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ALVIN TITANIUM ELECTRICAL PENETRATOR DESIGN, MANUFACTURE, AND TESTING: INTERIM REPORT

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May 1976

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ABSTRACT

Under the U.S. Navy's Project TITANES a new titanium alloy pressure hull has been designed, built, and installed for use in the deep-submersible ALVIN. The Woods Hole Oceanographic Institution was assigned the task of designing, procuring and testing the through-hull electrical penetrators for the new sphere. This interim report traces the progress of this Woods Hole program from the initial design stage, through the various phases of manufacture and electrical testing, to the installation of the units in the completed hull, and the numerous laboratory, pressure tank, and at-sea tests conducted to verify the satisfactory performance of the new penetrators. The results of all laboratory and in-service testing done to date support the conclusion that the performance of the titanium penetrators meets all of the original specifications.

TABLE OF CONTENTS

Page

Introduction 1

Design Guidelines 2

ALVIN Steel Hull Penetrator 4

Titanium Penetrator Design 6

Design Verification Test Program 9

Production Manufacturing 10

Production Test Program 13

Installation of Penetrators and Proof Test of Hull 14

Hull Compression Squeeze Force on Penetrator 15

Belleville Washer Installation 17

Woods Hole Penetrator and Blanking Plug Inspection and Installation 19

Annapolis Testing 21

Woods Hole Inspection of Blanking Plugs 27

Blanking Plug Resurfacing and Installation 28

Inboard Thread Destructive Test 29

New Inboard Retaining Nuts 32

Carderock Tests of Hull II 34

Friction Tests 59

At-Sea Testing 61

Conclusions 64

Acknowledgements 67

TABLE OF CONTENTS (Continued)

Page

References 68

Appendix A - Figures

Appendix B - Penetrator Assembly and Test Procedures

Appendix C - Penetrator Installation Procedures

Appendix D - Memoranda Outlining The At-Sea Testing Procedures

INTRODUCTION

One of the goals of the TITANES program was to install a titanium pressure hull in the research submersible ALVIN. The requirement to produce operational hardware placed realistic and desirable pressures on the development-oriented manufacturing program. Also, the experience gained from the use of this hardware should provide the best possible feedback on the design and manufacturing process. The task of obtaining electrical penetrators for the titanium hull was assigned to the Woods Hole Oceanographic Institution. As the operator of the final hardware, W.H.O.I. could utilize the experience gained from the ALVIN steel hull penetrators and incorporate up-to-date goals into the design to satisfy future requirements. A contract was placed to develop the manufacturing techniques and to qualify the design by building two prototype units. The contract was to provide manufacturing specifications and drawings that could be used to obtain competitive bids on the production penetrator procurement. The qualification penetrators and design package were received in August 1971. Invitations to bid were sent to several qualified bidders in October 1971. The contract for twenty three production penetrators and one qualifying prototype was awarded in October 1971 and the twenty three production units were delivered to W.H.O.I. in the summer of 1972.

DESIGN GUIDELINES

Based on previous W.H.O.I. operating experience and current U.S. Navy practice on through-hull electrical penetrators, basic design guidelines were established at the start of the program. These are essential to the design and are reviewed here.

Simplicity. Successful ocean hardware depends on the simplicity of design and operation. The experienced ocean engineer reviews every design with the question - "what can be eliminated without compromising the function of the hardware?"

Minimum Number of Penetrator Types. The original ALVIN had three different types of penetrators with the associated logistical and operational limitations. There are currently two types used. The new configuration will result in only one type of penetrator.

Two Water Pressure Barriers. Current U.S. Navy practices require two water pressure barriers on all hull penetrators. Should one barrier fail, the second barrier will provide full and adequate protection to the personnel in the hull.

Titanium. The penetrator is required to have the same bulk modulus as the pressure hull to minimize stress concentrations. In addition, the non-corrosive properties of titanium are as desirable in the penetration as in any other part of the hull.

No Connectors. The original ALVIN was designed without connectors to improve external system reliability. Many years of experience with ALVIN has confirmed that connectors at the penetrator on a research submersible are not necessary.

Cable Suitable for Oil Hosing. The ALVIN electrical system is a pressure compensated system utilizing oil in all component boxes and cabling. The oil compensated design provides a more reliable, lighter system than could be obtained by using other techniques.

ALVIN Standard Taper. Operational experience at W.H.O.I. with the standard milling machine taper (3.500±.002 inches per foot of length) originally used on ALVIN has been quite good and formed the basis for the preference for this type of penetrator body. The taper provides a large surface contact for the metal to metal water seal. Testing has shown that this taper provides a total water seal without the external rubber gasket at all pressures. The rubber gasket is used in operational service however.

Design, Testing and Material Records Suitable for Certification. Since the penetrators are to be used in a man-rated hull, the documentation on design, testing and materials must meet NAVSHIPS 0900-028-2010 "Material Certification Procedures & Criteria".[1]

ALVIN STEEL HULL PENETRATOR

The design features of the ALVIN steel hull penetrator were reviewed to provide the historical background for the design of the new titanium penetrator. The old penetrator body has a standard milling machine taper (3.500±.002 inches per foot of length) that matches the taper of the hole in the hull. The exterior has a shoulder onto which a protective threaded nut is tightened against a rubber gasket to provide a low pressure seal against the hull. The inboard end of the body has a contoured washer and nut to hold the penetrator tightly into the hull (see Fig. 1).

Individual wires are soldered into shoulder pins that are installed in a header. These pins have insulators to provide electrical insulation from the header and to provide the pressure seal and water block. The cavity on the interior side of the header is filled with an epoxy for mechanical stability. The wires exterior to the header are molded to the header and penetrator body with a neoprene jacket. Individual wires can then be spliced to the appropriate circuits on the exterior of the submersible. Each pin and insulator provides a pressure barrier and the header is seated on a shoulder in the body with an o-ring to provide a pressure barrier from the header to the body. This design has provided very reliable service during the operating life of ALVIN thus far. Its simplicity offers a good design base for the titanium penetrator.

TITANIUM PENETRATOR DESIGN

Several changes in the original penetrator design were indicated. The first change developed from the requirement for two pressure barriers. This resulted in two complete headers, each one capable of withstanding full test pressure. In the original design, the pins had a solder cup at each side of the header but in the new design a male connector pin configuration is used. A double female connector socket is used to provide electrical contact between headers. The second change is the incorporation of the oil-filled jacketed cable for increased wire density and additional protection of the individual wires. A 90° elbow configuration was chosen to make installation of the wire harnesses easier. Another design feature was included that served several functions. Each header has a neoprene tapered puck molded to the pins and to the titanium header. This provides a better surface for bonding to the outer elbow and also, the taper provides an excellent pressure seal for the inboard header. The individual pins are bonded to the neoprene and the taper provides a seal to the surface of the body counterbore. Other changes are a) replacement of the outer protective nut with a simple torquing nut to properly squeeze the outboard rubber gasket in place, and b) the body length was increased to match the new hull thickness (see Fig. 2).

A failure analysis performed according to the procedures outlined in "Handbook of Vehicle Electrical Penetrators, Connectors and Harnesses for Deep Ocean Applications"[2], clearly illustrates the simplicity of the design and small number of failure modes.

The ALVIN steel hull has twelve (12) through-hull electrical penetrators installed around the forward and bottom viewports. The new titanium hull has twenty three (23) penetrations and will have penetrators installed in sixteen (16) of these. The remainder will be supplied with blanking plugs, which may be replaced with electrical penetrators in the future if there is a demand for additional wires. The new penetrators have eighteen (18) single conductor No. 16 AWG insulated wires (per MIL-W-16878) and two (2) No. 18 AWG two-conductor shielded and jacketed cables (per MIL-W-16878). Thus, the number of through-hull wires available for the 12,000 ft. ALVIN has been substantially increased.

The mechanical design was carried out using standard structural design and stress analysis procedures. Tensile, compressive, bending and shear stresses were considered at all applicable locations. Stress levels were limited by design to be less than the material **yield** strength at hydrostatic pressures up to 1.5 times the submersible's operating pressure, or about 8000 psi. In the recent hydrostatic pressure tests of Hull II (test hull), both sphere and penetrators were pressurized to 22,500 ft. (10,000 psi) without damage.

The material selected for the new penetrators is titanium alloy 6Al-4V ELI, which has the same modulus of elasticity as the titanium alloy of the hull, but which has a somewhat greater strength. This additional strength was considered advantageous in light of the expected stress concentration at the penetrator holes; while the use of dissimilar alloys in direct contact was considered desirable as an effort to reduce the possibility of galling.

DESIGN VERIFICATION TEST PROGRAM

The basic test program was patterned after the tests outlined in MIL C 24217[3] on penetrators, and included: continuity under rated load, withstanding voltage of 2000 volts, thermal shock, contact resistance, insulation resistance of 500 megohms, handling and flexing, 10,000 psi hydrostatic test of both the complete assembly and of the penetrator with the inboard header only, and hydro-cyclic test of 500 cycles at 10,000 psi. After the cyclic test the outboard header and elbow were removed and inspected for "z" bending. A hydro test of the inboard header was done again to constitute a destructive test. There was no indication of "z" bending on any wires. The combination of oil hosing and stress loops in the elbow are felt to have accomplished this. All hydro testing was accomplished without the external gasket and nut. There was a complete water seal on the taper both at high and low pressures. One item of interest was the uniform and significant drop in insulation resistance on all pins immediately after molding the external elbow. Although the neoprene header pucks are of the same material, this IR drop was not noted there. The IR values were still above the specified value in all cases. The neoprene used on the design verification unit was a proprietary material developed for its good electrical properties and its low viscosity during molding. This material was not available for the production units.

PRODUCTION MANUFACTURING

Some problems were anticipated due to the production manufacturing being performed at a different company than the one where the design was developed. Initial areas of concern were those relating to the taper machining and the neoprene to be used. The production manufacturer had done considerable work with titanium previously but still approached the critical taper with caution. Standard neoprene offered proven service with salt water but there were questions about the electrical properties and the viscosity during molding. Several formulations that were liquid in the uncured state were ordered.

The final taper was excellent with a bluing transfer test in a master gage indicating nearly 70% surface contact over the taper, and 100% line contact around the taper. As with the design verification units, all testing was performed without the external rubber gasket, and a seal was obtained at all pressures. The taper was lubricated with Standard Pressed Steel Corporation's proprietary compound LF 31-35-8 as a protection against galling. This material had to be cleaned from the taper and fresh lubricant applied for each installation in the test facility to obtain a seal.

The first problem developed with the tolerances in the pin/insulator/header assembly. Extremely tight tolerance control was required, and even then all units had to be hand fitted. Any seizing of the insulator during insertion would cause a crack that would result in electrical failure. Insulation resistance and withstanding voltage tests were performed after pin assembly to detect any flaws.

At this time the various neoprene formulations were tested and were found to have poor mechanical properties. The decision was made to use the standard formulation that has been in use since 1948 and that has given good salt water service. The mechanical results were quite good and the insulation resistance tests on the header pucks were well within the specification. The next problem arose when repeated failures occurred with the insulation resistance measurement after open face testing. Some pins developed low IR readings and when they were removed from the header, each had a clear arc burn along the insulator from the pin to the header. It was noted that the header assembly should be sandblasted (with the contact areas shielded) since the neoprene will not bond to the gold plate. This solved the open face IR problem and the first elbow was molded. Some of the pins would not meet the IR specification and a plot of the IR values on the pin arrangement resulted in an interesting pattern. The lowest readings were at the edge nearest the neoprene injection ports and at the far edge the readings were quite high. Samples of the neoprene used for the puck and elbow were tested and found to have good IR characteristics. The primers used for bonding also showed good test results. The unit was milled out to within 1/16 inch of the puck interface and examined. After milling, the IR readings on all pins were back up to well within the specification but a lack of bond was observed in the area that had shown low readings. It is speculated that the viscous neoprene trapped air and possibly some moisture and compressed this into the corner of the body to cause the low IR readings. The cure for this was to put a polyurethane pre-potting into the top of the body that would prevent the pocket and also seal the exposed wire and solder cup area. After the next elbow molding the IR readings were all uniformly high. The IR drop noted during the design verification testing did not occur. The viscous neoprene was capable of causing one more problem, however. Wires around the outside of the header were pulled by the neoprene flow and broken free from the solder cup. This was prevented in future units by extending the polyurethane prepotting up around the wire bundle so that the neoprene became an external jacket.

PRODUCTION TEST PROGRAM

The production penetrators were tested at D. G. O'Brien, Inc. prior to their delivery to Mare Island Naval Shipyard for installation in the sphere. Mechanical, electrical, static pressure, cyclic pressure, dye penetrant, and dimensional tests were performed in accordance with W.H.O.I. Specification TP 4924-0502, Sheets 4 and 5 (see Appendix B). The manufacturer provided certification that each of the units passed all of the tests.

