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U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Apparatus for Testing Oceanographic Resistance Thermometers

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Apparatus for Testing Oceanographic Resistance Thermometers

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FOREWORD

The work of the Temperature Section of the Heat Division includes the application of its scientific and technical expertise in thermometry to assist in the solution of problems of general importance encountered by other government agencies and other groups. Calibration of thermometer standards, performance tests of thermometric equipment, development of thermometric procedures, training in thermometry, and design and construction of prototype thermometric facilities are some of the services of the Temperature Section. This report describes the design, the construction, and the performance of an apparatus for testing resistance-type deep-sea thermometers to 6.89×10^4 kPa (10,000 psi.)

James F. Schooley
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APPARATUS FOR TESTING OCEANOGRAPHIC RESISTANCE THERMOMETERS[1]

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ABSTRACT

The design and construction of an apparatus for testing resistance-type oceanographic thermometers to 6.89×10^4 kPa (10,000 psi) are described. Detailed operating procedures for the apparatus are given. The results of performance tests with the apparatus are discussed.

Key words: Bridge; deep-sea thermometer; high pressure; oceanographic thermometer; platinum resistance thermometer; pressure; pressure intensifier; pressure seal; pressure vessel; resistance; resistance thermometer; test; thermometer; thermometer leads; thermostated bath; vacuum; water tight.

1. Introduction

The National Oceanographic Instrumentation Center (National Ocean Surveys, National Oceanic and Atmospheric Administration, Department of Commerce), henceforth referred to as NOIC, requires reliable performance of deep-sea thermometers at pressures to 6.89×10^4 kPa (10,000 psi). [The pressure corresponds approximately to an ocean depth of 6800 meters.]. It is desired that the resistance-type thermometers be pressure insensitive; the temperature error resulting from pressure effects should not be greater than ±0.01 °C over the entire 10,000 psi range. In close liaison with NOIC, in particular with respect to other thermometer testing activities and existing equipment at NOIC, apparatus and measurement procedures were developed at the National Bureau of Standards (NBS) for testing resistance-type oceanographic thermometers. The performance of the apparatus was tested employing three commercially available platinum resistance thermometers (PRT) that were designed for temperature measurements at high pressures. The development of the apparatus was supported by NOIC; when the apparatus was proved to perform satisfactorily, it was transferred to NOIC. This report presents the description of the apparatus and procedures for testing PRT's with the apparatus. The results of experiments in which the performance of the apparatus was tested are given.

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[1] Common units of measurements of the United States have been used in describing this apparatus: its design, testing, and its operation. The thermometers were designed and constructed in customary units and currently are in use by the National Oceanographic Instrumentation Center; accordingly, these units have been retained in this publication to facilitate the description.

2. Apparatus

Briefly, the apparatus is a small pressure vessel of about 156 cm^3 capacity which can be immersed in a temperature-controlled water bath for obtaining temperatures that occur in oceans. The PRT's to be tested are installed within the vessel which can be filled with water and pressurized to pressures corresponding to that at various ocean depths. The electrical leads from the PRT's are directed through water-tight tubes and chambers (attached to the pressure vessel) to external resistance measurement instruments. A standard reference PRT is placed in a re-entrant well of the pressure vessel for temperature measurements. The arrangement of the components of the apparatus is shown schematically in figures 1 and 34. Figure 2 is a photograph of the apparatus. The PRT lead terminal box with cables to a Mueller bridge and the valve to a compressor for pressurizing the vessel are shown mounted on top of the supporting flange. (The flange dimension and overall length of the apparatus were designed so that it can be accommodated by the existing temperature-controlled water baths at the NOIC and at the NBS.)

2.1. Pressure Vessel

A schematic drawing of the pressure vessel assembly is shown in figure 3. Details of the dimensions and locations of mounting holes and connections are given in figures 4 and 5 for the vessel body and the pressure head, respectively. Since the pressure vessel and the connecting components will be immersed in water for many days, stainless steels were used wherever possible in the construction to avoid "rusting". The vessel body and pressure head are constructed of Type 316 stainless steel; the two are sealed employing a copper gasket. The well for the reference PRT is Type 304 stainless steel. The cap and the ten thrust bolts are also constructed of Type 304 stainless steel; however, the thrust ring is constructed of Type 420 stainless steel which was hardened (see figures 1 and 3). The pressure vessel was tested at a pressure of 18,000 psi.

In addition to the well for the reference PRT the vessel body has an opening for connection to a 1/4-inch pressure tubing (The 1/4-inch tubing is reduced to 1/8-inch pressure tubing for its greater flexibility.) Threaded holes are also provided in the vessel body for three suspension tubes (see figures 1, 2, and 6) and a ring (see figure 7) that is used principally to clamp the apparatus during assembly and disassembly (see figure 18 and Operating Procedure). One of the holes in the ring positions the guide tube for a second reference PRT that is used to monitor the thermostated bath temperature (see figure 2). A vee groove is provided to enhance the sealing of the pressure vessel with the copper gasket (see figure 1).

The pressure head contains a groove to retain the copper gasket for sealing the pressure vessel. On the same face, three threaded (5/16"-24) openings are provided for the test PRT's. These openings continue on through to the opposite face of the head where a water-tight chamber is attached; within this chamber, the terminal posts for the test PRT's are located. The face where the test PRT's are installed is sufficiently flat and smooth to make a high-pressure seal with the rubber "O" ring on the test PRT (see figure 8 for a schematic drawing of a deep-sea type PRT that can be accommodated for testing). [When the pressure vessel was received from the fabricator, the threaded holes for the test PRT's were excessively countersunk. Because of the relatively close tolerance of the rubber "O" ring pressure seal for the PRT, the rubber "O" ring tended to extrude into the countersunk portion of the pressure head when the vessel was pressurized, causing the seal to fail. By re-facing the region of the pressure head where the test PRT's are installed, the amount of the countersink was reduced so that the rubber "O" ring would be sufficiently supported to make a satisfactory pressure seal.]

A copper block (see figure 9) occupies most of the interior space of the vessel to minimize the amount of water that would be compressed when the test PRT's are subjected to pressures from ambient conditions to 10,000 psi. (Holes are provided in the copper block to accommodate three test PRT's.) The specific volume of water decreases by about 4 percent with such pressure increase [1][2] and the thermostated water in the pressure tubing

[2] The figures in brackets indicate literature references listed in Section 5.

(see figure 1) is introduced into the pressure vessel during the compression process. By minimizing the volume of water in the pressure vessel the volume of water that is needed, thermostated in the pressure tubing external to the pressure vessel, is also minimized. As a consequence, the length of this pressure tubing is also minimized. Also, the total heat of compression of the water is minimized. The copper block serves also to enhance temperature equilibration inside the pressure vessel. (The pressure vessel and copper block also generate heat associated with the work of compression.)

2.2. Water-tight terminal box

The water-tight terminal box (figures 1, 10, and 11) is attached to the bottom end of the pressure head and is sealed water-tight by rubber "O" rings. The PRT leads pass through the pressure head and enters the water-tight terminal box. The leads are connected to radially arranged copper terminal strips. Connections to the strips are made by binding-head screws. Figure 12 shows the construction of the plastic insulating ring, figure 13 the gold-plated copper terminal strip, figure 14 the copper washer, and figure 15 the label ring for identifying the PRT leads. Copper lead wires (insulated with polytetrafluoroethylene) are connected to the terminal strips (figure 13) and are passed through the lead tube to the upper terminal box (see figures 1, 2 and 24). A special vacuum (water-tight) coupler (see figures 16 and 17) is used with the lead tube so that the water-tight terminal box can be conveniently detached from the pressure head and swung away.

The lead tube is constructed of thin-wall stainless-steel tubing (Type 316) silver soldered to the water-tight terminal box and, at its upper end, to a tube (see figure 16) of somewhat thicker wall for making an "O" ring seal with the lead-tube coupler (see figure 17). The lead-tube coupler permits the lead tube to be translated along its axis about 5/8 inch and also permits the lead tube to be rotated about its axis so that the water-tight terminal box could be moved away from the pressure vessel. [The lead tube has collars attached at two locations to limit its "travel" to 5/8 inch. For the assembly or disassembly, the apparatus is mounted on the test stand as shown in figure 18 and the water-tight terminal box is rotated back onto a shelf (barely visible in the photograph). The thrust bolts, cap, and pressure head are then readily accessible. See the Operating Procedure for details.]

2.3. Upper terminal box

The upper terminal box assembly has as its principal component the previously mentioned "coupler" shown in figure 17. The coupler has three functions. At its lower end, an "O" ring seal is made with the lead tube; at its upper end, an "O" ring seal is made with the multi-header assembly (figure 19). At about the middle of the coupler is a tube opening for pumping the entire lead chamber and refilling with dry air. Figures 1 and 2 show where the vacuum valve is attached to the pump-out tube and fastened to the supporting flange.

Insulated copper lead wires are connected to the radially arranged terminal strips in the water-tight terminal box and are passed through the lead tube and then into the coupler. [The copper lead wires are arranged and cemented along the length of a plastic tube in such a manner that when the wire assembly is inserted into the lead tube the wires touch the inner surface of the lead tube. Hence, the lead wires should become very close to the temperature of the bath in which the apparatus is immersed.] The copper lead wires enter the coupler in a small tight bundle (sixteen wires, No. 30 B and S gauge). A short section of the bundle is coiled inside the coupler to accommodate the 5/8-inch axial travel needed for the lead tube during the assembly and disassembly of the apparatus. The lead wires are then directed out through the tubes of the multi-header (figure 19) and connected to the posts on the terminal strips of the upper terminal box. [Sixteen copper lead wires originate from the lower water-tight terminal box. Four wires are spares. The multi-header has fifteen "lead-throughs"; hence, one of the copper leads is coiled inside the coupler.]

The support ring (figure 20) for the barrier-type terminal strip assembly is shown located schematically in figure 17. Figure 21 shows the plate on which the terminal strip mount is attached; the plate has three holes to accommodate three four-wire cables from the terminal strips to the measurement equipment. Figures 1 and 2 show how the cables enter the plate. The terminal strip mount (figure 22) accommodates three commercially available barrier-type terminal strips with four terminals. The original nickel-plated terminals have been replaced with gold-plated copper strips and washers to minimize stray emf's in the connections. Figure 23 shows the rods that support the plate (figure 21) and the terminal strip mount (figure 22) on the support ring (figure 20). The plate shown in figure 24 is attached to the lower surface of the terminal strip mount (figure 22) to stabilize the terminal strip assembly. The aluminum cylinder shown in figure 25 serves to protect the assembly (see figures 1 and 2).

2.4. Supporting flange

The pressure vessel assembly and the associated components for pressurization and electrical measurements are all supported on a single stainless-steel flange (plate); see figure 26. Three suspension tubes (figure 6) support the pressure vessel assembly from the flange. The valve bracket (figure 27) which is attached to the flange supports a commercially available high-pressure valve designed for 1/4-inch pressure tubing connection. For flexibility 1/8-inch pressure tubing is used between the high-pressure valve and the pressure vessel (which has also a connection for a 1/4-inch pressure tubing). Short sections of 1/4-inch pressure tubing were welded to the ends of the 1/8-inch pressure tubing so that the 1/4-inch pressure connections can be made. One-half of the 1/8-inch pressure tubing is coiled in one direction and the other half in the opposite direction so that there will be no torque at the pressure connections when the system is pressurized (see the coil of pressure tubing in figures 2 and 18). The other opening of the high-pressure valve leads to the pressure intensifier and to the pressure gauge (see Operating Procedure). A special nut (figure 28) is fitted to the 1/8-inch pressure tubing to close the opening on the flange where the pressure tubing emerges and connects to the high-pressure valve. The location of this special nut is shown in figures 1 and 2.

Two "openings" are provided on the flange for two reference PRT's. These openings consist of a gland nut (figure 29) which holds a thin-wall stainless-steel tube (figure 30) in place. The gland nut has a conical opening for inserting the reference PRT. The tube for one of the openings guides the reference PRT into the re-entrant well of the pressure vessel; the other tube locates the reference PRT at the support ring (figure 7) on the pressure vessel (see figure 2).

An opening for the coupler (figure 17) is provided on the flange. The coupler is "locked" into position on the flange by two nuts on the coupler and by the valve for the pump-out tube of the coupler which is fastened to the flange.

A bracket (figures 31 and 32) for hoisting and lowering the apparatus into the thermostated water bath is provided. The bracket also gives protection to the super structure which includes the high-pressure valve and the upper terminal box.

3. Test Stand

A test stand (see figure 18) is provided with the apparatus. Figure 18 shows the apparatus supported upside down on the test stand using the support ring (figure 7) on the apparatus. The apparatus is disassembled and assembled on the test stand. Also, after assembly, the preliminary tests on vacuum tightness of the lead chamber, integrity of the lead wires, and pressure leaks in the pressure vessel system (after filling with water) are made with the apparatus on the test stand. Figure 33 shows a schematic of how the apparatus is connected to the valve manifold of the test stand. (See details of how the test stand is used with the apparatus in the Operating Procedure.)

4. Performance test of the apparatus

The performance of the apparatus was tested employing three oceanographic PRT's. One of the thermostated water baths usually used at the NBS for calibrating liquid-in-glass thermometers was employed in the test. The bath is normally used with the temperature gently drifting upward; it does not have a means to maintain the temperature constant for long periods. The preliminary tests were made with the bath operated in this usual manner. The reference PRT in the pressure vessel was observed continuously employing an AC bridge with its dial setting nearly balanced against the reference PRT [2,3]. A strip chart recorder traced the state of unbalance of the bridge. The resistance of the oceanographic PRT's under test was observed using a G-3 Mueller bridge and a null detector consisting of a photocell amplifier and galvanometer [4].

The following are the preliminary results that were obtained.

1.) Ambient pressure	Ohms[3]
Reference PRT (S/N 241)	26.5722
Test PRT	
S/N 6104	209.1494
S/N 974	96.7145
S/N 6106	208.9909
Reference PRT (S/N 241)	26.5722

2.) Pressure at 10,000 psi	Ohms
Reference PRT (S/N 241)	26.5734
Test PRT	
S/N 6104	209.1592
S/N 974	96.7207
S/N 6106	209.0071
Reference PRT (S/N 241)	26.5745

The observations with the reference PRT before and after the observations on the three test PRT's are given. At the initial ambient pressure the reference PRT and all three of the test PRT's were found to be stable. When the pressure was increased to 10,000 psi the reference PRT showed an increase in temperature of over 0.15 °C. In one minute the temperature returned to within 0.04 °C of the initial temperature and in 14 minutes within about 0.01 °C. (In the meantime the bath temperature has also increased.) Making allowances for the increase in the bath temperature, the test PRT's seem to be insensitive within 0.01 °C or smaller to the pressure change from 15 to 10,000 psi. The apparatus for testing the PRT's performed satisfactorily.

The apparatus was tested next with the water bath at constant temperature. The bath temperature was controlled (maintained constant) manually for the experiment by observing the resistance of the second reference PRT immersed directly in the bath. The following are the results of this test.

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[3] The sensitivity, dt/dR, for PRT's is approximately 10 °C/ohm for thermometers of R(0 °C) = 25 ohms.

1.)	Ambient pressure	Ohms
	Reference PRT (S/N 241)	26.6233
	Test PRT	
	S/N 6104	209.5522
	S/N 974	96.5384
	S/N 6106	209.3919
	Reference PRT (S/N 241)	26.6233
2.)	Pressure at 10,000 psi	Ohms
	Reference PRT (S/N 241)	26.6233
	Test PRT	
	S/N 6104	209.5512
	S/N 974	96.9016
	S/N 6106	209.3925
	Reference PRT (S/N 241)	26.6233
3.)	Pressure at 5,000 psi	Ohms
	Reference PRT (S/N 241)	26.6232
	Test PRT	
	S/N 6104	209.5507
	S/N 974	96.9002
	S/N 6106	209.3906
	Reference PRT (S/N 241)	26.6231

In these experiments the reference PRT in the pressure vessel well showed a temperature increase of 0.35 °C when the pressure was increased from 15 to 10,000 psi. In 15 minutes the temperature was within about 5 mK of the initial temperature. When the pressure was decreased from 10,000 to 5,000 psi, a temperature decrease of 0.19 °C was detected by the reference PRT. Similarly, in 15 minutes the temperature of the pressure vessel well was within 5 mK of the initial temperature. These results show that the oceanographic PRT's with S/N 6104 and S/N 6106 are insensitive to much less than 0.01 °C to the pressure change from 15 to 10,000 psi. Although the results at 10,000 psi and 5,000 psi seem favorable, the PRT with S/N 974 was observed to be erratic after the first pressurization to 10,000 psi; this PRT should be considered defective. After a suitable pressure insensitive PRT is found, it can be used directly in the pressure vessel as an additional reference PRT to observe the heating effects that result from the work of compression.

5. References

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Control in Science and Industry, Vol. 4, Part 1, 247-263 (Instrument Society of America, Pittsburgh, Pa., 1972).

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6. Operating Procedure

Apparatus for Testing
Resistance-Type Oceanographic Thermometers

1. General description

The apparatus was designed for testing the effect of pressure on resistance-type oceanographic thermometers at pressures encountered in oceanographic environment. With the apparatus and auxiliary equipment tests can be performed up to 10,000 psi at temperatures from about -10 °C to 50 °C.

The apparatus is in principle a pressure vessel containing a pressure transfer fluid (in this case water or a water-alcohol mixture) at a known pressure in which the resistance-type oceanographic thermometers are immersed. The vessel is connected through a small pressure tubing to a pressure intensifier, for varying the pressure of the fluid, and to a pressure gauge. The temperature of the pressure vessel and the test thermometers is determined by the thermostated water bath in which the apparatus is immersed. A re-entrant well is provided in the pressure vessel for a reference platinum resistance thermometer (PRT) for determining the accurate value of the temperature. An opening is provided for a second reference PRT to determine the water bath temperature directly. The electrical leads of the test thermometers exit from the apparatus through a water-tight chamber and tubing for connection to instruments for determining their resistances. The vessel can accommodate three test thermometers with Swagelok No. 201-A-OR-316 (or equivalent) pressure fitting with 5/16" - 24 thread and an "O" ring pressure gasket.

2. Related equipment and accessories

To employ the apparatus the following equipment must be provided:

a) Water bath controlled to ±1 mK or better. There must be an unobstructed space in the bath 8" diameter and 25" deep for the apparatus.

b) Two reference PRT's calibrated in terms of the IPTS-68.

c) Mueller bridge and accessory equipment for reading the reference PRT's to 1 mK or better. The bridge shall be calibrated.

d) Depending upon the resistance of the test thermometers, the range of the Mueller bridge may not be adequate. An extended resistance bridge may be required.

e) Water triple-point cell for determining the R(0 °C) of the reference PRT's.

f) Pressure intensifier that would yield pressures up to 10,000 psi.

g) Pressure gauge, range: 0 to 10,000 psi.

h) Vacuum pump with water trap. (A water pump is better suited for the test procedures described here.)

A stand is furnished with the apparatus for assembling and testing the apparatus prior to immersing in the thermostated bath and for disassembly of the apparatus after the experiments.

3. Physical description (refer to figures 1, 2, 18, and 34).

The following is a list of the principal components of the apparatus. The numbers are used to identify the components.

3.1. Pressure vessel

3.1.1. Pressure vessel body with re-entrant well for the reference PRT.

3.1.2. Pressure head with holes to accommodate test thermometers.

3.1.3. Cap.

3.1.4. Thrust bolts (10).

3.1.5. Copper gasket.

3.1.6. Thrust ring.

3.1.7. Copper block for minimizing liquid volume of pressure vessel and to enhance thermal equilibrium.

3.1.8. Ring to clamp the apparatus to the test stand (3.6).

3.2. Lower water-tight terminal box.

3.2.1. Enclosure with thin-wall tube leading upward to the upper terminal box.

3.2.2. Thin-wall lead tube.

3.2.3. Terminals for connecting thermometer leads and lead wires to measurement equipment.

3.2.3.1. Plastic insulating ring.

3.2.3.2. Copper terminal strips (12) with screws.

3.2.4. Cover plate.

3.2.5. Rubber "O" rings (2), one for sealing the terminal box to the pressure head (3.1.2.) of the pressure vessel (3.1) and one to seal the cover plate (3.2.4).

