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PRESSURE MEASURING SYSTEMS FOR CLOSED CYCLE LIQUID METAL FACILITIES

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FOREWORD

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ABSTRACT

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Continuing development of a thermionic diode pressure transducer for liquid metal applications is described. Thermionic diode characteristics are being evaluated using transducer test models incorporating both C-129Y and FS-85 pressure capsules. To achieve maximum capsule stability, W-25 Re appears to be the best choice for the 80 psia and ± 5 psid transducers. A capsule design has been developed and the 80 psia capsule was fabricated. Work on the fabrication of the ± 5 psid capsule is in progress. Continuing study and experimentation indicate that the metal-ceramic seal techniques developed for use in the transducer are acceptable. Thermal cycling tests of a representative seal were conducted successfully and a potassium compatibility program was initiated. A breadboard model of the transducer electrical signal conditioning system has been constructed for test purposes.

Author

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1.0 Introduction

The objective of this program is to develop pressure transducers which can be used in advanced closed cycle power systems using liquid metals such as mercury, sodium, potassium and other alkali metals as working and heat transfer media at elevated temperatures. Accurate pressure measurements in the high temperature liquid, vapor, and two phase streams are required for research, design and control purposes. In addition, space flight requires lightweight systems capable of enduring long periods of unattended operation.

Liquid metal pressure measurements at elevated temperatures pose many design problems demanding the best from available materials. To establish a firm design base for the transducer equipment, four diaphragm materials and two transducer systems were chosen for evaluation. The selected transducer system using a thermionic diode sensor will be developed for use as either ground or flight hardware for measuring absolute and differential pressures. The absolute pressure instrument will be developed for a full scale range of 80 psia and the differential instrument for ±5 psid.

2.0 Summary

During the report period, laboratory testing was done on transducer test units T-2, T-3, T-4 and T-5. The two latest units, T-4 and T-5, included the C-129Y and FS-85 double convolution pressure capsules respectively.

Data were obtained on the pressure-output current (i_a - i_r) characteristics of T-4 as a function of test chamber temperature. Linear characteristics were obtained with changes in the output current occurring as a function of test chamber temperature. Analysis of the data indicated that these current changes mainly were due to thermal expansion effects in the C-129Y pressure capsule causing shifts in the position of the active collector surface relative to its emitter.

At the conclusion of the report period, the sensors of T-4 and T-5 completed about 1500 and 850 hours, respectively, of continuous operation. Emission losses observed at that time limited further testing. Future thermionic diode sensors will include improvements intended to extend these lifetimes.

Using W-25 Re as the diaphragm material, design calculations were completed for the 80 psia and ±5 psid pressure capsule configurations. The 80 psia pressure capsule was successfully fabricated and the component parts of the ± 5 psid pressure capsule were prepared.

A thermal cycling test was performed on a representative Nb-1Zr/Lucalox seal. The results served as a further indication of the acceptibility of the seal fabrication technique. Work was started on the fabrication of test seals for potassium compatibility testing. Both Lucalox and alumina ceramics will be used in the compatibility testing along with various metallizing and brazing procedures to obtain a comprehensive evaluation of the integrity of the seal in a potassium environment.

The breadboard signal conditioning system was completed. Preliminary testing of the input-output parameters of the various control loops was started.

3.0 Thermionic Diode Pressure Transducer

During the report period, laboratory work was concentrated on the following transducer test units.

T-2 (micrometer head fixture)
T-3 (C-129Y double convolution pressure capsule)
T-4 (modified C-129Y capsule taken from T-3)
T-5 (FS-85 double convolution pressure capsule)

The design and construction details of T-2 and T-3 were presented fully in Reference 1. Due to problems encountered in the testing of T-3, the C-129Y pressure capsule was modified and a new thermionic diode sensor was fabricated to put together T-4. T-5 was identical to T-4 except that the FS-85 double convolution pressure capsule was used. Both the C-129Y and FS-85 capsules had been used in previous deflection tests using the optical method for measuring displacement (Reference 2).