INSTALLATION OF PENETRATORS AND PROOF TEST OF HULL

The penetrators and blanking plugs were installed in the new hull by Mare Island Naval Shipyard. Surface finishing of each penetrator body tapered section was done using a lapping process with the aid of a cast iron lap and fine abrasive compound. The blanking plugs were surface-finished in a lathe using fine emery cloth. The units were installed according to procedure TP 4924-0500-A. The sphere was then sent to the Naval Ship Research and Development Center, Carderock, Maryland, for hydrostatic pressure testing. The test procedure was as follows:

1. Pressurized to 9000 ft. in oil at 32-40 deg. F; strain gage readings taken at increments of increasing and decreasing pressure; monitored leak detection pressure gages.
2. Same as Step 1 except maximum pressure was equivalent to 13,200 ft.; hull release mechanism operated.
3. Repeated Step 2.
4. Twenty-four hour creep test at 13,200 ft. in salt water.
5. Visually inspected entire assembly; performed dye penetrant, ultrasonic, and x-ray inspections of welds.

During these tests all of the penetrators and blanking plugs performed satisfactorily.

HULL COMPRESSION SQUEEZE FORCE ON PENETRATOR

When the submarine operates at a given depth in the ocean, the hydrostatic pressure produces compressive stresses in the spherical hull wall which are in a direction tangential to the wall. If there are holes which penetrate the spherical wall, these holes, if unsupported, would decrease slightly in diameter; but if the holes are plugged by a tightly fitting member, a significant squeezing force may be exerted on the plug. In the case of the electrical penetrators and blanking plugs, the shape is a tapered one, and the squeezing force will have an outward component tending to push the penetrator out of its hole. This outward force is resisted by a.) hydrostatic pressure acting on the outer face of the penetrator; b.) the friction force at the mating conical surfaces, a function of surface roughness and type of lubricant used, if any; and c.) the inboard retaining nuts. Calculations indicate that the effect of hydrostatic pressure is small relative to the magnitude of the other forces acting on the penetrator. If the friction at the mating surfaces is great enough, the nuts may be loaded only slightly, or not at all. If the friction is small, the nut loading could be great. The nut loading is transmitted to the penetrator threads, causing shear and bending stresses, and to the thread neck (a short portion of reduced diameter adjacent to the threads) where a tensile stress is produced. In order to calculate the value of these stresses an accurate value of the coefficient of friction for the conical surfaces is required. Calculations done at Woods Hole showed that thread and neck stresses would be equal to zero if a coefficient of friction of 0.13 or greater could be obtained. Although this is a reasonably low value, some doubt still remained concerning the presence of sufficient friction, and it was felt that further testing was needed to fully qualify the penetrator installation for operation at a depth of 12,000 feet.

BELLEVILLE WASHER INSTALLATION

One phase of the testing which followed involved the installation of belleville spring washers at the inboard end of the penetrators, between the contour washer and the retaining nut. These springs resemble flat washers that have been deformed permanently to have a shallow conical configuration. If loaded axially, these washers tend to flatten, but they return to their initial shape upon release of the load. As installed, the washers were flattened slightly by a partial tightening of the retaining nut. This provided enough axial force to hold the penetrator body firmly in its seat. However, additional belleville washer flattening would be possible if the hull squeeze should cause outward penetrator movement. Mechanical dial gages were affixed to the inside hull surface for measurement of relative penetrator body motion. Thickness gages were used to determine the degree of belleville washer flattening. The belleville washer installations were used for the penetrators and blanking plugs during the Annapolis hydrostatic pressure tank tests of the assembled vehicle, and during the early series of ocean dives that were primarily for test and training purposes. Also, during portions of the NSRDC (Carderock) tests of Hull II, certain penetrators and blanking plugs were installed with belleville washers so that comparisons could be made with units installed by other means.

WOODS HOLE PENETRATOR AND BLANKING PLUG INSPECTION AND INSTALLATION

Prior to the Annapolis 12,000 ft. tank tests of the entire submarine, personnel at Woods Hole removed and inspected the penetrators and blanking plugs. No significant changes in the measured dimensions were noted, which indicated that the Carderock testing had little, if any, effect on the penetrators and plugs.

Visual inspection showed that the tapered surface finish of the penetrators was different from that of the plugs. This can be accounted for by the fact that the penetrator tapers received a final lapped finish at Mare Island Naval Shipyard while the blanking plug tapers were finished in a lathe. The differences did not appear significant at the time these operations were performed.

Several special cases will be noted. Of the original production run of 25 units, unit SN 12 had a defective thread neck and was to be scrapped. SN 25 was to be renumbered SN 12 for continuity. By mistake, the new SN 12 was placed in bonded storage and the faulty SN 12 was assembled and delivered. It had been installed in the hull by Mare Island and tested later during the proof test of the sphere to 13,200 ft. without damage. It was removed from the hull and set aside, and used later in the inboard thread destructive test described in this report. If any of the penetrators are to be rebuilt in the future, the new SN 12 body can be used.

Another unit, SN 15, was the prototype test unit. It had been subjected to 500 pressure cycles to 10,000 psi with both headers (pressure barriers) in place, and 10 cycles to 10,000 psi with the outer header removed. This unit was completely rebuilt and tested as a production unit.

A third special case is that of SN 10, which later would be modified so that strain gages could be installed internally in the area of the inboard thread neck.

Prior to installation in the hull, those penetrators and plugs which were to be placed in holes not occupied by them previously were checked for proper fit by bluing with Dykem High Spot Blue No. 107. All fits were found to be acceptable.

Following the inspection outlined above, the penetrators and blanking plugs were installed following the procedure of TP 4924-0500-C (belleville washer installation).

ANNAPOLIS TESTING

Introduction

To certify the integrity of DSRV ALVIN, hydrostatic testing was conducted by the W.H.O.I. Deep Submergence Group in conjunction with the U.S. Navy at the Naval Ship Research and Development Center, Annapolis, Maryland from 5-10 July, 1973.

The tests consisted of five simulated dives to 12,000 feet (5,330 psi) the last of which was manned; and an eight hour hold at 12,000 feet.

Fourteen strain gages were monitored during the tests. Gages 1-4 (BLH FAET-12D-12S6ET, installed by Teledyne Materials Research) were located in a "dummy" penetrator as two biaxial pairs. The purpose of these gages was to measure the strain encountered in the predicted outward movement of the penetrator under hull loading. Gages 5-14 (BLH FAER-12R-12S6ET, installed by Teledyne) were located on the inboard side of the titanium hull in three biaxial pairs and one three gage rosette. The position of the gages was chosen to correspond to points where the greatest stresses were recorded during the Carderock test of the completed hull prior to delivery to Woods Hole. Biaxial stresses for each pair were then calculated from the strain gage data.

On the manned dive, dial indicators were positioned to record hatch, window and blanking plug deflections.

Procedure

The test procedure consisted of taking sets of reference data with ALVIN in air, and after the tank was flooded but at zero pressure. Readings were then taken at predetermined steps of 444, 1000, 2000, 3000, 4000, 4300, 4600, 4900, 5100, 5200 and 5330 psi. During the eight hour hold at 5330 psi, readings were taken each half hour. The strain data was converted to stress data using Hooke's law:

$$s_1 = \frac{E}{1-\mu^2}(e_1 + \mu e_2)$$

$$s_2 = \frac{E}{1-\mu^2}(e_2 + \mu e_1)$$

where:

s_1 = principle stress in the direction of strain e_1

s_2 = principle stress in the direction of strain e_2

μ = possion's ratio = 0.3

E = Young's modulus of elasticity - 18×10^6 psi

To effectively use the strain gages, the hull was assumed to be in an unstressed state with no residual stress. This assumption plus the inclusion of the gage factors changes the preceeding equations to the following form:

$$s_1 = \frac{2E}{GF\ (1-\mu^2)}\ (e_{1\ load} - e_{1\ static}) + \mu(e_{2\ load} - e_{2\ static})$$

$$s_2 = \frac{2E}{GF\ (1-\mu^2)}\ (e_{2\ load} - e_{2\ static}) + \mu(e_{1\ load} - e_{1\ static})$$

Where:

GF = gage factor = 1.98 for gages 1-4

= 1.96 for gages 4-14

e_{static} = The dry reference reading

e_{load} = Load reading

The stress data was plotted vs hydrostatic pressure. During the eight hour hold, stress was plotted against time. Dial indicator readings were plotted versus hydrostatic pressure.

Discussion

Hull

In all cases, the hull behaved elastically. Stress was a linear function of hydrostatic pressure. The maximum stress computed was 65,452 psi in compression, based on strain data from gages 9 and 10. All stresses were within the design criteria.

The eight hour hold revealed no discernible changes in stress. These tests tend to support the contention that creep and stress relaxation are not a problem at the loading levels experienced by the hull.

A Mohr circle analysis of the three gage rosette revealed proper orientation of the gages to the principal stresses to within ± 2 degrees.

Penetrators

The data recorded on the "dummy" penetrator was inconclusive. Each dive resulted in an independent and unpredictable stress record, often involving stress reversals. Initial analysis indicated a number of possible explanations for these results.

First, the assumed biaxial pairing of the strain gages could have been incorrect resulting in erroneous data. To clarify this, the penetrator was removed and sent to Teledyne for confirmation of the gage pairing. The results showed that 1-2 and 3-4 are the gage pairs with 1, 3 indicating circumferential strains and 2, 4 indicating axial strain. Pair 1-2 was installed closest to the viewport during the tests.

The second possible explanation is lateral movement at low pressure until hull squeeze is sufficient to cause metal-to-metal contact over a substantial area of the taper. This movement would account for the stress reversals since bending stresses could be developed as a result of the unsymmetrical restraining forces.

Despite the erratic stress records, one important result was obtained. The maximum stress recorded in the penetrator neck area was 7,000 psi which is approximately 1/17 of the yield value (120,000 psi). This would seem to indicate that at least with the present installation procedure, the penetrator neck stresses are maintained well within acceptable limits.

The final problem encountered during the testing was slight leaking of the blanking plugs at a band of hydrostatic pressure between approximately 2000 and 3000 psi. There appeared to be three possible causes for the leakage. First, the belleville washer installation may prevent adequate metal-to-metal high pressure sealing until a point beyond the upper limit of the low pressure seal. Second, the surface finish used by Mare Island on the blanking plugs may not have been adequate to insure sealing until high values of hull squeeze exist. Finally, it may not be possible for the solid plugs to closely follow the irregular hole deformation resulting from hull squeeze until a certain amount of squeeze is obtained. The first two are obviously closely related since better finish on the plug tapers would probably help in both instances. It should be noted that the penetrators did not leak, and that these had been given a better surface treatment by Mare Island.

To further clarify this problem, blanking plug Number 2 was tightened sufficiently to fully compress its belleville washer prior to the manned test. No leaking was observed for this plug while the others continued to leak. This seemed to eliminate the third possibility and therefore it was decided that after the tests the surface finish of the blanking plug tapers would be improved by the same lapping process that was used by Mare Island for the penetrator bodies.

WOODS HOLE INSPECTION OF BLANKING PLUGS

Following the Annapolis testing, ALVIN was returned to Woods Hole and the six blanking plugs were removed for inspection. An optical comparator was used to examine the inboard thread and the adjacent neck area on each of the units. Plug No. 28 also was inspected although it was not installed during the Annapolis test; it had been replaced by the strain-gaged penetrator in hole No. 10.

Each threaded portion was inspected and measured on the optical comparator projection screen for major diameter, crest width, root width and thread depth. All units were rotated and inspected at four locations 90 degrees apart. In a number of cases minor flaws were observed, i.e., slight rounding of thread crests, slight bending of the profile at the end of a thread where only a partial section exists, and one small step-like defect in a 3/8 in. length of one thread. All of these flaws were considered to be machining errors and of negligible importance. It was concluded that the inspected blanking plugs had suffered no damage during the Annapolis tests.

BLANKING PLUG RESURFACING AND INSTALLATION

As a result of the leakage of the blanking plugs during the Annapolis testing, it was decided that the surface treatment used on the penetrator tapers should also be used on the plugs. The female lapping tool was obtained from Mare Island Naval Shipyard and all existing blanking plugs were lapped following the procedure used for the penetrator bodies.

After completion of the lapping, the fit of the plugs in their specified locations was checked using Dykem High Spot Blue #107. These tests revealed that the fit of plug #19 in hole #14 was not as good as that of plug #28 (previously a spare) in the same hole. Therefore it was decided to replace #19 with #28 in this location.

The installation of the blanking plugs in the hull was done following the procedure outlined in TP 4924 0500-C.

