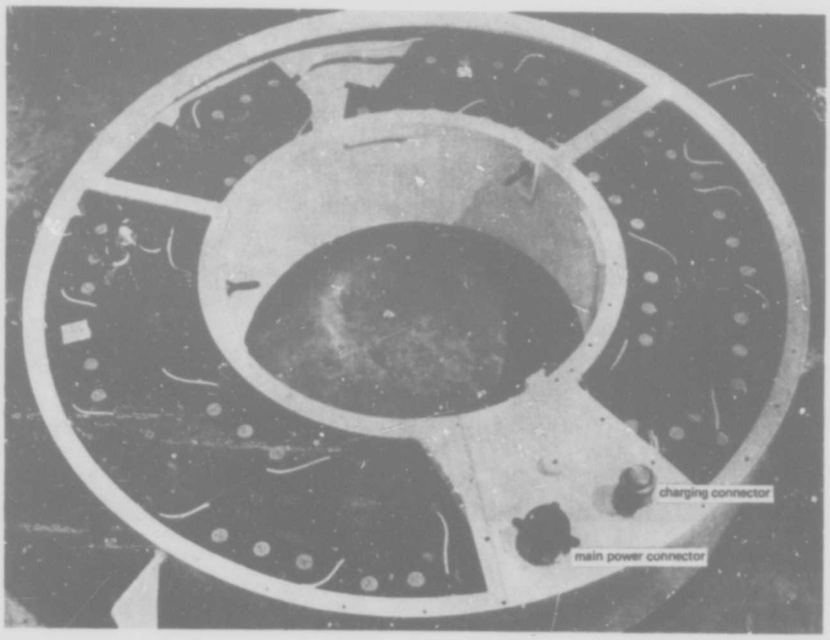
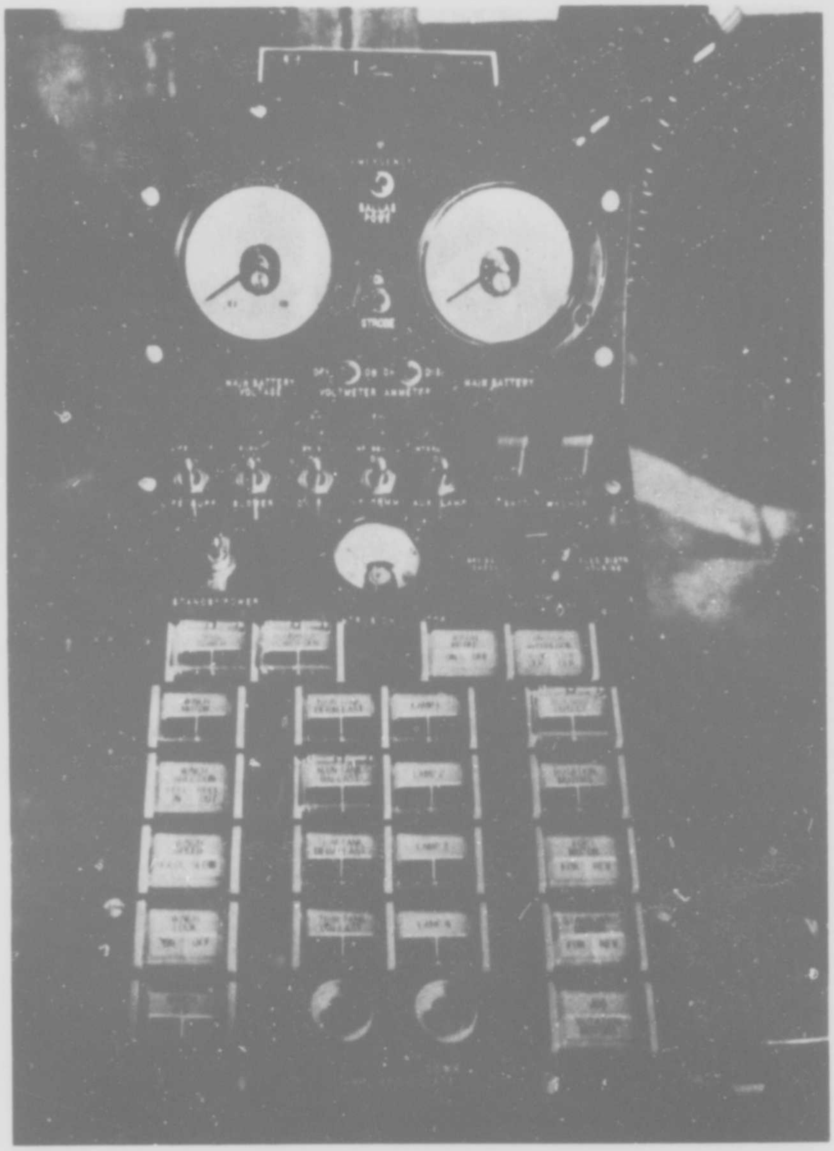
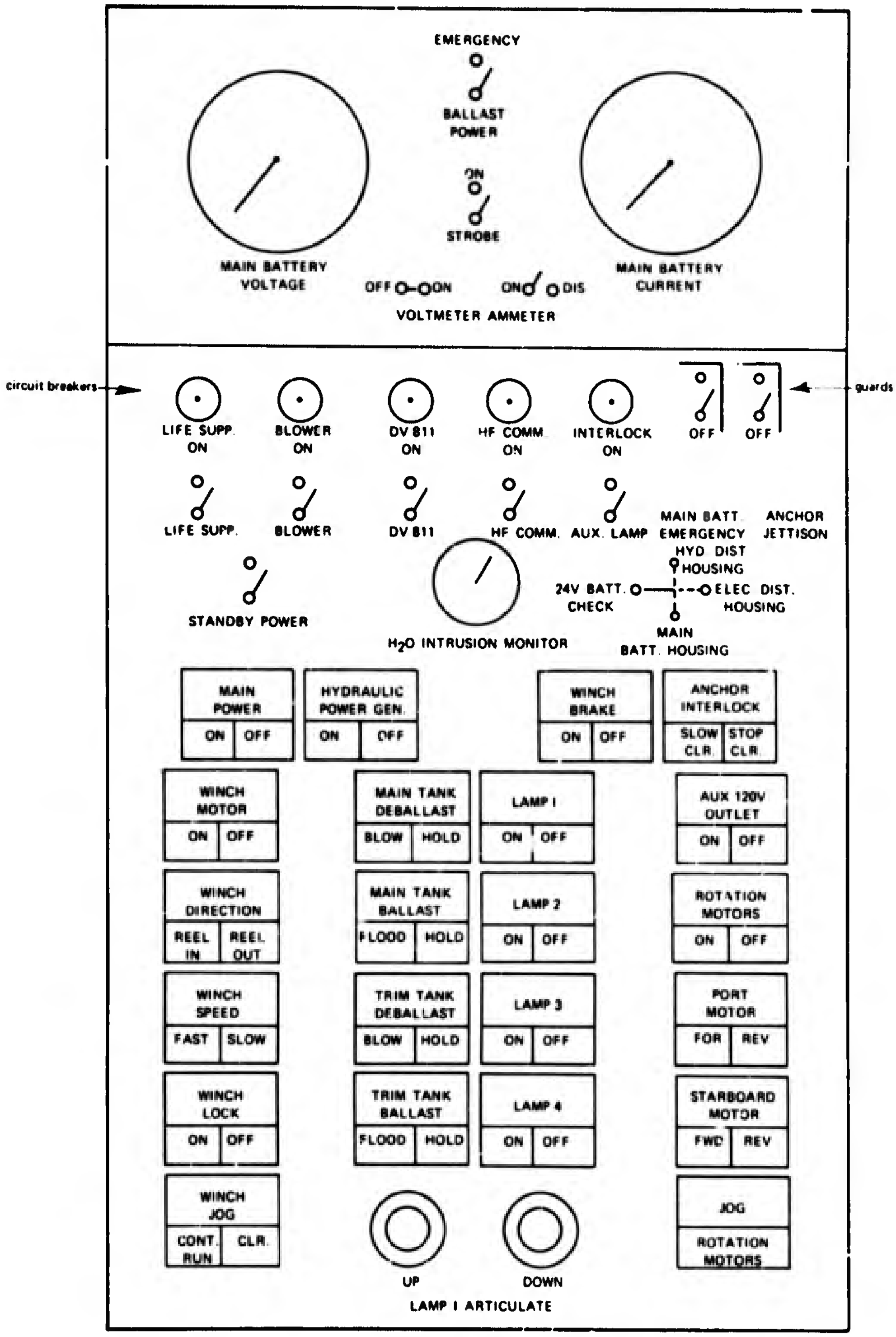


Figure 10. Main battery.



(a) Actual unit.

Figure 11. Control console.



(b) Drawing.

Figure 11. Control console.

Normal operation of the vehicle power system includes two system checks before the main power is turned on. Figure 11b illustrates the control panel switches and their location. The life support switch supplies power from the emergency life support battery to the life support power circuits. These circuits supply power to the scrubber blower, the underwater communicator, the HF transceiver, and the battery/water-intrusion status switch. This switch is used to check the voltage of the emergency battery, and to check for water intrusion in the electrical and hydraulic distribution housings and the main battery housing. The explosive squibs for cable cutting also operate from the life support power circuit.

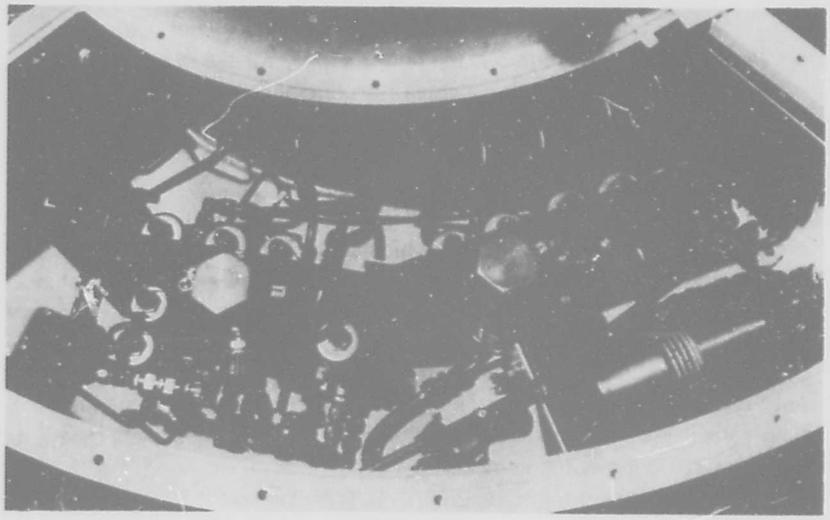
After the life support power circuits and water intrusion monitor are checked, the standby power switch is thrown. This switch transfers life support power from the emergency battery to the main battery (24-volt tap). Standby power, protected by 25-amp slow-blow fuses, is obtained ahead of the main circuit breaker, directly from the power input connector. Standby power energizes all of the indicator lamps in the illuminated pushbutton microswitches on the control panel, allowing the operator to determine the status of all of the control buttons prior to energizing the main breaker. The control panel is designed so that the standby or "make ready" condition exists when the green segments of all of the control switches are illuminated.