3.1 Transducer Test Units

Following initial bake-out in the Vacuum Test Facility, transducer test units T-2 and T-3 underwent emitter activation (see Page 9). The active collector and reference collector currents of T-2 were found to be lower than expected. The activation process was continued but no appreciable increase in current could be obtained. A possible reason for this condition could have been a deterioration of the emitters brought about by handling when rebuilding T-2.

During emitter activation, transducer T-3 exhibited an electrical short-circuit between the C-129Y capsule and the emitter housing of the thermionic sensor. The electrical short appeared to have occurred in the spacing between the hole in the C-129Y capsule (0.216 inch I.D.) and the emitter housing (0.206 inch O.D.). A slight change in alignment of the thermionic diode sensor in the pressure capsule coupled with any shifts in alignment at 1800°F could have resulted in the electrical short circuit. T-3 was disassembled. The C-129Y capsule was modified as described below and a new thermionic diode sensor was fabricated to resolve the shorting problem. The new unit was denoted T-4.

The thermionic diode sensor of T-4 used a 0.003 inch diameter W-3 Re heater with 0.012 inch diameter rhenium external leads. The heater exhibited good ductility during assembly and the W-3 Re/rhenium spot-welded joint appeared sound. The heater was wound on the alumina coil form and cast into the molybdenum emitter housing using the procedures described in Reference 3. The emitters were brazed into the molybdenum emitter housing with a nickel-oxide/molybdenum alloy. Rhenium wires (0.016 inch diameter) were used as the secondary reference collector (see Reference 1, page 43) and to provide the electrical connection to the reference collector. A tungsten/yttria layer, metallized to the Lucalox, was used as the reference collector surface. The interior surface of the end convolution of the C-129Y capsule was used as the active collector. Ni/Nb/Ti alloy was used to braze (1) the secondary reference collector into the Lucalox base and (2) the Lucalox base to the Nb-1Zr mounting ring.

In addition, transducer T-4 incorporated the following changes from T-3..

1. The hole in the C-129Y capsule was opened to 0.250 inch I.D.

2. The Lucalox ceramic base outside diameter was increased to 0.236 inch. Since the outside diameter of the emitter housing remained at 0.206 inch, the Lucalox base served as an insulator between the pressure capsule and the emitter housing.

3. The three wires running through the Lucalox which are used to position the emitter housing were replaced by 0.015 inch diameter Nb-1Zr wires, that had one end flattened to form a bolt head, and the other end threaded. Holes were drilled in the emitter housing mounting tabs and the Nb-1Zr wires were passed through the

housing mounting tabs and the holes in the Lucalox. The flattened heads of these wires were used to exert pressure on the housing mounting tabs. The threaded ends of the wires leaving the Lucalox end of the assembly were held with Nb-1Zr nuts. This method of assembly resulted in a more stable mounting of the emitter housing on the Lucalox base. One of the Nb-1Zr "bolts" was used as the electrical connection to the emitters.

4. To monitor the emitter temperature, a Pt/Pt-13 Rh thermocouple was spot-welded to the emitter housing.

Because of the relatively successful fabrication of T-4, future efforts will concentrate on transducer models using pressure capsules instead of the micrometer head fixture used in T-2. Accordingly, tests on T-2 were suspended and another test unit, T-5, was fabricated incorporating the FS-85 double convolution pressure capsule previously tested using the optical measuring technique. In all respects, T-5 was identical to T-4.

3.2 Test Results

The procedure used to evaluate the performance of the transducer test units consisted of the following steps.

1. The emitters were activated by applying about 15 volts to the diode with the emitters at 2280°F as measured by the thermocouple installed on the emitter housing. The emission currents increased to a stable level at which point the emitter temperature was lowered to the operating level of 2100°F. For an emitter-collector spacing of about 0.006 inch, the stable current level is about 45 milliamperes for an applied voltage of 15 volts.

2. The space-charge characteristics were determined by measuring the active and reference collector currents as a function of increased voltage. These data served two purposes. When plotted on log-log coordinates with emitter-collector distance as a parameter related through theoretical space-charge formulae (Reference 4), the data indicated the reference collector and

active collector distances. The data also indicated any emission limiting effects (poisoning) occurring at applied voltages up to about 20 volts. Since the thermionic sensor must operate in the space-charge limited region, any emission-limited condition will introduce error into the output signal and must be avoided.