INBOARD THREAD DESTRUCTIVE TEST

On August 16, 1973 a test was conducted to determine the strength and ductility of the penetrator inboard thread when mated with a standard penetrator retaining nut. A Baldwin 60,000 pound capacity tension-compression machine was used to determine the failure point of the retaining nut fully engaged on the threads of the rejected penetrator No. 12. Deflection of the threads prior to failure was determined and recorded at various force values. Following the tests, the Baldwin testing machine was calibrated and found to be accurate within 1 percent.

A mechanical dial gage (smallest division, .0001 in.) was used to measure the deflection of the nut relative to the penetrator body. During the first phase of the test the compressive load was increased to 37,050 pounds and the total deflection at that load was 0.027 in.

The compressive force was then reduced to zero and the penetrator was removed for inspection. The nut was backed off by hand but the threads were found to be deformed. The crests of the threads had been damaged on the penetrator body side, causing a stepped appearance. This occurred at only one location on the circumference, but all threads in line with this location exhibited the same damage. Loose pieces of thread were found, so that it can be concluded that the failure was not simply a compressive one.

The nut and penetrator were reassembled with the same circumferential alignment as before. The test was then continued, but complete failure occurred at 34,000 pounds, some 3,000 pounds less than the maximum load reached earlier.

In order to determine how much of the deflection measured in the experiment must be attributed to the reduction in length of the entire penetrator and test fixtures, a second set of readings were taken while applying the compressive force to the top of the penetrator rather than the nut. Two dial indicators were used and the results were as follows:

Run #1	Deflection Indicator #1	Deflection Indicator #2
0 36000 psi	.01225	.0070
36000 0 psi	.01205	.0080
Run #2		
1000 36100 psi	.01075	.0088
36100 1000 psi	.0110	.0080

These deflection values indicate that the penetrator and test set-up used in the nut destructive test deflected about .012". Some of this amount cannot be considered as helpful to the penetrator neck stress situation and therefore must be subtracted from the deflection measured during the nut test. From considerations of the geometry of the penetrator and test fixtures, it would seem reasonable that at least 1/2 of penetrator - test fixture deflection is beneficial to the neck stress problem and therefore .006" maximum should be subtracted from the nut test deflection readings.

The nut destructive test indicated that a deflection of approximately .026" was obtained before gross yielding and eventual failure occurred. Subtracting .006" leaves .020" as the deflection which can be expected in the neck area before failure.

The penetrators and blanking plugs installed with the belleville washers are free to move outward between .015" and .020" before meaningful neck stresses begin to develop. Therefore, the total outward movement before thread failure would be between .035" and .040" for those installations employing the belleville washers.

NEW INBOARD RETAINING NUTS

The March, 1973, Woods Hole inspection of the completed penetrator and blanking plug assemblies disclosed the fact that the inboard retaining nuts mated with the inboard threads with more clearance than could be considered good practice. In one case (penetrator #10) the side-to-side clearance was measured to be 0.013" which is close to the design thread height of 0.01875".

It was decided that new nuts should be manufactured as quickly as possible to correct the excessive clearance problem. Material availability and manufacturing expense dictated that 17-4 PH stainless steel be selected as the new nut material. Material documentation can be found in the purchase orders and vendor's test reports.

The design of the new nut thread was based on measurements made at Woods Hole of the male threads on all available penetrators and plugs. These measurements were used to establish the required minimum, maximum, and pitch diameters of the new nuts so that the nuts would be interchangeable, and fit all of the penetrator and plug bodies with minimum clearance.

The tolerance originally placed on the male thread pitch diameter was 0.015" which is close to the basic thread height

(0.01875") and therefore simply decreasing the nut thread pitch diameter would not necessarily eliminate excessive side-to-side clearance, and could result in interference.

The new nut threads have been specified so that the pitch diameter is as close to that of the male thread as is reasonable and the major diameter is .002" greater than the largest measured major diameter of the male threads. This results in a maximum predicted side-to-side clearance of .0087" and a minimum of .0020".

The new nuts were manufactured in accordance with W.H.O.I. Drawing No. TP-499-014-E.

CARDEROCK TESTS OF HULL II

The Carderock N.S.R.D.C. tests were planned in four phases as follows:

1. Phase I - Three static tests to pressure equivalent of 9000 ft., 13,200 ft., and 13,200 ft. with a 24 hour hold.
2. Phase II - 2000 pressure cycles between pressures equivalent to 500 ft. and 12,000 ft.
3. Phase III - 4000 pressure cycles, 500 ft. to 12,000 ft.
4. Phase IV - Creep test with holds at various high levels of pressure until collapse of sphere or cessation of test.

The following pages describe the penetrator installation procedures prior to, and the inspection results following, each of the four phases of the tests of Hull II.

Included here is a quotation from the final NSRDC report on these tests.[4] "The David W. Taylor Naval Ship Research and Development Center (DTNSRDC) has completed the test and evaluation of the second of two identical 7 ft. diameter titanium pressure hull spheres fabricated for Project Titanes. The second sphere had been fabricated to provide a "test" hull designed to undergo a series of tests to demonstrate the adequacy of the first sphere which was installed in the Navy's

ALVIN. The test and evaluation program included a static proof test identical to that conducted on the first sphere, a cyclic test and a creep test. In addition, residual stresses were determined as well as measurements on the hull release mechanism.

"Results show residual stresses approaching the material yield strength are present in the hull welds after fabrication. Maximum shell stress levels measured during the static proof test were below 70,000 psi at the pressure equivalent to the 12,000 ft. operating depth. No crack initiation or growth took place during 6000 full-reversed cycles of testing between depths of 300 ft. and 12,000 ft. (After the first 2000 cycles machined flaws were introduced in the hull in an unsuccessful attempt to initiate fatigue cracks.) The hull withstood pressures equivalent to depths from 18,000 ft. to 22,500 ft. for a period of seven days without failure demonstrating a factor of safety in excess of 1.5 times the design operating depth. Physical characteristics such as yield strengths, circularities, and shell thicknesses were measured and found to be similar to the physical characteristics measured for hull I.

"Four strain gages were located in a "dummy" electrical penetrator as two biaxial pairs. These were placed in the bore of the penetrator body near the threads. In testing the

No. 2 hull any tendency for outward motion of the penetrator would show up as a tensile strain in the threaded area which would be indicated by these gages.

"The penetrator areas were inspected carefully after the static test. Slight leakage was visible in areas around the penetrators installed with belleville washers. Very low strains were recorded by the strain gages on the penetrator threads and on the belleville washers during the test. The belleville washers were tightened to a flat position after the test and strains of 1000-1200 microinch per inch were recorded. Maximum strains recorded during the test were less than 1/4 this amount indicating only a small outward force was acting on the penetrator during the test. The force required to flatten a washer is also considerably less than the force required to damage the penetrator threads. No damage was visible in any of the penetrator threads after the test."

Carderock Test Program for Hull II

February 7, 1974

I. Measurement of residual stresses in weld areas.

II. Baseline non-destructive testing and inspection of hull.

III. Pressure Cycles - Phase I

  A. Static test to 9000 ft. in oil at 32°-40°F

  B. Static test to 13200 ft. in oil at 32°-40°F

  C. Static test to 13200 ft. in oil at 32°-40°F
  24 hr. hold at 13200 ft.

IV. Non-destructive testing and inspection (2-3 weeks minimum)

V. Pressure Cycles - Phase II

  2000 cycles between 500 ft. and 12,000 ft. Saltwater internally and externally. No strain gages. ALVIN plugs will replace caps (2), feedthrough (1) and strain gaged penetrator (1). Method of installation will be selected based on results of Phase I.

VI. Non-destructive testing and inspection. Machine elliptical flaws into weld area (4 weeks).

VII. Pressure Cycles - Phase III

  4000 cycles between 500 ft. and 12000 ft. Saltwater internally and externally.

VIII. Non-destructive testing and inspection.

IX. Reinstrument hull for creep test. Also install instrument to determine force required to operate hull release mechanism.

X. First run of creep test to 13,200 ft. in oil with hold for one or more hours.

XI. Oral report and decision on whether to go to 18,000 ft. or collapse.

XII. Final run. Continuous creep test to 18,000 ft. or collapse. Hold for 16 or more hours at various pressures.

CARDEROCK TEST, HULL II

Penetrator Installation For Initial Pressure Test (Phase I - 9000', 13200', 13200' with 24 hour hold)

Hole No.	Penetrator No.	Installation Procedure
1	7	Belleville (.030" Clearance)
2	21	"
3	20	"
4	18	"
5	10	"
6	16	"
7	22	Flattened Belleville (125 ft.-lbs.)
8	30	Belleville (.015" Clearance)
9	Strain Gaged (19E Nut)	125 ft.-lbs.
10	9	MINSY
11	DOT	Not installed by W.H.O.I.
12	DOT	Not installed by W.H.O.I.
13	D. G. O'Brien	Not installed by W.H.O.I.
14	14	MINSY
15	4	MINSY
16	Capped	MINSY
17	Capped	MINSY
18	Electrical Feed-Through	MINSY
19	26	Wiped, 125 ft.-lbs.
20	32	MINSY
21	31	MINSY
22	27	Wiped, 125 ft.-lbs.
23	13	Wiped, 125 ft.-lbs.

Belleville Installation Procedure

Penetrators were installed per installation procedure TP4924-0500-C except that inboard nuts were tightened only enough to give the clearances noted above. Clearances were checked with feeler gages.

MINSY Installation Procedure

Penetrators were installed in accordance with installation procedure TP4924-0500-A.

Wiped Installation Procedure

Penetrators were installed with a thin coat of M-77 applied to the tapered section of the penetrator body and then burnished with a soft cloth or paper material. The correct application was achieved when a soft cloth lightly wiped over the tapered section did not pick up traces of the M-77.

The hull penetration hole did not receive an application of M-77.

Belleville washers were used but were flattened by the application of 125 ft.-lbs. to the inboard retaining nut. The outboard retaining nut was tightened to 40 ft.-lbs.

This installation was in agreement with procedure TP4924-0500-D with the exception of the flattened belleville washers.

CARDEROCK TEST, HULL II

Inspection - following Phase I (cycles to 9,000, 13,200 and 13,200 with 24 hour hold) - February 25, 1974

Initial Inspection

No damage apparent. Hull maintained 25 inches of water vacuum over the weekend. Approximately 1 pint of oil had leaked into the hull and was puddled around the release mechanism. Oil streaks were noticeable as follows:

Hole No.	
1	very small amount
2	" " "
3	" " "
4	" " "
5	" " "
15	moderate amount
18	moderate amount

Testing before removal

1. Precision potentiometer - Hole #8

   The potentiometer was moved inward and outward and readings were obtained on the readout in the control room. The mounting bracket was flimsy so that repeatable data could not have been expected but it appears that some readings would have been obtained if the penetrator had moved.

2. Strain gaged bellevilles

   The bellevilles installed on the plugs in holes 1 through 6 had a clearance of .030+ as when they were installed prior to the test.

Initial strain gage readings were taken after which the nuts on these penetrators were loosened 1/4 turn and strain gage readings taken again (10% on printout). The nuts were then tightened approximately 1/4 turn which returned them to close to their initial condition and readings were taken (20% on printout). Following this, the nuts were tightened in 1/8 turn increments until the bellevilles were flat, or a torque in excess of 100 foot pounds was required to continue tightening. Readings were taken at each increment. The results show that approximately 1000 micro-inches per inch of compression would have been measured if the bellevilles had flattened.

3. The belleville on the plug in hole No. 8 had a clearance of .015" indicating no change from the initial installation.

Removal

The following torques were required to loosen the retaining nuts:

Hole No.	Torque (ft.-lbs.)	Installation Type
1	35	030" Belleville
2	40	" "
3	40	" "
4	35	" "
5	40	" "
6	45	" "
7	120	Wiped, 125 ft.-lbs.
8	60	.015 Belleville
9	Not removed	
10	65	MINSY
14	100 125	MINSY

Hole No.	Torque (ft.-lbs)	Installation Type
15	50	MINSY
19	125	Wiped, 125 ft.-lbs.
20	75	MINSY
21	90	MINSY
22	100	Wiped, 125 ft.-lbs.
23	125	Wiped, 125 ft.-lbs.

Final Inspection of Removed Plugs

Hole No.	Penetrator No.	Installation	Remarks
1	7	.030" Belleville	Leaked
2	21	.030" Belleville	Leaked
3	20	.030" Belleville	Leaked
4	18	.030" Belleville	Leaked
5	10	.030" Belleville	Leaked
6	16	.030" Belleville	Leaked
7	22	Wiped, 125 ft.-lbs.	No leakage
8	30	.015" Belleville	Slight leakage
9	Strain Gaged	Not Removed	
10	9	MINSY	No leakage
14	14	MINSY	No leakage
15	4	MINSY	Leaked
19	26	Wiped, 125 ft.-lbs.	No leakage
20	32	MINSY	No leakage
21	31	MINSY	Slight leakage
22	27	Wiped, 125 ft.-lbs.	Slight leakage
23	13	Wiped, 125 ft.-lbs.	No leakage

Those that leaked had oil covering the entire tapered section. The ones marked "slight leakage" had oil on the tapers but it did not extend the entire length and it might possibly have run in as the penetrator was removed.