When a "green board" condition is ascertained, the main power switch is set to "On." This switch supplies current to the main circuit breaker actuator motor which closes the main breaker; the motor and breaker are located in the electrical distribution housing. Until now, only the life support and standby circuits were energized. When the main circuit breaker is closed, the 24-volt control and 120-volt main power circuits are energized, enabling the remaining circuitry of the vessel to function. The main breaker stays closed until the main power switch is set to the "Off" position.

Four external incandescent lights are supplied for NEMO: two EG&G 750-watt quartz iodide lamps (one wide-angle and one 12-degree spotlight) and two Hydro Products 500-watt wide-angle quartz iodide lights. Each lamp is provided with 120 VDC via relays in the electrical distribution housing; switches on the control console activate the lamps. The light circuitry is protected by 10-amp slow-blow fuses. The 12-degree spotlight can be articulated up and down by a small 6-inch-stroke hydraulic cylinder, also controlled from the control console.

Hydraulic Systems

Main Hydraulic Supply and Distribution. The main hydraulic system (Figure 12) consists of the hydraulic power generator and flow controls which operate the winch, thrusters, the articulation cylinder for the 750-watt spotlight, and an external hydraulic power tap.



(a) Housing.

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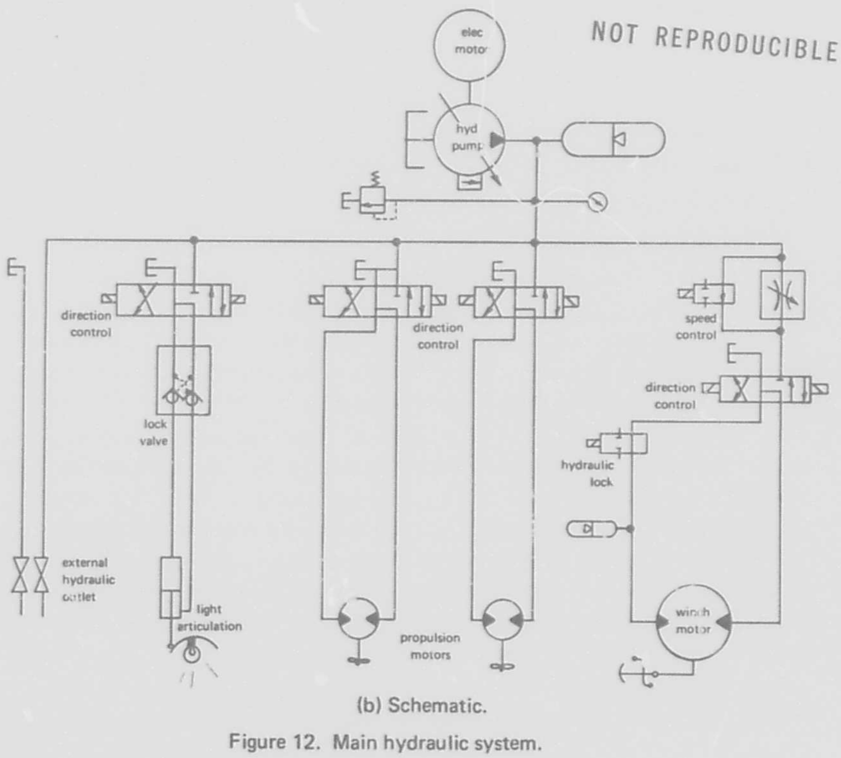


(b) Schematic.

Figure 12. Main hydraulic system.

A Lear Siegler 5-hp 120-VDC motor driving a Vickers variable displacement hydraulic pump is the power supply for the main hydraulic system. The power supply is capable of producing a 2.8-gpm flow rate at 3,000 psi. These units plus all control valves, filters, accumulators, and associated piping are located in the hydraulic distribution housing, in the starboard section of the service module.

The hydraulic motor is started with the Hydraulic Power Generator on-off switch on the control panel, which actuates the motor starting relay in the electrical distribution housing. A time delay relay places a resistance load in series with the electric motor armature for 1.5 seconds during motor start-up to prevent excessive current draw. If the motor is overloaded, an overload relay shuts it off. The motor circuit then remains de-energized until restarted with the Hydraulic Power Generator switch. If the motor field voltage is lost, a relay stops the motor. The relay then resets the motor for a restart when the field power is restored.

The output of the hydraulic pump is connected to the main high-pressure manifold, which contains a relief valve (3,200 psi) as a backup against failure of the built-in pump relief valve. Two 25-in.^{3} accumulators are provided to absorb hydraulic shocks caused by actuating the various solenoid valves.

The hydraulic pump output pressure is measured by a diver's Sea View gage mounted outside the NEMO hull in a position readily seen by the operators. The hydraulic distribution housing is pressure compensated to ambient pressure plus a 4-psi overpressure by a spring-loaded Bellofram rolled diaphragm compensating cylinder.

Rotation Motors. Two hydraulic motor thrusters are located halfway between the service module and the pressure hull on the port and starboard sides of the main ballast tank (Figure 13). The primary function of the thrusters is to rotate the vessel around the vertical axis to facilitate viewing of the dive site. A secondary function is to allow short horizontal translation once NEMO has attained neutral buoyancy.

The drive unit used in each of the thrusters is a Vickers hydraulic motor that develops 1-1/2 hp. The screws are standard 8-inch-diameter outboard motor screws protected by a shroud and grill. Both motors are referenced to the hydraulic distribution housing for pressure compensation.

The rotation thrusters are controlled by four switches on the control panel (Figure 11). The Rotation Motors switch furnishes 24-VDC control power to the port and starboard motor switches. These motor switches select the direction of thrust (forward or reverse) by changing the position of solenoid valves located in the hydraulic distribution housing. A momentary action (Jog) switch is provided to supply momentary power to the hydraulic thrusters.

Figure 13. Rotation motors and articulated light.

Anchor Winch. NEMO's primary vertical mobility and station keeping modes are provided by the self-contained winch/motor system housed in the main ballast tank (Figure 14). The winch drive motor is a Vickers fixed-displacement, fully reversible hydraulic motor. It is located in a housing directly beneath the bottom plate of the NEMO sphere, with pressure compensation being provided by reference to the hydraulic distribution housing. The winch motor drives a drum which can hold 1,200 feet of 1/4-inch nonrotating wire rope. The winch features a barrel gear level wind assembly and cable guide which assures proper cable laying. The guide also houses the hydraulic cable cutter, pyrotechnic cable cutter, and an interlock sensing assembly to override the winch control. This interlock arrangement automatically slows and stops the winch as the anchor approaches NEMO.

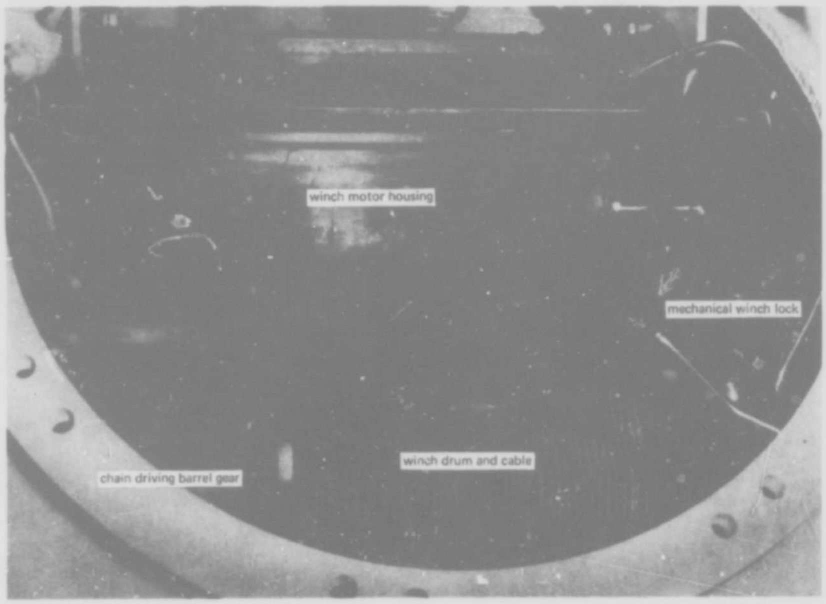


Figure 14. Winch, looking down through the Main Ballast Tank (MBT) area.

Winch operations are controlled by four switches on the control console (Figure 11) in much the same way as the propulsion motors are controlled. The Winch Motor switch and the Winch Jog switch supply power to the winch speed and winch direction switches, which in turn actuate hydraulic solenoid valves The Winch Motor switch is used for continuous operation, and the Jog switch is used for momentary operation. If the hydraulic generator is on and either the jog or the run switch is actuated, the winch will start operating in the direction selected by the direction switch ("Reel In" or "Reel Out") and at the speed selected on the speed switch ("Fast" or "Slow"). The Winch Lock switch actuates a solenoid valve which provides a hydraulic lock on the winch motor. This lock is automatically overridden when either the Run or Jog switch is used. In addition, the winch can be free-wheeled in four ways:

1. Winch Motor switch in "Hold" and the Winch Lock switch in "Off."
2. The Hydraulic Power Generator switch "Off," the Winch Motor switch in "Run," and the Winch Lock switch in "Off."
3. Main Power switch in "Off."
4. Electrical power failure.

To reset the interlock system (which automatically slows and then stops the incoming anchor before it reaches the winch housing), the Jog switch is operated twice. A 25-in.^{3} accumulator is incorporated in the winch motor hydraulic loop to cushion sudden anchor stops.

Manual System. The manual hydraulic system (Figure 15), located inside the pressure hull, serves two functions: it provides a means of cutting the anchor cable and dropping the battery pack in an emergency, and it controls the mechanical winch brake.

The power source for the manual hydraulic system is a Star hand-operated hydraulic pump located beneath the operator seat. The pressure capacity is 5,000 psi, but the winch brake circuit pressure is limited by a 500-psi relief valve and the jettison circuit pressure is limited by a 3,000-psi relief valve. All of the control valves are located on the manual hydraulic/oxygen control panel (Figure 9). The oil reservoir is attached beneath the step panel (where the pO_2 and pCO_2 meters are located). The removable step can be used as a pump handle for the Star hand pump.

The design of the valve controls is such that accidental operation of the jettison circuit is nearly impossible. Five steps are required to jettison the anchor (refer to Figure 9):

1. Place the system selector valve in the jettison mode (up).
2. Select the jettison system valve for the anchor jettison position.
3. Close the crossover to sump on the jettison system valve.