3.2.6. Screws to attach the enclosure (3.2.1) and plastic ring (3.2.3.1) to the pressure head (3.1.2).

3.2.7. Screws to hold cover plate (3.2.4) on the enclosure (3.2.1).

3.3. Supporting flange.

3.3.1. Flange.

3.3.2. Bracket for lifting the apparatus.

3.3.3. Angle bracket for mounting pressure valve.

3.3.4. Gland nut with opening for introducing the reference PRT and means for aligning the thermometer guide tube.

3.3.5. Opening for mounting the vacuum lead-tube coupler (3.4.1) of the upper terminal box (3.4).

3.3.6. Exit for pressure tubing.

3.3.7. Openings for attaching tubes (3) for suspending the pressure vessel (3.1).

3.3.8. Suspension tubes (3).

3.3.9. Gland nut and thermometer guide tube for a second reference PRT.

3.3.10. Guide tube for pressure-vessel well reference PRT.

3.4. Upper terminal box.

3.4.1. Vacuum lead-tube coupler.

3.4.2. "Multi-header" vacuum feed-through.

3.4.3. Vacuum coupler for (3.4.2).

3.4.4. Terminals for leads from the lower terminal box and for cables to the measurement equipment.

3.4.5. Cylindrical cover for the terminals.

3.4.6. Valve for pumping out any moisture from the lead tube (3.2.2) and the lower terminal box (3.2) and for refilling with dry air.

3.4.7. Cables to measurement equipment.

3.5. Pressure line.

3.5.1. Pressure tubing from vessel (3.1).

3.5.2. Valve mounted on the bracket (3.3.3) on top of the supporting flange (3.3).

3.6. Test stand (refer to figures 18 and 33).

3.6.1. High pressure valves.

3.6.1.1. Valve to pressure intensifier.

3.6.1.2. Valve to pressure vessel and valve (3.6.1.3).

3.6.1.3. Valve to valve manifold for air, water, and vacuum.

3.6.2. Low pressure valves.

3.6.2.1. Valve to air supply.

3.6.2.2. Valve to water supply.

3.6.2.3. Valve to vacuum via trap.

3.6.3. Platform for clamping the pressure apparatus upside down.

3.6.4. Pressure intensifier (in existence at the NOIC facilities).

3.6.5. Pressure gauge (in existence at the NOIC facilities). May be a part of the pressure intensifier (3.6.4) or separately connected to the above valve system.

3.6.6. Shelf for supporting the water-tight terminal box (3.2.1) while working on the pressure vessel.

4. Operation

4.1. Condition of the apparatus when delivered by the National Bureau of Standards (NBS).

4.1.1. When the apparatus is delivered by the NBS, the pressure vessel (3.1) will not contain any test thermometers.

4.1.2. The thrust bolts (3.1.4) will be nominally tight.

4.1.3. The cover plate (3.2.4) of the water-tight terminal box (3.2.1) will be attached by screws (3.2.7) to the enclosure (3.2.1).

4.1.4. The enclosure (3.2.1) and the plastic ring (3.2.3.1) will be attached to the pressure head (3.1.2) by screws (3.2.6).

4.1.5. The nut on the vacuum lead-tube coupler (3.4.1) will be tight so that the thin-wall lead tube (3.2.2) does not slide.

4.1.6. Cables for connection to the Mueller bridge will be attached to the upper terminal box (3.4). If the cables must be removed or replaced, refer to step (4.7).

4.1.7. The valves and connecting pressure lines on the test stand will be blown free of water and pumped.

4.2. Installation of the test thermometers. (Refer to figures 1, 2, 18, 33, and 34).

4.2.1. Firmly attach the apparatus upside down to the test stand (3.6) by clamping the support ring (3.1.8), attached to the pressure vessel body (3.1.1), to the platform (3.6.3).

4.2.2. Remove the cover plate (3.2.4).

4.2.3. Loosen the nut on the vacuum lead-tube coupler (3.4.1).

4.2.4. Remove the screws (3.2.6) that hold the plastic ring (3.2.3.1) and water-tight enclosure (3.2.1) to the pressure head (3.1.2).

4.2.5. Lift the enclosure (3.2.1) about 1/2" and rotate approximately 90° about the axis of the thin-wall lead tube (3.2.2). Rest the enclosure (3.2.1) on the test stand shelf (3.6.6) and tighten the nut on the vacuum lead-tube coupler (3.4.1) to hold the lead-tube (3.2.2) in place.

4.2.6. Loosen the thrust bolts (3.1.4).

4.2.7. Remove the cap (3.1.3) and thrust ring (3.1.6). Note the position of the scribe lines on the pressure head (3.1.2) and on the vessel body (3.1.1). When the head is replaced, the scribe lines must be matched exactly.

4.2.8. Lift the pressure head (3.1.2) out. (It is not necessary to remove the copper cylinder (3.1.7) from the body (3.1.1).) If the copper gasket (3.1.5) is adhering to the head (3.1.2) or to the body (3.1.1), do not disturb it.

4.2.9. Insert the test thermometers, leads first, in the pressure head (3.1.2) and screw tightly with fingers. (Wrench is not necessary.)

4.2.10. If the pressure vessel is already filled with water, go to step (4.4.6) to remove the water or go directly to step (4.2.11) if the assembly process can be done without entrapping much air.

4.2.11. Replace the pressure head (3.1.2) with the test thermometers on the pressure vessel body (3.1.1) making certain that the thermometers are located in the holes of the copper cylinder (3.1.7), the copper gasket (3.1.5) is in place, and the scribe lines (see 4.2.7) match. If water is already in the pressure vessel, it should be completely filled with water to minimize entrapped air.

4.2.12. Replace the thrust ring (3.1.6), screw the cap (3.1.3) on, and tighten the thrust bolts (3.1.4). Make certain that the pressure head (3.1.2) has not been displaced in the process. At this point the integrity of the closed pressure vessel and the connecting pressure line (3.5.1) should be checked. Go to step (4.3).

4.3. Testing of the integrity of the pressure vessel.

4.3.1. If the apparatus and the pressure intensifier are already connected to the test stand and the system is filled with water go to step (4.3.13); if not, connect pressure tubing from the "cross" between valve (3.6.1.2) and valve (3.6.1.3) on the test stand (3.6) to valve (3.5.2) at the top of supporting flange (3.3.1).

4.3.2. Disconnect pressure tubing from valve (3.6.1.1) on the low pressure end or the end opposite the pressure intensifier (3.6.4).

4.3.3. Open valve (3.6.1.1) slightly and pump pressure intensifier (3.6.4) until water seeps out of the valve connection. Close valve (3.6.1.1) and wipe dry.

4.3.4. Reconnect the pressure tubing disconnected in (4.3.2).

4.3.5. Open valve (3.6.1.2) to the pressure vessel (3.1) and open valve (3.5.2) at the top of the mounting plate (3.3.1). [If the pressure vessel is already full of water do not open valve (3.5.2).]

4.3.6. Open valve (3.6.1.3) to the low-pressure valves (3.6.2.1, 3.6.2.2, and 3.6.2.3).

4.3.7. Close air valve (3.6.2.1) and water valve (3.6.2.2).

4.3.8. Open vacuum valve (3.6.2.3) and connect to vacuum pump and evacuate system. A trap at the "dry ice" temperature or lower should be between the vacuum valve (3.6.2.3) and the vacuum pump to trap any water. If a water pump is used the "dry ice" trap is not needed.

4.3.9. Connect the opening of the water valve (3.6.2.2) to a source of distilled water using a clean Tygon tubing.

4.3.10. If the system is air tight, a good vacuum will be obtained in a few minutes. If a leak in the pressure vessel is suspected, the thrust bolts should be tightened slightly. (Torque wrench should be employed here to monitor the tightening process).

4.3.11. If the system is air-tight, open slightly the water valve (3.6.2.2) to remove any air between it and the source of water (see 4.3.9)). When the air is removed, close the water valve (3.6.2.2) and continue pumping. When the vacuum of the system is satisfactory, close the vacuum valve (3.6.2.3) and then open the water valve (3.6.2.2). No air bubble should be in the system.

4.3.12. Close high pressure valve (3.6.1.3) and then close the water valve (3.6.2.2). Open valve (3.5.2) if it has remained closed until now.

4.3.13. Employing the pressure intensifier (3.6.4), increase the system pressure to about 1000 psi. Check for leaks. If the system is free of leaks the pressure gauge should remain steady. (If air bubble is present in the system, the initial compressibility will be relatively greater.)

4.3.14. If no leak is present, increase the pressure to 5,000 psi. Check for leaks.

4.3.15. If no leak is present, increase the pressure to 10,000 psi. Check for leaks.

4.3.16. If the pressure test shows that the pressure vessel system is sound, go to (4.5). If the apparatus leaks, go to (4.4).

4.4. Presence of pressure leak.

4.4.1. When the pressure vessel system is pressurized and a pressure leak is observed, the most likely source of the leak is the test thermometer. Since the "O" ring seal of the thermometer should be reliable, the tubing that encases the thermometer element or the welding around the tubing should be examined first for defects. When the pressure leak is associated with the thermometer, water should become visible in a few minutes where the thermometer leads emerge from the pressure head (3.1.2).

4.4.2. If the pressure leak is associated with the copper gasket (3.1.5), water should eventually become visible at the vent holes in the cap (3.1.3). Leaks at the other locations should be detectable by the appearance of water.

4.4.3. Before opening the pressure vessel, first open the water valve (3.6.2.2) and then the high pressure valve (3.6.1.3) to release any pressure in the system. The pressure intensifier (3.6.4) may also be adjusted to reduce the pressure to ambient conditions. Loosen the thrust bolts (3.1.4), unscrew the cap (3.1.3), and lift out the pressure head (3.1.2) containing the test thermometers.

4.4.4. Remove any moisture adhering to the test thermometers by blowing high velocity air over the thermometers. Examine the test thermometers for any defects under the microscope. (This examination for defects should have also been performed before the installation of the thermometers.)

4.4.5. Unscrew the defective thermometer from the pressure head (3.1.2). Dry the test thermometer lead hole in the pressure head (3.1.2) and install a new test thermometer. Go to step (4.2.11) if the pressure vessel could be closed with only a small amount of entrapped air or go to step (4.4.6) to remove the water in the pressure vessel.

4.4.6. The water in the pressure vessel (body) (3.1.1) and the pressure lines may be removed before installing the pressure head (3.1.2). If the amount of air in the system is not too large, it will dissolve in the water at the high pressures.

4.4.7. To remove the water from the pressure vessel body (3.1.1) close valve (3.6.1.1) to the pressure intensifier (3.6.4). Close water valve (3.6.2.2) and open vacuum valve (3.6.2.3) to the vacuum pump. (Open also valve (3.6.1.2) and valve (3.6.1.3), if they are not already open). The water in the pressure vessel (3.1.1) and the pressure lines will be forced into the water trap by the pumping process. (A water pump may be used instead at this point.)

4.4.8. When air is freely passing through the system by the pumping process, close vacuum valve (3.6.2.3) and install the pressure head (3.1.2) with the copper gasket (3.1.5) in place. Match the scribe lines (see 4.2.7)) on the pressure head (3.1.2) and on the vessel body (3.1.1).

4.4.9. Close pressure vessel as described in step (4.2.12) and go to step (4.3.5) to fill the system with water.

4.5. Connecting the test thermometer lead wires. (To be followed only after the pressure vessel containing the test PRT's is tested to be leak proof.)

4.5.1. Check to see that the rubber "O" ring (3.2.5) is in the groove on the under side of the water-tight terminal enclosure (3.2.1).

4.5.2. Loosen the nut on the vacuum lead-tube coupler (3.4.1) and rotate the terminal enclosure (3.2.1) over the pressure head (3.1.2) while inserting the leads from the test thermometers in the holes provided in the terminal enclosure (3.2.1) and the plastic ring (3.2.3.1). Locate the terminal enclosure assembly (3.2.1 and 3.2.3.1) on the pin protruding from the pressure head (3.1.2).

4.5.3. Slide the thin-wall lead tube (3.2.2) into the vacuum lead-tube coupler (3.4.1) while aligning the terminal enclosure (3.2.1) over the pressure head (3.1.2). Replace screws (3.2.6) to fasten the terminal enclosure (3.2.1) and plastic ring (3.2.3.1) to the pressure head (3.1.2).

4.5.4. Tighten the nut on the vacuum lead-tube coupler (3.4.1).

4.5.5. Check for any obvious moisture inside the terminal enclosure (3.2.1). Before attaching the test thermometer leads, check the resistance between the apparatus leads and the resistance between the apparatus leads and the apparatus. The resistance should be 1000 megohms or higher. Attach the thermometer leads to the appropriate terminals, observing the markings, T, t, C, and c.

4.5.6. Place a rubber "O" ring (3.2.5) in the groove of the flange of the terminal enclosure (3.2.1). Attach cover plate (3.2.4) with screws (3.2.7).

4.5.7. Make a vacuum hose connection to the valve (3.4.6) and pump out any moisture in the lead tube (3.2.2) and the lower terminal box (3.2). By admitting dry air and pumping repeatedly any moisture should eventually be removed.

4.5.8. Check the resistance between the leads and the apparatus again; the resistance should be 1000 megaohms or higher.

4.6. Immersing the apparatus in the thermostat bath.

4.6.1. Close valve (3.5.2) on the top of the supporting flange (3.3.1).

4.6.2. Close valve (3.6.1.1) to the pressure intensifier (3.6.4).

4.6.3. If experiments are to be carried out with the test stand soon, the water in the connecting lines of the test stand need not be removed; disconnect the pressure line at valve (3.5.2) and go to step (4.6.4). If water is to be removed from the test stand, open vacuum valve (3.6.2.3) to vacuum pump and then open high pressure valve (3.6.1.3). Disconnect pressure line at valve (3.5.2). By this process, the water in the pressure line will be forced into the water trap by the vacuum pump. When air flows freely close vacuum valve (3.6.2.3) and turn vacuum pump off.

4.6.4. Attach bracket (3.3.2) for lifting the apparatus.

4.6.5. Unclamp (see (4.2.1)) the apparatus from the test platform (3.6.3) and upright the apparatus and suspend it from a hoist using the eye bolt provided on the lifting bracket (3.3.2).

4.6.6. Using the hoist, gently lower the apparatus into the thermostated water bath. Remove the bracket (3.3.2) used for hoisting the apparatus.

4.6.7. Wheel the test stand to the thermostated water bath and reconnect the pressure line to the valve (3.5.2) on the top of the apparatus (see (4.6.3)).

4.6.8. If the system is already filled with water go to step (4.6.9); if not, open vacuum valve (3.6.2.3) and start vacuum pump. When the vacuum is adequate, close vacuum valve (3.6.2.3) and open water valve (3.6.2.2) to fill the pressure line with water. Close high pressure valve (3.6.1.3), then close the water valve (3.6.2.2).

4.6.9. Open high pressure valve (3.6.1.1) to the pressure intensifier (3.6.4). (The arrangement of the valves, pressure intensifier, pressure gauge, and pressure lines at the NOIC facilities may be different from those described here.)

4.6.10. Open valve (3.5.2) on the top of the apparatus. The system is now set for pressurizing and measurement of pressure.

4.7. Connecting thermometer leads.

4.7.1. The four-lead thermometer cables (3.4.7) may be already connected to the upper terminal box (3.4), if so, go to step (4.7.2). Open the cover (3.4.5) that houses the terminals (3.4.4) to which the leads from the terminals in the lower water-tight terminal box (3.2) are connected. Connect the four-lead cables (furnished with the apparatus) to the appropriate terminals T, t, C, and c.

4.7.2. Connect the leads on the opposite end of the cable to correspondingly labeled posts on the Mueller bridge or selector switch.

4.7.3. Insert the reference PRT through the hole (3.3.4) located in the middle of the mounting plate (3.3). Connect the thermometer leads to the appropriate posts on the Mueller bridge or selector switch. Repeat for the second reference PRT in the second gland nut opening (3.3.9).

4.7.4. The system is now set to observe the reference PRT or the test thermometers or, if two Mueller bridges and two operators are available, to make simultaneous observations of the reference PRT and the test thermometers.

4.8. Observation of pressures and thermometer resistances.

4.8.1. Adjust the pressure intensifier (3.6.4) to obtain a pressure in the pressure vessel that would correspond to 1 atm absolute or about 14.7 psi.

4.8.2. Observe the resistance of the reference PRT until the readings indicate that the water bath is steady to about ±0.001 °C. Record the reading. Determine next the resistance of one of the test thermometers. Follow this with the reading on the reference PRT.

4.8.3. Measurements on the test thermometers should be bracketed, before and after, by measurements on the reference PRT. The mean of the two readings on the reference PRT should be associated with the readings obtained on the test thermometer.

4.8.4. After measurements on the thermometers at the ambient pressure, increase the pressure to 1000 psi. The temperature of the pressure vessel should increase somewhat when the pressure was increased. Either the temperature of the vessel could be allowed to fall to the bath temperature or the bath temperature could be raised to "meet" the temperature of the vessel. (Performance tests show equilibration time to be about 15 minutes.)

4.8.5. Observe the resistance of the reference PRT at the new pressure until the readings are steady to ±0.001 °C for about 5 minutes or more. Proceed with the measurements on the test thermometers as in (4.8.2) and (4.8.3).

4.8.6. After completion of measurements at 1000 psi, increase the pressure to 5000 psi and then observe thermometer resistances following procedures and precautions outlined in (4.8.4) and (4.8.5).

4.8.7. Finally increase the pressure to 10,000 psi, allow time for the system to equilibrate, then observe the thermometer resistances.

4.8.8. It is expected that the oceanographic thermometers under test would not be affected by pressures up to 10,000 psi. If the pressure does affect the thermometer, the pressure at which the effect becomes significant can be determined by the "process of bracketing" the measurements. For example, if the effect became large between 5,000 psi and 10,000 psi, the measurements should be made next at 7,500 psi. This process should be continued until the bracketing pressure interval is small enough.

4.9. Disassembling the apparatus after completion of measurements.

4.9.1. Remove the reference PRT and coil the cables attached to the upper terminal box (3.4).

4.9.2. Adjust the pressure intensifier (3.6.4) to reduce the pressure of the system to 1 atm absolute.

4.9.3. Close valve (3.6.1.1) to the pressure intensifier (3.6.4). Close valve (3.5.2) at the top of the mounting plate (3.3.1). If more experiments are planned soon, disconnect the pressure line at valve (3.5.2) and go to step (4.9.5). Open vacuum valve (3.6.2.3) and start vacuum pump. Open high pressure valve (3.6.1.3).

4.9.4. Disconnect pressure line at valve (3.5.2) on the top of mounting plate (3.3.1). The water will be forced into the water trap. Close vacuum valve (3.6.2.3) and turn pump off when air is flowing freely.

4.9.5. Attach the bracket (3.3.2) for lifting and hoist the apparatus out of the water bath.

4.9.6. After most of the water has dripped off, wipe the apparatus as dry as possible. Turn the apparatus upside down and clamp to the test stand (3.6) as outlined in (4.2.1).

4.9.7. Remove cover plate (3.2.4) and disconnect the leads of the test thermometers and straighten them out so that the leads can easily slide through the 3/16-inch hole of the pressure head (3.1.2).

4.9.8. Follow steps (4.2.4) and (4.2.5). During step (4.2.5) free the test thermometer leads from the holes of their terminal box (3.2).

