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Design and Development of the "All-Welded-and-Brazed" Instrumentation Ports for NERVA Reactors

(Title Unclassified)

UNCLASSIFIED NERVA RESEARCH
AND DEVELOPMENT REPORT.

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Summary

This report discusses the design and development of an all-welded-and-brazed instrumentation port for NERVA reactors. The instrumentation ports permit passage of bundles of instrumentation leads through the pressure vessel wall. Brazing and welding processes are utilized in the port assembly to provide a leak-tight seal between the stainless steel sheathed instrumentation leads and the reactor's aluminum pressure vessel. Comprehensive testing demonstrated that the subject assembly remains leak tight (leakage rate less than 10^{-6} standard cc hydrogen/sec.) through resonant vibrations, hydraulic and structural shock loads and during extreme thermal cycles.

Introduction

As the duration of reactor tests has increased, the allowable rate of hydrogen leakage has become correspondingly more restricted. A permissible leakage rate for a 15 minute test becomes an unacceptable hazard for a 60 minute test. Consequently, all penetrations through the reactor pressure vessel have been scrutinized to determine whether they could be deleted or modified to reduce leakage. The relatively large penetrations through the pressure vessel closure for the instrumentation ports constituted a large potential source of leakage. To minimize this leakage potential, an all-welded and-brazed instrumentation port was designed, as shown in Figure 1. The objective of this design was to produce a joint with "zero leakage", (less than 1×10^{-6} STD cc/sec.)

Discussion of Design

The instrumentation leads passing through the instrumentation ports are brazed to a stainless steel seal block. In the first four NERVA reactors the interface between the seal block and the aluminum pressure vessel closure was sealed by mechanical means. The replacement of the mechanical seal with a brazed and/or welded joint required joining dissimilar metals. A bi-metallic transition sleeve assembly (See Figure 1) utilizing a special, closely controlled, brazing technique to join aluminum to stainless steel was employed. After making the bi-metallic joint, the aluminum member of the transition sleeve was welded to the pressure vessel closure, and the steel member of the transition sleeve was welded to the seal block. The stainless steel fillet weld between the instrumentation seal block and the stainless steel transition sleeve serves a dual function as a seal and as a structural member. The primary function of the aluminum fillet weld is to seal the interface between the transition sleeve and the pressure vessel closure. The structural loads imposed upon the aluminum transition sleeve are transmitted through mating threads to the pressure vessel.

The aluminum transition sleeve is in an annealed condition as a result of the bi-metallic brazing operation. The threads of the transition assembly were hard coated, electrolytically, (per AMS 2469-1) to provide protection against galling. One of the instrumentation port assemblies was disassembled after testing to determine whether the assembly and welding operations had produced any galling of threads. The transition assembly was easily screwed out of the test block, after the aluminum fillet weld was removed by grinding. Visual examination of the threads after disassembly revealed no sign of galling.

Analysis of the new design disclosed that moderately high thermal stresses may occur during a 150° R/second, start-up transient. These stresses were reduced approximately 30 per cent by adding a 0.010 inch thick stainless steel sleeve with a 0.005 inch air gap inside the seal block to act as a thermal sleeve. The addition of the thermal sleeve also provides protection of the instrumentation leads from overheating during the welding of the seal block to the transition adapter.

Three ports in the pressure vessel closure are used for the emergency purge system in NRX-A5. These purge ports utilize the bi-metallic transition adapters. They do not include an instrumentation seal block. Instead, they are welded to stainless steel piping which is mounted to the test car. Flexible metallic hose assemblies are incorporated in the external piping to minimize the loading that can be transmitted from the piping system to the transition adapters; however, the ability of the transition adapters to sustain piping loads was verified by structural load tests.

Recordings were made of temperatures at significant locations during assembly of the parts, to determine whether welding caused excessive heating of the brazed sections. When the steel inner sleeve was welded to the steel seal block (in four 90° beads), the following maximum temperatures were recorded:

Bi-metallic Brazed Joint	141° F
Closed End of Seal Block	293° F (where instrumentation leads are brazed to the seal block).
I. D. of Seal Block Adjacent to Weld	1,600° F +
O. D. of Inner Sleeve, Adjacent to top of Aluminum Sleeve	649° F

Figure 2 shows the location of these temperatures. The only potential problem associated with these temperatures is that the I. D. of the seal block adjacent to the weld would be too hot for some of the instrumentation leads if they contacted this area, however, the thermal sleeve inside the seal block prevents contact and will provide some insulation for the leads.

When the transition adapter was welded to the aluminum test block, the maximum temperatures at the following locations were recorded:

Bi-metallic Brazed Joint	384° F
I. D. of Steel Inner Sleeve	369° F
O. D. of Aluminum Test Block	390° F (adjacent brazed joint)

These relatively low temperatures do not have any adverse affect upon the bi-metallic brazed joint.

Figure 3 is a photograph of the instrumentation port and the purge port test specimens. Figure 2 is a cross section view of the instrumentation port test assembly. The diameter of the test fixture housing was made identical to the diameter of the instrumentation and emergency purge port bosses on the pressure vessel.