4. Close the normally open to sump valve.

5. Pump.

Jettisoning the battery pack is a similar operation, except that the main power cable must be cut pyrotechnically first. Check valves have been included in both jettison lines to prevent seawater intrusion into the pressure hull if any of the jettison cylinders or hydraulic lines develop a leak.

The winch brake is used whenever the winch is not being run. The manual pump actuates a hydraulic cylinder which inserts a dog into the winch pinion gear. A lock valve is provided to keep the winch brake cylinder from moving when it is not being actuated by the manual pump.

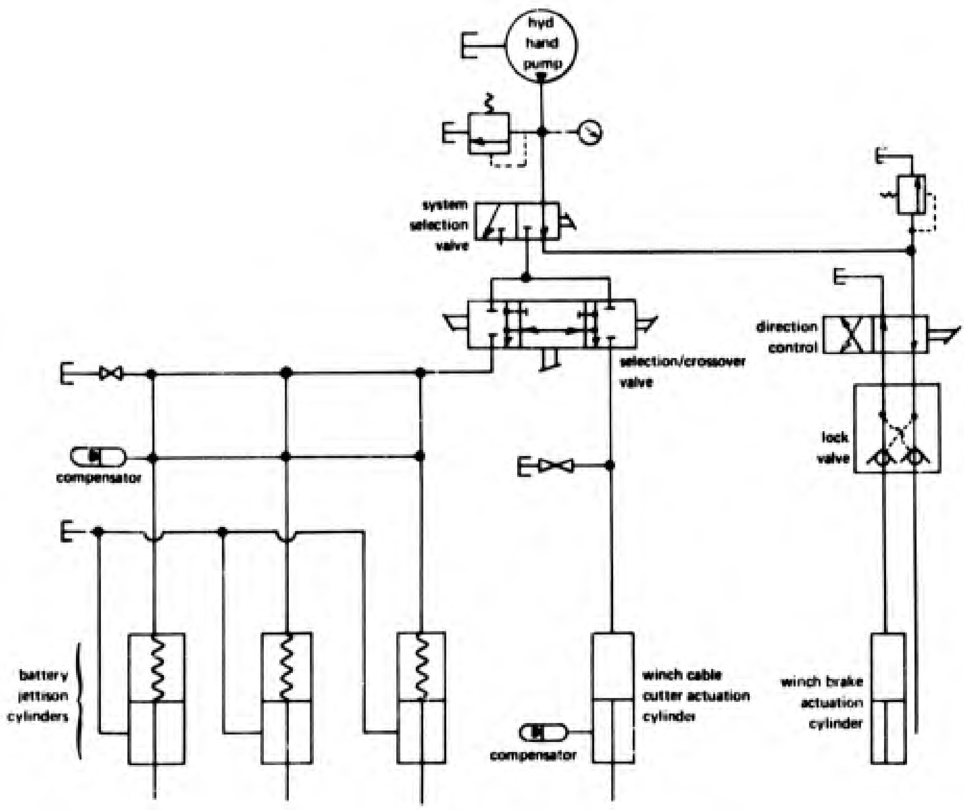


Figure 15. Schematic of manual hydraulic.

Ballast

NEMO controls its buoyancy by means of a high-pressure air supply, solenoid valves, and two open ballast tanks.

The main ballast tank (MBT), located directly beneath the NEMO hull (Figure 16), is a cylindrical free-flooded tank with a capacity of approximately 8 ft^3. When NEMO is placed in the water, air is trapped in the MBT, giving NEMO (including the anchor) about 300 pounds of buoyancy. At the lower end of the MBT is an air baffle to prevent air from spilling out when NEMO is tipped. Just below the air baffle is a series of holes to prevent the MBT from being overfilled.

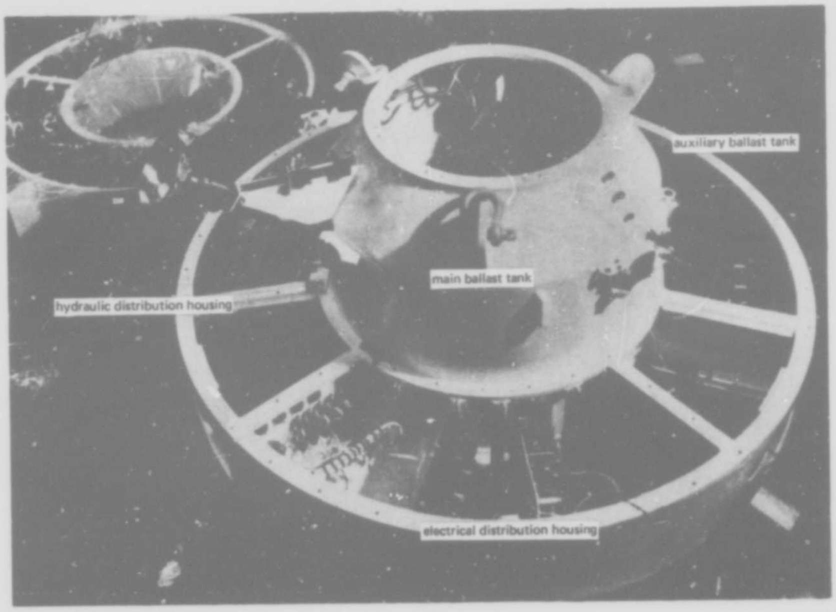


Figure 16. Lower unit.

The free-flooding auxiliary ballast tank (ABT) located in the aft section of the service module has a capacity of approximately 2 ft^3.

Six 50-ft^3 and one 71-ft^3 commercial air bottles, filled to 2,250 psi, supply the deballasting air supply for NEMO. These make available 371 scf of air, or 19.2 ft^3 of air at a depth of 600 feet. Therefore, at the 600-foot depth, the MBT can be blown twice or neutral buoyancy can be attained six times. Normally, ballast air is not used at depth unless neutral buoyancy is desired for translation.

The seven air supply bottles are manifolded together (Figure 17). The blowing and venting for both ballast tanks are controlled by 1/2-inch Morotta solenoid valves. A regulator limits the pressure from the bottles through the two blow valves to 400 psi (or less if the pressure in the bottles is less). The air regulator has a manual adjustment, which must be set prior to diving, so that regulation can be changed to meet any desired response or mission requirement. The low pressure side of the air ballast system is also used to charge the two hydraulic accumulators in the hydraulic distribution housing.

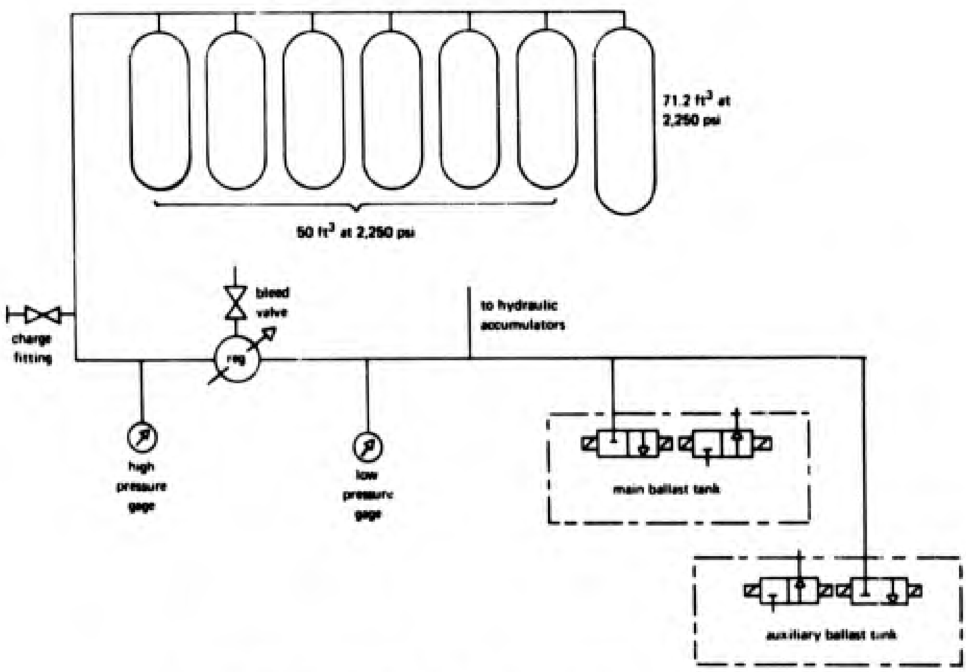


Figure 17. Schematic of high pressure air ballast system.

The ballast solenoid valves are controlled with four illuminated pushbutton momentary action switches on the control console—one each for MBT blow, MBT flood, ABT blow, and ABT flood (Figure 12) Ballast control power is obtained through a power selector switch labeled Emergency Ballast Power. In the normal (Off) position, this switch selects ballast control power from the 24-VDC tap on the main battery. If the main power fails, the power selector switch can be moved to provide control power from the emergency 24-VDC life support battery. This allows deballasting to surface under emergency conditions.

Normally, lead weights are used for additional ballast to bring NEMO to the proper operating weight. They are located inside the battery pack so that, if the batteries are jettisoned, the weights are jettisoned also.

Communications

A Johnson Messenger HF transceiver and 1/4-wavelength antenna serve as the surface communication system.

Subsurface communication utilizes an Aquasonics underwater communicator and acoustic transducer. The unit has a slant rating of 4,000 yards for voice communication to the surface. Included are a microphone, a loudspeaker, and headphones inside the pressure hull. The Aquasonics unit is compatible with standard Navy AN/UQC-1 systems. Compatible transceivers for both the HF and the underwater transceivers are carried in the support van for use on the support ship. A diver-operated acoustic transceiver is also available for communications between NEMO and a scuba diver.

Support Facilities

A 28-foot trailer with a fiber glass van and shock absorbing pad comprises the support package for NEMO. Battery chargers for both the main and the emergency battery systems, hydraulic and electronic test equipment, communication transceivers, repair and recharge facilities, and spare parts are included in the support van. The trailer can be used on the ship as a total at-sea support package (normal), or the van and shock pad can be removed from the trailer when the support ship is too small to carry the entire package. Figure 18 shows the NEMO support package.

OPERATIONS

Emergency and Safety

The most critical design criterion for manned submersibles is the safety of the men on board. This requirement implies that the vehicle must be able to surface despite component failure, as well as being capable of supporting the life of the operators under all foreseeable circumstances. Submersible operations have been remarkably devoid of serious accidents; this is due in large part to reliability and redundancy of design.

The emergency features included in the NEMO system are:

- An MSA (Mine Safety Appliances) explosive cable cutter or a hand-operated hydraulic cutter can cut the cable to the 400-pound anchor. Main or emergency batteries are used to detonate the explosive squibs.