4.9.9. Follow steps (4.2.6), (4.2.7), and (4.2.8).

4.9.10. Unscrew the test thermometers from the pressure head (3.1.2). If more PRT's are to be tested go to step (4.2.9).

4.9.11. To remove the water in the pressure vessel, reconnect the pressure line (see (4.9.4)) to valve (3.5.2) on the apparatus and open vacuum valve (3.6.2.3) and turn the vacuum pump on. When air is flowing freely, close vacuum valve (3.6.2.3) and turn vacuum pump off. (The apparatus can be safely stored on the test stand. If the system is to be shipped, the apparatus and the test stand should be shipped separately.)

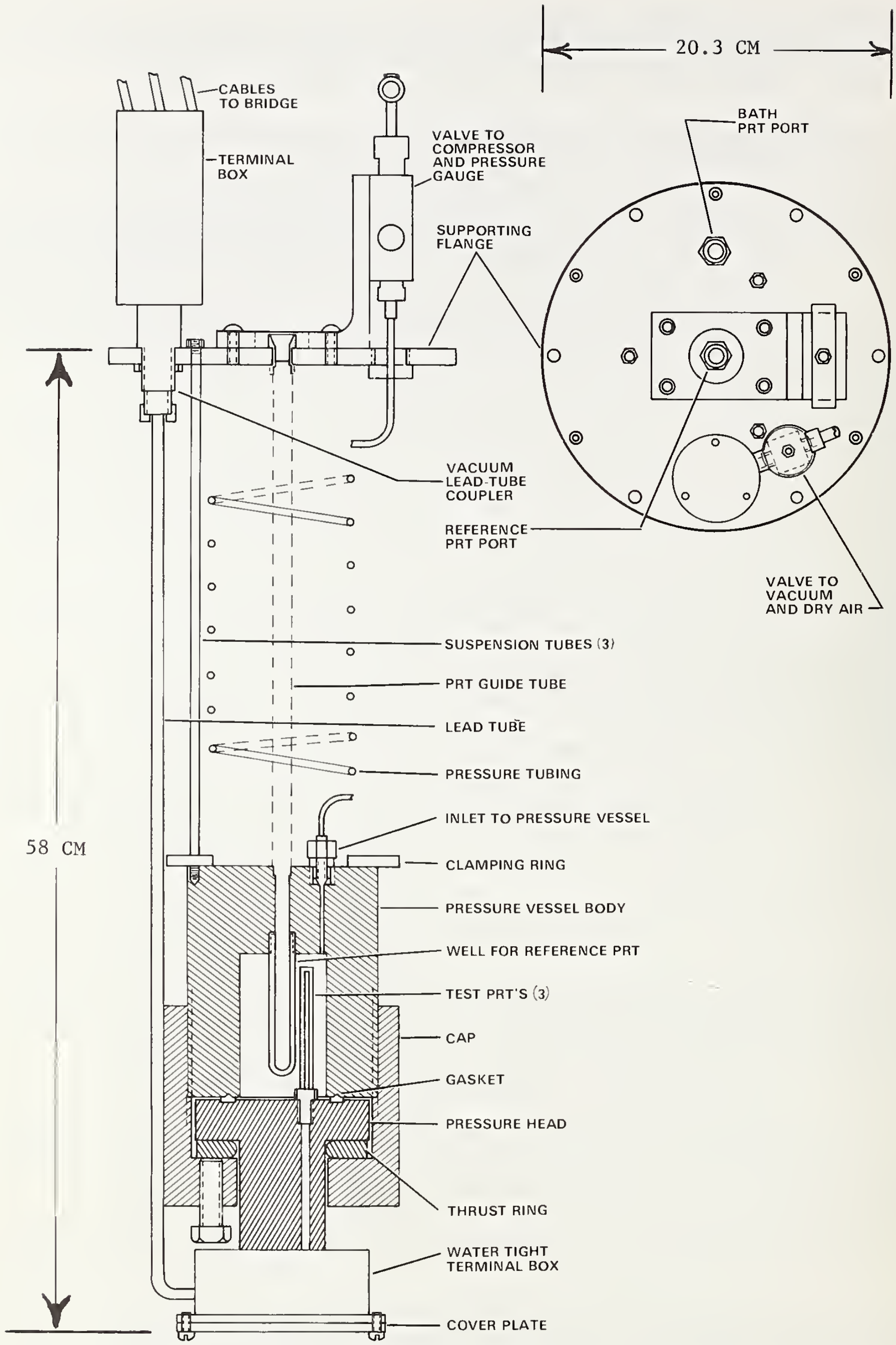


Figure 1. Schematic drawing of the NOIC apparatus for testing oceanographic resistance thermometers. Some of the parts are shown rotated about the vertical axis of the apparatus. The supporting flange shows the parts located accurately.

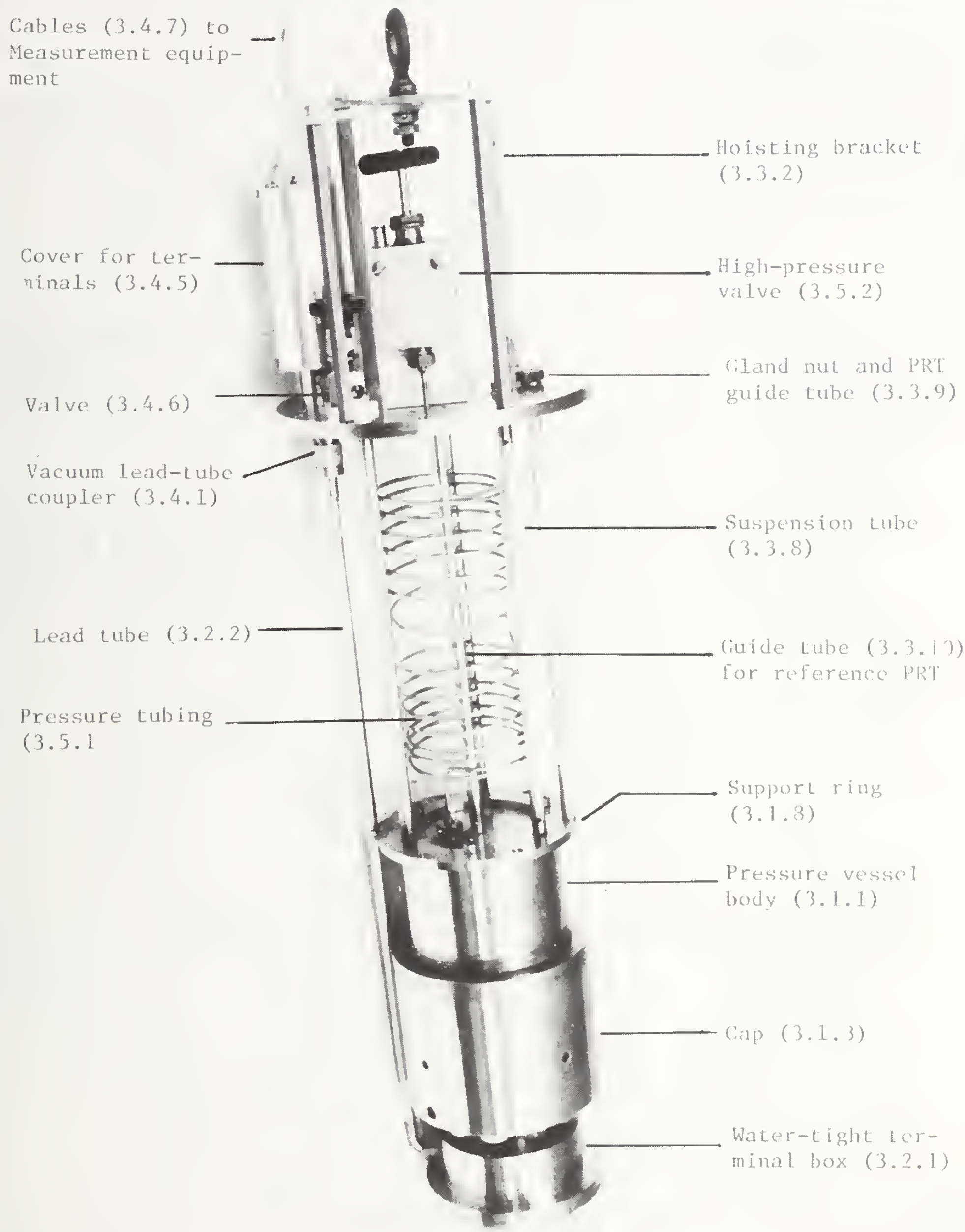


Figure 2. NOIC apparatus for testing oceanographic resistance thermometers.

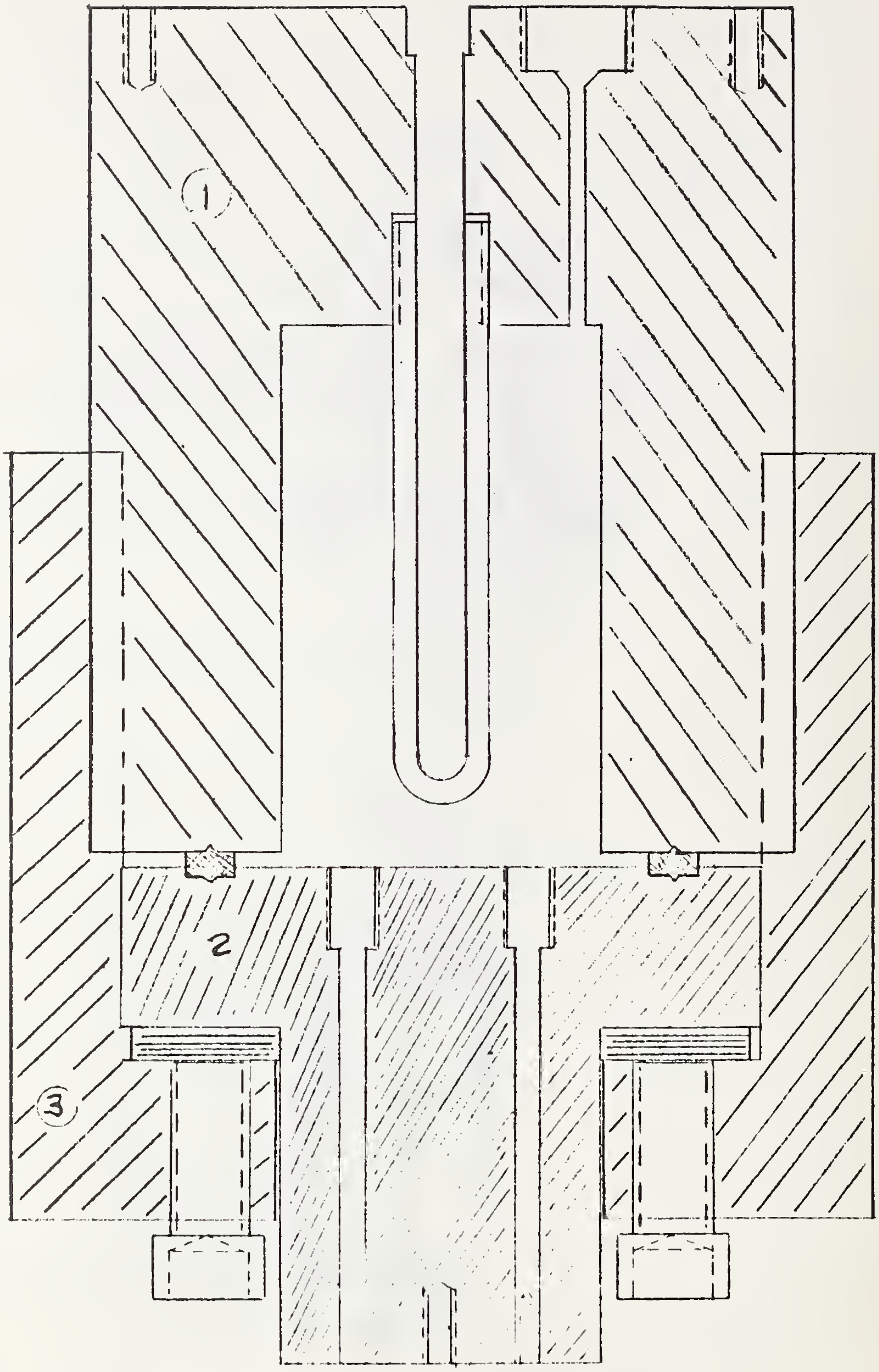


Figure 3. Schematic drawing of the pressure vessel assembly consisting of vessel body (1), pressure head (2), and cap (3) with gasket, thrust ring, and thrust bolts.

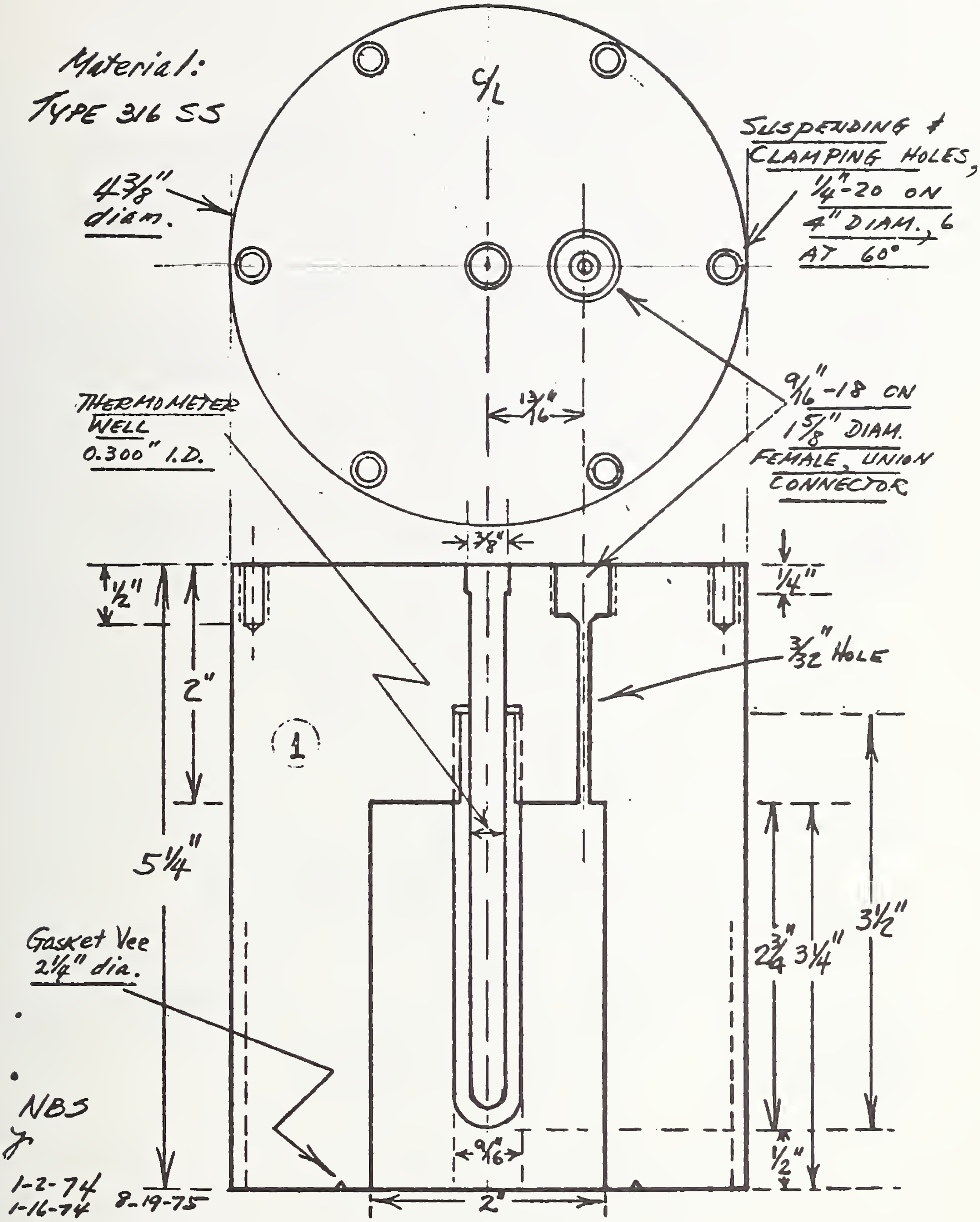


Figure 4. Pressure vessel body with re-entrant well for the reference PRT and opening for pressure connection.

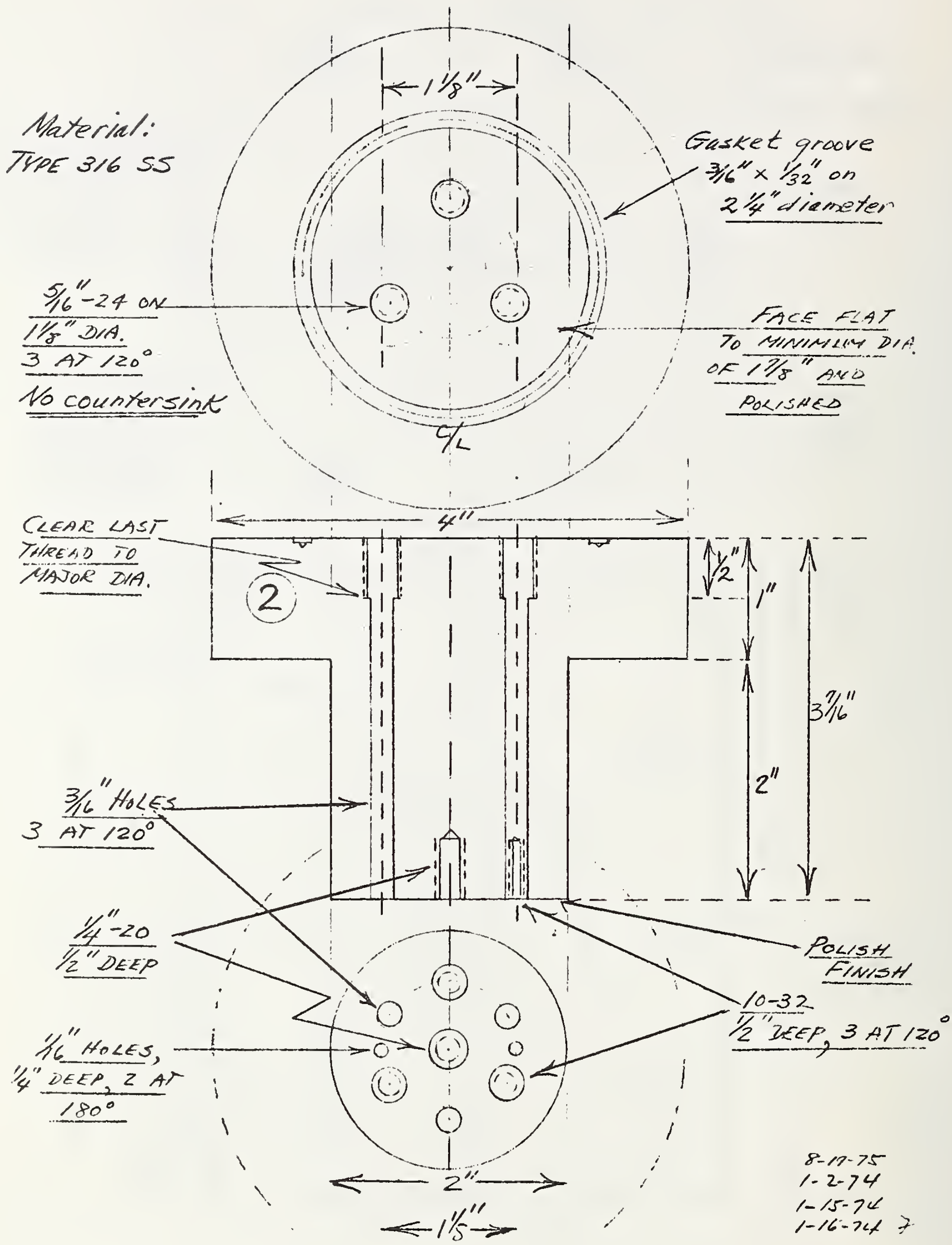


Figure 5. Pressure head with holes to accommodate the oceanographic PRT's (figure 8) and with holes to attach the water-tight terminal box (figure 10).