In order to qualify the all-welded-and-brazed instrumentation port assembly for reactor service, a comprehensive testing program was conducted to demonstrate that the assembly was reliable under all anticipated operating and handling conditions. The testing program primarily investigated whether mechanical and hydraulic shock loads and vibrations at ambient and cryogenic temperatures would develop leaks in the assembly.

TEST PROGRAM

Hydrogen Leakage Tests*

Three instrumentation port assemblies were extensively tested for hydrogen leakage while pressurized at 800 psi. Prior to the leak checks, each unit was hydrostatically tested at 1500 psi. The leakage rate with 800 psi hydrogen at ambient temperature was less than 10^{-6} STD cc/sec for each assembly. To determine whether severe thermal cycles would initiate any leakage, each assembly was subjected to 15 cycles in which the temperature was cycled from -30° F to -320° F. An internal pressure of 800 psi was maintained in each assembly during the thermal cycling; however, helium was used instead of hydrogen to take advantage of its greater heat conductance to reduce the time required for thermal cycling. After the third and fifteenth cycles, the test assemblies were pressurized with 800 psi hydrogen and checked for leaks. The leakage rate in each assembly was less than 10^{-6} STD cc/sec.

Vibration

Test specimens of the instrumentation port and of the emergency purge port were subjected to shake tests to determine their resonant frequencies between the range of 10 to 1,000 cycles per second, at room temperature and at -200° F. These assemblies are not expected to be cooled below -200° F during reactor operation. The resonances were determined by monitoring input and output accelerometers (shown in Figures 4 and 5). The resonant frequencies are listed in Table I. No other significant resonances occurred in this range.

After determination of the resonant frequency at -200° F, each assembly was subjected to 12 thermal cycles, with the temperature cycling from -30° F to -300° F, while under continuous vibration at its resonance frequency. The input acceleration was 2G applied perpendicular to the longitudinal centerline of the assembly. After cycles 2, 4, 8 and 12, the vibration was stopped and the assembly was pressurized to 200 psig with helium. No leaks were detected when checked with a mass spectrometer having a sensitivity of four parts per million.

Vibration Endurance

The purge port and the instrumentation port assemblies were vibrated for a two hour duration at their ambient resonant frequency and at 240 cps with 2G input acceleration. Data from previous reactor tests had disclosed that the pressure vessel closure had a resonant frequency of 240 cps and that the maximum acceleration of the closure was 2G. After each half hour of endurance testing, the vibration was stopped and the assemblies were leak tested in the same manner as above. No leaks were observed with a mass spectrometer on either assembly during or after these tests. After completion of the vibration tests, one of the instrumentation port assemblies was pressurized with 800 psi hydrogen and tested for leakage. The leakage rate was less than 10^{-6} STD cc/sec.

Shock Test

Pressure shock load tests were conducted to simulate the expected loads on the emergency port assemblies by gas flow during an emergency reactor shutdown. These tests included an initial shock load coupled with a static load at the elbow.

The assembly shown in Figure 9 was clamped to a rigid support, and a high pressure hose from a helium supply system was connected to the elbow adapter. The shock load was induced by actuating the supply valve to release a surge of gas which developed a pressure of 250 psi in the purge port elbow within 0.08 second. A static force of 540 pounds was then applied to the elbow with a hydraulic cylinder. The combined loads were maintained for 90 minutes. No evidence of leakage was detected by a mass spectrometer during or after the test. The 540 pound static force was the resultant of a 378 pound axial force and a 378 pound lateral force which had been calculated on the basis of a total emergency purge flow rate of 14 pounds of hydrogen per second.

Pendulum Shock Load Test *

Two instrumentation port assemblies were subjected to shock loads by a pendulum. The test assembly was mounted rigidly, and the pendulum struck the seal block perpendicular to the instrument port axis. Figure 7 shows the pendulum test apparatus. A two pound weight was swung from a height of four feet and from a height of eight feet. After the eight foot drop, each assembly was pressurized to 800 psi with hydrogen and checked for leaks. The leakage rate was less than 10^{-6} STD cc/sec.

One of these assemblies was tested by hitting it with a ten pound weight dropped from four feet and from eight feet and with a twenty pound weight dropped from four feet and from eight feet. The fixture was turned approximately 60° after each impact. Although permanent deformation resulted from the twenty pound impact, the leakage rate was less than 10^{-6} STD cc/sec when tested with 800 psi hydrogen.

Tests to Destruction *

Two tests were conducted under conditions far in excess of the extreme conditions anticipated during handling or reactor operation to provide an approximate measure of the factor of safety for the brazed-and-welded instrumentation port assembly. One assembly was filled with oil, and the pressure was increased to 8,000 psi, at which time a fine spray was observed at the inside diameter of the aluminum fillet weld. A pinhole at this location produced a large source of leakage. No other failure was noted; however, subsequent sectioning of the test assembly disclosed that the inner (steel) sleeve of the transition assembly had bowed, although the steel fillet weld and the bi-metallic brazed joint appeared to be in excellent condition. This test indicated that the assembly had a safety factor of approximately ten.