3. Using the data of (2) above, an upper limit was placed on the applied voltage to insure that no poisoning effect was present. With this pre-determined applied voltage at zero pressure, pressure-output current (i_a-i_r) characteristics were obtained for chamber temperatures of 1800, 1600, 1400, 1200 and 1000°F while the emitter temperature was maintained at 2100°F. As the pressure was changed, the applied voltage was varied to keep the sum (i_a+ i_r) constant at its zero pressure value. For the transducer test units, the active collector distance was adjusted to be equal to the reference collector distance at room temperature prior to installation

in the Vacuum Test Facility. However, at 1800°F, motion of the pressure capsule caused the active collector distance to increase. Since no further adjustment was made, the difference current (i_a - i_r) was not zero at zero pressure.

Figure 1 presents the space-charge data gathered from T-4. The data is plotted on log-log coordinates with emitter-collector distance as a parameter. The current scale was obtained from the space-charge current density, assuming an emitter of 0.125 inch diameter. The reference collector spacing was seen to be about 0.006 inch while the active collector spacing was about 0.0045 inch. A severe emission-limited condition existed for i_r above an applied voltage of 18 volts. An operating voltage of 16 volts was chosen for the pressure - output current tests. An operating pressure range of 0 to 50 inches of mercury was chosen for T-4.

Figure 2 presents the pressure-output current characteristics for T-4. Figure 3 shows the device heater power necessary to maintain the emitters at 2100°F as the test chamber temperature was varied.

Analysis of the i_a and i_r data indicated that the relatively large shifts in the output current characteristics with temperature as shown in Figure 2 could be caused by thermal expansion effects between the pressure capsule (active collector) and the Lucalox base of the thermionic sensor. Both i_a and i_r were observed to decrease with increasing temperature. For given pressure and voltage conditions, this decrease in current can be attributed to a increase in the collector spacing. When referred to the chamber temperature, the most probable explanation for this shift is that both the C-129Y capsule and the Lucalox posts on which the emitter housing was mounted experienced thermal expansions.

These expansions would result in increased collector distances and decreased values of i_a and i_r respectively.

Figure 4 shows the experimental values of i_a and i_r as functions of chamber temperature at zero pressure and an applied voltage of 16 volts. In the temperature range of interest (1000 to 1800°F), the coefficients of thermal expansion of both niobium, the main component of C-129Y, and alumina, the main component of Lucalox, vary linearly with temperature.

The active and reference collector distances also vary linearly with temperature if the coefficients of thermal expansion vary linearly. If the values for i_a and i_r corresponding to 1000 and 1800°F are accepted as valid, interpolated current values for 1200,1400 and 1600°F may be obtained from theoretical space-charge relations (Reference 4) involving voltage, current and distance. These theoretical relations are represented graphically by the distance lines of Figure 1. Scaling off linear distance changes on the space-charge plots resulted in the interpolated current values shown in Figure 4. Close agreement was observed between the experimental and interpolated current values, with the exception of the 1200°F value for i_r. It appears that this experimental value was probably in error.

Correction factors were calculated to adjust the curves of Figure 2 to an 1800°F reference. Table 1 presents the values of i_a and i_r measured at 16 volts and zero pressure for the various test temperatures. The changes in i_a and i_r with temperature were used to compute an (i_a-i_r) correction. A correction was not obtained at 1200°F since the experimental value for i_r appears to be in error. Applying the corrections of Table 1 to the measured values of $(i_a - i_r)$ shown in the curves of Figure 2 resulted in the curves shown in Figure 5. The sensitivity of the

TABLE 1

TRANSDUCER T-4 OUTPUT CURRENT CORRECTIONS

	(i_a)		(i_r)		$(i_a - i_r)$
TEMP °F	EXP. ma	CORRECTION ma	EXP. ma	CORRECTION ma	CORRECTION ma
1800	97	0	47	0	0
1600	113	16	51	4	12
1400	132	35	54	7	28
1200	159	62	52	-	--
1000	189	92	61	14	78

transducer (change in current with change in pressure) appears to decrease for increasing temperature because the decrease in i_a due to thermal expansion of the capsule is greater than the change in Young's modulus of the capsule material with temperature.