Thread Inspection

No damage to the threads was discovered on any of the penetrators over the length of nut engagement. Penetrator number 7 had a damaged thread close to the neck area and it was determined to have been caused by the contour washer. It was found that if the contour washer is not positioned correctly on the hull insert, subsequent tightening of the retaining nut will turn the washer in such a manner as to damage the first thread of the penetrator in some cases. Corresponding damage was noted on the contour washer.

Taper Markings

In general, those penetrators which leaked had circumferential marks around their tapered sections resembling tool marks. It appears that this marking may be caused by movement of the penetrators in the holes. The marks are barely detectable by running a finger up and down the tapered section.

CARDEROCK TEST, HULL II

Penetrator Installation for Cyclic Test, Phase II (2000 cycles)

Hole No.	Penetrator No.	Installation Procedure
1	7	ALVIN
2	21	"
3	20	"
4	18	"
5	10	"
6	16	"
7	22	"
8	30	Belleville
9	6	"
10	9	"
11	DOT	
12	DOT	
13	D. G. O'Brien	
14	14	M-77
15	4	"
16	12	"
17	29	"
18	Feed Through	
19	26	ALVIN
20	32	Oakite R6
21	31	"
22	27	"
23	13	"

ALVIN Installation Procedure

Penetrators were installed per installation procedure TP4924-0500-E.

Belleville Installation Procedure

Tapers had a wiped application of M-77. No M-77 was applied to the insert penetration holes. Inboard retaining nuts were tightened sufficiently to result in a belleville clearance of .015". Outboard retaining nuts were torqued to 50 ft.-lbs.

M-77 Installation Procedure

Penetrators were installed in accordance with installation procedure TP4924-0500-E except that an excess of M-77 was applied to the insert penetration holes and the penetrator tapers. The amount applied was not sufficient to result in penetrator rotation while applying torque to the inboard nuts.

Oakite R6 Installation Procedure

Penetrators were installed in accordance with installation procedure TP4924-0500-E except that the tapered sections were cleaned with Oakite R6. The insert penetration holes were not cleaned with the Oakite cleaning agent. In all cases the hull insert penetration holes were cleaned with repeated applications of Freon cleaning agent.

CARDEROCK TEST, HULL II

Inspection After Phase II (1st 2000 cycles) - April 22, 1974

Belleville Installation

Penetrator No.	Remarks
30	1st thread damaged. Slight circumferential marks present.
6*	1st thread damaged. Slight circumferential marks and rub marks present.
9	1st thread damaged. Slight circumferential marking.

All nuts run free and nut threads look perfect.
Contour washers show signs of yielding (denting) in area of contact with belleville.
Bellevilles are badly rusted and pitted.
Contour washers have rub marks galling at thinnest section in contact with hull.

ALVIN Installation TP4924-0500-E

Penetrator No.	Remarks
7	1st thread damaged. Circumferential marking present.
21	Slight damage to 1st thread. Circumferential marking on one side, most severe at small end over 60° of circumference.
20	1st thread damaged. Circumferential markings severe in one area.
18*	1st thread damaged. Circumferential markings severe on one side of taper.

Penetrator No.	Remarks
10	1st thread looks good. Circumferential markings heavy on one side.
16	1st thread damaged slightly. Circumferential marking heavy all around.
22*	1st thread looks good. Slight circumferential marking.
26	1st thread good. Circumferential markings severe through 60°. All threads ran smoothly. It is obvious that some M-77 was washed into the taper area by the internal pressure. It appears that damage was greater where this happened.

M-77 Excess

Penetrator No.	Remarks
14	Removed for pressure piping feed through.
4*	1st thread looks good. Taper badly marked (galled).
12*	1st thread damaged slightly. Circumferential marks severe.
29	1st thread damaged. Circumferential marking pronounced.

Threads run free and look good.

Oakite Installation

Penetrator No.	Remarks
32	1st thread damaged. Circumferential marking slight.

Penetrator No.	Remarks
13	1st thread good. Circumferential marks minor over 30° for 3/4 of taper.
27	1st thread good. Slight circumferential marking most pronounced over 30° for 1/4 of taper at small end.
31*	1st thread damaged at 2 locations. Circumferential marking pronounced over 60° for 1/3 of taper starting at small end.

All threads run free and look good.

General Remarks and Comparison

The most severe rub marks occur at the small end of the taper at a point on the circumference corresponding to the shortest length of taper engagement (location on circumference farthest from viewport, 180° out from most severe contour washer marking).

The hull is marked in the manner similar to the penetrators and contour washers.

The contour washer markings are as severe on the belleville installations as on the other installation methods. The DOT penetrator contour washer was not marked.

The belleville, ALVIN and Oakite circumferential markings are all about the same in severity. The M-77 markings are more pronounced.

There is no sign of a difference in the threads. All tapers were wet most likely due to leakage from inside outward. It should be emphasized that the terms "severe", "heavy", or "pronounced", used to describe surface markings on the penetrator and plug bodies, are relative ones, and that all affected surfaces were easily returned to their original condition by a light lapping treatment.

*Returned to W.H.O.I. for detailed inspection.

CARDEROCK TEST, HULL II

Penetrator Installation for Cyclic Test, Phase III (4000 cycles between 500 and 12,000 ft.) - May 13, 1974

Hole No.	Penetrator No.	Condition Prior to Installation
1	7	(P) Circumferential marking pronounced
2	21	(G) Some marking at small end
3	20	(VG)
4	18	(VG)
5	10	(VG)
6	16	(VG)
7	22	(G) Very slight marking at small end
8	30	(G) Light circumferential marking
9	6	(F) Circumferential marking. Galling just starting at small end.
12	9	(VG) Light circumferential marking

NOTE - DOT penetrator moved from hole 12 to hole 10.

Hole No.	Penetrator No.	Condition Prior to Installation
14	4	(F) Galling at small end. Some circumferential marking.
16	12	(P) Heavy galling at small end. Light galling at large end.
17	29	(F) Galling at small end. Very little circumferential marking.
19	26	(VG) Light marks just appearing at small end.
20	32	(G) Circumferential marking at small end.
23	13	(VG) Light marking just appearing at small end.

Installation Procedure

All penetrators and holes were lapped and cleaned prior to installation. The lapping was intended to remove high spots which might have existed as the result of previous testing and therefore it was not done sufficiently to return the surfaces to original condition.

The penetrators in the forward, starboard and bottom inserts were installed in accordance with TP4924-0500-F, April 25, 1974. The penetrators in the port insert, No. 30, 6 and 9, were installed with a finger wiped application of lubriplate on the tapers. The inboard and outboard threads were lubricated with M-77.

CARDEROCK TEST, HULL II

Inspection After Phase III (2000-6000 cycles)- May 29, 1974

Lubriplate Installation

Penetrator Number	Torque Required To Remove Inboard Nut	Remarks
6	40 ft.-lbs.	Galling and circumferential marking evident. Threads excellent
30	40	Galling and circumferential marking. Threads excellent
9	Hand tight	Rubber gasket destroyed due to oversized penetration hole. Taper good, threads excellent

All of the above installations showed signs of M-77 in the tapered areas probably due to wash-in from the inboard threads.

ALVIN Installation TP4924-0500-F

Penetrator Number	Torque Required To Remove Inboard Nut	Remarks
27	90 ft.-lbs.	Taper generally good. Darkened area at small end just beginning to gall. Threads good
13	35	Taper darkened and beginning to gall. Threads good
26	60	Taper good. Darkened area at small end. Threads good
32	75	Taper and threads look good
31	50	Taper and threads look good

Penetrator Number	Torque Required To Remove Inboard Nut	Remarks
4	40	Taper good. Darkened area at small end. Threads good
12	25	Taper scarred from previous tests. Threads good
29	25	Taper fair. Darkened area and galling at small end. Threads good
7	50	Taper has large area showing light galling. Circumferential marking present. Threads good
22	50	Darkened area and slight marking. Threads good
16	25	Taper very good. Threads good
10	25	Taper good. Slight darkened area and light circumferential marking. Threads good
18	50	Taper fair. Dark spot present and light pitting. Threads good
20	50	Taper good. Dark spot present. Threads good
21	25	Taper fair. Circumferential marking present and dark spot at small end. Threads good

Generally, all penetrators except Nos. 31 and 32 showed signs of M-77 wash-in from the inboard side, probably occurring when the hull was filled with water at the start of the test. This wash-in may be responsible for the darkened areas and galling symptoms usually found at the small end of the taper. It is possible that the galling symptoms are actually the result of a chemical action between the M-77 mixed with water and the titanium.

CARDEROCK TEST, HULL II

Penetrator Installation Procedure For Test Phase IV (Creep Test and Final Pressure Test) - May 29, 1974

Hole No.	Penetrator No.	Installation Procedure
1	7	ALVIN TP 4924-0500-F
2	21	"
3	20	"
4	18	"
5	10	"
6	16	"
7	22	"
8	30	Lubriplate
9	6	"
12	9	"
14	4	ALVIN TP 4924-0500-F
16	12	"
17	29	"
19	26	Lubriplate
20	32	"
21	27	"
22	31	"
23	13	"

The Lubriplate installations were done in accordance with TP 4924-0500-F except that a light coat of Lubriplate was used on the taper, inboard threads, outboard threads and outboard gasket. The outboard retaining nut was tightened to 50 ft.-lbs. In Test Phase III there were numerous instances of discoloration and slight surface damage to penetrators which had Molykote M-77 applied to the tapered surfaces (Installation Procedure TP 4924-0500-F). Relatively good performance was observed in the cases where Lubriplate grease was substituted for the Molykote M-77. The Lubriplate grease is known to be an inert substance in the presence of seawater, but some doubt existed about the chemical inertness of the Molykote. Accordingly, the installation procedure was revised again to incorporate the Lubriplate substitution. Procedure TP 4924-0500-G is the latest designation, and is the installation procedure currently in use.

CARDEROCK TEST, HULL II

Penetrator Inspection Following Final Pressure Testing (Phase IV) - January 1, 1976

As of this date, the penetrators have not been inspected by the ALVIN group following Phase IV. Verbal communications indicate that no penetrator failures occurred during this test which reached a maximum simulated depth of 22,500 feet.

FRICTION TESTS

Laboratory tests were continued during 1974 in an effort to ascertain that the tapered penetrator bodies would not tend to be squeezed and forced to move outward due to the relatively high hull compressive stresses at the 12,000 ft. depth. While the outward force on the penetrator can be calculated, the results of such calculations depend on the value of the coefficient of friction for the mating surfaces. In most friction-force calculations a handbook value of the friction coefficient is accurate enough; however in this case where both mating parts are of titanium, and some form of anti-galling compound should be used, a more exact determination of the frictional behavior was considered necessary.

Wedge-shaped titanium blocks were used to model the hull-squeeze situation. A strain-gaged bolt prevented outward motion of the central block but permitted direct measurement of the outward force on the block as the assembly was loaded in compression. About three dozen separate tests were conducted, some of 24-hours duration. Tests were run with the mating surfaces a) clean and dry, b) treated with the anti-galling compound Molykote M77 according to manufacturer's instructions, and c) treated with an excessive amount of the

Molykote M77. Tests indicated that with the excess amount of anti-galling compound the surfaces essentially were prevented from coming together and the resulting frictional resistance was very low. However with the compound correctly applied, the coefficient of friction averaged about 0.27, and for the surfaces clean and dry, the coefficient had approximately this same value. Earlier, calculations had indicated that a value of coefficient of friction of 0.13 or greater would be sufficient to prevent any tendency for the tapered penetrators to be forced outward by the squeezing action of the hull (see Fig. 3).