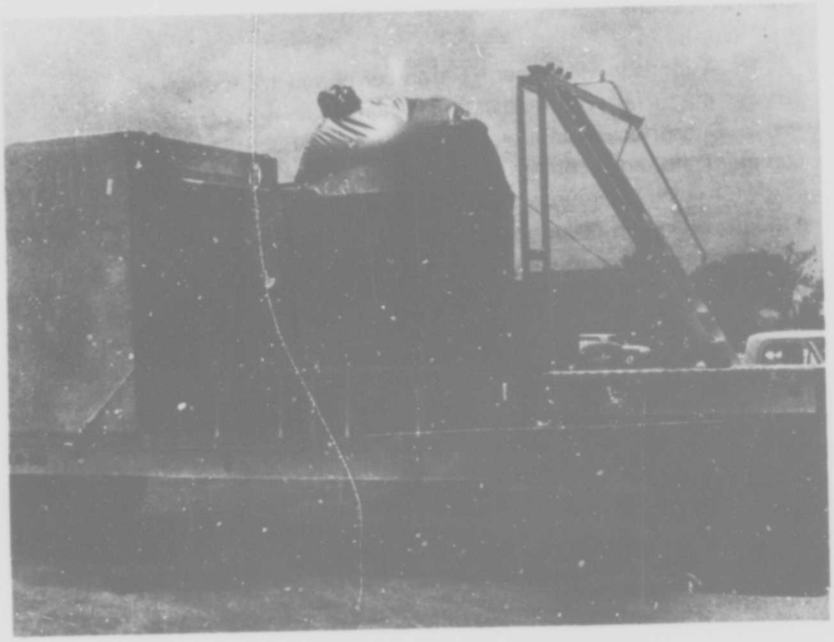


Figure 18. NEMO support package.

- The main battery pack can be jettisoned by explosively cutting the main power cable, then using the manual hydraulic system to pull the three battery retaining pins. Either the main or emergency battery can be used to fire the squib cutter.
- The emergency battery inside the pressure hull operates the life support and all emergency systems if the main power supply fails.
- Free wheeling of the winch to return NEMO to the surface can occur in three ways as discussed in the Anchor Winch section above.
- The main ballast tank can be blown two ways if main power is lost:

    1. The internal battery can operate the air ballast solenoid valves.
    2. The oxygen supply bottles can be connected to a valve on the bottom plate which leads to the MBT.

- Closed-circuit oxygen rebreathers can be used if the cabin breathing air becomes fouled.

Additional safety features are:

- Gages are supplied to monitor the pO_2 and pCO_2 concentrations, with a backup Drager kit to determine the oxygen and carbon dioxide content.
- All internal equipment is fireproof and nonoutgassing. If a fire should occur, a dry chemical fire extinguisher is provided.
- The oxygen supply system has two separate oxygen flow control paths and two separate oxygen supply bottles.
- The total life support system is capable of 24-hour emergency operation.
- The hatch can be opened either from the inside (normal) or outside. It has an open-lock to prevent it from accidentally closing on the operators.
- The structural cage protects the acrylic plastic pressure hull from impact against large, relatively flat surfaces.
- The lower unit is smaller in diameter than the structural cage and has no protrusions, thus minimizing snagging problems.
- The main ballast tank has enough buoyancy to float the entire NEMO system (including the anchor). It is provided with an air baffle to prevent air from spilling out if NEMO is tipped, and holes to prevent overfilling and wasting air.
- NEMO, without its anchor, has 150 pounds of positive buoyancy.
- The life support circuits and control console are checked before the main power is turned on. All circuits are protected by circuit breakers or fuses.
- Water intrusion devices can detect seawater in the electrical distribution, hydraulic distribution, and main battery housings.
- An overload protection relay and a field loss relay are provided to turn off the hydraulic power supply motor before it is damaged.
- NEMO can be held in place indefinitely with a manually operated hydraulic brake or by hydraulically locking the winch motor.

- An automatic sensing unit slows and stops the winch motor as the anchor approaches the up position, thus preventing the anchor from slamming into the lower unit.
- All external systems, except the NEMO hull, the lights, and three small pressure gages, are pressure compensated.
- All external surfaces, except the winch and acrylic plastic hull are mild steel protected with an epoxy paint. Any scratches and ensuing rust are easily detected and repaired.

Surface Support

The NEMO system can easily operate from a vessel of 100 tons or greater with an over-the-side handling capability of at least 10 tons. Figure 19 illustrates the NEMO support package aboard the NCEL warping tug. The lifting lines—spreader bar combination used for lifting NEMO is shown in Figure 20. Each lifting line is capable of lifting more than twice the static in-air weight of NEMO.

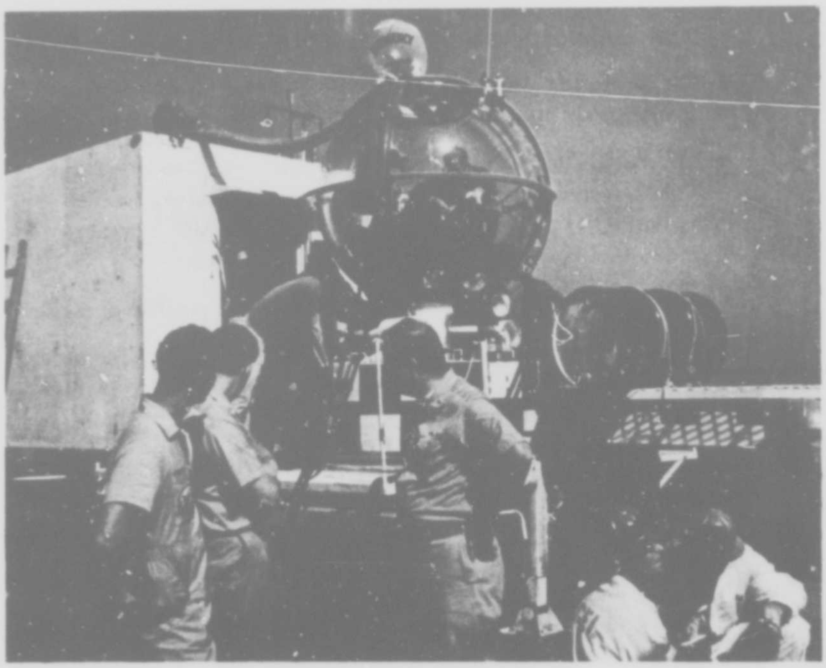


Figure 19. Support package aboard NCEL warping tug.

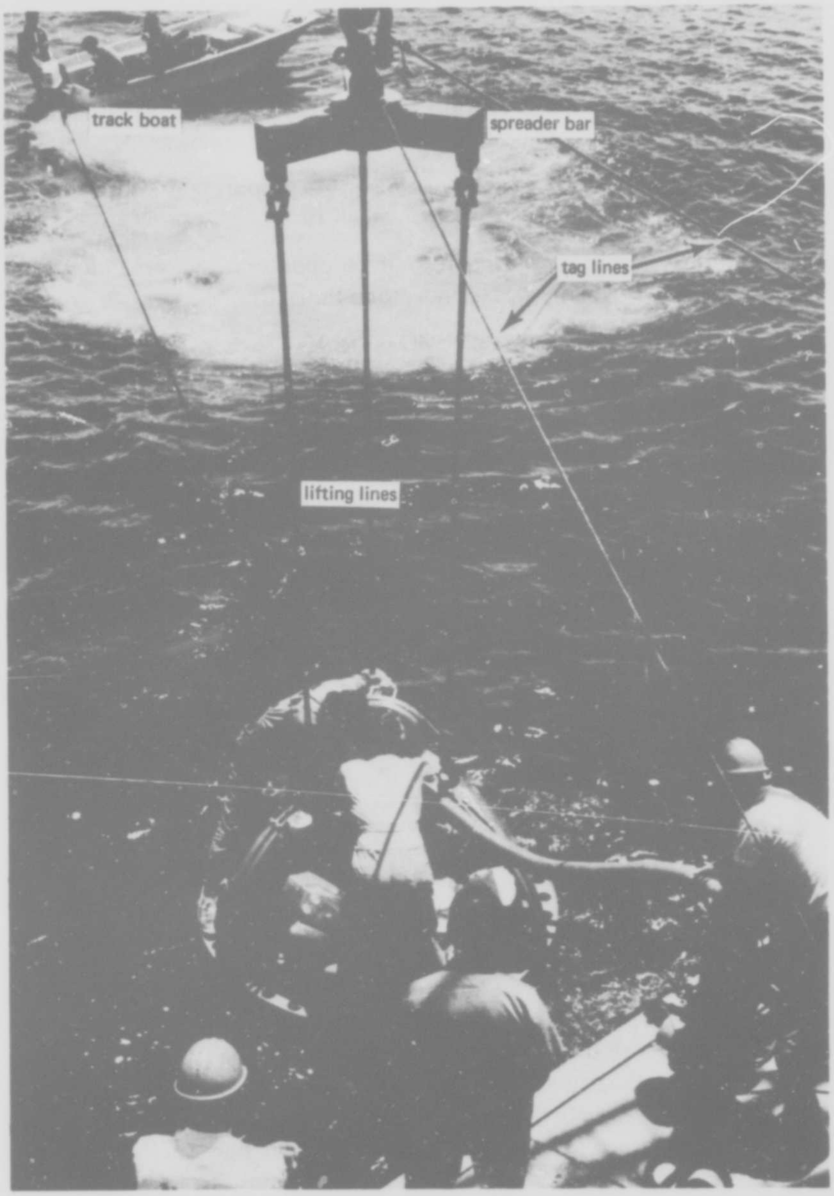


Figure 20. Lifting lines and spreader bar.