Unfortunately, the data gathered on T-5 using the FS-85 capsule yielded erratic results. At the conclusion of the report period, the sensors of T-4 and T-5 had been in continuous operation about 1500 and 850 hours respectively. Both test units exhibited some losses in emission from the emitters used in the reference circuit. To a lesser extent, the same effect was noticed in the active emitter circuits.

Three possible problem areas exist that may account for the loss in emission. One is the braze joint holding the secondary reference collector in the Lucalox section of the sensor. During operation, the braze material may have reacted with the emitter. The second is the platinum thermocouple used to monitor the emitter temperature. The emission could have been degraded by platinum migration over the emitter surfaces. Lastly, the loss in emission may be due to an over-extended activation procedure which resulted in excessive loss of impregnant material from the emitters.

3.3 Pressure Capsule Design

Experimental results presented in Reference 2 indicated that the W-25 Re pressure capsule was the most stable of the four (C-129Y, FS-85, T-222 and W-25 Re) tested. Assuming that W-25 Re will be used as the final pressure capsule material, design calculations led to the absolute and differential pressure capsule configurations presented in Figure 6. The capsule is a double convolution assembly consisting of three ring members (1, 2, 3 in Figure 6) and a disc member (4 in Figure 6). The dimensions of part numbers A and B refer to the 80 psia and ± 5 psid capsules respectively. Three criteria were used to establish the pressure capsule design.

1. The maximum design stress in any capsule member was limited to 10,000 psi. This stress level was chosen to limit creep of the W-25 Re capsule.

2. The full-scale deflection of both the absolute and differential pressure capsules was chosen to be about 0.001 inch for the intended temperature range (1000-1800°F).

3. To insure liquid metal containment, the thickness of any capsule member was held to a minimum of 0.020 inch (dimensions B and C of Figure 6).

The capsule design was established using stress and deflection formulae such as found in Reference 5. The ring and disc members were treated separately.

For the ring member, the maximum stress and deflection are related to the capsule parameters by the following expressions:.

$s_r = 0.976 \beta w a^2/t_r^2$

$yr = 0.976 \alpha w a^4/E t_r^3$

where s_r = maximum stress in the ring member (psi); occurs in the radial direction at the outer edge.

β = function of a/b (tabulated on p.215, Reference 4).

a = radius to the outer edge (inch)

b = radius of the central boss (inch)

w = applied load (psi)

t_r = thickness of the ring member (inch)

y_r = deflection of the ring member (inch)

α = function of a/b (tabulated on p.215, Reference 4).

E = Young's modulus for W-25 Re (psi)

The constant 0.976 includes the effect of the W-25 Re value of Poisson's ratio (0.336).

For the disc member, the maximum stress and deflection are related to the capsule parameters by the following expressions:

$s_d = 3\ w\ a^2/4\ t_d{}^2$

$y_d = 3\ (m^2-1)\ w\ a^4/\ 16E\ m^2 t_d{}^3$

where s_d = maximum stress in the disc members (psi); occurs in the radial direction at the outer edge.

w = applied load (psi)

a = radius of the member (inch)

t_d = thickness of the disc member (inch)

y_d = deflection of the disc member (inch)

m = reciprocal of Poisson's ratio (1/0.336 = 2.98)

E = Young's modulus for W-25 Re (psi)

Table 2 presents the pressure capsule parameters as determined from the above expressions. For the 80 psia capsule, the limiting value of stress (10,000 psi) was used to determine the thicknesses of the ring and disc members. For the ±5 psid capsule, the member thickness was held to a minimum of 0.020 inch for liquid metal containment, leading to the decreased stress levels shown in Table 2.