One instrumentation port assembly was subjected to axial, compressive loads. Measurements of the overall length of the assembly taken during the load test indicated the following deflections:

Load	Deflection of Assembly
6,000 pounds	None
13,000 pounds	5 mills
18,000 pounds	10 mills
27,000 pounds	30 to 40 mills (step change)
28,000 pounds (Limit of loading apparatus)	50 mills

After the final compressive load was removed, the instrumentation port assembly was pressurized with 800 psi hydrogen and checked for leaks. The leakage rate was 5×10^{-2} STD cc/sec; an excessive rate for this application. Examination of the sectioned assembly disclosed that the bi-metallic brazed joint was still intact. No axial compressive loads are anticipated during reactor operation or handling. Compression of the test assembly subjected the bi-metallic brazed joint to tension. This test demonstrated that the bi-metallic brazed joint can withstand large tensile loads, whereas the 8,000 psi hydrostatic test demonstrated its strength in compression.

Conclusions

The extensive testing conducted with the bi-metallic brazed joint demonstrated that it can withstand at least two hours of resonant vibration with a 2G input, and thermal cycles to -320° F, and maintain the leakage rate to less than 10^{-6} STD cc hydrogen/sec. On the basis of these tests the bi-metallic brazed joint has been recommended for NERVA service. Additional structural load tests have demonstrated that the all-welded-and-brazed instrumentation port assemblies can withstand tensile, compressive and lateral loads far in excess of any anticipated operating and handling conditions.