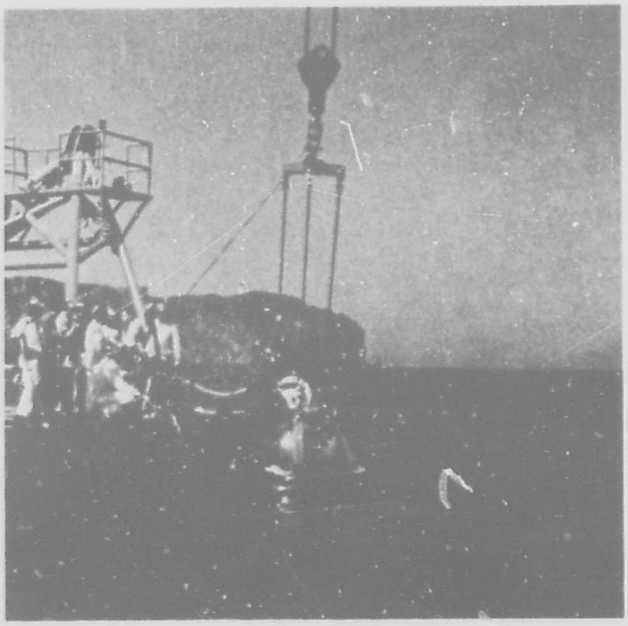
Operating Modes

The mode of operation for NEMO varies significantly from conventional submersibles due to its primary function of observation at a particular location. A typical dive scenario (illustrated in Figure 21) is as follows:

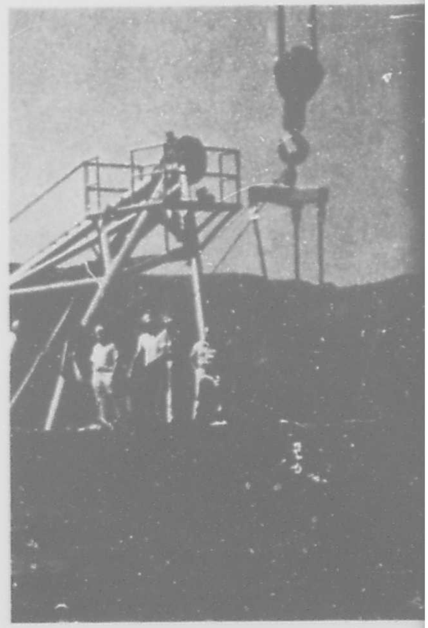
1. NEMO is held against the side of the support craft, submerged to the hull equator, for personnel entry.
2. NEMO is swung away from the support craft, lowered into the water, and divers disconnect the three lift lines.
3. The track boat tows NEMO 50 to 100 yards away from the support craft to the dive location.
4. The anchor is lowered to the bottom, and the track boat line is disconnected.
5. The ballast tanks are flooded, and NEMO winches to the bottom. (NEMO, without the anchor, is 150 pounds positively buoyant. The anchor is 380 pounds negatively buoyant.)
6. After completing the mission, NEMO free-wheels or winches to the surface.
7. The track boat re-attaches to NEMO, the ballast tanks are blown, and the anchor is winched up into its housing.
8. NEMO is brought alongside the support craft where divers attach the lift lines.
9. NEMO is raised out of the water to the hull equator, is snubbed alongside the support craft, and the crew exits.

Alternate modes of operation are available also. Once NEMO is in the water, it can deballast and free descend to the bottom. The anchor is lowered 10 to 20 feet from NEMO so that when the anchor strikes the bottom the descent stops. The high-pressure air ballast system can be used in conjunction with the propulsion motors to achieve neutral buoyancy and to translate short distances along the bottom. Finally, the air ballast system can be used to overcome the weight of the anchor, allowing NEMO to free ascend to the surface. The safest mode of operation, however, is a controlled ascent—descent using the self-contained winch system. On ascent, NEMO usually stops 20 feet short of the surface to insure that the surface is clear of obstructions.

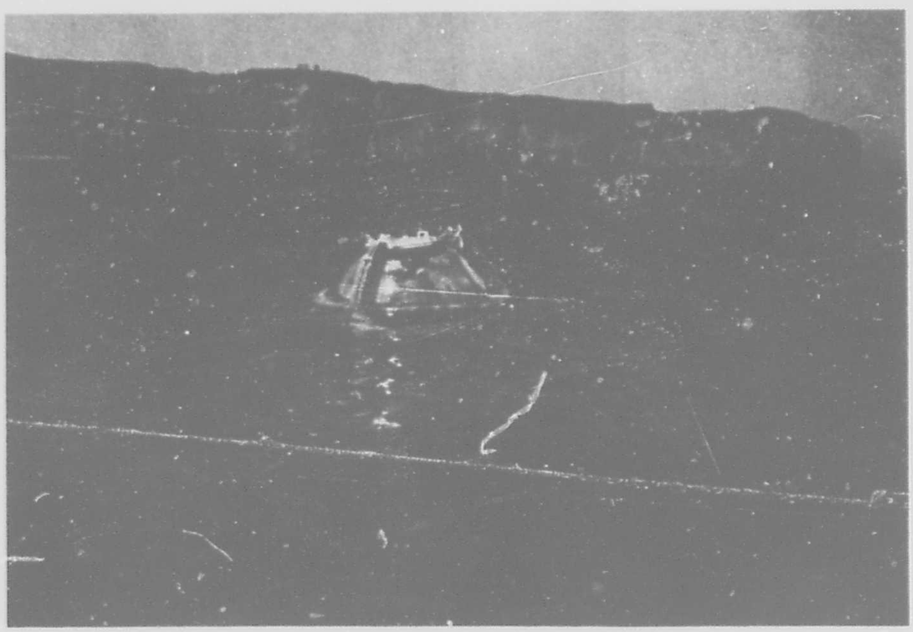
A



(a) NEMO is held against the side of the support craft, submerged to the hull equator, for personnel entry.

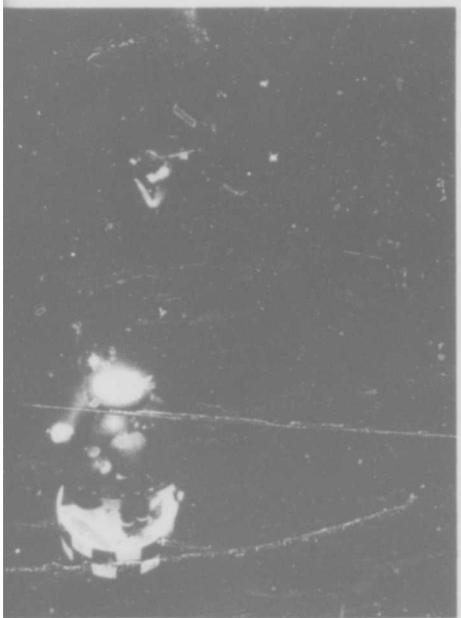


(b) NEMO is swung away from the support cr
and the three lift lines are disconnected by



(d) The anchor is lowered to the bottom, and the track boat line is disconnected.

(c) NEMO is towed 50 to 100 yards away from the support craft to the dive location by the track boat.



ks are flooded, and NEMO winches to the bottom.

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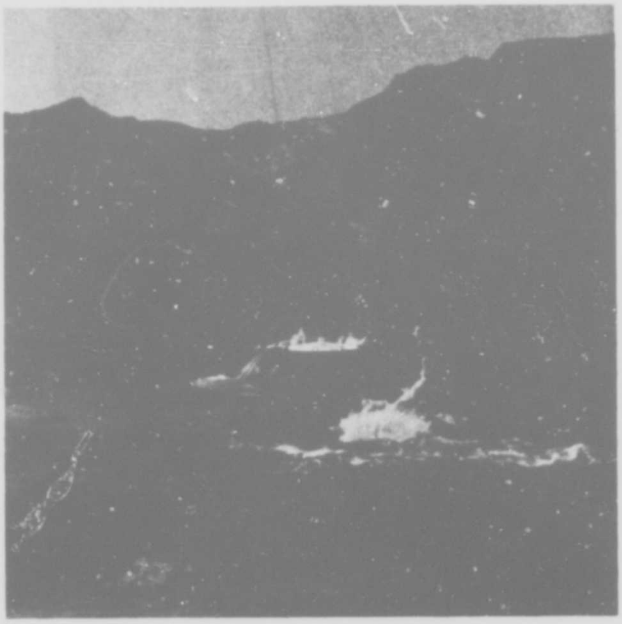
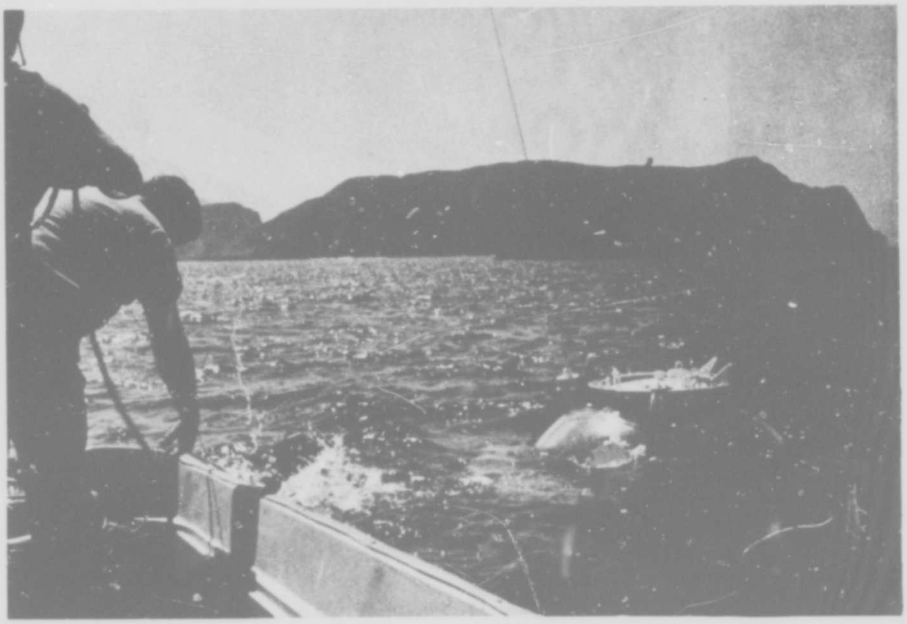
Figure 21. Typical dive scenario.

A

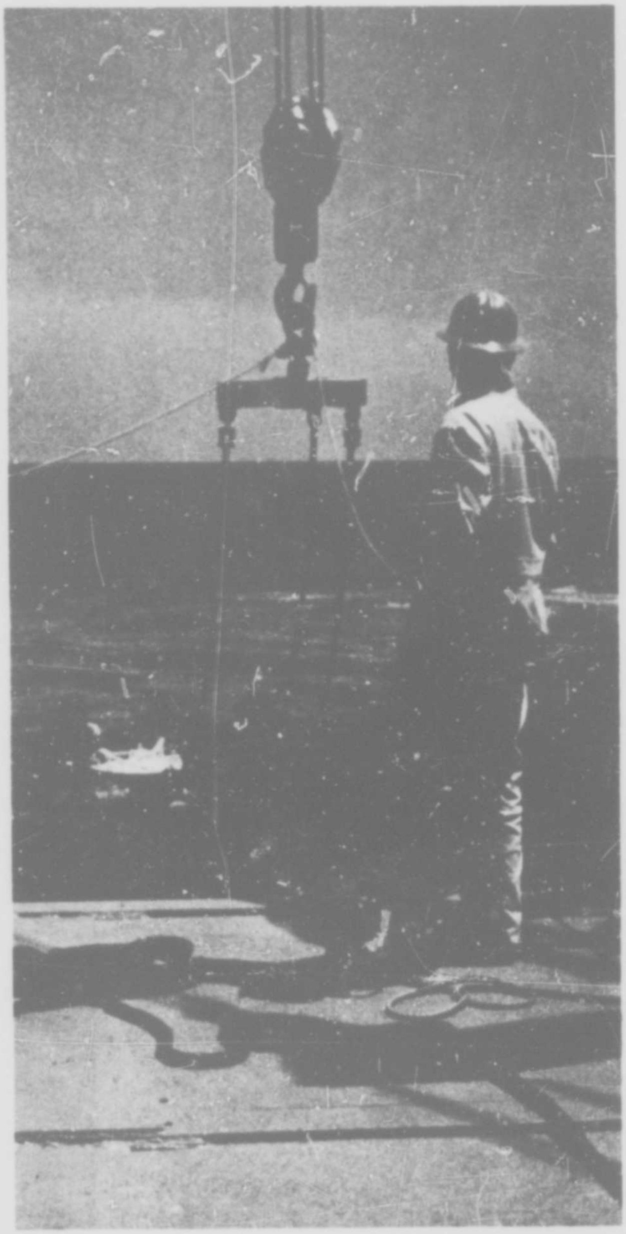


(f) After the mission is completed, NEMO free wheels or winches to the surface.