TABLE 2

PRESSURE CAPSULE PARAMETERS

	80 psia Capsule	±5 psid Capsule
w (psi)	80	5
a (inch)	0.750	0.750
b (inch)	0.464	0.464
m	2.98	2.98
E (psi,1800°F)	52.5×10^6	52.5×10^6
E (psi,1000°F)	56.3×10^6	56.3×10^6
S_γ (psi)	10,000	3,900
t_γ (inch)	0.050	0.020
y_γ (inch,1800°F)	0.267×10^{-3}	0.261×10^{-3}
S_d (psi)	10,000	5,250
t_d (inch)	0.058	0.020
y_d (inch,1800°F)	0.411×10^{-3}	0.627×10^{-3}
total deflection	$y = 3y_\gamma + y_d$	
(inch, 1800°F)	1.21×10^{-3}	1.41×10^{-3}
(inch, 1000°F)	1.13×10^{-3}	1.31×10^{-3}

3.4 Pressure Capsule Fabrication

The double convolution pressure capsule design shown in Figure 6 requires that each convolution be electron-beam welded on the circumference (joints between elements 1 and 2, and 3 and 4) and the two convolutions electron-beam welded at the center (joint between elements 2 and 3). The center weld between the two convolutions has proved to be an extremely difficult operation for two reasons.

1. It was impossible to visually observe the weld as it was being made between the convolutions.

2. The width of the electron beam above its focal point at the weld increased to such an extent that at times the beam grazed the convolutions at the outer edges, partially melting the material.

The 80 psia pressure capsule assembly was successfully electron-beam welded and is shown in Figure 7. Also shown in Figure 7 is a Nb-1Zr transition piece which was electron-beam welded to the W-25 Re pressure capsule to facilitate installation of the capsule into the transducer housing.

Because of the difficulties described above and encountered in the fabrication of the 80 psia pressure capsule, the center weld was eliminated in the ± 5 psid pressure capsule by spark-discharge machining a deep groove in the edge of a relatively thick disc of W-25 Re. Effectively, elements 2 and 3 of Figure 6 were made from a single piece of W-25 Re.

The electrode wear is severe in spark-discharge machining W-25 Re, and if normal electrodes made of metal shim stock were used to machine the groove, continual shut-downs would be required to re-face the electrode. To machine the groove in the edge of the W-25 Re disc, a technique using a travelling tantalum wire electrode, was developed by Omega Machine Company, Bloomfield, Connecticut. The equipment used is shown in Figure 8. The entire assembly, which consisted of a plate on which was mounted a number of adjustable pulleys and spools, together with a drive motor, was bolted onto the head of the spark-discharge machine. The electrode, which was of 0.020 inch diameter tantalum wire several hundred feet long, was pulled over the pulleys with a drive motor. The pulleys were adjustable, so that up to four pieces could be machined simultaneously.

Preliminary tests, in which the workpiece was rotated continuously, resulted in a groove that had two large bumps in the bottom, becoming progressively larger as machining proceeded. When the workpiece was kept stationary, machining proceeded normally and no bumps were encountered. The groove when finished was 0.020 inch wide at the center of the piece and tapered outward to 0.032 inch at the outer edge. This taper was caused by the groove opening up as a result of the removal of the internally stressed central layers of the disc. A photograph of the disc after machining is shown in Figure 9 . Work is in progress to prepare the remaining W-25 Re pieces needed to complete the fabrication of the ±5 psid pressure capsule.

4.0 Metal-Ceramic Seal Development

Metallographic and X-ray microprobe analysis performed on the representative Nb-1Zr/Lucalox seal, which was life tested, was presented in Reference 1. Another seal configuration, using the same fabrication technique as the life test unit, was prepared and subjected to a thermal cycling test. The configuration, shown in Figure 10, used a Lucalox plug metallized with a tungsten/yttria compound and brazed to a Nb-1Zr tube with a nickel/niobium/titanium braze alloy. A seven degree taper was chosen for the Lucalox and Nb-1Zr braze areas.

The thermal cycling test was performed according to the following schedule:

10 cycles	1472°F	(800°C)	in flowing argon;	leak tight
10 cycles	1832°F	(1000°C)	in flowing argon;	leak tight
10 cycles	2192°F	(1200°C)	in flowing argon;	leak tight
5 cycles	2552°F	(1400°C)	in flowing argon;	leak tight
10 cycles	2552°F	(1400°C)	in flowing argon;	leaked

Relatively short cycle times were used; six minutes to attain temperature, one minute at temperature, three to five minutes to cool to about 500°F. The seal was helium leak-tested after each of the sets of cycles outlined above.