AT-SEA TESTING

Submersible operations for the year 1974 began on January 4th with Dive No. 487. Despite the fact that all indications up to that time were that no serious problem existed with the electrical penetrators, the high priority given to personnel and vehicle safety dictated that further testing be carried out. Belleville washers were installed on all penetrators (Nos. 1 through 23). These conically shaped spring washers are designed to deflect when loaded axially, and to become completely flattened at a specified value of load. Thus, the penetrators could be firmly seated with a preload resulting from a small initial tightening of the retaining nut. At the same time the penetrator would be allowed some outward axial motion at depth, without damage, since additional deflection of the belleville washer would be possible. Mechanical dial gages were mounted to the inside surface of the hull and adjusted to sense any motion of penetrator bodies Nos. 3, 7, 9, 11, 15, 16, 17. A feeler gage of .005 in. thickness was used to determine the extent of belleville washer flattening (if any) for all 23 penetrators. This testing was done at sea during actual working dives in the dive series Nos. 487 through 508. With one exception, that of a 40 ft. deep pilot qualification dive, all dives were deep enough to provide typical operational environment for penetrator evaluation. Throughout this period close contact was maintained between the Head of the Deep Submergence Engineering and Operations Section, the Institution Staff Engineer, the Provost and the Director; and detailed reports were forwarded by the DSE&O Section Head describing penetrator behavior during the dives. In turn the Director, via the Provost, authorized increasingly deep operation for ALVIN subject to conditions relating to dial gage readings, feeler gage measurements, and visual inspections of all penetrators. In this series of dives there was virtually 100 percent monitoring of penetrator performance during submerged operation. All dial gage and feeler gage readings and all visual inspection results were such as to warrant continued diving to greater depths in accordance with the procedures specified by the Director's office. During dive No. 508 on March 5, 1974, a depth of 10,000 ft. (2960 m) was reached with no significant outward motion of penetrators and no evidence of excessive stresses in the penetrator bodies or retaining nuts. Continued successful diving experience during the 1974 FAMOUS expedition led to authorization by the Director, in August of that year, for a 12,000 ft. operating depth for ALVIN. The first 12,000 ft. ocean dive was made on May 19, 1975. Details of the testing procedures are outlined in the memoranda exchanged by Dr. Fye, Dr. Maxwell, and Mr. Shumaker (see Appendix D).

CONCLUSIONS

The results of the friction tests, the at-sea tests, and the Carderock tests of hull No. 2, all point to a resolution of the titanium penetrator question that may be summarized as follows:

a. <u>At-sea tests</u> All dial gage readings and all feeler gage readings made for the belleville washer-equipped penetrators during working dives Nos. 487 through 508 indicated that outward axial penetrator motion was very small or non-existent. All the penetrators passed the required feeler gage test (no less than 0.005 in. of space to remain at any depth); and subsequent visual inspection of all penetrator threads and all retaining nuts confirmed that no excessive stresses or deformations were present at any time during these dives.

b. <u>Friction tests</u> Laboratory tests were performed in which wedge-shaped titanium blocks were used to model the hull-squeeze situation. A strain-gaged bolt held the central block in place but allowed the outward component of force on that block to be measured. Test results indicated that when the mating surfaces were clean and dry, or were treated correctly with the anti-galling compound, the coefficient of friction averaged about 0.27. This is approximately twice the calculated minimum value needed to prevent any outward motion of the electrical penetrator.

c. <u>Carderock Test of Hull No. 2</u> During this test very low strains were recorded by the strain gages installed by W.H.O.I. in the bore of a penetrator near the threads. Also, a number of penetrators were installed with belleville washers and these washers were equipped with strain gages. After the test the belleville washers were tightened to the flat position and strains of 1000-1200 micro-inch per inch were recorded. The maximum strains observed during the test were less than one-quarter this amount. The force required to flatten a belleville washer is considerably less than the force required to damage penetrator threads. No damage was visible in any of the penetrator threads or retaining nuts after the test. In the final phase of this Carderock test, hull No. 2 was pressurized to the equivalent of 22,500 ft. with 72 hour holds at

18,000 ft. and 19,100 ft., and a 10 hour hold at 22,500 ft. The test was terminated after the 10 hour hold at 22,500 ft. This latter figure is 3500 ft. greater than the lower bound collapse depth predicted by NSRDC personnel using their method based on average thickness and local radius at a flat spot over a critical arc length. They have emphasized in their final report[4] that there was no indication of damage to the penetrator threads at any time during or after the tests.

ACKNOWLEDGEMENTS

Members of the Deep Submergence Engineering and Operations Section of the Ocean Engineering Department are indebted to Edwin A. Link and the Harbor Branch Foundation at Fort Pierce, Florida, for their support of portions of the work described in this report.

The work of designing, manufacturing, and testing of the penetrators was supported primarily by the Deep Ocean Technology TITANES Program of the U. S. Navy.

We also thank Robert Hamlin of Oceanic Industries, Inc. for his careful preparation of the friction test models, and Margaret Stern for her patient work in typing a difficult manuscript.