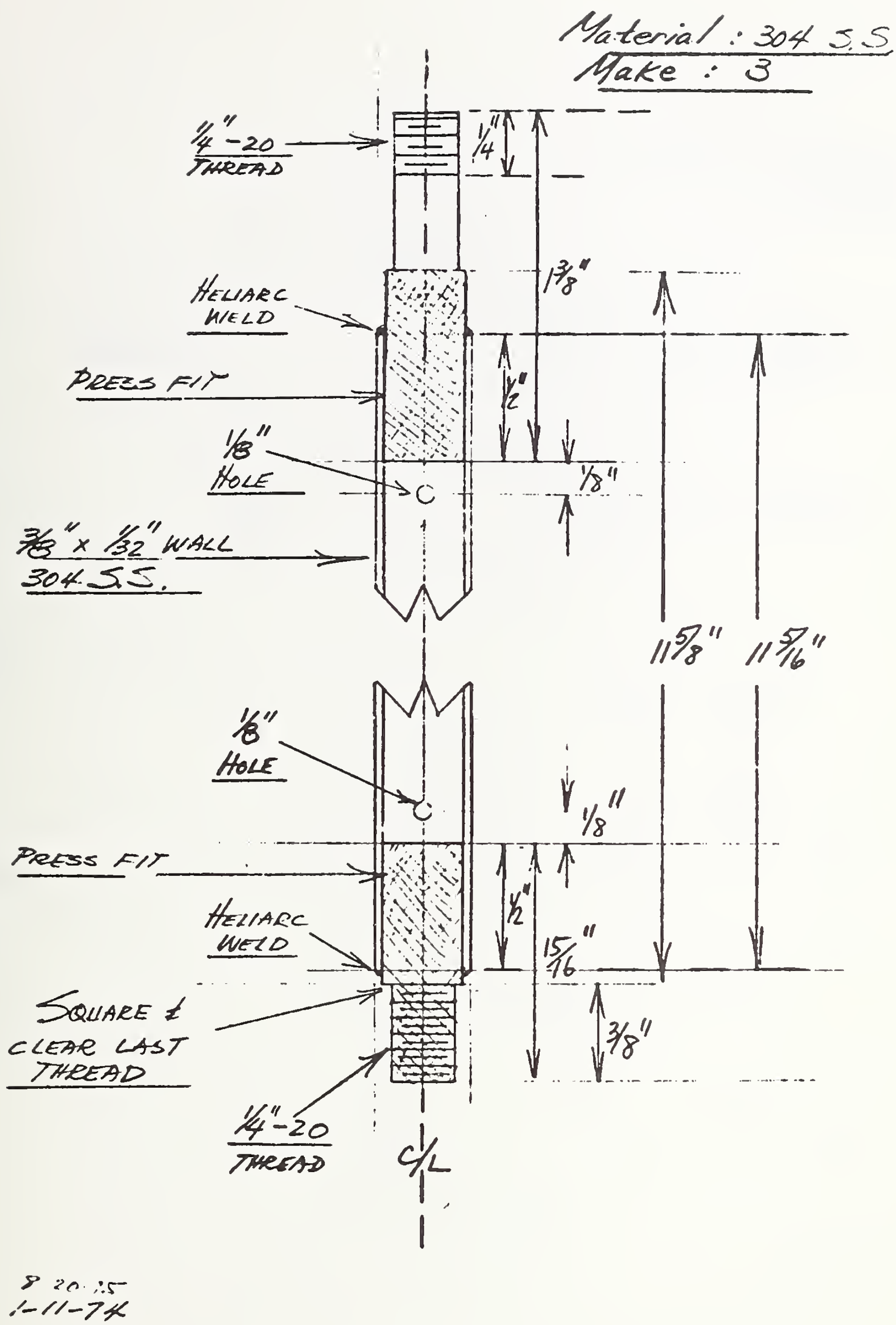


Figure 6. Suspension tube for suspending the pressure vessel assembly (figure 3) from the supporting Flange (figure 26).

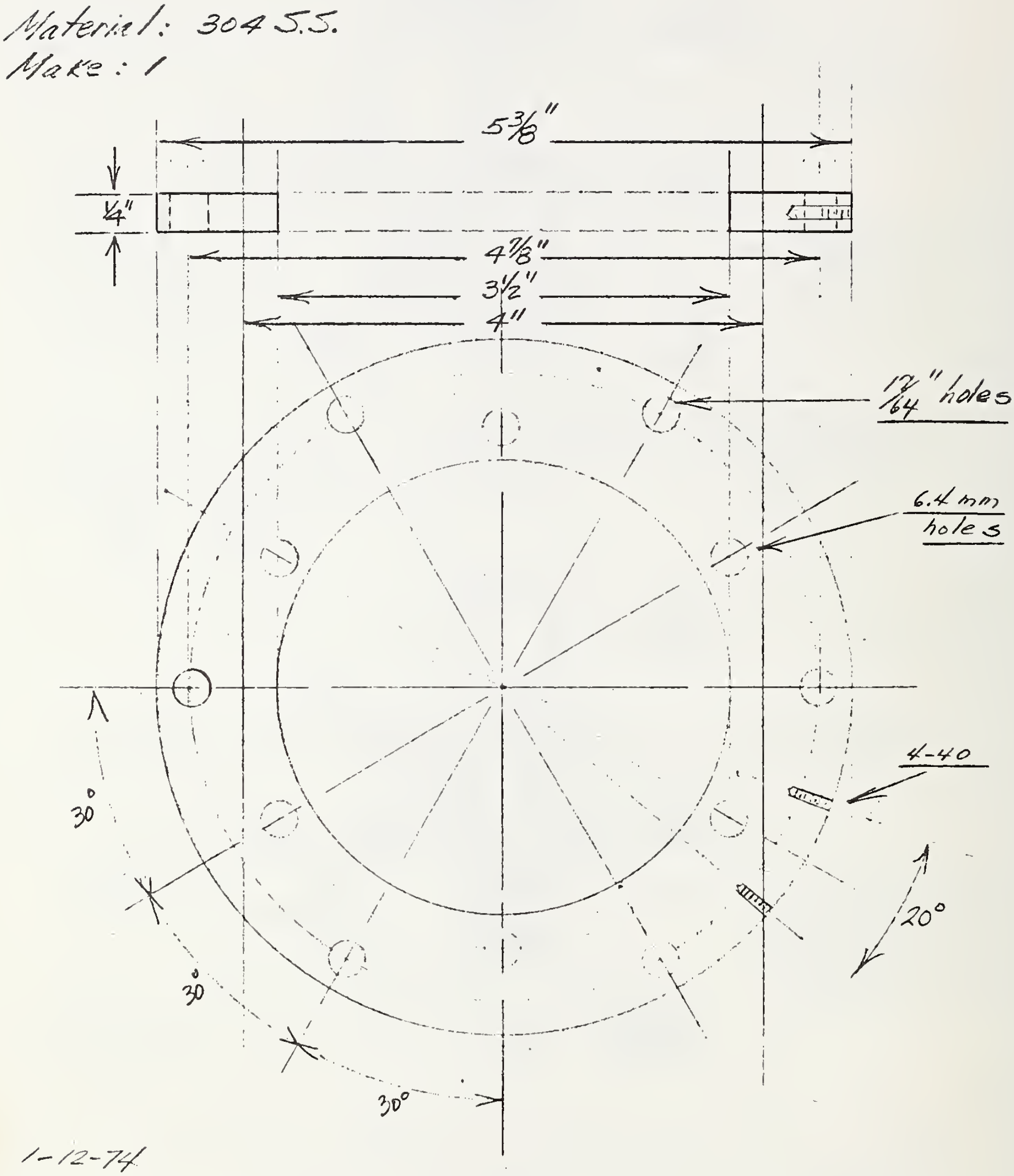


Figure 7. Ring support for clamping the apparatus to the test stand (figure 18).

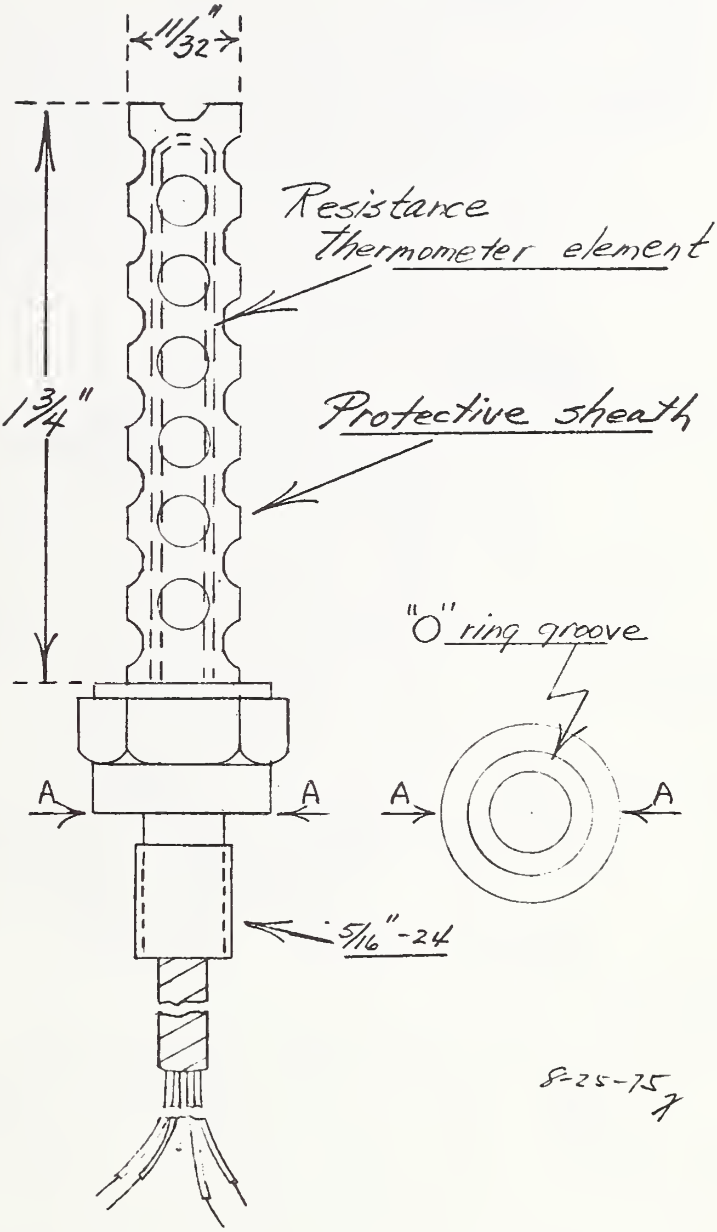


Figure 8. Schematic drawing of a high-pressure oceanographic PRT with an "O" ring pressure seal.

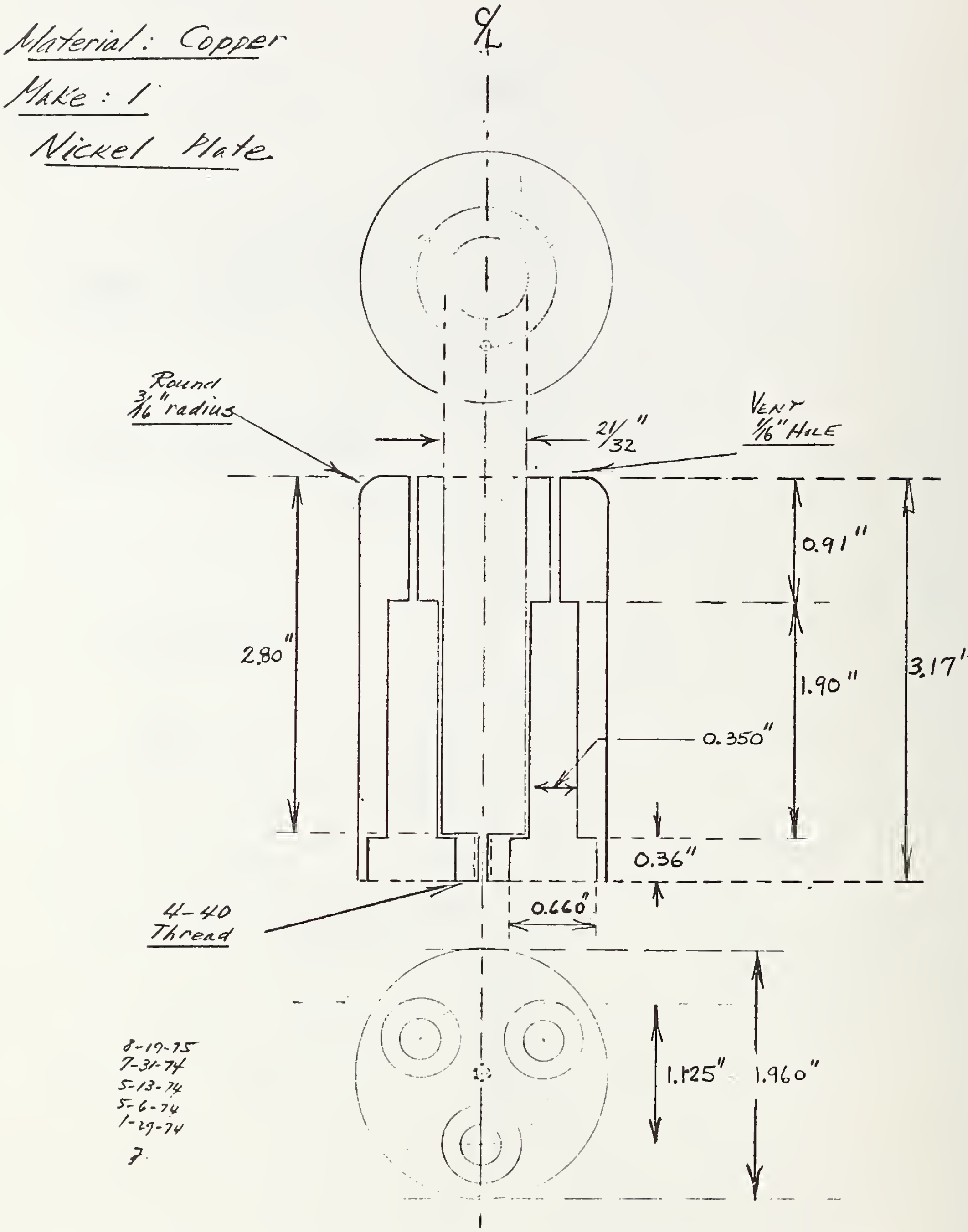


Figure 9. Copper block for reducing the volume of water in the pressure vessel and for enhancing temperature equilibration. The block has three holes to accommodate three test PRT's.

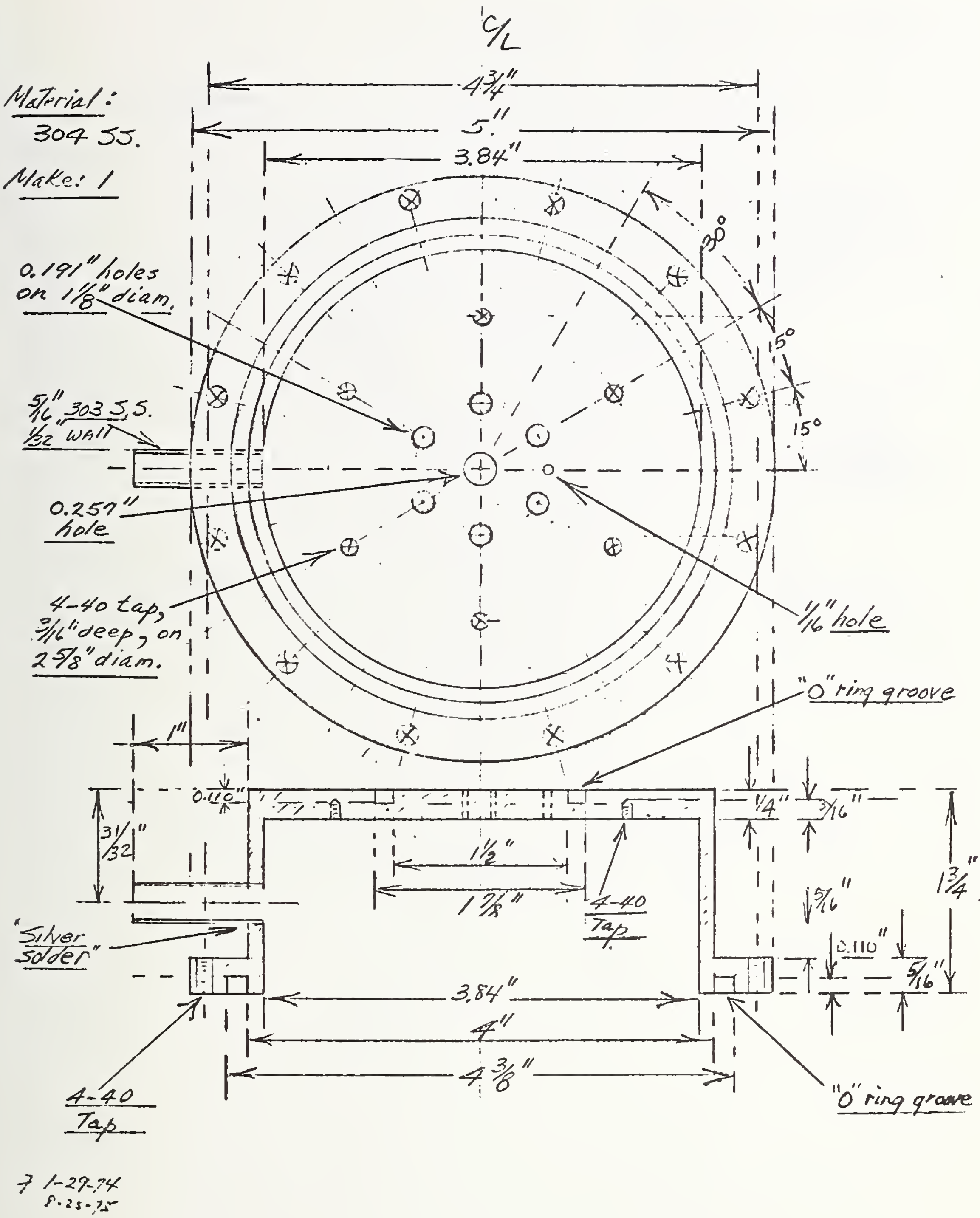


Figure 10. Water-tight terminal box which makes an "O" ring seal with the exposed bottom surface of the pressure head (figure 5). The PRT leads are connected to terminal strips in the terminal box.