The testing demonstrated the acceptibility of the seal for use in the pressure transducer temperature environment (1800°F). Test temperatures in excess of 1800°F were introduced to evaluate the upper limits of seal operation.

The fact that the seal was cycled between 35 and 44 times at temperatures up to 2552°F before failure indicated that 2552°F was not the upper operating temperature of this seal. While the initial melting point of the Ni/Nb/Ti braze alloy was 2300 to 2450°F, it appeared that its remelt temperature was about 2700 to 2900°F, since no remelting was observed during the testing.

4.1 Metal-Ceramic Seal Compatibility Program

Five compatibility test assemblies, each containing four metal-ceramic test seals, are being fabricated. Sketches of the assemblies are shown in Figures 11 through 15. The variations in length of fill tube, diameter of test cavities, and configuration are necessary to accommodate a standard potassium filling charge of 0.125 cubic inches (STP). The following procedure has been used to prepare the test seals.

1. The ceramics were metallized.
2. The metal seal parts were manufactured to fit.
3. The test seals were brazed by the particular method to be evaluated.
4. The test seals were leak-checked, cleaned and stored awaiting installation in the compatibility test capsules.

Closure of the test capsules will be made by electron-beam welding. The finished assemblies will be shipped for potassium filling under a protective atmosphere of helium. A number of metal-ceramic parts have been set aside for thermal cycling and metallurgical study.

To obtain a comprehensive evaluation, the five compatibility test assemblies reflect fundamental differences in seal fabrication technique. The variables chosen for evaluation include the ceramic body and the metallizing and brazing procedures. Table 3 presents the various parameters applicable to the seals assigned to each compatibility test capsule.

TABLE 3

METAL-CERAMIC SEAL COMPATIBILITY TEST CAPSULES

CAPSULE	METAL	CERAMIC	METALLIZING(b) ATMOSPHERE	BRAZING(c) ATMOSPHERE
1	Nb-1Zr	Lucalox	Multiple Gas(d)	Hydrogen
2	Nb-1Zr	Lucalox	Multiple Gas	Vacuum
3	Nb-1Zr	Alumina(a)	Compound Gas(e)	Vacuum
4	Nb-1Zr	Alumina(a)	Compound Gas	Hydrogen
5	Nb-1Zr	Lucalox	Compound Gas	Vacuum

(a) Alumina material is 99.7% Al_2O_3, 0.3% silica-free glass.

(b) For all test seals, the metallizing is tungsten/yttria.

(c) For all test seals, the braze material is nickel/niobium/titanium.

(d) Various gas atmospheres used in the metallizing procedure are not allowed to mix.

(e) Various gas atmospheres used in the metallizing procedure are allowed to mix.