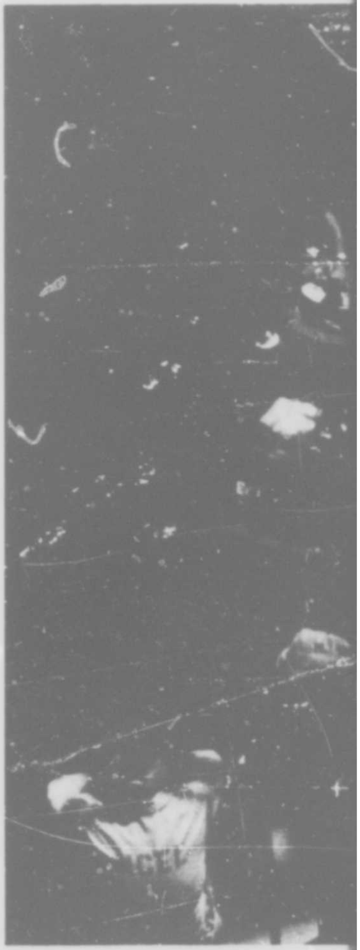


(g) The track boat re-attaches to NEMO, the ballast tanks are blown, and the anchor is winched up into its housing.

B



(h) NEMO is brought alongside the support craft where divers attach the lift lines.



(i) NEMO is raised out of the wate
support craft, and the crew exi

Figure 21.

1c

(i) NEMO is raised out of the water to the hull equator, is snubbed alongside the support craft, and the crew exits.

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Figure 21. Continued.

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Operational safety is of primary concern for NEMO. Appendix D contains the operational checklists and procedures which insure NEMO is operated safely at all times.

SUMMARY

In summary, acrylic plastic hull technology was developed by NCEL to provide continental shelf depth submersibles and other manned undersea systems with improved visibility, better payload capabilities, reduced fabrication and maintenance costs, greater operator comfort, and better cold water capabilities. A 66-inch-diameter acrylic plastic hull, 2.5 inches thick, has been provided with life support, power, control, and communications systems in order to evaluate the acrylic plastic hull concept. This integrated system, NEMO, was designed and built by Southwest Research Institute under contract to NCEL.

NEMO has life support for two personnel for up to 32 hours; position control via hydraulic thrusters, a hydraulic-winch-operated anchor, and air ballast tanks; surface and submerged communications; emergency surfacing systems; adequate electrical power for the above; and the necessary support facilities for at-sea operations.

To date, NEMO has completed successful contractor sea trials, Navy material and operator certification, and a brief shallow water test of the vehicle's visual characteristics. There is every indication that the concept will meet or surpass all requirements in its upcoming evaluation.

Appendix A

MATERIAL CERTIFICATION

Material certification procedures and requirements are well documented in two publications of the Naval Ship Systems Command—the Material Certification Procedures and Criteria Manual for Manned Non-Combatant Submersibles[7] contains instructions and regulations regarding material certification, and a Pre-Survey Outline Booklet for Manned Non-Combatant Submersibles[8] is used in conjunction with the criteria manual to define which systems and subsystems are within the scope of certification. The systems which are within the scope of certification, that is, the systems of particular interest to NAVSHIPS as the certifying agency, are as follows:

1. All components, systems, and portions of the submersible which are required to return operators and passengers safely from any depth down to the maximum operating depth back to the surface or to a submerged base under abnormal conditions following any noncatastrophic accident or casualty which precludes continued normal operation of the submersible.

2. All components, systems, and portions of the submersible which through malfunction or failure could prevent the return of the submersible to the surface or to a submerged base.

3. All components, systems, and portions of the submersible required to keep operators and passengers safely on the surface following any ascent.

4. All components, systems, and portions of the submersible provided to rescue personnel from the submersible and return them to the surface, a support ship, or a submerged base.

5. All systems and components, including temporary test equipment, affecting trim and stability conditions, both surfaced and submerged, which could prevent the safe return and egress of personnel from the submersible.

To determine the items which fall within the certification scope, representatives of the agencies involved in the design and construction of the submersible meet with the NAVSHIPS review project engineer and jointly arrive at the selection of scope items. The Pre-Survey Outline Book is filled out for the submersible under study. All items which appear in the scope are subjected to the following review:

1. The design drawings and bill of materials are reviewed by NAVSHIPS.

2. Records must be kept to insure that the materials and fabrication processes are in accordance with the design.

3. A NAVSHIPS inspection team inspects the as-built hardware for conformance to the design drawings. Any deviations must be justified.

4. Tests as required by NAVSHIPS must be performed on subsystems and components.

5. The submersible must perform a dive to its operational depth with a NAVSHIPS representative on board.

The Material Certification procedure for NEMO presented no particular problem. All systems and components other than the hull were selected primarily because they had already been certified for other submersibles; all materials used were category 1 materials, that is, they had all been used extensively in submersible applications in the past. The hull, a category 3 material (little or no prior application for submersible pressure hulls) was also no problem because of the extensive experimental and analytical studies which had been performed on the hull.

When all of the above steps have been completed, the submersible receives a certification document which must be carried aboard the vessel. The duration of the certification is usually limited by number of dives, amount of time, and, of course, by depth.

Appendix B

FABRICATION OF NEMO ACRYLIC PLASTIC PRESSURE HULL[3]

1. Twelve acrylic plastic sheets, 48 inches by 60 inches by 2-1/2 inches thick, were rough-sawed to a circular shape with a 46-inch diameter. The periphery was machined to a 200-μin. finish. One edge was then chamfered to 1/16 inch by 1/16 inch.

2. One blank at a time was set in a female form die, with the chamfered edge against the die.

3. The flat acrylic plastic blank and form die were placed in an oven. A vacuum line was run from a vacuum pump outside the oven to the center of the form die where the vacuum holes are located. The oven was preheated to 165^{o}F overnight.

4. After preheating, forming was accomplished as follows:

   a. The oven temperature was raised to 310^{o}F.

   b. After 8 hours at 310^{o}F, vacuum was applied, and the blank formed to contour.

   c. After 15 minutes under vacuum, the oven was turned off. Vacuum was left on, and the oven doors remained closed.

   d. The oven was allowed to cool overnight, a minimum of 16 hours. The oven doors were opened, and the formed part in the form die was allowed to cool to room temperature.

5. The above procedure was followed for all twelve acrylic plastic blanks.

6. Each of the formed spherical blanks was checked for contour and thickness.

7. Each of the formed spherical blanks was annealed in the form die for 24 hours at 160^{o}F. The blanks were cooled to room temperature at a rate not exceeding 8^{o}F/hr.

8. Each of the formed spherical blanks was machined into a pentagon section on a milling machine.

9. A hole was machined with a vertical boring mill in two of the spherical pentagon sections. These two sections are used at the polar regions of the sphere.

10. Each of the machined spherical pentagons was annealed in the form die for 24 hours at 160°F. The spherical pentagons were cooled to room temperature at a rate not exceeding 8°F/hr. The machined spherical pentagons were reinspected for contour.

11. The periphery of each pentagon was sanded using 240- to 400-grit sandpaper.

12. One polar zone pentagon and five regular spherical pentagons were fitted together to form a hemisphere in the handling fixture, with the polar zone pentagon at the bottom center. The pentagons were spaced 0.125 inch apart with acrylic plastic spacers (0.125 inch by 0.250 inch by 0.500 inch). These spacers were located two on a pentagon side and approximately 2 inches in from each corner. The joints between the segments were matched on the outside surface so the external curvature across the joint was continuous.

13. The 0.125-inch spaces between the pentagon segments were prepared for cementing as follows: The joint on each side was covered with an adhesive-backed aluminum foil (Scotch Brand No. 425). The adhesive-backed aluminum foil was formed in a manner to allow it to protuberate slightly over the joint area. This protuberance left a bead in the cementing operation which compensated for shrinkage in the cemented joint.

14. Swedlow's proprietary casting material, SS-6217, was utilized to bond the pentagons together. A filling arrangement was adopted that allowed the six pentagonal sections to be cemented in two operations. The adhesive was poured and cured.

15. The first hemisphere was removed from the fixture with a hoist and sling.

16. The second hemisphere was constructed in the same manner except 0.188-inch acrylic plastic spacers were used, and the hemisphere was left positioned in the fixture.

17. The first hemisphere was elevated above the second one with a hoist and sling. It was positioned over the second hemisphere with 0.125-inch acrylic plastic spacers. The joints were prepared, and the adhesive poured as described in paragraphs 13 and 14. The joining of the two hemispheres completed the acrylic plastic sphere.

18. When the adhesive-backed aluminum foil was removed from the sphere, a number of bubbles were evident in the cement joint.

19. To repair the joint the bubbled area had to be removed by machining or drilling.

20. After the bubbled area was removed, the sphere was annealed at 160°F for a period of 27 hours. The sphere was cooled to room temperature at a rate not exceeding 8°F/hr; it was then removed from the oven.

21. The areas to be repaired were then filled with SS-6217 and cured.

22. This procedure was followed until the majority of the bubbles were repaired.

23. After repair, the adhesive beads were removed, and the joints were cleaned.

24. The completed sphere was then polished to remove scratches.

25. The completed sphere was then annealed, in the fixture, for a period of 27 hours at 160°F. The sphere was cooled to room temperature at a rate not exceeding 8°F/hr; it was then removed from the oven.

26. The annealed acrylic plastic sphere was moved to a temperature-controlled room where it was allowed to equalize to the temperature of the room.