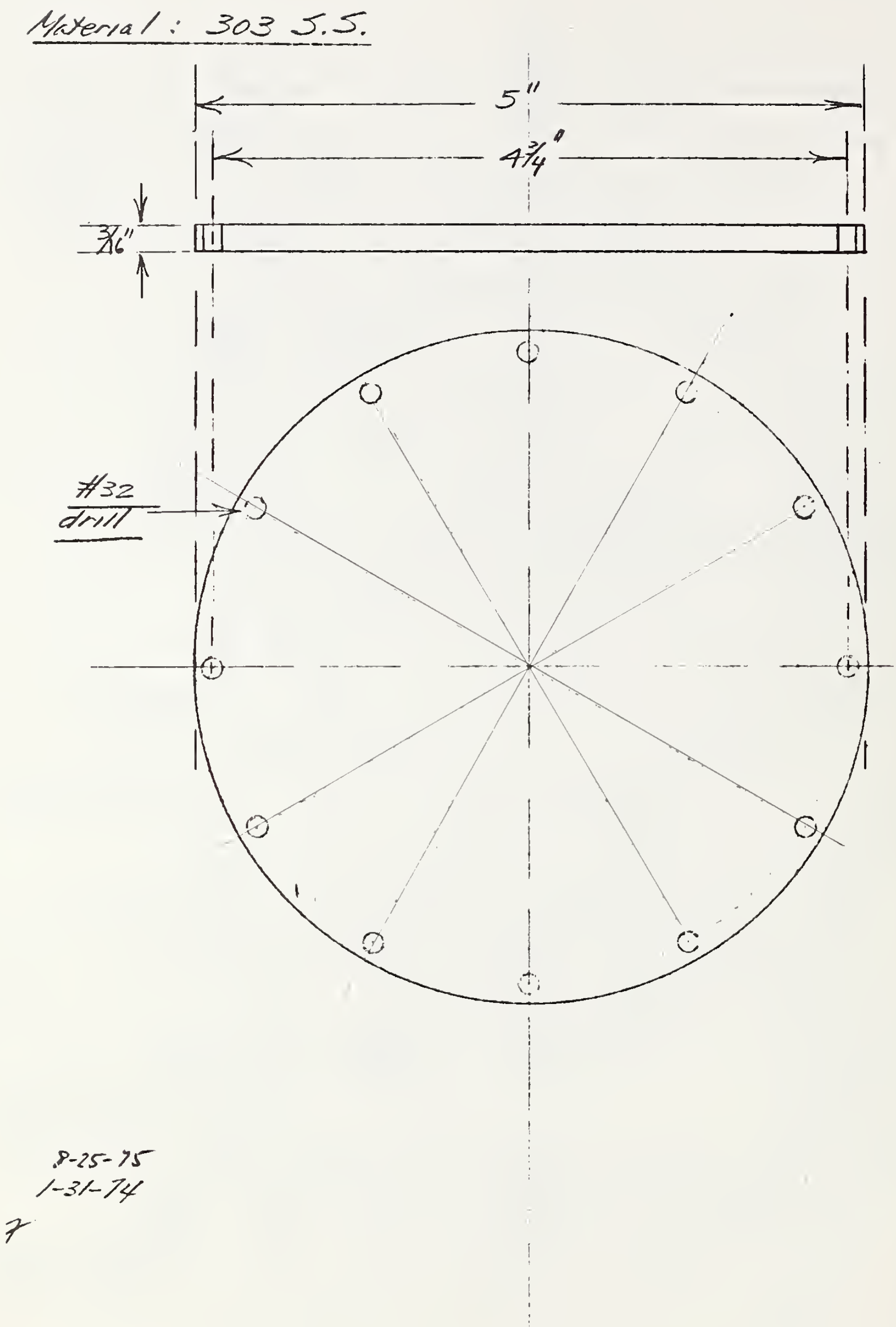
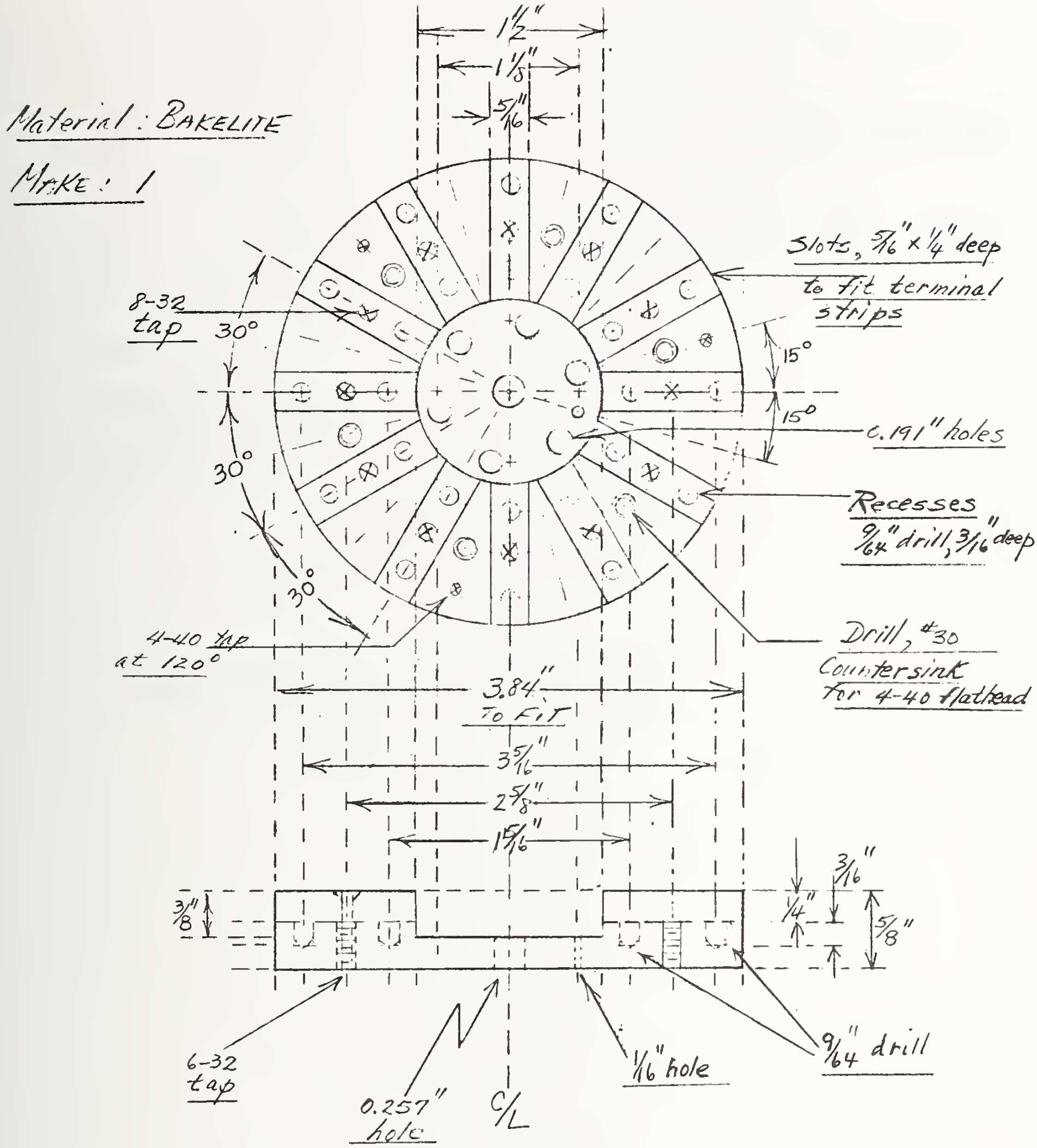


Figure 11. Lid which makes an "O" ring seal on the water-tight terminal box (figure 10).



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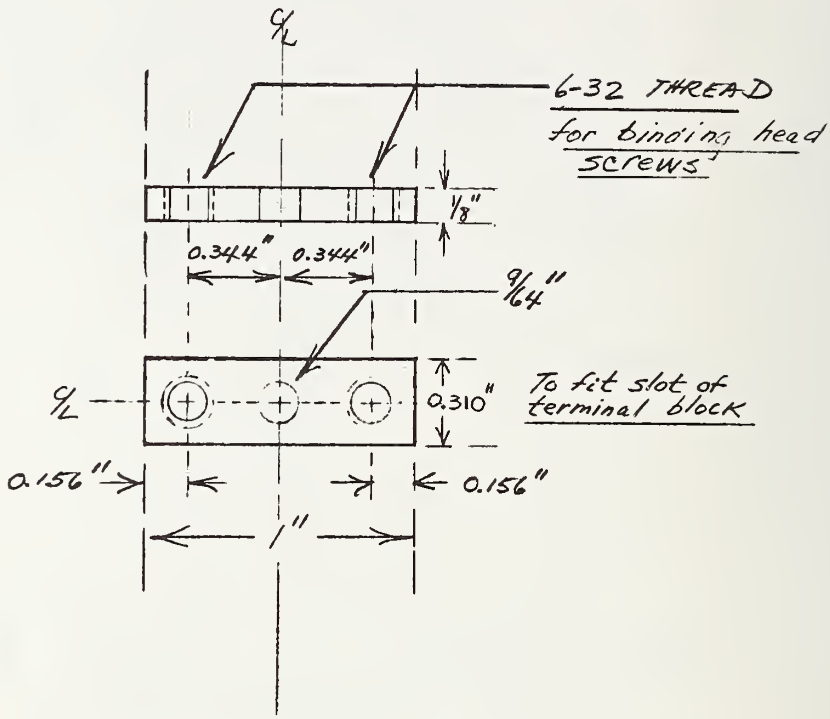
2-1-74

Figure 12. Plastic insulating ring for the water-tight terminal box (figure 10). Gold-plated copper terminal strips (figure 13) are arranged radially on the ring.

Material: Copper

Make: 16 (Gold Plate)



2-2-74

8-25-75

Figure 13. Gold-plated copper terminal strips for the plastic ring (figure 12) in the water-tight terminal box (figure 10). Binding-head screw connections of the PRT leads and of the copper lead wires are made on the terminal strips.

Material: Copper
Gold plate

Make: 50

Note:
Enlarge inner hole of washers to be supplied to size

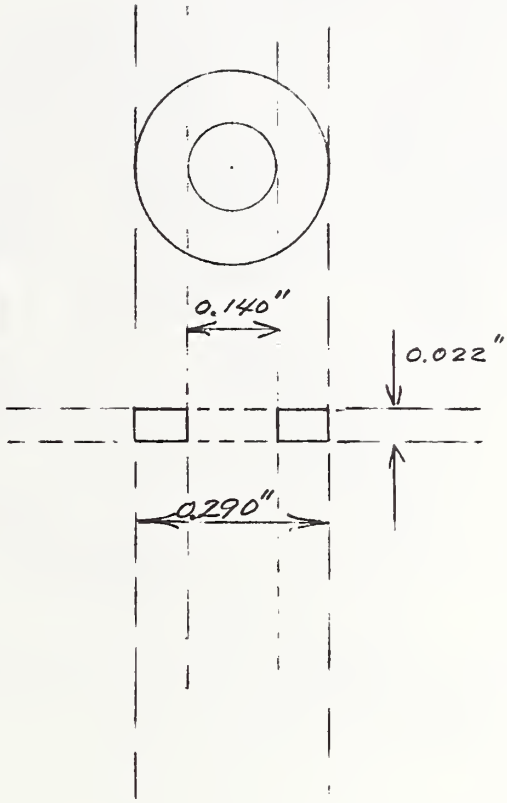
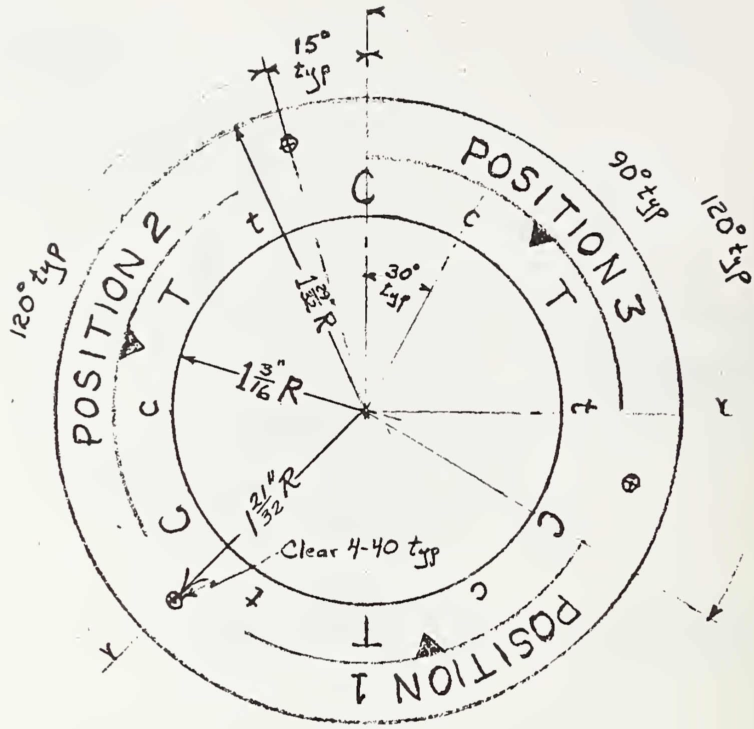


Figure 14. Gold-plated copper washers used with the gold-plated copper terminal strips (figure 13).



Material: $\frac{1}{16}$" laminated Bakelite

Make: 1

Figure 15. Label ring for the PRT connections on the copper terminal strips (figure 13) inside the water-tight terminal box.

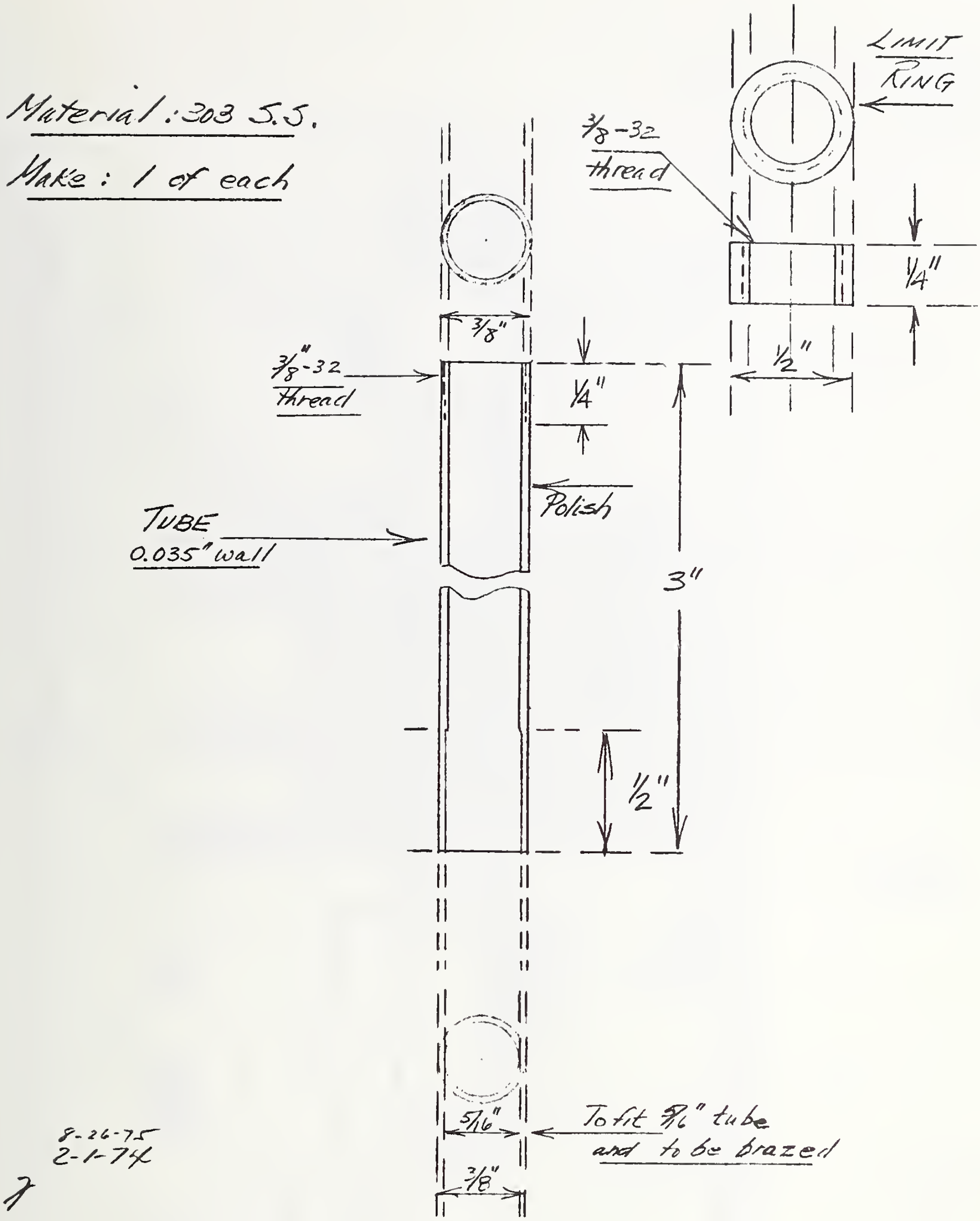


Figure 16. Tube (with screw-on limit ring) to which a thin-wall stainless-steel tube is silver soldered.(The combination is referred to as the lead tube.) The tube makes a vacuum tight connection with the coupler (figure 17).

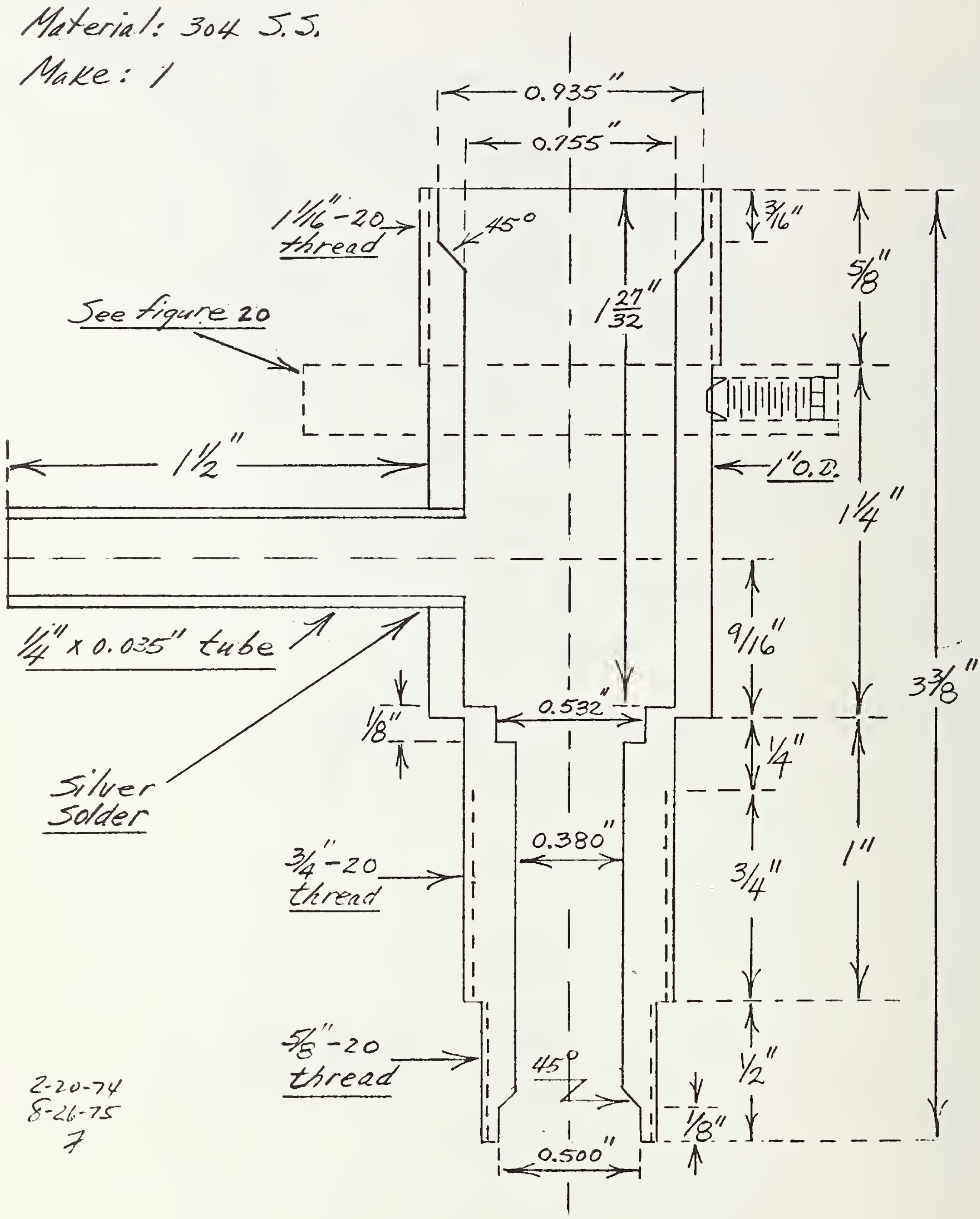


Figure 17. Coupler to which the lead tube (figure 16) and the multi-header assembly (figure 19) make vacuum tight connections. The pump-out tube permits the entire lead chamber to be evacuated and be refilled with dry air.