* Reference WANL-TME 1454

TABLE 1

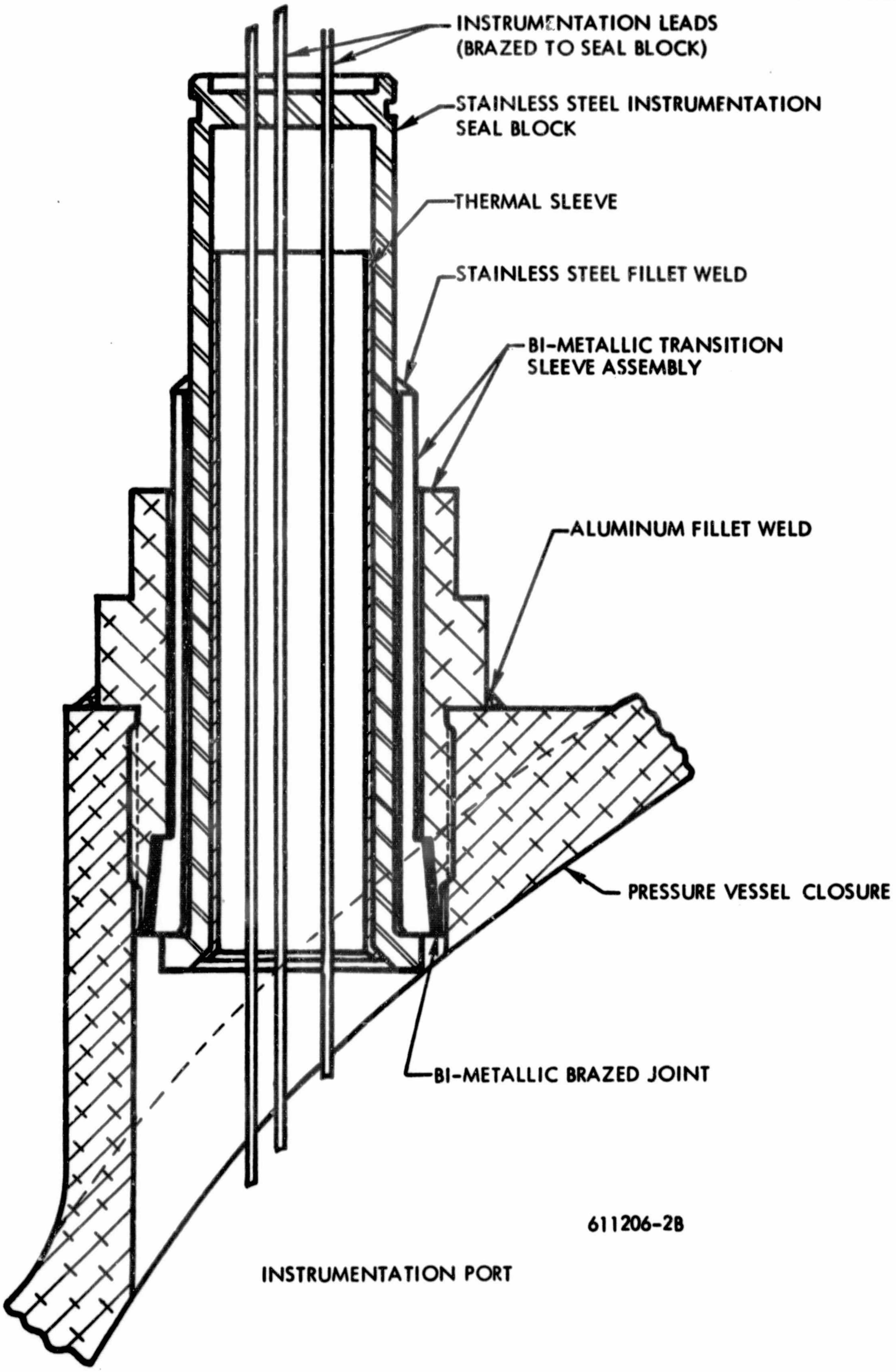
VIBRATION TEST RESULTS

TEST	SPECIMEN	TEMPERATURE	TEST CONDITIONS	DURATION OF TEST	RESULTS
1. Resonance Survey	Purge Port	Ambient	Frequency sweep 10-1000 cps at 1G input	15 min.	Resonance at 326 cps. with magnification factor of 135.
2. Resonance Survey	Purge Port	-200° F	Frequency sweep 10-1000 cps at 1 G input	15 min.	Resonance at 343 cps with magnification factor of 135.
3. Thermal Cycle Fatigue	Purge Port	-30° to .320°F (12 cycles)	343 cps 2 G input	184 min.	Total vibration cycles = 3,786,720. No failure or leakage of 200 psig. He.
4. Endurance	Purge Port	Ambient	240 cps 2G input	120 min.	No failure or leakage of 200 psig. He. Total vibration cycles = 1,728,200
5. Endurance	Purge Port	Ambient	326 cps 2 G input	120 min.	No failure or leakage of 200 psig. He. Total vibration cycles = 2,347,200.

TABLE 1 (continued)