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APPENDIX A - Figures

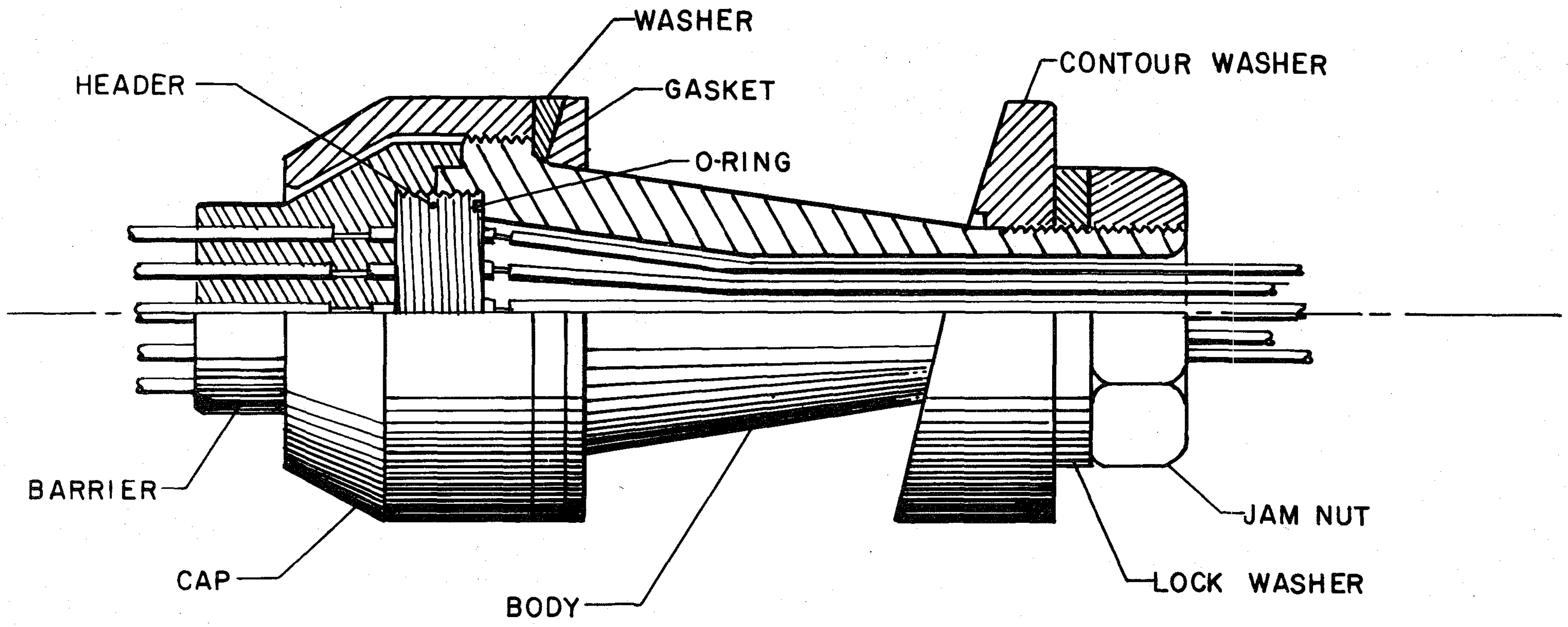

Fig. 1 ALVIN Steel Hull Electrical Penetrator

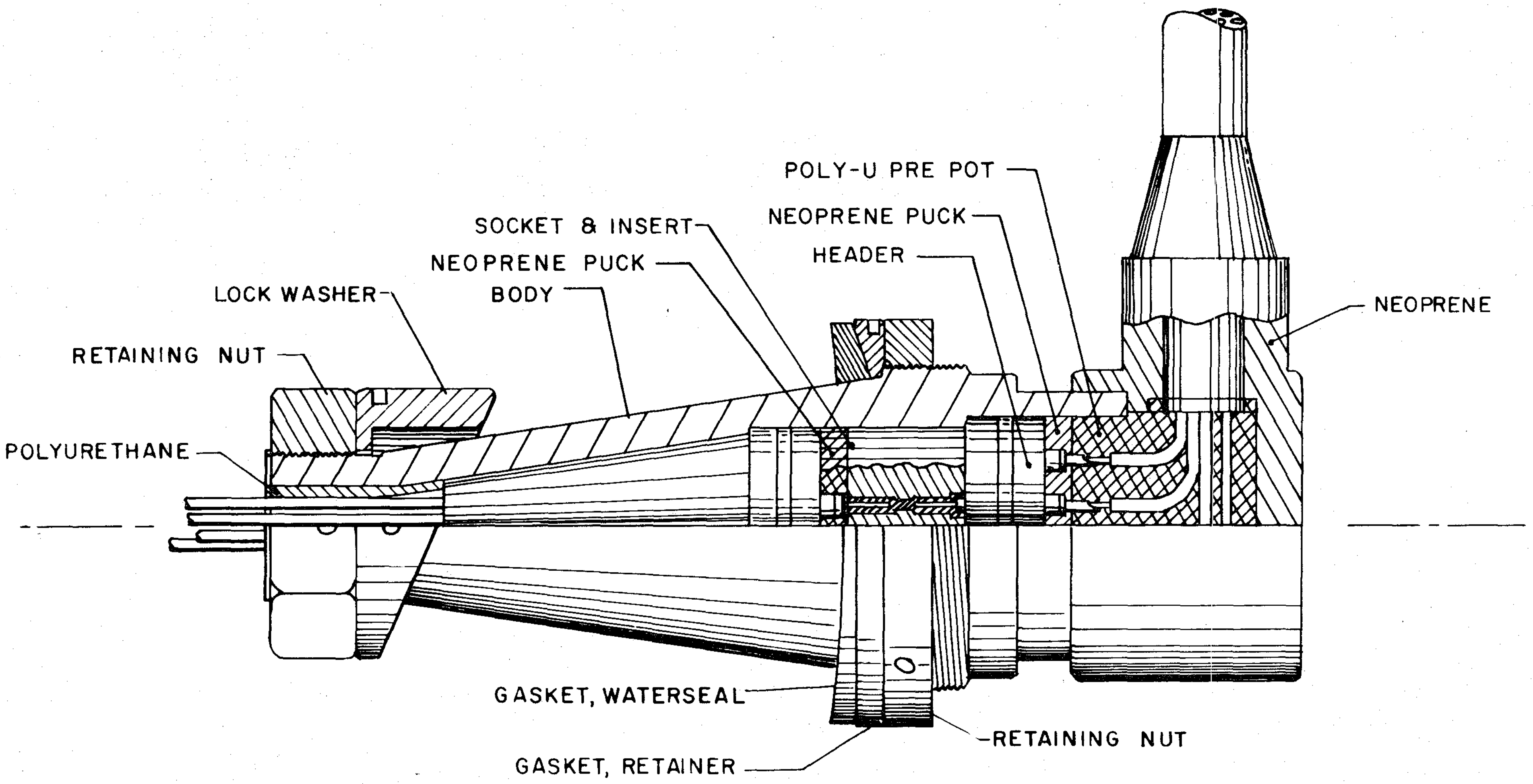

Fig. 2 ALVIN Titanium Hull Electrical Penetrator

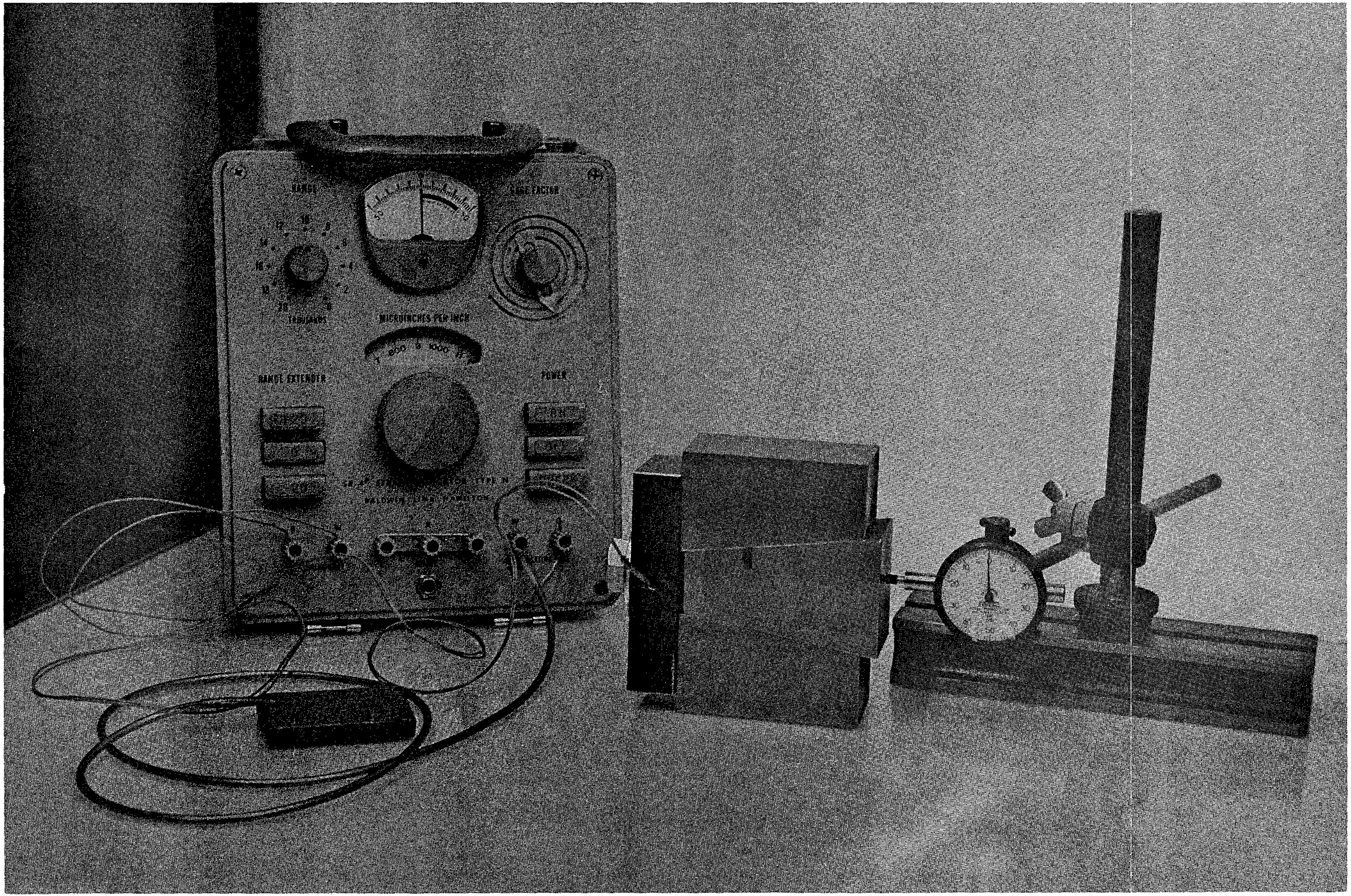

Fig. 3 Friction Test Apparatus

APPENDIX B - Penetrator Assembly and Test Procedures

MANUFACTURING PROCEDURE

D. G. O'BRIEN, INC.

MP. -EC-127
SHEET 1 OF 4
REV. N/C

TITLE ASSEMBLY PROCEDURE - TITANES EHP

DESCRIPTION: (* INDICATES INSPECTION REQUIRED) INSP. REQ'D

1.0 Inboard Header Assembly

1. Assemble pin contacts per drawing TP-420-003.
2. Insert pin contact assembly into header per TP-440-054.
3. Sandblast face of header and pins where primer must adhere. Protect the engaging portion of pins with shrink tubing.
4. Prime sandblasted surface with PRC420 per Mfg's instructions.
5. PRC 1547 mold per MP-RM-109 as required by drawing TP-440-055 using tool No. TP-T440-055.
6. Trim mold.
7. Etch teflon insulated conductors in area where epoxy will be potted. See MP-RM-178. The etched area shall be 4-1/4 inches long.
8. Wire header per print, TP-440-058. Follow MP-SP-102 for soldering instruction.
9. Pot back end of header with epoxy using tool No. TP-T440-104 and following instructions provided in MP-RM-107.

ORIG.	DWN.	APP'D	DATE	USAGE	TP4924 0502 REVISION	REV.NO.	APP'D	DA

MANUFACTURING PROCEDURE

D. G. O'BRIEN, INC.

MP. -EC-127
SHEET 2 OF 4
REV. N/C

TITLE ASSEMBLY PROCEDURE - TITANES EHP

DESCRIPTION: (* INDICATES INSPECTION REQUIRED) INSP. REQ'D

2.0 Outboard Header Assembly

1. Assemble pin contacts per drawing TP-420-004.
2. Insert pin contact assembly into header per TP-440-056.
3. Sandblast face of header and pins where primer must adhere. Protect the engaging end of pins with shrink tubing.
4. Prime sandblasted surface with PRC420 per Mfg's instructions.
5. PRC 1547 mold per MP-RM-109 as required by drawing TP-440-057 using tool No. TP-T440-059.
6. Trim mold.
7. Etch teflon insulated conductors in area where polyurethane will be molded. The etched area shall be 4-5/8 long.
8. Buff neoprene on header before wiring.
9. Wire header per print, TP-440-059. Each conductor requires a service loop. Following soldering instructions in MP-SP-102.

ORIG.	DWN.	APP'D	DATE	USAGE	TP4924 0502	REVISION	REV.NO.	APP'D	DA

MANUFACTURING PROCEDURE

D. G. O'BRIEN, INC.

MP. -EC-127
SHEET 3 OF 4
REV. N/C

TITLE ASSEMBLY PROCEDURE - TITANES EHP

DESCRIPTION: (* INDICATES INSPECTION REQUIRED)

INSP. REQ'D

3.0 Penetrator Assembly

3.1 Sandblast where neoprene and polyurethane bonding is mandatory. Protect all other surfaces.

3.2 Assemble inboard header, socket/insert assembly and outboard header and test as an assembly on the bench. Tests are as follows:

1. Examination of Product
2. Contact Resistance
3. Withstanding Voltage
4. Insulation Resistance
5. Examination of Product

3.3 Remove inboard header assembly TP-440-104 and install into the body TP-469-004.

3.4 Run an insulation resistance, continuity and hydrostatic pressure test on this assembly.

3.5 Disassemble and re-assemble with socket/insert assembly and outboard header. Install this assembly in the body. Arrange the cable entry opposite to Pin A on the header.

3.6 Pot this end with PRC 1547 to top of neck and cure. See MP-RM-109 for potting instructions.

3.7 Prime inside of hull penetration at outboard end with PRC 420.

3.8 Roughen cable jacket and prime cable jacket and neoprene on header with PRC 1523M. Jacket should be primed for approximately 1¼ inch.

ORIG.	DWN.	APP'D	DATE	USAGE	TP4924 0502	REVISION	REV.NO.	APP'D	DA

MANUFACTURING PROCEDURE

D. G. O'BRIEN, INC.

MP. -EC-127
SHEET 4 OF 4
REV. N/C

TITLE ASSEMBLY PROCEDURE - TITANES EHP

DESCRIPTION: (* INDICATES INSPECTION REQUIRED) INSP. REQ'D

3.9 Using mold 909-174, prepot with PRC 1547.

3.10 Run a insulation resistance and continuity check.

3.11 Prime EHP body with Chemlock 205 and 220 in area where neoprene will be bonded.

3.12 Roughen poly u and prime with Chemlock 220.

3.13 Roughen and prime cable jacket with Chemlock 231.

3.14 Neoprene mold following instructions MP-RM-128 and using mold No. TP-T4924-0502.

3.15 Trim and send completed unit to Quality Assurance for final test. Perform the following tests in accordance with QA-TM-171.

1. Continuity
2. Insulation resistance
3. Hydrostatic
4. Withstanding voltage
5. Continuity
6. Insulation resistance
7. Examination of product
8. Dye penetrant
9. Dimensional check

ORIG.	DWN.	APP'D	DATE	USAGE	TP4924 0502 REVISION Formerly sheets 2 and 3	REV.NO.	APP'D	DA

TP4924-0502
Sheet 4 of 5

Penetrator Testing Procedures [illegible].

The following test procedures are defined and are to be followed as called for in the test sequences outlined:

Test Procedure #1. Examination of Product

The product will conform to the applicable drawing, with regard to dimensions, materials and construction. Loose contacts, poor molding fabrication, loose materials, defective bonding, damaged or improperly assembled contacts, physical and electrical defects in the pin seals, poor finish, galling of mated parts, nicks or burrs of metal parts and post molding warpage will be considered adequate basis for rejection of items.

Test Procedure #2. Contact Resistance

The contact resistance of each set of contacts in the assembly will be measured as follows:

Place the inner header, double socket assembly, and outer header in a suitable jig, without wires being attached. Using a test current of 13 amps and measure a maximum potential drop of 110 millivolts across each set of contacts. Record the results.

Test Procedure #3. Continuity.

Each #18 AWG conductor and shield of the shielded pairs will be tested for continuity with a test current of 7.5 amperes. Each #16 AWG single conductor will be tested for continuity with a test current of 13 amperes. Record the voltage drop through each conductor. [illegible]

Test Procedure #4. Insulation Resistance

The insulation resistance shall be measured using a standard 500 VDC ± 10% meggar between each conductor to each other conductor and between each conductor and the body of the penetrator. The minimum acceptable reading will be 500 megohms. Record the results.

Test Procedure #5. Handling and Cable Flexing

A 100 cycle, hand held bending test will be performed. There shall be no evidence of damage to the molded parts or cable jacket or any evidence of electrical defects detrimental to the operation of the penetrator. Bending shall be 90° in each direction.

Test Procedure #6. Hydrostatic - Static

a.
Prior to hydrostatic testing, of the "complete assembly", install on the high pressure end of the cable, a vessel (item 6 of TP 4924-0502) filled with ~~Hoover Electric Company submersible fluid Number 2.~~ BRAY Oil Co 3M-626-2,

b.
The test fluid will be tap water. Record the temperature at the start of the test. the "inner header installed and wired" assemblies per TP460-005 will be tested without outboard accessory seals. The "complete assembly" will be tested with all normal attaching accessories.

c.
Pressurize from 0 psig to 10,000 psig, hold 10 minutes at 10,000 psig and reduce the pressure to 0 psig and hold for 5 minutes. Repeat for 9 cycles. Record all times and pressures.

d.
Pressurize from 0 psig to 10,000 psig. Hold for 10 hours at 10,000 psig on the pre-production units only. Hold for one hour at 10,000 psig on the production units. Record time and pressure.

e.
At the end of step (d.), while still at 10,000 psig, conduct an insulation resistance test per test procedure #4. After completion of test procedure #4, return to 0 psig. Record all data.

Test Procedure #7. - Thermal Shock

The penetrator assembly shall be subjected to five cycles of the following:

	Temperature °F	Time
(a)	-65°F	1/2 hr/lb.
(b)	+68° ± 5°	----------
(c)	+165°F	1/2 hr./lb.
(d)	+68° ± 5°	----------

Record times and temperatures.

WOODS HOLE OCEANOGRAPHIC INSTITUTION
WOODS HOLE, MASS. 02543
PROJ. TITANES BY D Hosom
SHEET 4 OF 5 DATE 8/12/71

TITLE PENETRATOR
TP 4924 0502

TP4924-0502
Sheet 5 of 5

Penetrator Testing Procedures [illegible].

Test Procedure #8 - Water Soak

Soak the inboard end of the complete assembly in tap water at a pressure of at least 1/2 psig, for a period of 8 hours. Then conduct an Insulation Resistance-Test Procedure #4. Record all data.

Test Procedure #9 - Hydrostatic - Cycling

The following will be the minimum acceptable test specified:

a. Test fluid to be tap water. Temperature noted. Install vessel per Test 6 (a)

b. All lead wires will be connected in series. A 500 VDC megger will be connected between the leads and the body. The minimum acceptable megger reading will be 20 megohms or greater. Monitor insulation resistance during steps c, d and e.

c. 0-10,000 PSIG, hold 8 minutes 10,000 PSIG, repeat for 99 cycles. Hold 4 minutes at zero pressure between each cycle.

d. 0-10,000 PSIG, hold 8 hours, one cycle.

e. 0 PSIG, hold 4 hours, one cycle.

f. Conduct insulation resistance per Test Procedure #4

g. Connect all similar wires in series. Apply 7.5 amps through the #18 AWG wires and 13 amps through the #16 AWG wires thru all conductors. Monitor voltage drop for each series wired circuit during steps h, i and j.

h. 0-10,000 PSIG, hold 10 minutes at 10,000 PSIG, repeat 99 cycles. Hold 4 minutes at zero pressure between each cycle.

i. 0-10,000 PSIG, hold 8 hours, one cycle.

j. 0 PSIG, hold 4 hours, one cycle.

k. Conduct insulation resistance per Test Procedure #4.

l. Repeat steps (c) thru (k) as appropriate to provide 500 cycles on each unit.