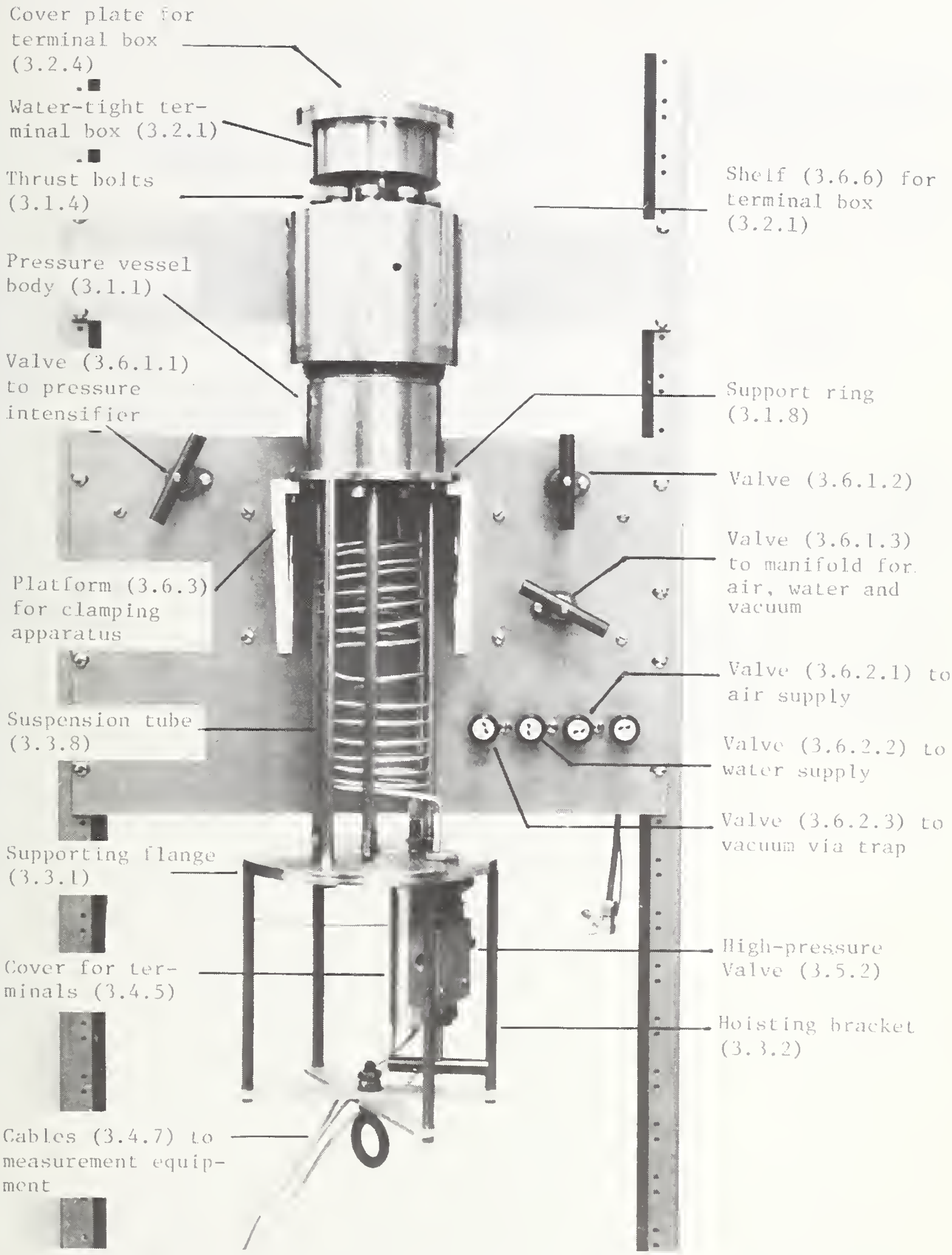


Figure 18. NOIC apparatus for testing oceanographic resistance thermometers clamped on the test stand.

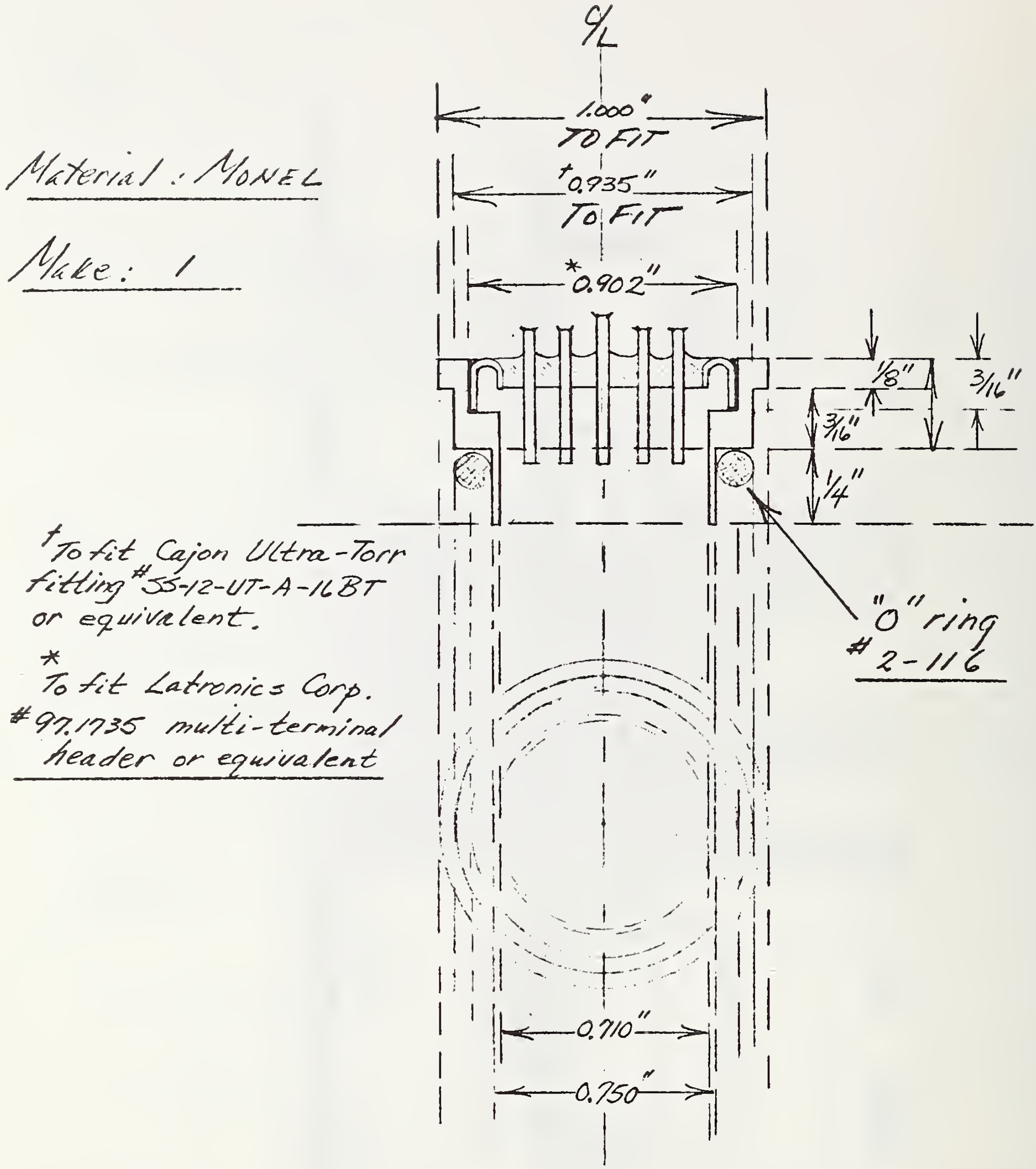


Figure 19. Multi-header assembly through which the copper lead wires emerge from the lead chamber. The ring, on which the multi-header is soft soldered, makes vacuum tight "O" ring seal with the coupler (figure 17).

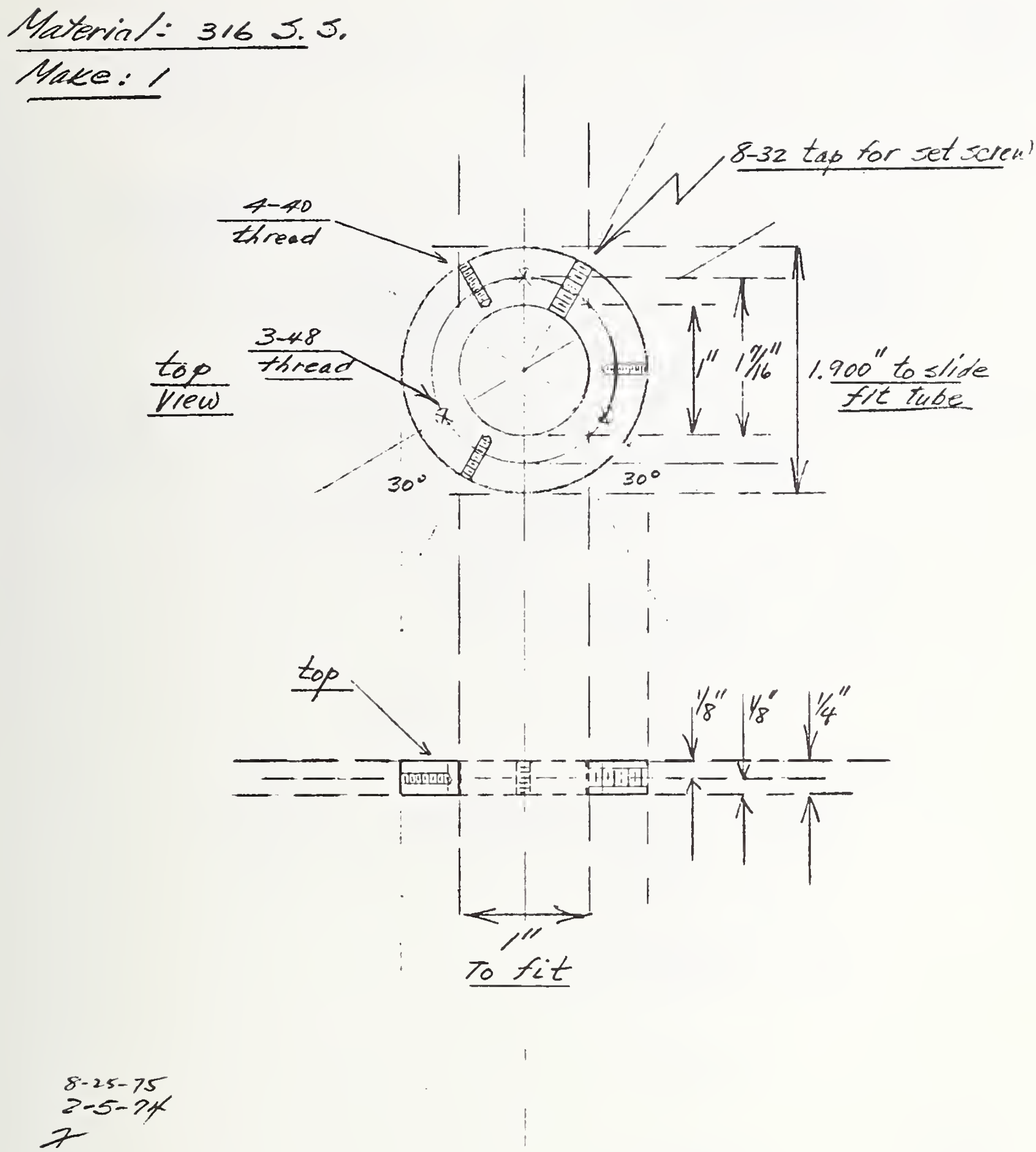
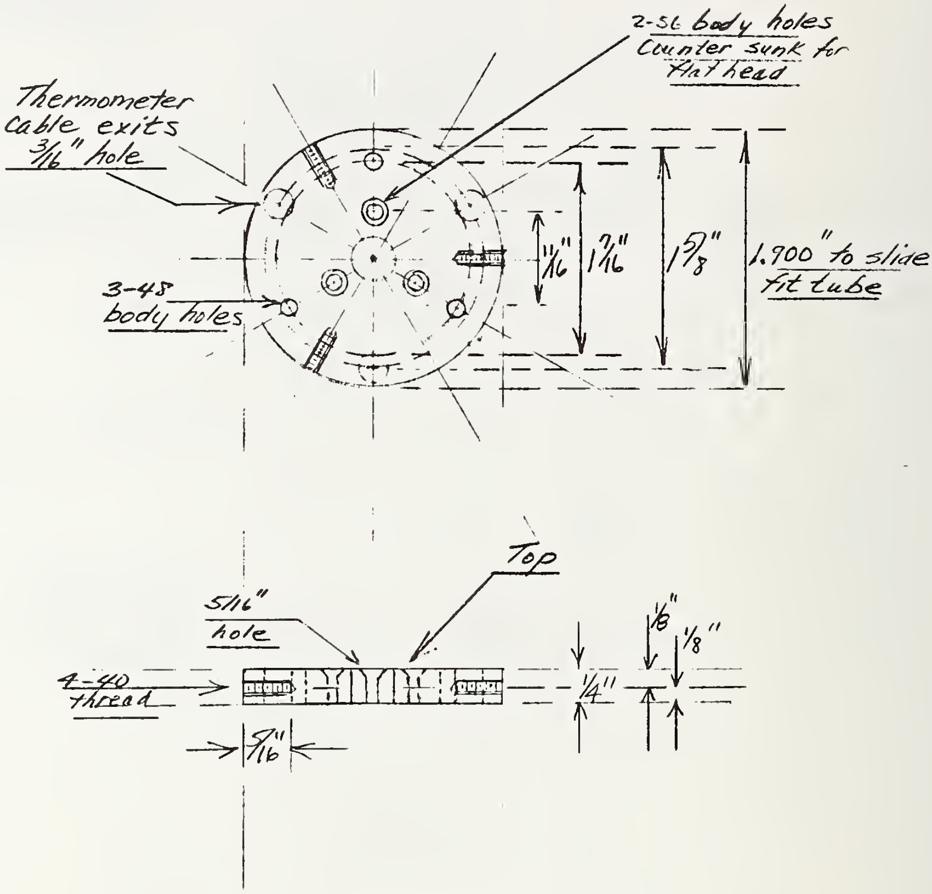


Figure 20. Ring for supporting the terminal strip assembly (figures 21, 22, 23, 24, and 25) to which the copper lead wires and the cables to the measurement equipment are connected. The ring is sketched in figure 17 on the coupler to show its location.

Material: Aluminum alloy

Make: 1



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F.

Figure 21. Plate for supporting the terminal strip mount (figure 22) and to which the support rods (figure 23) are attached. Holes are provided for cables to the measurement equipment (see figure 2).

Material: Aluminum alloy

Make : 1

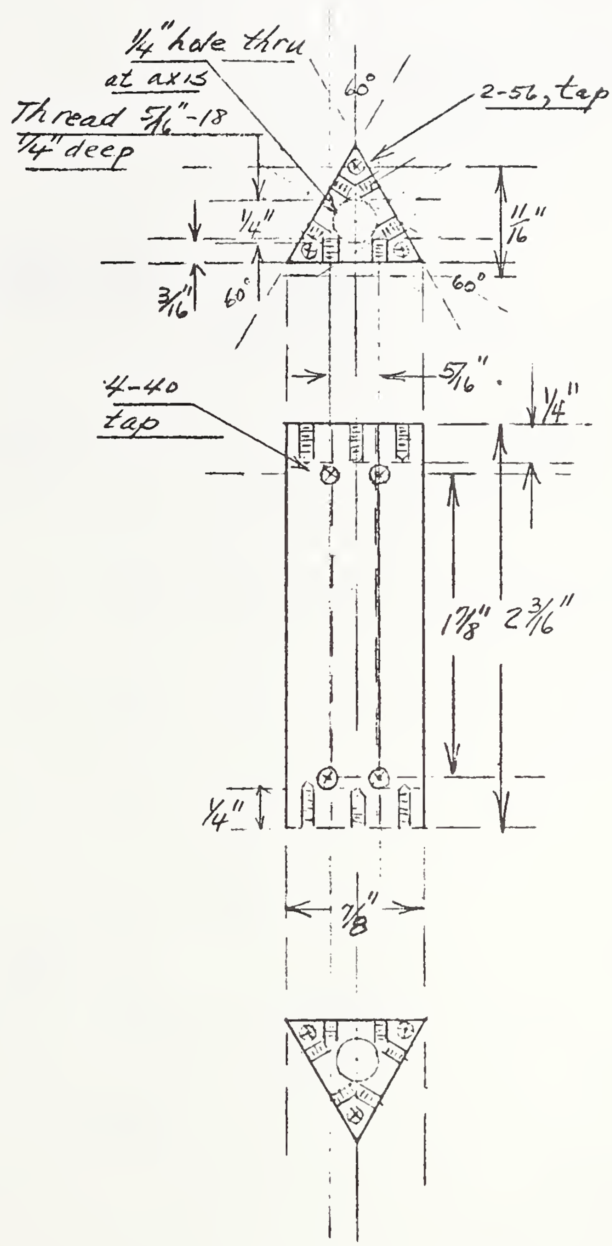
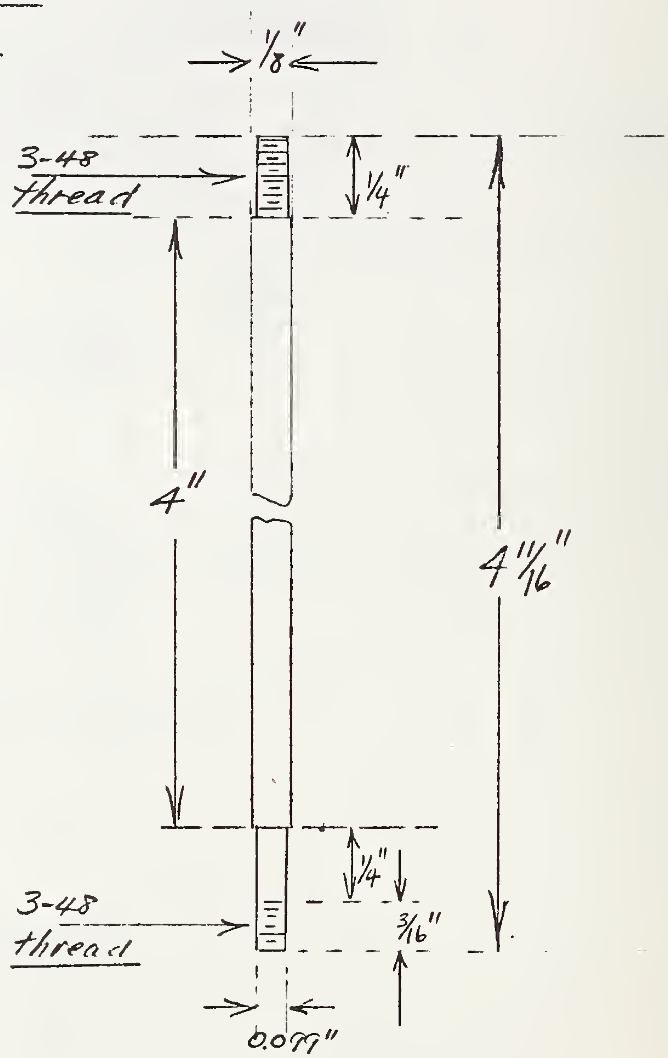


Figure 22. Terminal strip mount to which three four-terminal barrier-type strips are mounted.