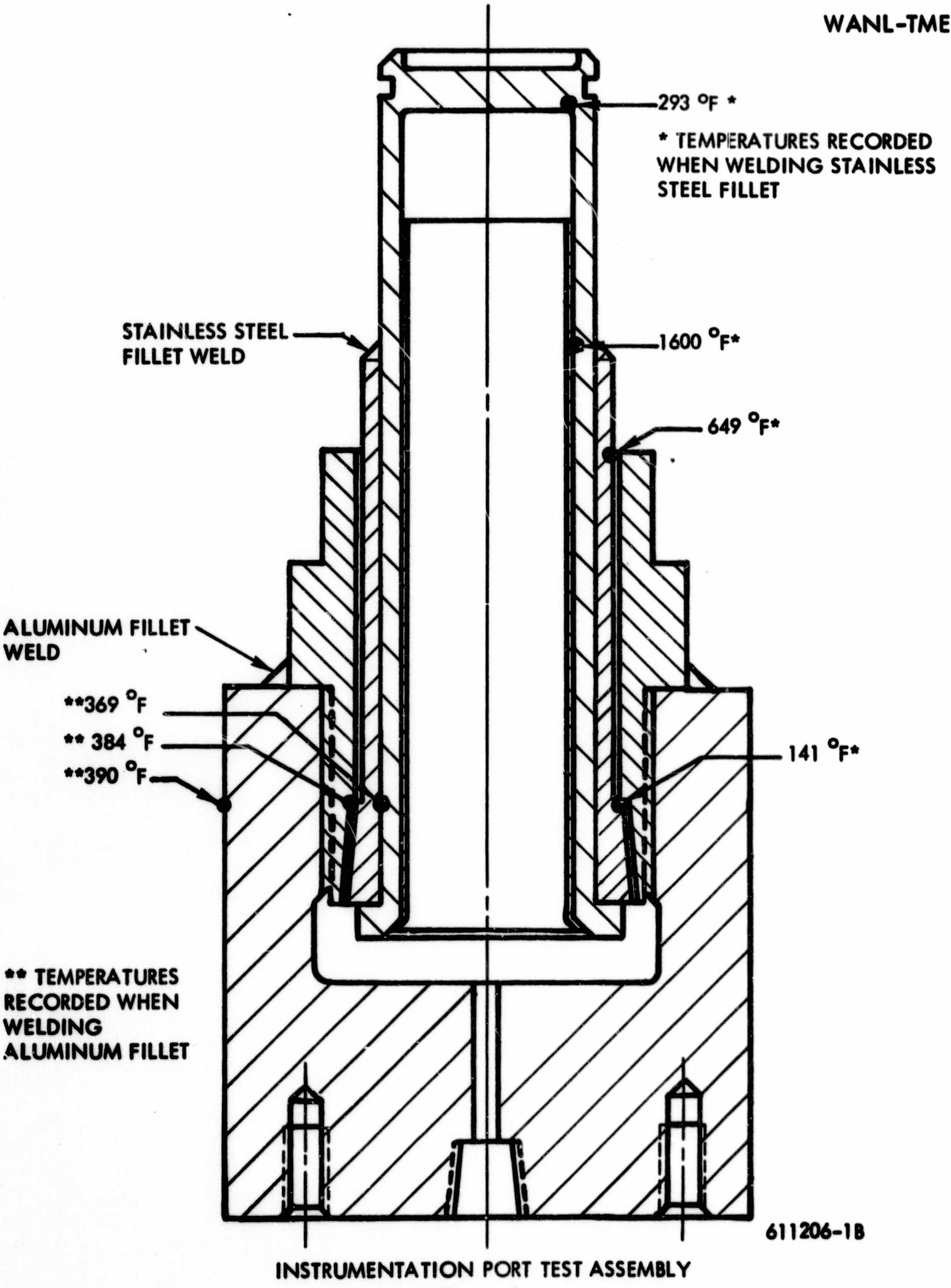
VIBRATION TEST RESULTS

TEST	SPECIMEN	TEMPERATURE	TEST CONDITIONS	DURATION OF TEST	RESULTS
6. Resonance Survey	Instrumentation Port	Ambient	Frequency sweep 10–1000 cps at 1 G input.	15 min.	Resonance at 925 cps. Magnification Factor 100. No leakage at 200 psig.
7. Resonance Survey	Instrumentation Port	-200° F	Frequency sweep 10–1000 cps at 1 G input.	15 min.	Resonance at 975 cps. Magnification factor of 100. No leakage at 200 psig.
8. Thermal Cycle Fatigue	Instrumentation Port	-30° to -320° F (12 cycles)	975 cps 2G input	233 min.	Total vibration cycles = 13,637,300. No failures or leakage at 200 psig. He.
9. Endurance	Instrumentation Port	Ambient	240 cps 2G input	120 min.	No failure or leakage of 200 psig He. Total vibration cycles = 1,728,000.
10. Endurance	Instrumentation Port	Ambient	925 cps 2G input	120 min.	No failures or leakage of 200 psig. He. Total vibration cycles = 6,660,000.