Appendix C

PROPERTIES OF ACRYLIC PLASTIC (ROHM & HAAS PLEXIGLAS G)[5]

Tensile strength (maximum)	10,500 psi
Modulus of elasticity (tensile)	450,000 psi
Compressive strength (maximum)	18,000 psi
Modulus of elasticity (compressive)	450,000 psi
Flexural strength (maximum)	16,000 psi
Shear modulus	166,000 psi
Impact (Charpy)	14.0 ft-lb/in.^{2}
Poisson's ratio	0.35
Hardness	M-93 Rockwell
Deformation under load	0.5% (4,000 psi at 122°F, 24 hr)
Specific gravity	1.19
Specific heat	0.35 Btu/lb °F
Coefficient of thermal conductivity	0.11 Btu/hr ft °F
Coefficient of thermal expansion	40×10^{-6} in./in./°F
Water absorption	0.2%
Corrosion resistance	Excellent
Refractive index	1.49
Light transmission	92%

Appendix D

PROCEDURES AND CHECKLISTS

STANDARD OPERATING PROCEDURES

I. Predive

A. Perform predive briefing.

B. After operator starts predive inspection, absolutely no personnel permitted near NEMO without operator authorization.

C. Never interrupt predive inspection. Predive inspection should be last step before launch.

D. Predive inspection sheet initiated and signed by operator, affirmed by chief operator.

II. Launch

A. Use lanyard to retain spider and retainer bolt.

B. Launch proceeds only upon signal from NEMO operator.

III. Dive

A. Initial checks.

1. Read pO_2 meter, adjust pO_2 primary system until proper (18-23%) pO_2 reading obtained, then set flow for 1 liter/min (two people on board).
2. pCO_2 meter should read 3 mm Hg or less in fresh air.
3. Make UQC check

B. 5-minute intervals

1. Determine pO_2 concentration at 5-minute intervals, and make necessary adjustments to primary flowmeter control. If pO_2 exceeds 25%, abort.
2. Read pCO_2 meter at 5-minute intervals. Operate Life Support Blower (intermittently if desired) to maintain pCO_2 less than 8 mm Hg.

C. 15-minute intervals.

1. Make UQC report to surface support ship at 15-minute intervals, or as necessary to report change in status, emergency, or for information purposes.
2. Read water intrusion meter for indication of water (any reading above 0 volt) at 15-minute intervals.
   a. Electrical distribution box.
   b. Hydraulic distribution box.
   c. Main battery pack.
3. Log voltage and amps of the 120V system. Monitor continuously; at no time should amp discharge be greater than 40 amps. If abnormal reading on ammeter is observed, see emergency procedures.

4. Log voltage and amps on the 24V system.

D. 30-minute intervals.

1. Read cabin pressure. Monitor carefully during ascent. Open vent valve during final ascent on last 100 feet if the cabin hull pressure exceeds 1 psi.
2. Turn over or change tapes on tape recorder; read in time, date, and personnel.

E. 60-minute intervals.

1. Verify pCO_2 and pO_2 with Drager Kit.
2. Determine 120V battery state by
   a. Turning on only the four lights, life support blowers, and control panel lights.
   b. Record voltage.
   c. Amperage should be 25 amps.
3. Determine 24V battery state (main battery pack).

F. General Notes.

1. All valves (especially O_2) should be tightened finger-tight only.
2. Leave main power switch off unless using power. Stand-by switch remains on.
3. Do not activate hydraulic generator unless intending to use a hydraulic subsystem.
4. Do not change winch or rotation motor direction without going through "off" position.
5. Limit simultaneous operation of rotation motors and hydraulic winch.

IV. Recovery

A. Never open the hatch in the water unless NEMO is attached to the lifting sling and raised out of the water at least to the equator of the sphere.

B. Always put console control panel cover in place prior to opening the hatch.

V. Post-Dive

A. Throw away baralyme from both canisters and both Min-o-Lungs after each diving day or 8 hours of diving.

B. Conduct Post-dive briefing.

C. Present Chief Operator with dive tapes and/or dive log, which should be identified with date, dive number, and personnel aboard.

VI. General.

A. Any time the NEMO hatch is closed with personnel aboard, one of the personnel must be a certified operator.

B. Do not leave underwater lights on for more than 5 seconds while out of the water.

L44/PKR/REE/RGL/dm
27 January 1971

DATE: ________
TIME: ________
DIVE NO: ________

NEMO PRELAUNCH CHECK LIST

Initial

I. External, General

____ 1. Make sure hatch opening devices are in the van and safety divers know how to use them.

____ 2. Check spare CO_2 canister—properly filled. Check label date, time, initials, and end closures in place and tight.

____ 3. Check Min-o-Lungs (2).

(a) CO_2 canisters for fill, label time, date, initials
(b) O_2 bottle labels for fill within 30 days

____ 4. Read HP air gage ______, max 2,300 psi, min 1,250 psi.

____ 5. Check weight and buoyancy sheet properly—filled out and signed. Check proper weights aboard and secure if applicable.

____ 6. Certify that observer has been briefed (if applicable) and has had proper physical.

II. MBT Area

____ 1. Unlock winch.

____ 2. Inspect battery jettison cylinders (3) and associated tubing for oil leaks.

____ 3. Check battery jettison system for proper alignment and remove safety pins (3).

____ 4. Inspect cable cutter flex line on level wind pawl for condition (leaks, cracks).

_____ 5. Inspect compensator system on pawl for leaks in diaphragm, bubbles, and proper amount of compensating fluid (2).

_____ 6. Check winch for general soundness:

Check

_____ (a) Gears and chain

_____ (b) Drum and proper cable lay

_____ (c) Level wind barrel gear and bearings

_____ (d) Barrel gear spacer and spacer retainer secure and against gear teeth

_____ (e) Set screws tight, (1) on level wind gear, (2) on winch motor gear

_____ (f) Barrel gear condition and adequate lube

_____ (g) Level wind pawl properly secured to level wind, set screws (2) tight

_____ (h) Teflon guides condition (wear and service)

_____ (i) Winch support structure for tight bolts

_____ (j) Winch motor area for fluid leaks

_____ (k) Winch motor hydraulic tubing (3) for leaks and damage

_____ (l) Winch manual lock cylinder and tubing for leaks, properly secured, and locking dog (use articulating mirror as required), observe actuation

_____ (m) Drum and pinion gears for chips or missing teeth

_____ (n) Anchor stop frame in place, oriented correctly and secure

_____ (o) Winch lock on

_____ 7. Check Protechnic devices (2).

Check

_____ (a) Anchor cable device for secure attachment

_____ (b) Power cable device for secure attachment

_____ (c) Anchor cable device for associated wiring condition

_____ (d) Power cable device for associated wiring condition

_____ (e) Anchor cable squib cartridge for continuity

_____ (f) Power cable squib cartridge for continuity

_____ (g) Anchor cable device circuit continuity

_____ (h) Power cable device circuit continuity

_____ (i) Anchor cable squib O rings for adequate lube (2)

_____ (j) Power cable squib O rings for adequate lube (2)

_____ (k) Anchor cable device for 24V. NOTE: Person actuating squib switch should visually see *both* squib cartridges outside of MBT area before throwing switch

_____ (l) Power cable device for 24V. (See NOTE above)

_____ (m) Anchor cable squib cartridge in place. NOTE: Check for short circuit before installing cartridge

_____ (n) Power cable squib cartridge in place. (See NOTE above)

_____ (o) Anchor cable device bolt and electrical connector in place

_____ (p) Power cable device bolt and electrical connector in place

_____ 8. Check power cable electrical connector lead secure and dummy plug in place (if applicable).

_____ 9. Check hydraulic tubing for leaks (3) winch lines, (6) motors, (2) lights.

_____ 10. Check anchor connection for soundness and swivel for free rotation.

III. External, Lower

_______ 1. Inspect light articulation cylinder for leaks (red stain) and associated hydraulic tubing.

_______ 2. Inspect articulated light cotter pins for soundness and wear, insure cylinder well-greased.

_______ 3. Check lights no. 1 and no. 2 (750 watt) bulb and reflector for condition.

_______ 4. Check fuse holders in forward access area (FAA) for leaks and secure.

_______ 5. Check electrical penetrators in FAA for leaks, and nut down tight (less than a 1/16-inch clearance).

_______ 6. Check hydraulic penetrators in FAA for leaks.

_______ 7. Check battery jettison cylinder in FAA for leaks and condition.

_______ 8. Check FAA battery relief valve for operation and adequate fluid level in battery container.

_______ 9. Check HP hydraulic output and gage for leaks.

_______ 10. Check forward 50 ft^3 air bottles (2), connections, and tubing for condition and bottles secure.

_______ 11. Check electrical distribution box, cover seal for leaks and secure nuts tight.

_______ 12. Check electrical distribution box for adequate fluid level.

_______ 13. Check port propulsion motor housing and tubing for leaks.

_______ 14. Check port propulsion motor attachment for soundness.

_______ 15. Check port propulsion motor screw secure.

_______ 16. Check light no. 3 (port side, 500 watt) for secure attachment, bulb, and reflector condition. Check locking retainer at connection for secure.

_______ 17. Check APT vent line in place and secure.

_____ 18. Check Port Access Area (PAA) fuse holders for secure and leaks.

_____ 19. Check PAA electrical penetrators for leaks and nut down tight (less than 1/16-inch clearance)

_____ 20. Check PAA gas line penetrators for secure.

_____ 21. Check PAA battery relief valve for operation and adequate fluid level in battery container.

_____ 22. Check battery jettison cylinder in PAA for leaks and condition.

_____ 23. Check battery compensator_____inches in the green.

_____ 24. Check diver electrical output penetrator for leaks and dummy plug in place.

_____ 25. Check port 50 ft^3 air bottles (2), connections, and tubing for condition and bottles secure.

_____ 26. Check HP air gage valve open.

_____ 27. Check HP air filling connection capped and valve closed.

_____ 28. Check electrical distribution box compensator.

<u>Check</u>

_____ (a) Valve open

_____ (b) Indicator shaft has ≤ 2-1/2-inch clearance from deck

_____ (c) Fluid leaks from compensator and associated tubing

_____ (d) Fill valve closed and capped

_____ 29. Check hydraulic distribution box compensator.

<u>Check</u>

_____ (a) Valve open

_____ (b) Indicator shaft has ≤ 2-1/2-inch clearance from deck

_____ (c) Fluid leaks from compensator and associated tubing

_____ (d) Fill valve closed and capped

______ 30. Check LP air gage valve open.

______ 31. Check external battery jettison connection capped and valve closed.

______ 32. Check starboard 50-ft^3 air bottles (2), connections, tubing for condition, and bottles secure.

______ 33. Charge hydraulic accumulator. Open valve—wait 15 seconds, close valve.

______ 34. Check hydraulic penetrators in Starboard Access Area (SAA) for leaks.

______ 35. Check battery relief valve in SAA for operation and adequate fluid level.

______ 36. Check battery charging connection and main power connection for leaks and cap down tight (less than 1/16-inch clearance).