Material: 1/8" o.d. 303 S.S. rod

Make: 3

Furnish: 3 Washers &
3 Nuts



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2-6-74

Figure 23. Rods which are attached to the support ring (figure 20) and to the plate (figure 21).

Material: Aluminum alloy 0.091" Thick

Make: 1

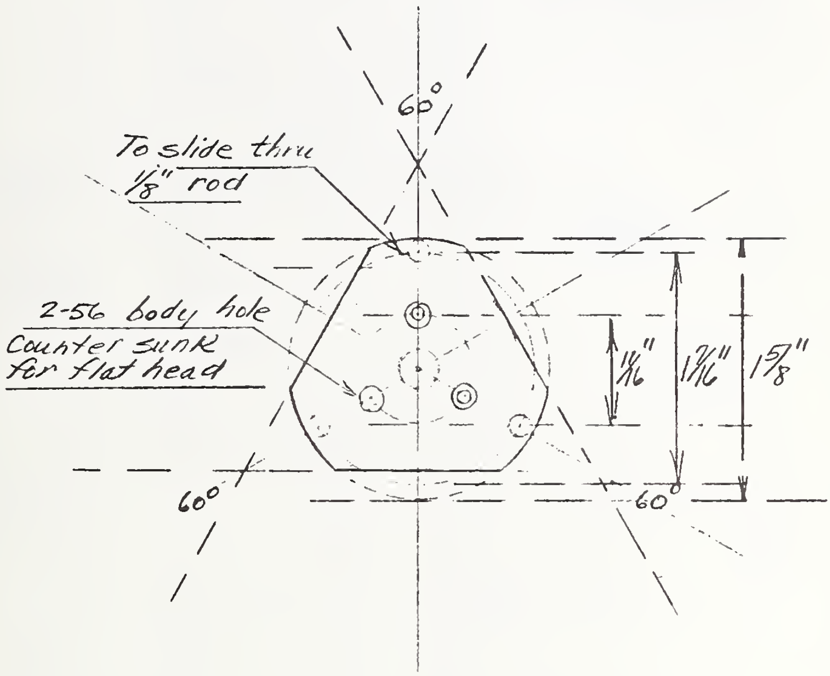

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Figure 24. Plate for stabilizing the terminal strip assembly.

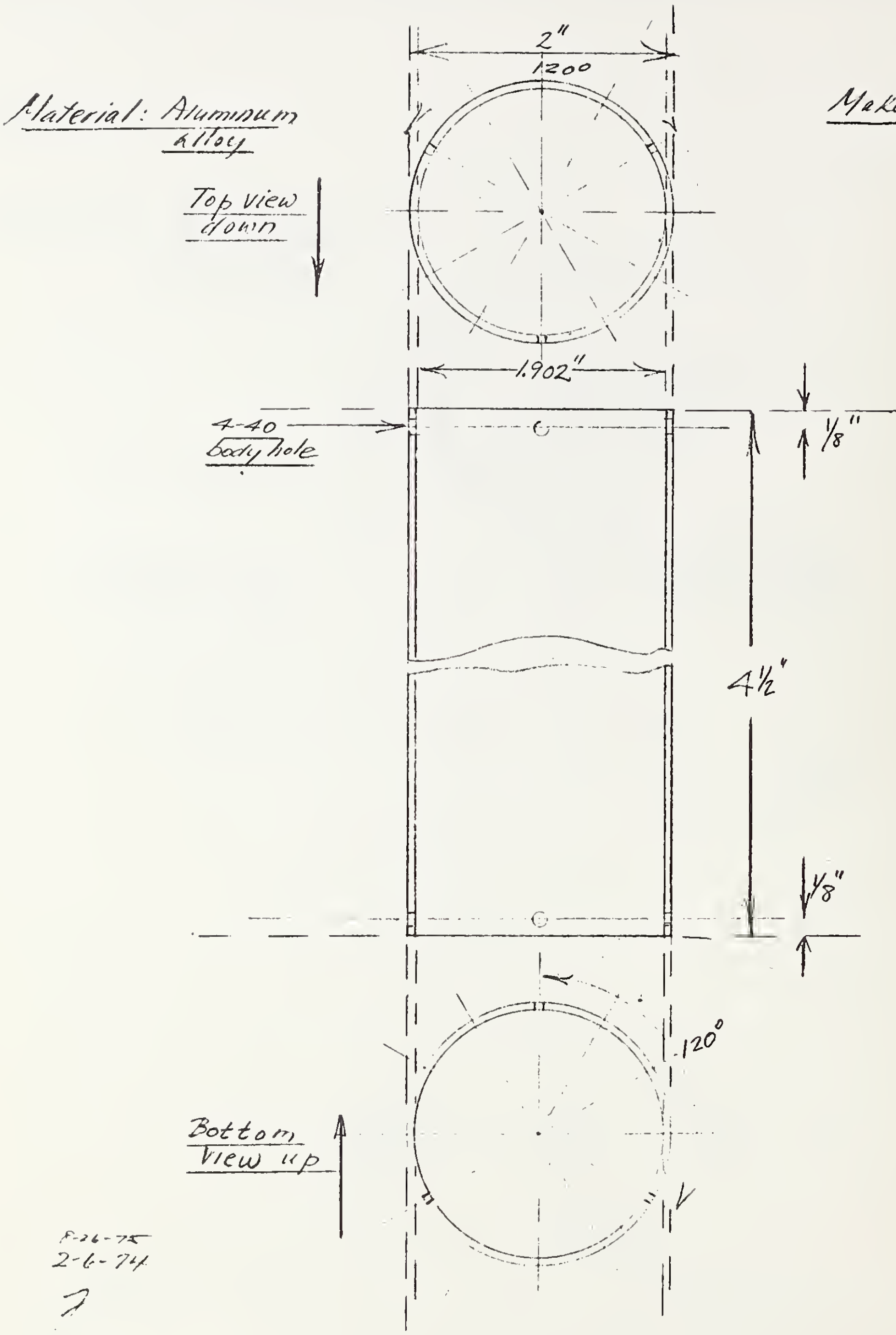


Figure 25. Aluminum cylinder for covering the terminal strip assembly.

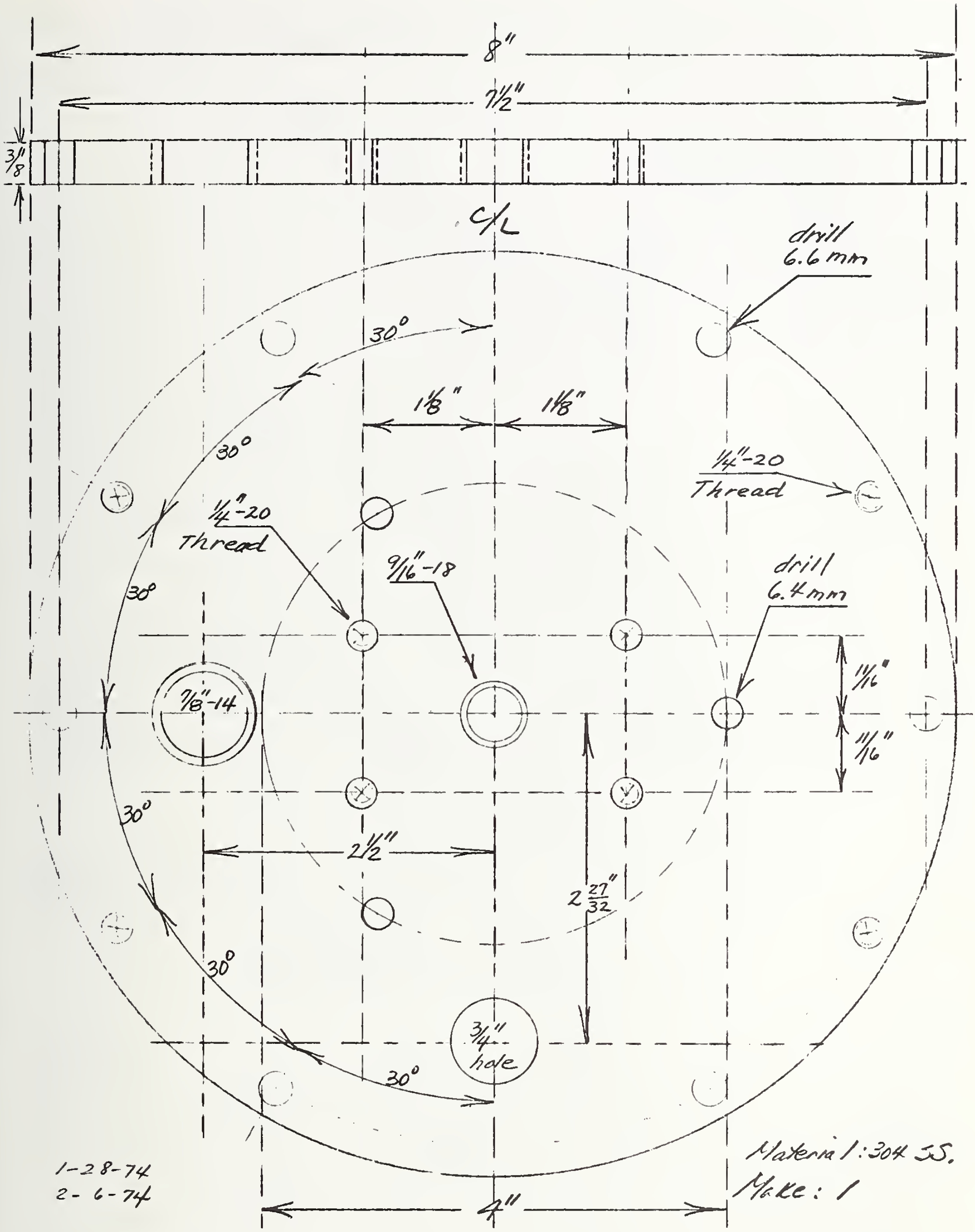


Figure 26. Supporting flange from which the pressure vessel assembly is suspended. The high-pressure valve and the upper terminal box are attached to the flange.

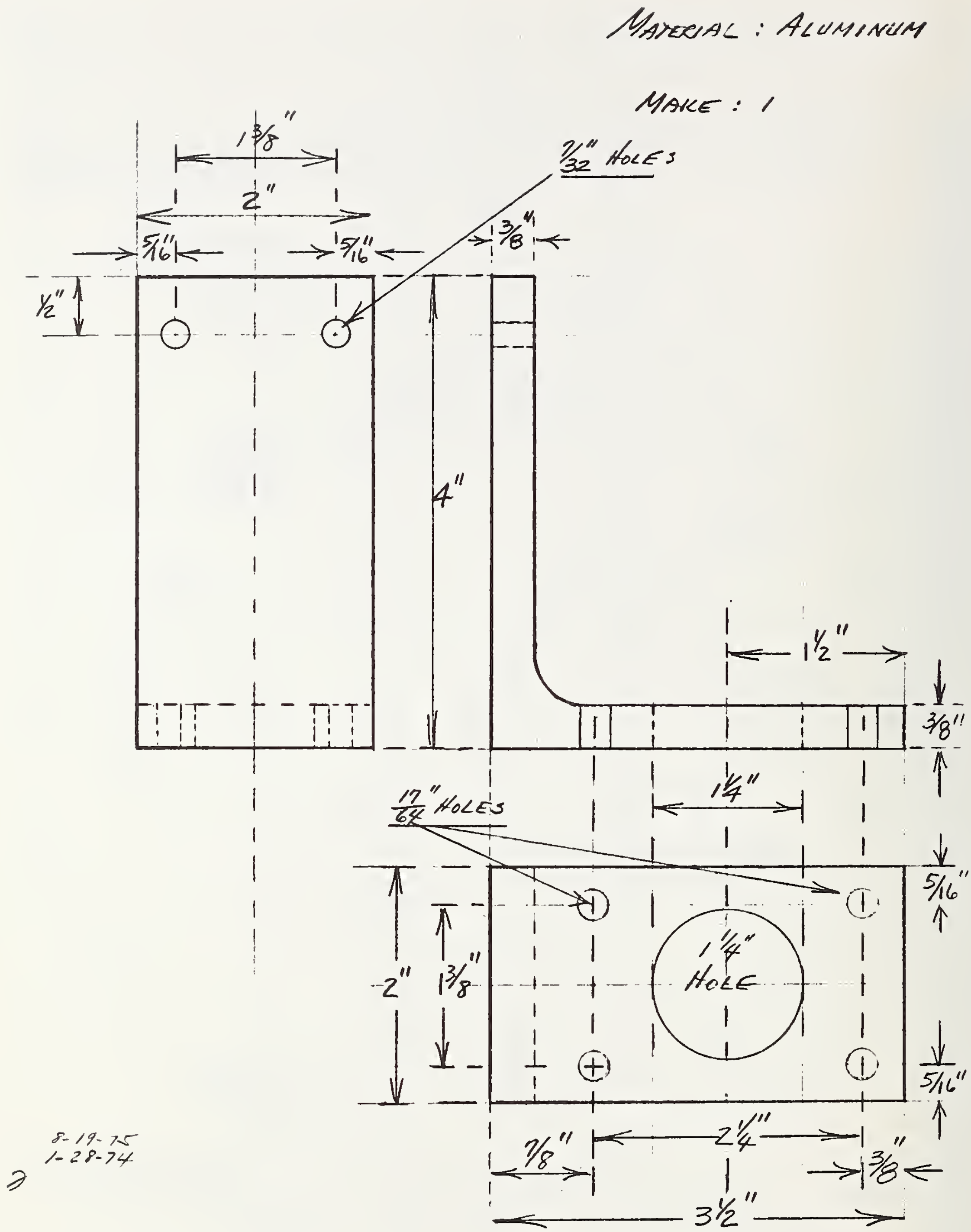
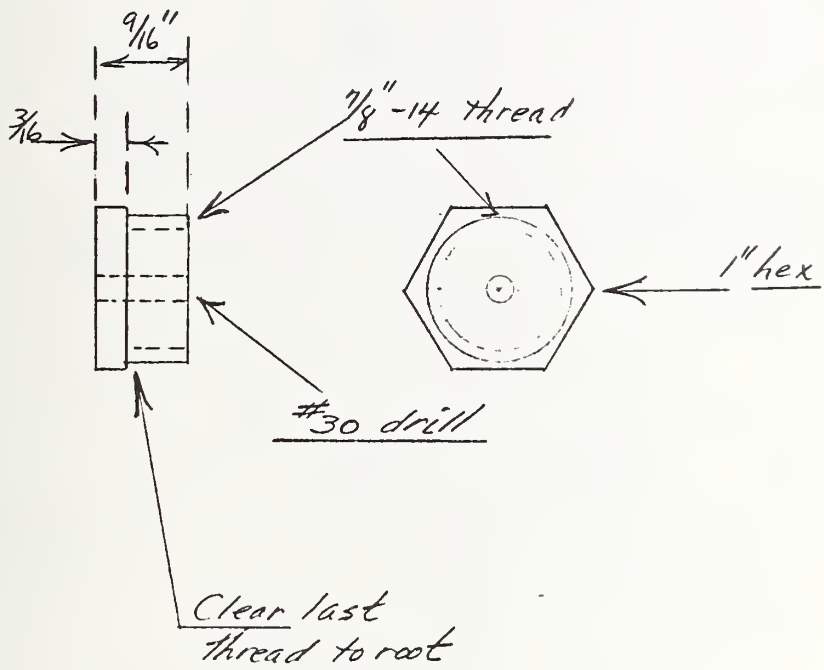


Figure 27. Bracket for mounting the high-pressure valve on the supporting flange (see figure 1).

Material: 303 S.S, 1" hex stock

Make: 1



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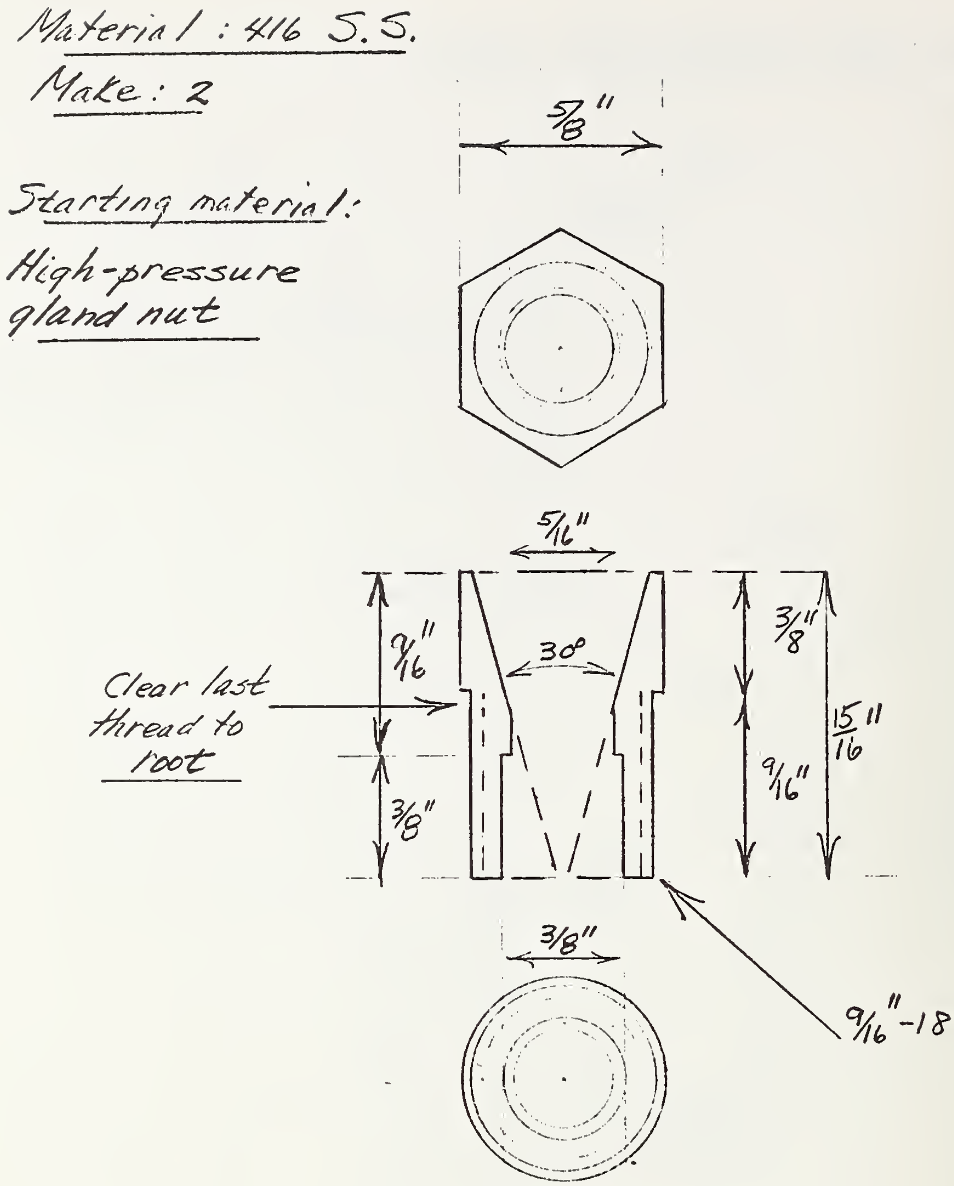
2-6-76

Figure 28. Nut for closing the hole in the supporting flange through which the pressure tubing emerge.



8-17-75

Figure 29. Gland nut for holding the PRT guide tube in place. The reference PRT is inserted through the conical opening in the gland nut.