INSTRUMENTATION PORT

Figure 1



INSTRUMENTATION PORT TEST ASSEMBLY
Figure 2

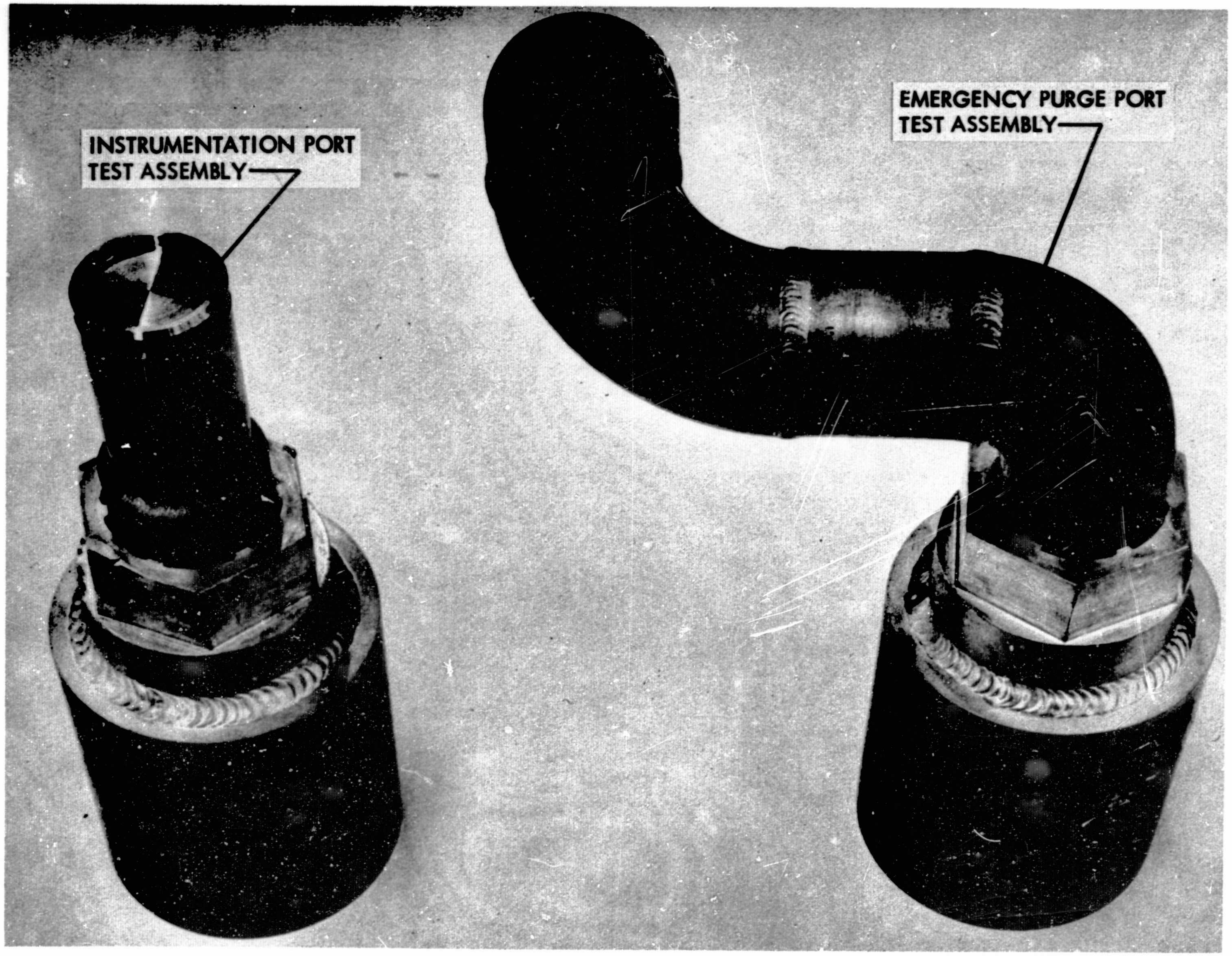