______ 37. Check SAA battery jettison cylinder for leaks and condition.

______ 38. Check diver hydraulic outputs for leaks and valves closed and capped.

______ 39. Inspect hydraulic distribution box cover seal for leaks cover-securing nuts tight.

______ 40. Check hydraulic distribution box relief valve for operation and adequate fluid level.

______ 41. Inspect light no. 4 (500-watt starboard side) bulb and reflector for condition and light attachment secure. Check locking retainer at electrical connectors for secure.

______ 42. Inspect starboard propulsion motor housing and tubing for leaks.

______ 43. Check starboard propulsion motor attachment.

______ 44. Check starboard propulsion motor screw secure.

______ 45. Check MBT vent line in place and tight.

______ 46. Check access area grates (3) in place.

______ 47. Check access area inspection covers (3) in place.

________ 48. Inspect acrylic plastic hull in vicinity of lower plate for cracks.

________ 49. Check lifting frame lower bolts (3) tight with cotter keys in place.

________ 50. Inspect acrylic plastic hull (lower hemisphere) for cracks and scratches. Pay special attention to areas under lifting frames (3).

________ 51. Check bolts on equatorial ring for tightness.

________ 52. Check adequate clearance between lifting frames and hull.

IV. External, Upper

________ 1. Check HP gage for leaks and attachment secure.

________ 2. Check LP gage for leaks and attachment secure.

________ 3. Check depth gage compensating system for adequate fluid and bubbles. Push compensator and note depth increase, check gage attachment to frame.

________ 4. Inspect UQC transducer for attachment and condition. Inspect associated wiring.

________ 5. Check strobe light for attachment and water intrusion.

________ 6. Check HF antenna mount for attachment and antenna secure in mount (all the way down).

________ 7. Check hull, upper hemisphere, for cracks and scratches.

________ 8. Inspect acrylic plastic hull in vicinity of hatch for cracks.

________ 9. Check lifting frame to hatch ring attachment bolts for tightness.

________ 10. Inspect top hatch external opening plug for secure.

________ 11. Check hatch hinges and open lock, check allen screws tight.

________ 12. Inspect hatch O-ring for condition and silicone grease.

________ 13. Inspect hatch and hatch ring mating surfaces for scratches and film of silicone grease.

________ 14. Check hatch relief valve for operation and note position of relief valve stop valve.

V. Internal

_____ 1. Turn on pO_2 and pCO_2 meters.

_____ 2. Check to make sure following items are aboard and in proper condition as stated.

Check

_____ (a) Baralyme canister (1 spare) with proper date-time-initial label

_____ (b) Log book/clipboard

_____ (c) EP's

_____ (d) Fire extinguisher. Check pressure in white, normal operating range

_____ (e) Food and water (if required)

_____ (f) Human range extenders

_____ (g) Tape recorder and extra tapes as needed

_____ (h) Flex hose for O_2 MBT blow

_____ (i) Smoke goggles (2)

_____ (j) Dreager and at least 4 unused tubes each for O_2 and CO_2 checks

_____ (k) Thermometer/hygrometer

_____ (l) Spider/drip ring and retaining bolt

_____ (m) Console cover

_____ (n) Extra baralyme (as required)

_____ (o) Desiccant

_____ (p) Vomit bag and desiccant bag

_____ (q) Teflon tubing

_____ (r) Towels

_____ (s) Extra wing nuts

_____ (t) Pencils

_____ (u) Tool Kit with following tools:

Check

_____ (1) Allen set

_____ (2) 3/16-inch allen

______ (3) Pliers

______ (4) Stubby screwdriver

______ (5) Needle nose

______ (6) Small crescent

______ (7) Small brush

______ (8) 7/16 box/open wrench

______ (9) 9/16 box/open wrench

______ (10) 1/2-9/16 open end

______ (11) 11/16-19/32 open end

______ (12) 5/8-3/4 open end

______ (13) Spare bulbs for panel (2)

______ (14) Jumper wire

______ (15) Soap bubble bottle

______ (16) Knife

______ 3. Check above gear properly stowed.

______ 4. Check O_2 pressure: Prim ______ psi, Sec ______ psi, Max 1,600 psi, Min 800 psi.

______ 5. pO_2 ______ mm should be about 160mm. Switch to other battery, reading should be same.

______ 6. Check O_2 flow from primary and secondary systems (finger over O_2 exhaust).

______ 7. Run O_2 directly on O_2 sensor through tube and check for 100%.

______ 8. Close hatch, and check for O_2 leaks. Secure O_2.

______ 9. pCO_2 ______ mm Hg should < 3mm. Switch to other battery—reading should be the same.

______ 10. Breathe on sensor and check for rise.

______ 11. Check manual hydraulic oil level. Not less than mark on dip stick.

______ 12. Insure manual jettison valves in correct position (selector valve in winch brake position, three handled valve closed and crossed over, red valves open).

_______ 13. Pressurize manual hydraulic brake to check for system operation.

_______ 14. Turn on life support switch and blower switch—check blower operation.

_______ 15. Turn on DV 811 and strobe light. Check for strobe operation and ping on DV 811, secure strobe.

_______ 16. Check auxiliary light for operation.

_______ 17. Check auxiliary battery voltage. 30V open circuit, 25.5 with load.

_______ 18. Turn standby power on, check voltage (24V) and note slight reduction in blower power.

_______ 19. Check for green board.

_______ 20. Turn on voltmeter and set ammeter to discharge.

_______ 21. Check voltmeter reading _____V (min 123V, under load).

_______ 22. Check ammeter reading _____ amps (should be 3.5 amps).

_______ 23. Secure DV 811, blower.

_______ 24. Place emergency ballast power switch in emergency (up) position. Turn off standby power. Actuate MBT blow switches (2) and verify air flow.

_______ 25. Change emergency ballast power switch to normal (down) position and turn on standby power. Check green board and turn on main power. Activate MBT blow switches (2) and verify air flow.

_______ 26. Check water intrusion in hydraulic, electrical, and battery housings.

_______ 27. Verify manual winch brake on and green board (except main power).

_______ 28. Using external observer perform following checks.

<u>Check</u>

_____ (a) All four lights. NOTE: Do not leave lights on for more than 5 seconds while on surface

_____ (b) Verify main power on

_____ (c) Turn on hydraulic generator and note current draw

_____ (d) Check hvdraulic pressure (FAA) (should be 3,000 psi)

_____ (e) Articulate light

_____ (f) Turn on propulsion motors

_____ (g) Record amps_____, volts_____

_____ (h) Secure propulsion motors

_____ (i) Secure hydraulic generator

_____ 29. Clock wound and set to proper time.

_____ 30. Make HF communication check.

_____ 31. Check scuttle valve closed and capped.

_____ 32. Min-o-Lungs (2) with proper date-time-initial label on CO_2 canisters and O_2 bottles, properly stowed.

VI. Final Checks

_____ 1. Check battery pack for gas bubbles.

_____ 2. Insure all battery pop offs are in place and adequate fluid level.

_____ 3. Inspect NEMO for tools, lines and other loose gear.

Date _____________ Time _____________

I certify that this boat is ready for a dive to _____ feet with the following inconsistencies or remarks:

____

____

____

Operator: _______________________________________

Chief Operator: __________________________________

L44/PKR/RGL/dm
27 January 1971

NEMO PREDIVE CHECKLIST

<u>Check</u>

_____ 1. CO_2 canister (date-time-initial) installed.

_____ 2. Desiccant filled.

_____ 3. Ice aboard.

_____ 4. Hatch closed, spider and lanyard on.

_____ 5. Fasten seat belts.

_____ 6. Remove console cover.

_____ 7. Standby switch on, check green board.

_____ 8. Life support switch on.

_____ 9. Scrubber blower on.

_____ 10. Humidity blower on.

_____ 11. O_2 on.

_____ 12. HF on, control panel and unit.

_____ 13. Manual hydraulic winch brake on.

_____ 14. Main power on.

_____ 15. pCO_2, pO_2 sensor units on.

_____ 16. Tape recorder on and recording.

_____ 17. Take system data.

_____ 18. HF transmit to chief operator ready to launch (thumbs up signal to chief operator).

_____ 19. UQC check (if applicable).

Operator ________________________ Date ______ Time ______

PREDIVE BRIEFING

Initials	Item
______	1. Review mission objectives with observer, deck officer, communication operator, warping tug OIC, and chief operator.
______	2. Instruct observer on use of Min-o-Lung.
______	3. Instruct observer on use of human range extenders.
______	4. Instruct observer on winch-up procedure in case of black out of operator.
______	5. Instruct observer to keep objects away from inside of acrylic plastic hull to prevent scratches.
______	6. Articles of exclusion: lighters, etc. Check pockets.
______	7. Instruct observer to keep seat belt fastened.

L43/REE/lj
15 January 1971

DIVE LOG

Date: ______________________ Time: ____________________

NEMO DIVE LOG Operator: __________________ Dive No.: __________________

Time	O_2[a] (%)	CO_2[a] (mm Hg)	Temp[a] (°F)	Humidity[b] (%)	Cabin Pressure[b] (in. H_2O)	Load[c] (vlts-amps-systs in)

GENERAL COMMENTS	
TIME	EVENT/COMMENT
Depth Bottom: ____________ Bottom Type: __________ Visibility: __________	

[a] Take reading every 30 minutes.

[b] Take reading every hour or before surfacing.

[c] Use following codes: 1-500w light; L-750w light; h-hydraulic generator with no load; H-hydraulic generator with load—Ex: 2LIH.

L43/REE/lj
15 January 1971

POST-DIVE DATA

Date ________________ Time ________________

Operator ________________ Dive No. ________________

I. Boat

1. Record load voltage ________. Amperage ________.
2. Record HP air ________.
3. Record O_2 pressure: Prim ________ Sec ________.

II. General Dive Data

1. Location: ________________________________
2. Purpose of dive: ________________________________
3. Observer: ________________________________
4. Sea Surface Condition:
   (a) Wind: ________________________________
   (b) Sea/Swell (HT & Dir): ________________________________
   (c) Temp: ________________________________
5. Water Depth: ________________________________
6. Time hatch shut ________________ Time hatch open ________________.
7. Time on bottom ________________ Length of dive ________________.

III. Tape Review, Operator/Observer debrief:

1. With operator/observer present, listen to tape and make comments concerning any problems that occurred, recommendations, etc.:

____

____

____

____

IV. System Post-Dive Steps (last dive of the day)

________ 1. Freshwater wash down.

________ 2. Clean out interior.

________ 3. Check O_2 off.

________ 4. Check both Beckman Minos meters off.

________ 5. Check O_2 and CO_2 sensors removed.

________ 6. Check main power off, voltmeter off.

________ 7. Make proper log entries.

________ (a) Main battery.

________ (b) Emergency battery.

________ (c) NEMO log, if maintenance performed.

________ 8. Console cover in place, hatch closed.

________ 9. Remove explosive cartridges.

________ 10. Install battery blurp bottle.

V. Perform predive check after last dive on cruise.

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