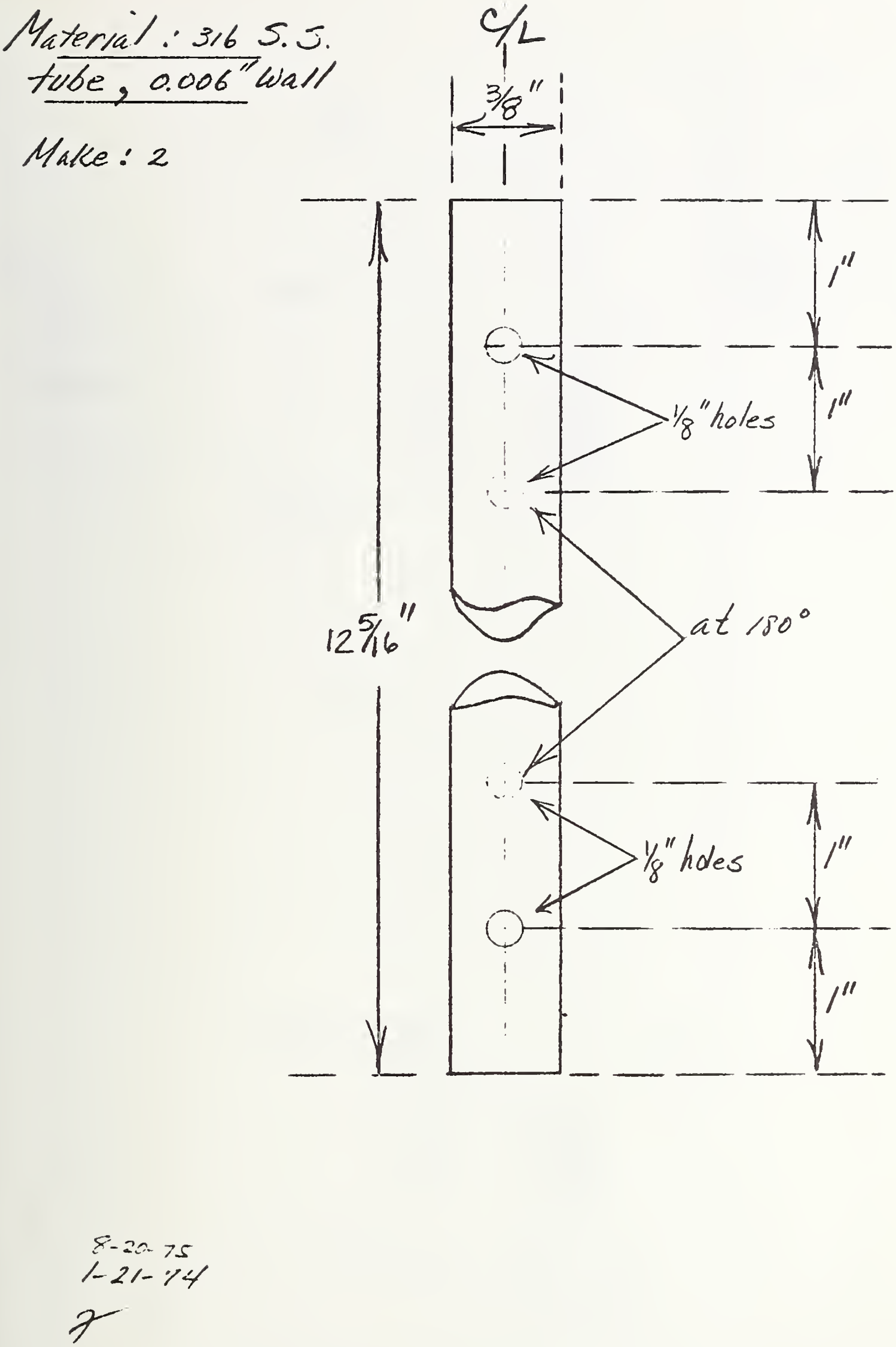


Figure 30. Thin wall stainless-steel guide tube for reference PRT.

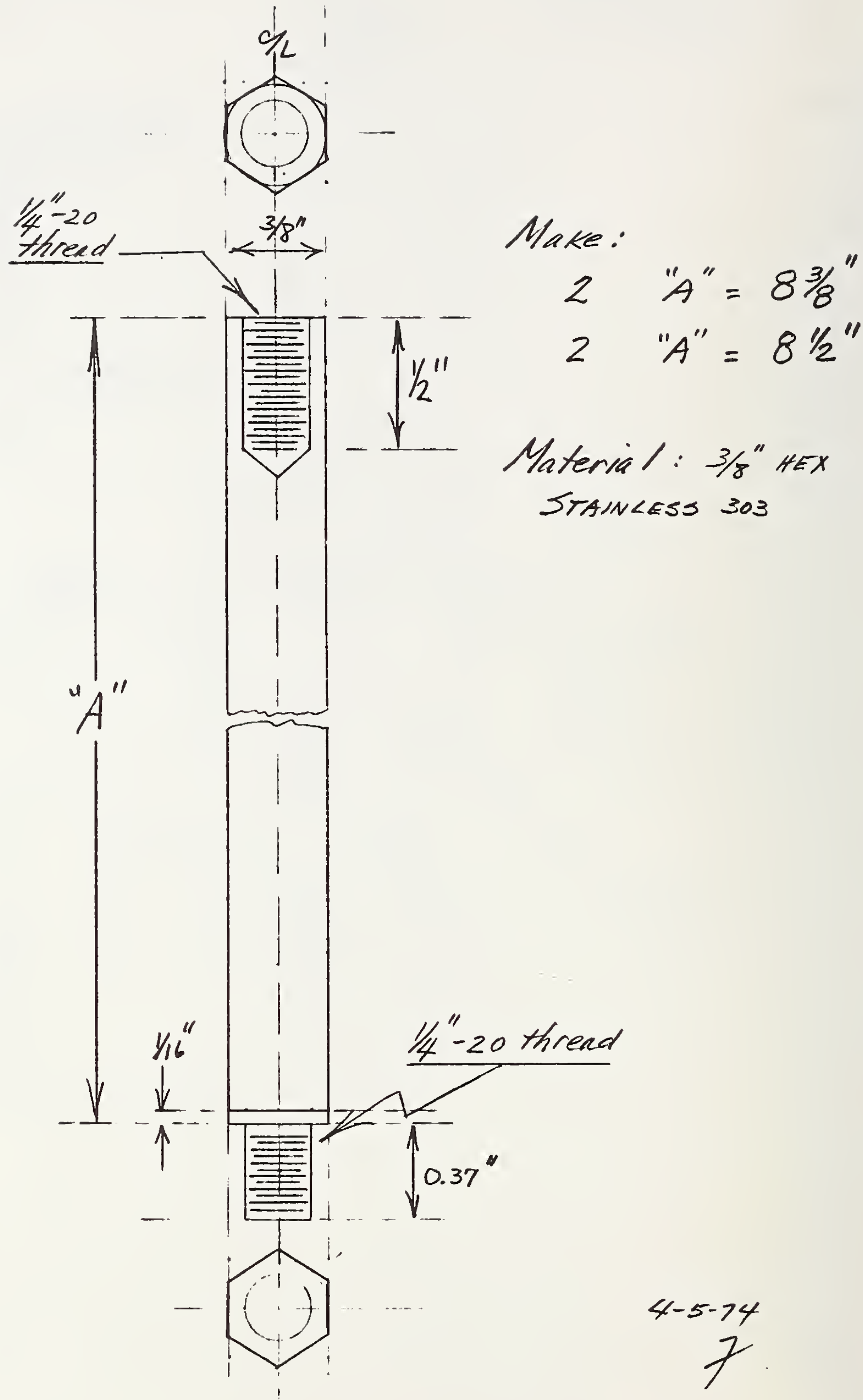


Figure 31. Hoist posts which can be screwed in place on the supporting flange (figure 26).

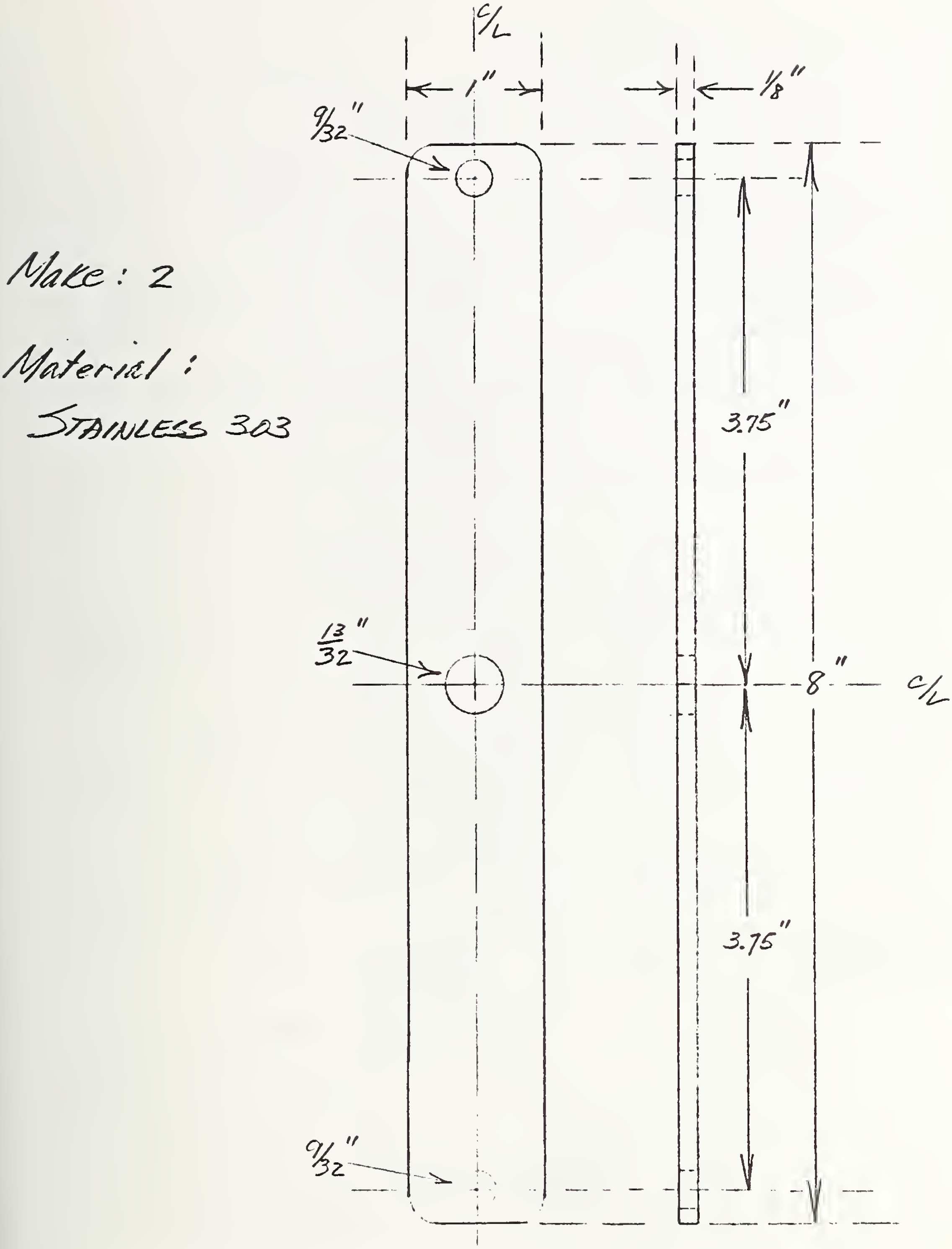


Figure 32. Cross members to be attached to the hoist posts (figure 31). An eye bolt is attached at the intersection of the cross members (see figures 2 and 18).

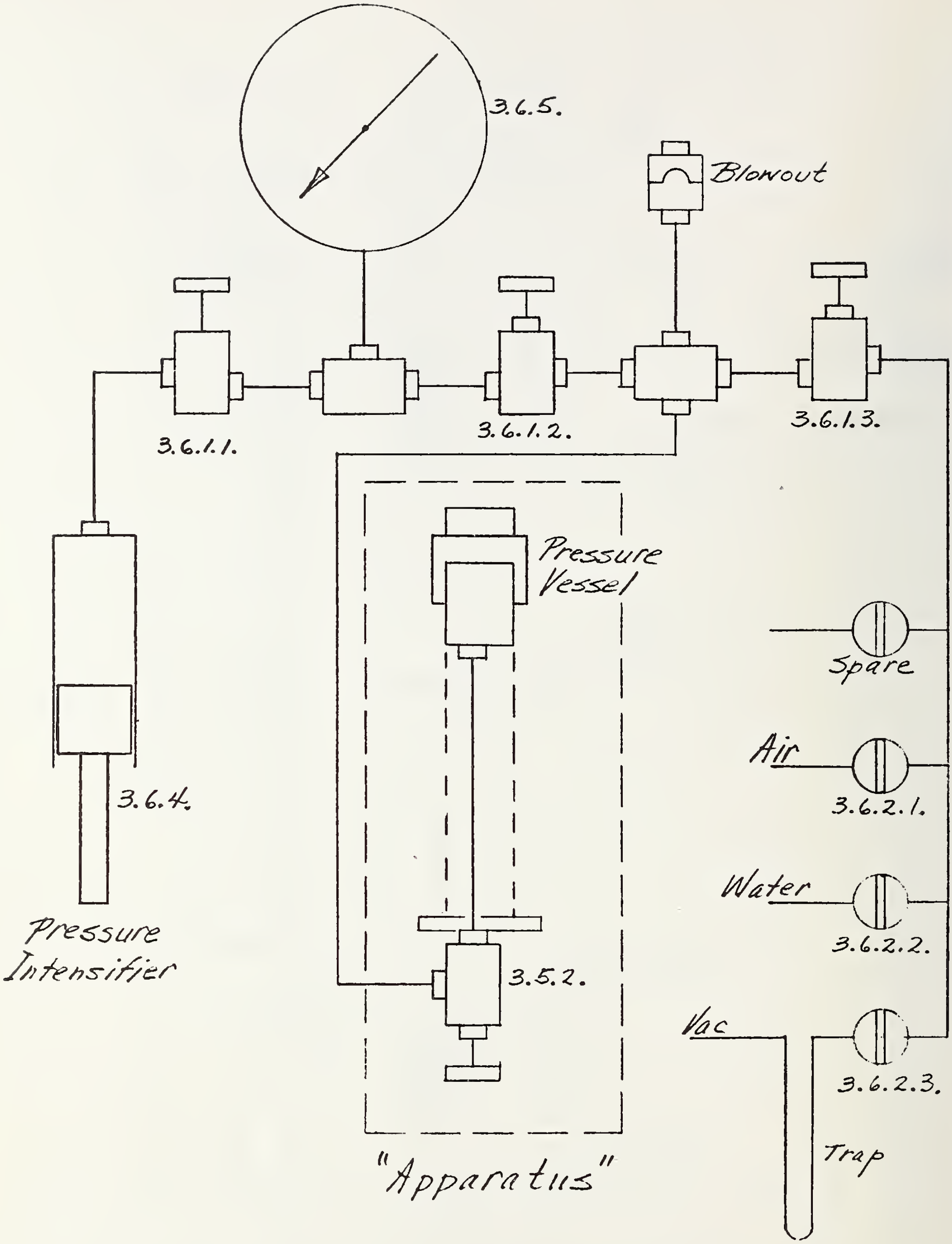


Figure 33. Schematic of the NOIC apparatus for testing oceanographic PRT's connected to the test stand.

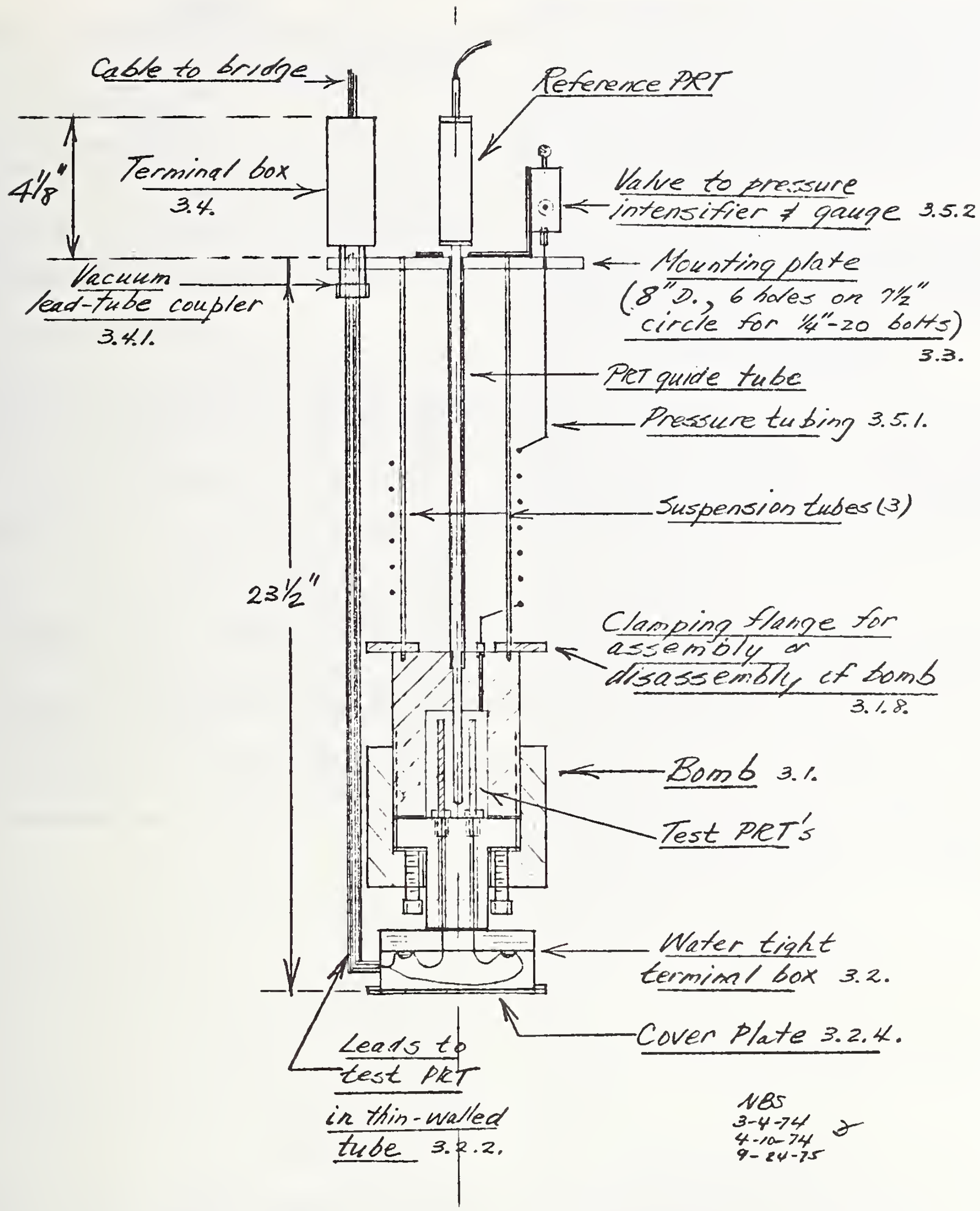


Figure 34. Schematic of the NOIC apparatus for testing oceanographic PRT's.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The design and construction of an apparatus for testing resistance-type oceanographic thermometers to 6.89×10^4 kPa(10,000 psi) are described. Detailed operating procedures for the apparatus are given. The results of performance tests with the apparatus are discussed.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Bridge; deep-sea thermometer; high pressure; oceanographic thermometer; platinum resistance thermometer; pressure; pressure intensifier; pressure seal; pressure vessel; resistance; resistance thermometer; test; thermometer; thermometer leads; thermostated bath; vacuum; water tight.

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