Test Procedure #10 - Withstand Voltage

Using a 2000 volt d. c. source, test between each conductor and each other conductor and between each conductor and the penetrator body (if part of assembly) for insulation breakdown.

Test Procedure #11 - Dye Penetrant/Dimension Check

The exterior of the penetrator body will be suitably cleaned and have a dye penetrant properly applied, removed and a proper developer applied, according to the directions supplied by the manufacture of the product. There shall be no linear indications on the exterior of the penetrator body. After suitable cleaning of the penetrator following the dye penetrant test, the dimensions of the penetrator body will be measured to determine that all dimensions are within the tolerances specified by the drawing.

Test Procedure #12 - Destructive Test - (Pre production only)

The preproduction unit will be subjected to this test. The minimum test specified will be to simulate a structural failure of the outboard header as follows:

a. Remove a minimum amount of outboard potting to permit removal of the outboard header. Remove the outboard header and cable assembly.

b. With the inner header exposed, conduct the tests that follow.

c. Hydrostatic pressure-static, per Test Procedure #6.

d. Continuity, Test Procedure #3.

e. Insulation resistance, Test Procedure #4.

f. Examination of product, Test Procedure #1.

WOODS HOLE OCEANOGRAPHIC INSTITUTION
WOODS HOLE, MASS. 02543
PROJ. TITANES BY D.
SHEET 5 OF 5 DATE 8/12/71
TITLE PENETRATOR
TP 4924 0502

APPENDIX C - Penetrator Installation Procedures

TP 4924-0500-A

Penetrator Installation Procedure

1. Prior to installation, the penetrator body, hardware, and hole surfaces will be carefully inspected for physical damage, and cleanliness. All surfaces will be cleaned with a mild detergent and water and then dried completely. Apply a very thin coat of SPS Lubricant LF 31-35-8 to all threaded areas and let dry. Record serial numbers, hole assignments and installation dates.

2. The outboard retaining nut (TP 499-010), outboard gasket retainer (TP 499-011), and the outboard waterseal gasket (TP 499-012) will be installed on the penetrator body per the assembly drawing (TP 4924-0500), sheet 1 of 3. The outboard retaining nut will be backed off completely clear of the outboard gasket retainer.

3. Insert the penetrator in the hull penetration from the outside after applying a very thin coat of SPS LF 31-35-8. Install the inboard washer (contoured) (TP 499-013). Install the inboard retaining nut (TP 499-014). Particular care must be taken that the inboard washer seats properly on the hull. The outboard waterseal gasket should be properly aligned to match the contour of the hull with the thin section pointed toward the viewport. The body of the penetrator must be held from the outside by a spanner wrench to ensure that it does not rotate while the inboard nut is tightened. The inboard retaining nut will be torqued down to 90 foot pounds, ±2 foot pounds.

4. After a 12 hour waiting period, the inboard retaining nut will be torqued down to 150 foot pounds, ±2 foot pounds. The body of the penetrator must be held by a spanner wrench to ensure that it does not rotate while the nut is tightened. Tighten the Nyloc locking screws on the nut.

5. Check to insure that the outboard retainer gasket is still properly aligned to the hull contour and realign if required. The thin section of the gasket should be pointed toward the viewport. Screw the outboard retaining nut down against the outboard gasket retainer and the outboard waterseal gasket. Use a spanner wrench to tighten the nut

to between 50 foot pounds and 90 ft. lbs. Inspect the gasket for an even extrusion around the penetrator. If the extrusion is not even, the assembly must be removed and the outboard waterseal gasket realigned. Then proceed as outlined.

6. Tighten the Nyloc locking screws on the outboard retainer nut to complete the installation.

TP 4924-0500-C

Penetrator Assembly

1. Prior to installation, the penetrator body, hardware, and hole surfaces will be carefully inspected for physical damage, and cleanliness. All surfaces will be cleaned with a mild detergent and water and then dried completely. Record serial numbers, hole assignments and installation dates.

2. The outboard retaining nut (TP 499-010), outboard gasket retainer (TP 499-011), and the outboard waterseal gasket (TP 499-012) will be installed on the penetrator body per the assembly drawing (TP 4924-0500), sheet 1 of 3. The outboard retaining nut will be backed off completely clear of the outboard gasket retainer. Molykote M-77 will be used as the thread lubricant.

3. Insert the penetrator in the hull penetration from the outside after applying a very thin coat of Molykote M-77 to the tapered section, the inboard threads and the hull penetration. Install the inboard contoured washer (TP 499-013) and the belleville washer per assembly drawing TP 4924-0500C, sheet 2 of 3, after applying a light coat of M-77 to all bearing surfaces. Particular care must be taken to insure that the inboard washer seats properly on the hull. Install the inboard retaining nut after insuring that the outboard waterseal gasket is properly aligned to match the contour of the hull (the thin section pointed toward the viewport). Tighten the inboard retaining nut 7/8 of a turn beyond hand tight. This will result in .0547 in. compression of the belleville washer, leaving .0194 in. remaining before the washer is flattened. The body of the penetrator must be held from the outside by a spanner wrench to insure that it does not rotate while the inboard nut is tightened.

4. Check to insure that the outboard retainer gasket is still properly aligned to the hull contour and realign if required. The thin section of the gasket should be pointed toward the viewport. Screw the outboard retaining nut down against the outboard gasket retainer and the outboard waterseal gasket. Use a spanner wrench to tighten the nut

to 30 foot pounds. Inspect the gasket for an even extrusion around the penetrator. If the extrusion is not even, the assembly must be removed and the outboard waterseal gasket realigned. Then proceed as outlined.

5. Tighten the Nyloc locking screws on the inboard retaining nut and outboard retaining nut to complete the installation.

TP 4924-0500-D February 14, 1974

Penetrator Installation Procedure

1. Prior to installation, the penetrator body, hardware, and hole surfaces will be carefully inspected for physical damage. All surfaces will be cleaned with a mild detergent in water and rinsed thoroughly in warm water to remove all traces of cleaning agent. Each piece and each penetration hole will be dried completely.

2. The outboard retaining nut (TP 499-010), outboard gasket retainer (TP 499-011), and the outboard waterseal gasket (TP 499-012) will be installed on the penetrator body per the assembly drawing (TP 4924-0500D, sheet 1 of 3). The outboard retaining nut will be backed off completely clear of the outboard gasket retainer. Molykote M-77 will be used as the thread lubricant.

3. Apply a thin coat of Molykote M-77 to the tapered section of the penetrator body and burnish this area with a soft cloth or paper material. The correct application has been obtained when a soft cloth lightly wiped over the tapered section does not pick up traces of the M-77. The hull penetration hole is not to receive an application of M-77 but is to remain clean and dry.

4. Insert the penetrator in the hull penetration from the outside. Install the inboard contoured washer (TP 499-013), the belleville spring washer and the inboard retaining nut per assembly drawing TP 4924-0500D, sheet 1 of 3, after applying a light coat of Molykote M-77 to all bearing surfaces and the inboard threads. Particular care must be taken to insure that the inboard contoured washer seats properly on the hull.

5. Align the outboard waterseal gasket so that its thinnest section is pointed towards the viewport in order to match the contour of the hull insert. Tighten the inboard retaining nut an amount sufficient to result in .030 in. remaining before the belleville washer is completely flattened (approximately 1/2 turn beyond hand tight). The existence of this condition is to be determined by insuring that a .030 in. feeler gage can just enter the space between

the belleville washer and the contoured washer. It is expected that the clearance will vary around the circumference of the washer and therefore the gage must be used in as many places as possible to insure that .030 in. is the minimum clearance. During this operation, the body of the penetrator must be held from the outside with a spanner wrench to insure that it does not rotate.

6. Check to insure that the outboard waterseal gasket is still properly aligned with the hull insert contour. (If it is not, loosen the inboard nut and repeat step 5). Screw the outboard retaining nut down against the outboard waterseal gasket retainer. Using a spanner wrench, tighten the outboard retaining nut to 40 foot pounds. Inspect the gasket for an even extrusion around the penetrator. If the extrusion is not even, the assembly must be loosened, the waterseal gasket realigned and the installation procedure from step 5 repeated.

7. After a period of approximately 4 hours, check the torque value on the outboard retaining nut and retighten to 40 foot pounds if required. Following this, the belleville washer clearance must be checked to insure that the .030 in. value has not changed during the last steps of the installation.

8. Tighten the Nyloc locking screws on the inboard retaining nut and outboard retaining nut. Molykote M-77 should be used as a thread lubricant.

TP 4924-0500-E February 28, 1974

Penetrator Installation Procedure

1. Prior to installation, the penetrator body, hardware, and hole surfaces will be carefully inspected for physical damage. All surfaces will be cleaned using a strong detergent in water (Boraxo hand cleaner is recommended) and rinsed thoroughly in warm water to remove all traces of the cleaning agent. Particular attention must be paid to the penetration hole and the penetrator tapers since these areas are to have no lubrication. Each piece and the penetration hole will be dried completely.

2. The outboard retaining nut (TP 499-010), outboard gasket retainer (TP 499-011), and the outboard waterseal gasket (TP 499-012) will be installed on the penetrator body per the assembly drawing (TP 4924-0500E, sheet 1 of 3). The outboard retaining nut will be backed off completely clear of the outboard gasket retainer.

3. Conduct a final cleanliness inspection of the penetrator tapered section and the penetration hole and if satisfactory, insert the penetrator in the hull from the outside. Install the inboard contoured washer (TP 499-013), the belleville spring washer and the inboard retaining nut per assembly drawing TP 4924-0500D, sheet 1 of 3, after applying a light coat of Molykote M-77 to all bearing surfaces and the inboard threads. Particular care must be taken to insure that the inboard contoured washer seats properly on the hull.

4. Align the outboard waterseal gasket so that its thinnest section is pointed towards the viewport in order to match the contour of the hull insert. Tighten the inboard retaining nut to 125 foot pounds. This will flatten the belleville spring washer although it may still be possible for a .001 in. feeler gage to just enter the space between the belleville spring washer and the contoured washer at some locations on the circumference. During this operation, the body of the penetrator must be held from the outside with a spanner wrench to insure that it does not rotate.

5. Check to insure that the outboard waterseal gasket is still properly aligned with the hull insert contour. (If it is not, loosen the inboard nut and repeat step 4.) Lubricate the outboard threads and the bearing surface between the outboard retaining nut and the outboard gasket retainer with a thin coating of Molykote M-77. Screw the retaining nut down against the outboard waterseal gasket retainer. Using a spanner wrench, tighten the outboard retaining nut to 75 foot pounds. Spanner wrenches must be used on the outboard gasket retainer and the penetrator body to insure that they do not rotate during this torquing operation. Inspect the gasket for an even extrusion around the penetrator. If the extrusion is not even, the assembly must be loosened, the waterseal gasket realigned and the installation procedure repeated from step 4.

6. After a period of approximately 12 hours, check the torque value on the outboard retaining nut and retighten to 75 foot pounds if required.

7. Tighten the Nyloc locking screws on the inboard retaining nut and the outboard retaining nut. Molykote M-77 should be used as a thread lubricant.

TP 4924-0500-F April 25, 1974

Penetrator Installation Procedure

1. Prior to installation, the penetrator body, hardware, and hole surfaces will be carefully inspected for physical damage. All surfaces will be cleaned using a strong detergent in water (Boraxo hand cleaner is recommended) and rinsed thoroughly in warm water to remove all traces of the cleaning agent. Particular attention must be paid to the penetration hole and the penetrator tapers since these areas are to have no lubrication. Each piece and the penetration hole will be dried completely.

2. The outboard retaining nut (TP 499-010), outboard gasket retainer (TP 499-011), and the outboard waterseal gasket (TP 499-012) will be installed on the penetrator body per the assembly drawing (TP 4924-0500E, sheet 1 of 3). The outboard retaining nut will be backed off completely clear of the outboard gasket retainer.

3. Conduct a final cleanliness inspection of the penetrator tapered section and the penetration hole and if satisfactory, insert the penetrator in the hull from the outside. Install the inboard contoured washer (TP 499-013), and the inboard retaining nut per assembly drawing TP 4924-0500D, sheet 1 of 3, after applying a light coat of Molykote M-77 to all bearing surfaces and the inboard threads. Particular care must be taken to insure that the inboard contoured washer seats properly on the hull.

   During the 1974 spring overhaul, the titanium inboard retaining nuts are to be replaced with 17-4PH stainless nuts (Dwg. number TP 499-014E). These nuts can be distinguished from the titanium nuts by the fact that they have the letter E stamped after the serial number.

4. Align the outboard waterseal gasket so that its thinnest section is pointed towards the viewport in order to match the contour of the hull insert. Tighten the inboard retaining nut to 125 foot pounds. During this operation, the body of the penetrator must be held from the outside with a spanner wrench to insure that it does not rotate.