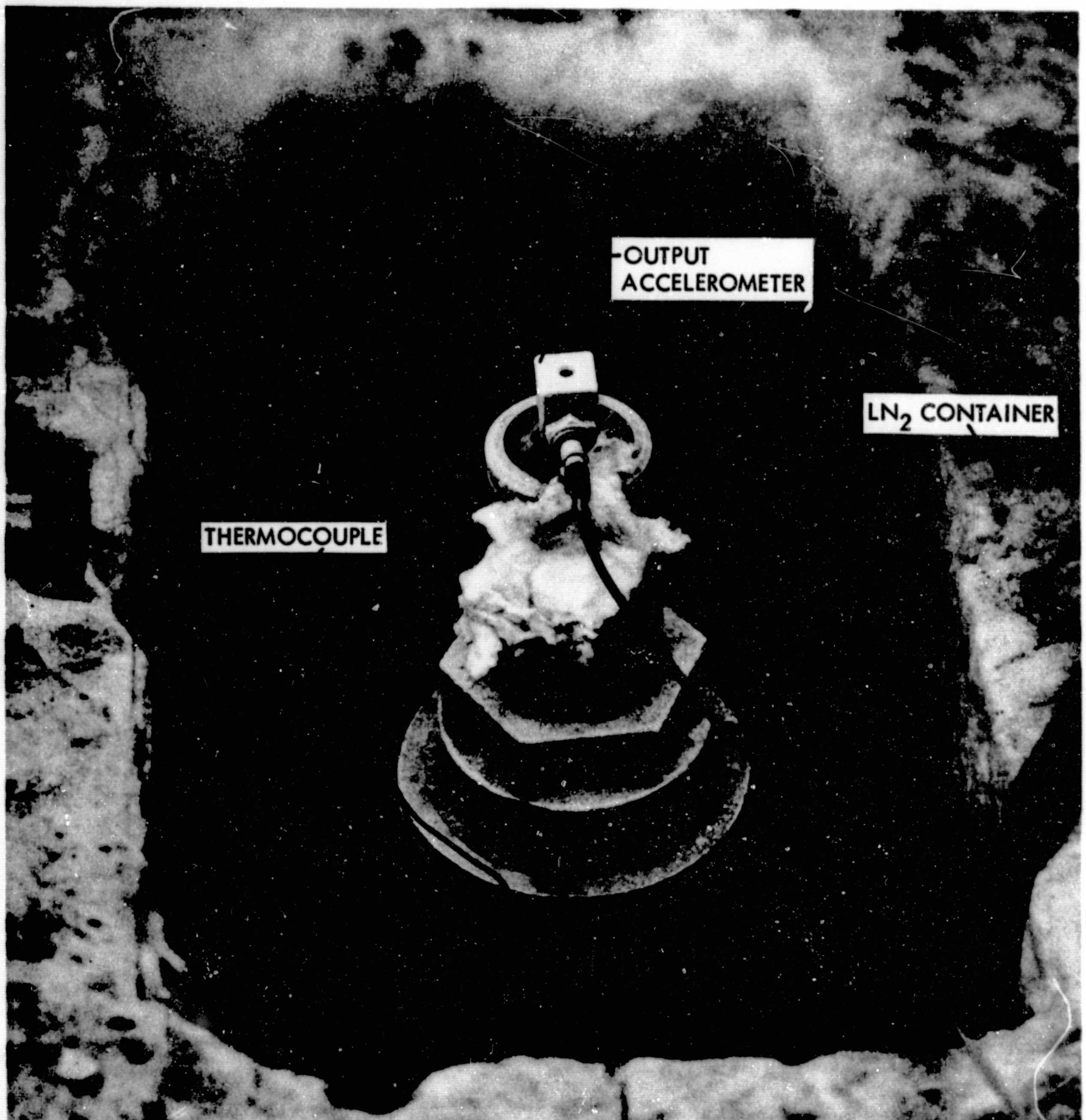
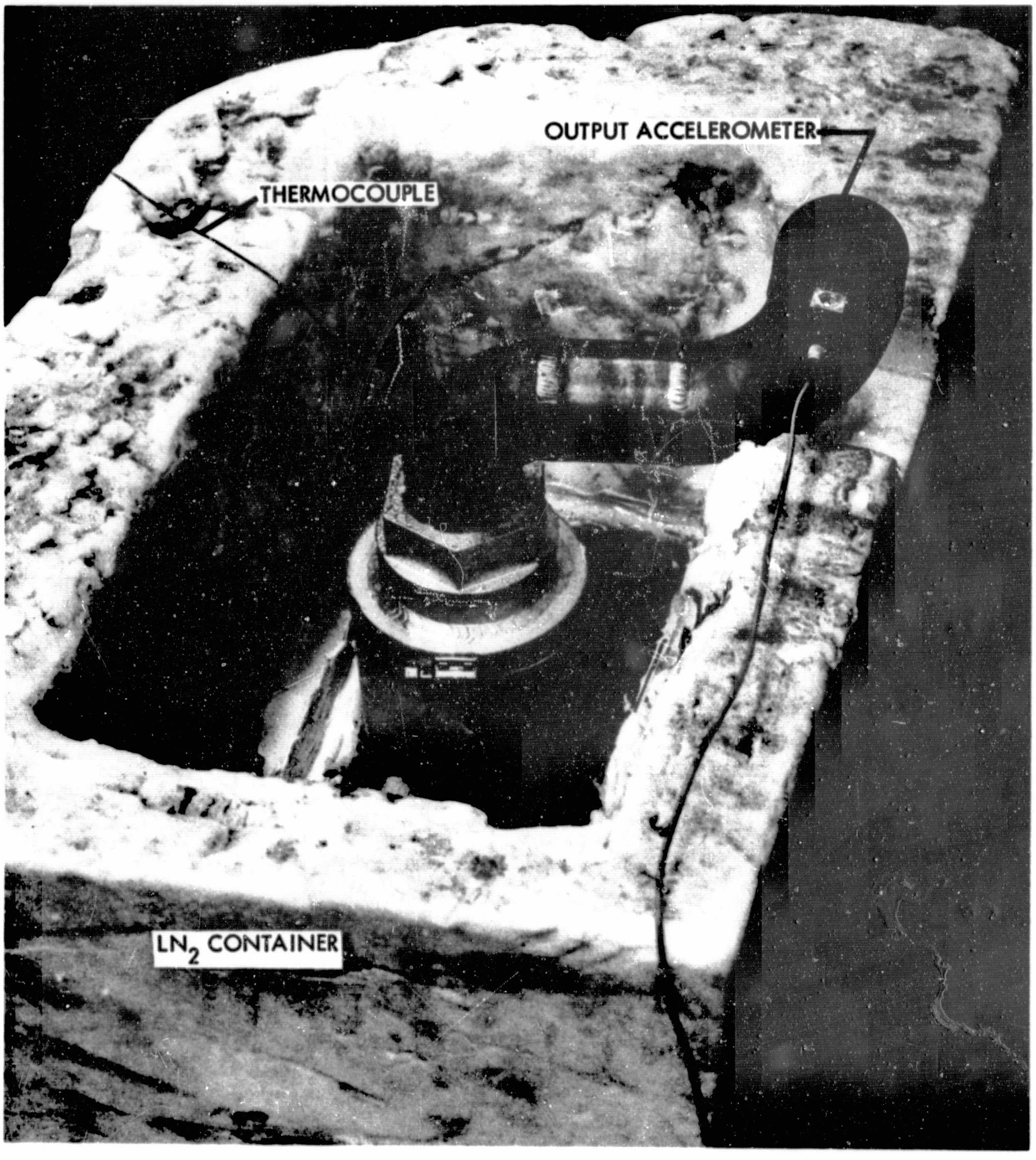