5. Check to insure that the outboard waterseal gasket is still properly aligned with the hull insert contour. (If it is not, loosen the inboard nut and repeat step 4.) Lubricate the outboard threads and the bearing surface between the outboard retaining nut and the outboard gasket retainer with a thin coating of Molykote M-77. Screw the retaining nut down against the outboard waterseal gasket retainer. Using a spanner wrench, tighten the outboard retaining nut to 75 foot pounds. A spanner wrench must be used on the outboard gasket retainer to insure that it does not rotate during this torquing operation. Inspect the gasket for an even extrusion around the penetrator. If the extrusion is not even, the assembly must be loosened, the waterseal gasket realigned and the installation procedure repeated from step 4.

6. After a period of approximately 12 hours, check the torque value on the outboard retaining nut and retighten to 75 foot pounds if required.

7. Tighten the Nyloc locking screws on the inboard retaining nut and the outboard retaining nut. Molykote M-77 should be used as a thread lubricant.

TP 4924-0500-G May 30, 1974

Penetrator Installation Procedure

1. Prior to installation, the penetrator body, hardware, and hole surfaces will be carefully inspected for physical damage. All surfaces will be cleaned using a strong detergent in water (Boraxo hand cleaner is recommended) and rinsed thoroughly in warm water to remove all traces of the cleaning agent. Each piece and each penetration hole will be dried completely.

2. The outboard retaining nut (TP 499-010), outboard gasket retainer (TP 499-011), and the outboard waterseal gasket (TP 499-012) will be installed on the penetrator body per the assembly drawing (TP 4924-0500E, sheet 1 of 3). The outboard waterseal gasket is to be lubricated with Lubriplate and the bearing surfaces of the outboard retaining nut are to be given a light coating of Molykote M-77. The outboard retaining nut must be backed off completely clear of the outboard gasket retainer.

3. Apply a moderate, even coating of Lubriplate grease to the penetrator taper. Conduct a final cleanliness inspection of the penetration hole and if satisfactory, insert the penetrator in the hull from the outside. Install the inboard contoured washer (TP 499-013), and the inboard retaining nut per assembly drawing TP 4924-0500D, sheet 1 of 3, after applying a light coat of Molykote M-77 to all bearing surfaces and the inboard threads. Particular care must be taken to insure that the inboard contoured washer seats properly on the hull.

   NOTE: During the 1974 spring overhaul, the titanium inboard retaining nuts were replaced with 17-4PH stainless nuts (Dwg. number TP 499-014E). These nuts can be distinguised from the titanium nuts by the fact that they have the letter E stamped after the serial number.

4. Align the outboard waterseal gasket so that its thinnest section is pointed towards the viewport in order to match the contour of the hull insert. Tighten the inboard retaining nut to 125 foot pounds. During this operation, the body of the penetrator must be held from the outside with a spanner wrench to insure that it does not rotate.

5. Check to insure that the outboard waterseal gasket is still properly aligned with the hull insert contour. (If it is not, loosen the inboard nut and repeat step 4.) Screw the retaining nut down against the outboard waterseal gasket retainer. Using a spanner wrench, tighten the outboard retaining nut to 25 foot pounds. A spanner wrench must be used on the outboard gasket retainer to insure that it does not rotate during this torquing operation. Inspect the gasket for an even extrusion around the penetrator. If the extrusion is not even, the assembly must be loosened, the waterseal gasket realigned and the installation procedure repeated from step 4.

6. After a period of approximately 12 hours, retorque the inboard retaining nut to 125 foot pounds and increase the torque on the outboard retaining nut to 50 foot pounds.

7. Tighten the Nyloc locking screws on the inboard retaining nut and the outboard retaining nut. Molykote M-77 should be used as a thread lubricant.

APPENDIX D - Memoranda Outlining The At-Sea Testing Procedures

5.2

Office Memorandum • WOODS HOLE OCEANOGRAPHIC INSTITUTION

TO : Art Maxwell

DATE: November 5, 1973

9033

NOV 6 1973

FROM : Paul Fye

SUBJECT:

In response to your memorandum of October 29, 1973, concerning ALVIN safety, I first wish to thank you and your committee for the excellent and thorough job you have done in investigating the matters relating to ALVIN operations. The questions you have identified seemed to be clear, and I assume that these will be followed-up promptly by the ALVIN group.

Therefore, I approve your recommendation that ALVIN be authorized to make dives of increasing depths from 200 to 6,000 feet with reporting to you of the success of the work at depth levels of 200 ft., 1,000 ft., 2,500 ft., 4,000 ft., and 6,000 ft. It is, of course, assumed that any unusual circumstances will be reported immediately and a plan modified appropriately, if this is necessary. Therefore, the above approval is conditional, both on the fulfillment of the requirements of your memo of October 29th and conditional on the successful completion of operations on a continuing basis. Again, I appreciate everyones cooperation in tackling a difficult and important requirement for safe ALVIN operation.

P.M.F.

Copy to:
Dr. Webster
Dr. Morse
Mr. Scott
✓ Mr. Schumaker
Mr. Berteaux
Dr. Hays

9033

Office Memorandum • **WOODS HOLE OCEANOGRAPHIC INSTITUTION**

TO : Larry Shumaker **DATE:** Jan. 11, 1974

FROM : A. E. Maxwell

5.2

SUBJECT: ALVIN Diving Depth Limitations

This memorandum constitutes W.H.O.I. authorization to extend the depth of ALVIN dives to 8000 ft. maximum. This memorandum supersedes H. O. Berteaux's memorandum of Nov. 30, 1973 regarding a thousand foot additional depth beyond Belleville washer's bottoming point. The above authorization is conditional on the fulfillment of the following requirements:

1. A 100% feeler gage inspection (all of the 23 penetrators with as well as without dial indicators) will be conducted at the maximum depth reached for all dives between 3000 ft. and 6000 ft. A feeler gage thickness of .005 will be used.

2. For dives greater than 6000 ft., 100% feeler gage inspection as above will be conducted at 6000 ft., 7000 ft., 7,500 ft. and 8,000 ft. A feeler gage thickness of .005 will be used.

3. For all dives, dial indicator readings will be taken and recorded at intervals of approximately 1000 ft. and every hour at the maximum depth obtained.

4. For dives in excess of 6000 ft., dial indicator readings will be taken and recorded at 6000, 6500, 7000, 7500 and 8000 ft. and every hour at the maximum depth obtained. A graph of indicator readings vs depth will be made as the dive proceeds for the penetrator which previous dives show to be experiencing the most outward displacement. It is suggested, but not mandatory, that graphs of displacements for other penetrators be made during the dive.

5. The maximum authorized depth for any dive will be either:

    a. The depth reached when anyone of the 23 penetrators indicates bottoming of a Belleville washer by either a .012" reading on a dial indicator or by failure of the feeler gage to fit between the Belleville washer and the contour washer.

b. 7000 ft. if the dial indicator readings suggest a tendency for the penetrators to move outward suddenly in a stick and slip fashion rather than smoothly. Maintenance of the in situ graphs should help in the determination of the existence of this condition.

c. 8000 ft. maximum if neither of the above applies.

6. The results of the above inspections and measurements will be transmitted to Woods Hole as soon as possible after each dive (copies to Berteaux).

A. E. Maxwell

cc: P. M. Fye
F. Webster
R. W. Morse
D. D. Scott
E. Hays
H. Berteaux
W. Marquet

9033

Office Memorandum • WOODS HOLE OCEANOGRAPHIC INSTITUTION

TO : Art Maxwell DATE: Feb. 11, 1974

FROM : Larry Shumaker Code 5.2

SUBJECT: Extending ALVIN Operations to 10,000 feet

Encl: (1) ALVIN Diving Depth Limitations - Feb. 11, 1974

As of this writing, ALVIN has made four (4) dives to 8,000 feet without indications of problems affecting the safety of personnel. In order to best prepare ourselves for FAMOUS operations, it is highly desirable to make dives to 10,000 feet during the southern operational period. The major problem area requiring review prior to extending the depth limitation is the hull penetrator and blanking plug installation. This memorandum reviews this subject and makes recommendations for installation changes intended to maximize our confidence in the penetrators for dives to a depth of 10,000 feet. Also included is a recommendation on the procedure to be followed for all dives between 6,000 feet and 10,000 feet which is essentially identical to that presently being used per your memorandum dated Jan. 11, 1974.

The maximum allowable axial loading of the ALVIN penetrator neck is 30,000 lbs. Beyond this, yielding will occur for a distance of approximately .020 followed by complete failure of the retaining nut threads. For this reason, Belleville spring washers have been installed between the retaining nuts and the hull so that if friction is not sufficient to hold the penetrators in place, they will be able to move outward without neck stress buildup. The present installation allows an outward movement of .015" which is the amount expected in a dive to 6,000 feet if there is no frictional retaining force. Dives to this depth and beyond have been made with careful monitoring of the penetrator outward motion and, as expected, the zero friction movement has not been obtained. The greatest amount of outward motion observed in dives to 8,000 feet is .0055". This would seem to indicate that dives to 21,000 feet are possible before neck stresses develop but, plots of displacement vs. depth are erratic and a linear relationship obviously does not exist.

Extrapolating the worst case curve from 8,000 feet shows that a depth of 10,000 feet can be easily obtained before the washer flattens. This is in agreement with the five (5) Annapolis tests to 12,000 feet which showed no penetrator damage.

On the face of this evidence, it would seem that dives to 10,000 feet can be conducted safely with the present installation. None the less, since the outward motion exhibited by any particular penetrator appears to be variable, it remains remotely possible that at some future time, a penetrator will move out close to the amount calculated for the zero friction condition (.030" @ 12,000 feet). For this reason, it is planned to back off the penetrator retaining nuts approximately 3/8 of a turn, which will result in an increase in the allowable motion from .015" to .030". This change decreases the Belleville spring force from approximately 1,500 lbs. to 1,000 lbs. which is still more than sufficient to maintain the water tight seal at the outer surface.

The above installation modification will allow the penetrators to move outward more than the calculated .025" at 10,000 feet with zero friction. Therefore, axial neck stresses exceeding those developed by the flattened Belleville washer (2,000 psi) cannot be obtained unless high velocity penetrator motion occurs resulting in dynamic loading. Indications of this type of motion have not been observed and its occurrence is considered highly unlikely. Calculations have been made however, which show that a penetrator which does not move during a dive to 10,000 feet will have a stored energy of 2110 in.-lbs. If for some reason, the restraining frictional forces were instantaneously reduced to zero, this amount of energy would be expended in an outward penetrator motion of approximately 0.070 in. Test data indicates that after this amount of motion, the retaining nut threads would be damaged but the nut would remain in place and there would be no possibility of the penetrator leaving the hull completely. Hydrostatic force would immediately reseat the penetrator and the possibility of leakage is remote. There is no evidence to suggest that this type of motion could occur and it has been included only as a worst case condition.

It is planned to modify the penetrator installation, as noted above, during the week of Feb. 11, 1974. The subsequent diving schedule will include dives to 10,000 feet and all dives in excess of 6,000 feet will follow the procedures for dial indicator readings and feeler gage measurements as outlined in enclosure (1).

Larry Shumaker

LS:ms
Enclosure

Office Memorandum • WOODS HOLE OCEANOGRAPHIC INSTITUTION

TO : Larry Shumaker

DATE: 1 March 1974

9033

FROM : Provost

SUBJECT: ALVIN Diving Limit
Ref. Code 3121.1 of 28 February 1974

This memo authorizes you to extend the depth limit of ALVIN to 10,000 feet. During the remaining dives of the Bahama operation, the dial indicators installed to measure relative motion between the penetrator neck and retaining nut should be monitored and recorded every 1000 feet to 8000 feet and continuous visual surveilance thereafter, recording every 500 feet. If there is motion in excess of 0.005 inch, the dive should be aborted.

A E Maxwell
A.E. Maxwell

AEM:ejb

cc: Earl Hays
Henri Berteaux
Paul Fye
Ferris Webster
David Scott

Office Memorandum • WOODS HOLE OCEANOGRAPHIC INSTITUTION

TO : Larry Shumaker

DATE: August 26, 1974

FROM : Provost

AUG 27 1974

9033

SUBJECT: ALVIN Depth limitation

The Director and I have reviewed H. Berteaux's memo of August 21, 1974 and concur that ALVIN meets all safety requirements for diving to 12,000 feet depth. Accordingly, this memo authorizes the submarine to dive to 12,000 feet. Dives should not be undertaken in any water depth exceeding 12,000 feet without the express permission of the Director. Safety procedures contained in the D.S.R.V. Management Plan will be followed rigorously for all dives.

A. E. Maxwell

AEM/wvw

cc: Drs. Fye, Webster, Hays, Capt. Scott, Mr. Berteaux