INSTRUMENTATION PORT TEST ASSEMBLY
EMERGENCY PURGE PORT TEST ASSEMBLY

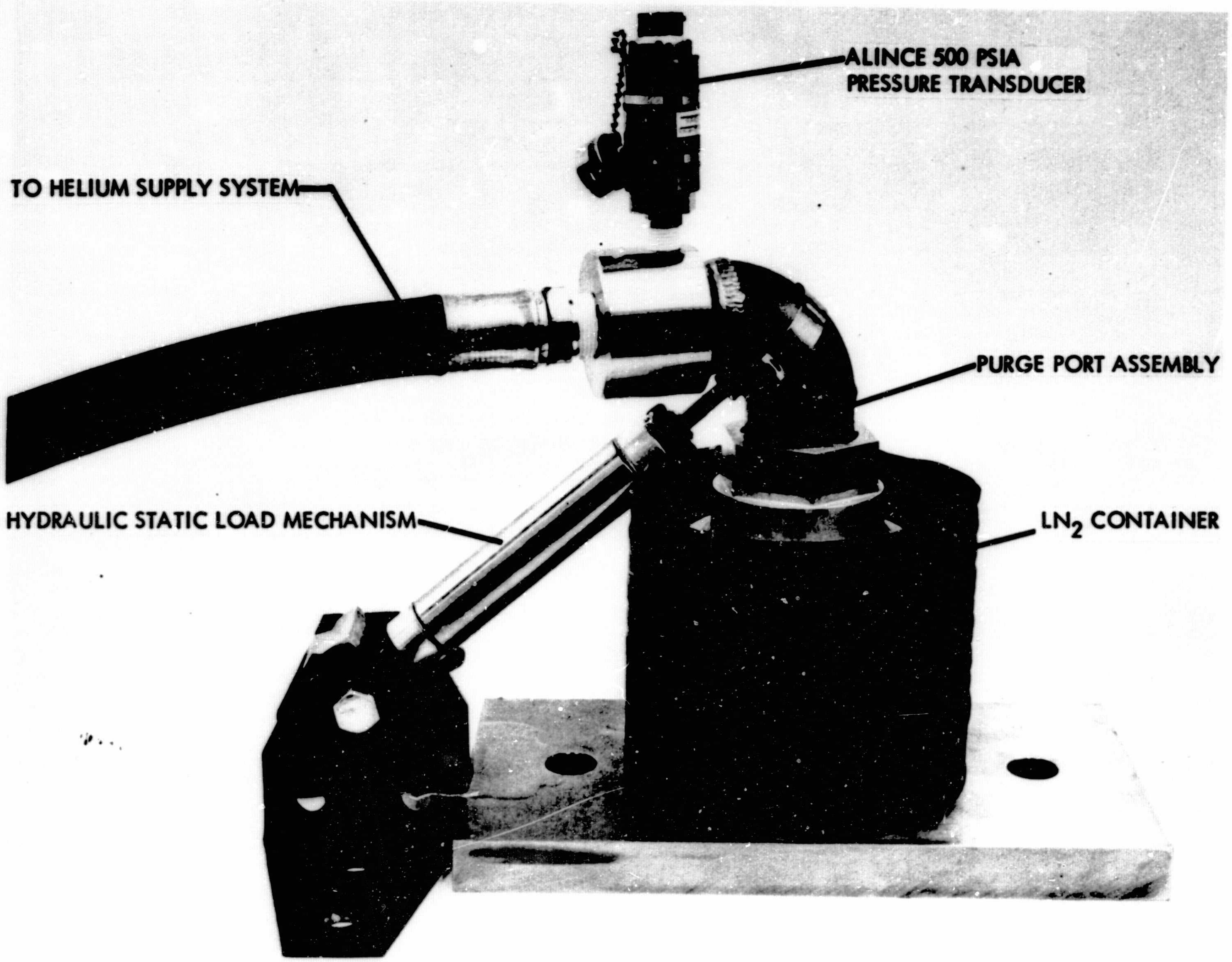
FIGURE 3



INSTRUMENTATION PORT
MOUNTED ON VIBRATION TABLE
FIGURE 4

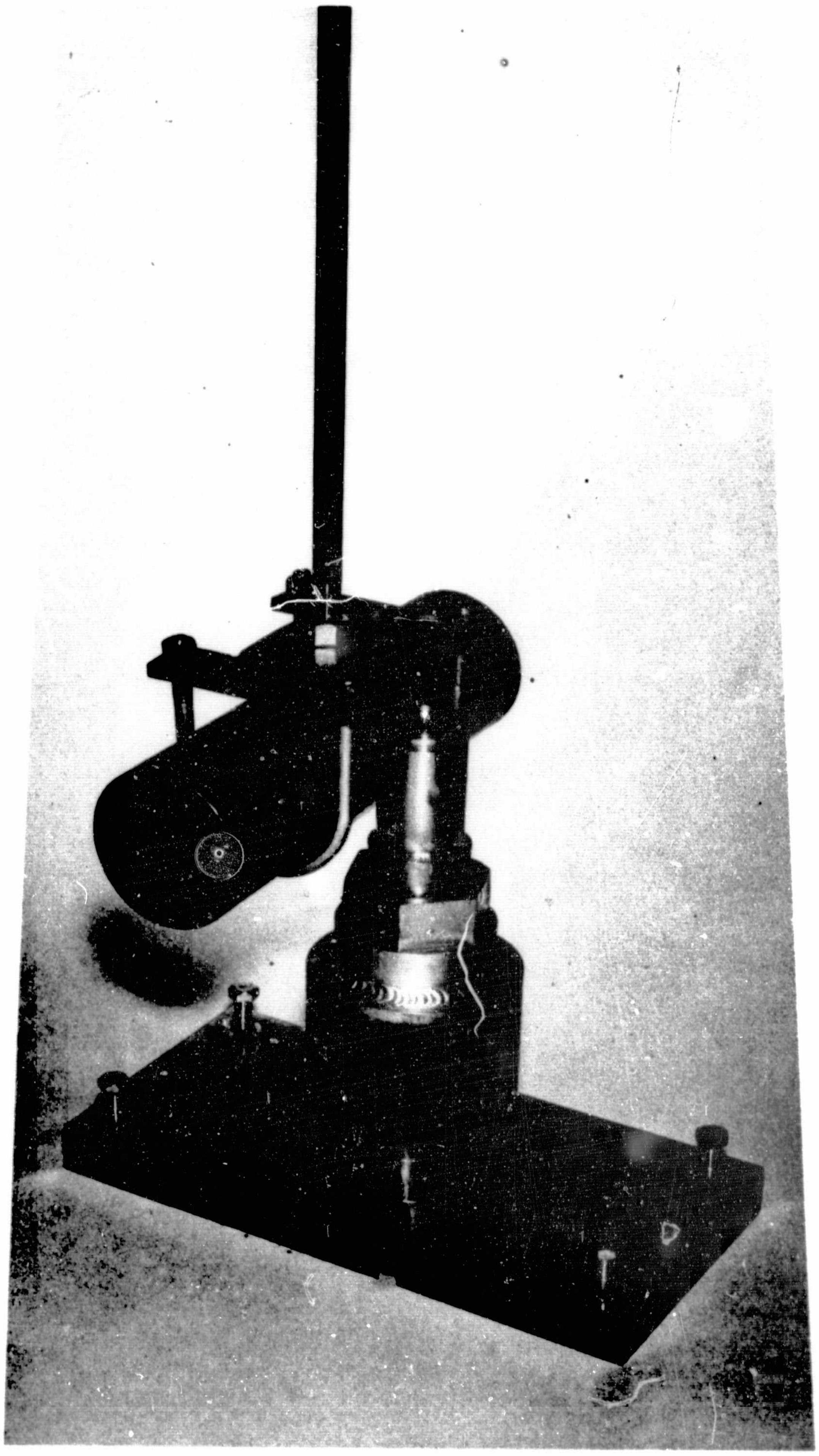


PURGE PORT ASSEMBLY MOUNTED ON VIBRATION TABLE
FIGURE 5



SHOCK LOAD TEST APPARATUS

FIGURE 6



PENDULUM TEST APPARATUS
FIGURE 7