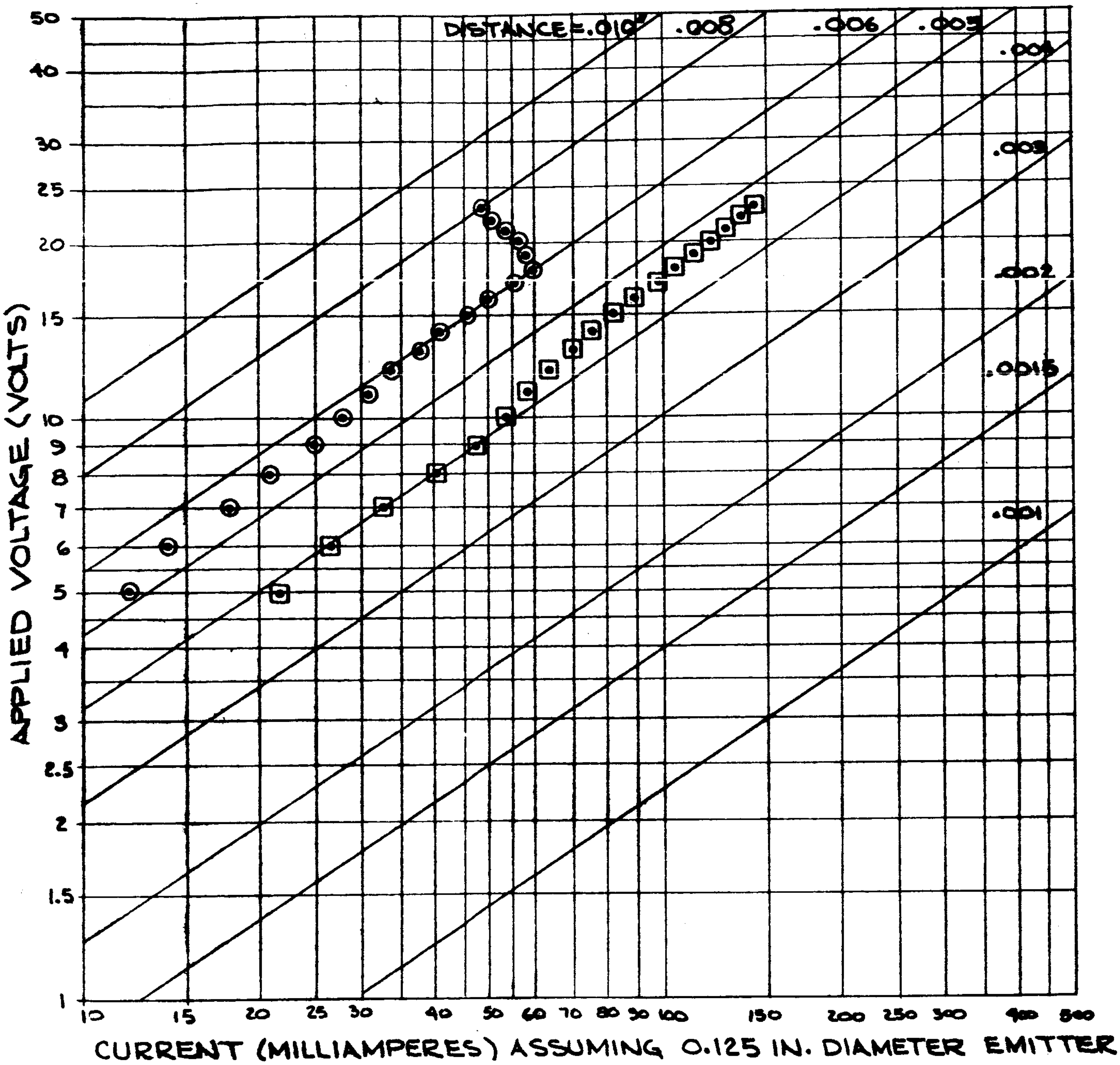
Figures 16 through 18 show the seal configurations to be tested. Figure 19 is a photograph of a compatibility test capsule and a representative test seal prior to assembly. The tapered seal design insured the most consistent fit over a wide variety of parts. Two sizes of Lucalox were available (0.187 and 0.236 inch diameters). The alumina ceramic (0.236 inch diameter) has several small holes which do not affect its sealing characteristics. Both the Lucalox and the alumina are silica-free ceramic bodies, and are both commercially available.

The commonly used methods of metallizing these two ceramics were not used because of the possibility of introducing silica additives or other contamination. A tungsten/yttria metallizing compound has been developed for this application. Experience has shown that the techniques for metallizing the two ceramics differ and cannot be used interchangably. This variation in processing is significant enough to warrant separate potassium testing of each set of seals.

The brazing alloy chosen as a common factor for all the seals is a unique nickel/niobium/titanium mixture developed for this purpose by this company. The fact that this alloy can be used in both a protective atmosphere and vacuum introduced another variable into the compatibility test program.

5.0 Transducer Signal Conditioning

During the report period, work on the electrical conditioning system concentrated on the fabrication of an initial breadboard model. A block diagram of the electrical circuitry and a description of the various control loops of the system were presented in Reference 1. Construction of the breadboard circuit was completed and testing was begun on the control loops to verify the various input-output parameters.



CAPSULE TEMP. 1800°F

EMITTER TEMP. 2100°F

—— CALCULATED FROM EQ.1, REF.4

⊙ REFERENCE COLLECTOR, ZERO PRESSURE

⊡ ACTIVE COLLECTOR, ZERO PRESSURE

FIGURE 1

SPACE-CHARGE CHARACTERISTICS FOR T-4

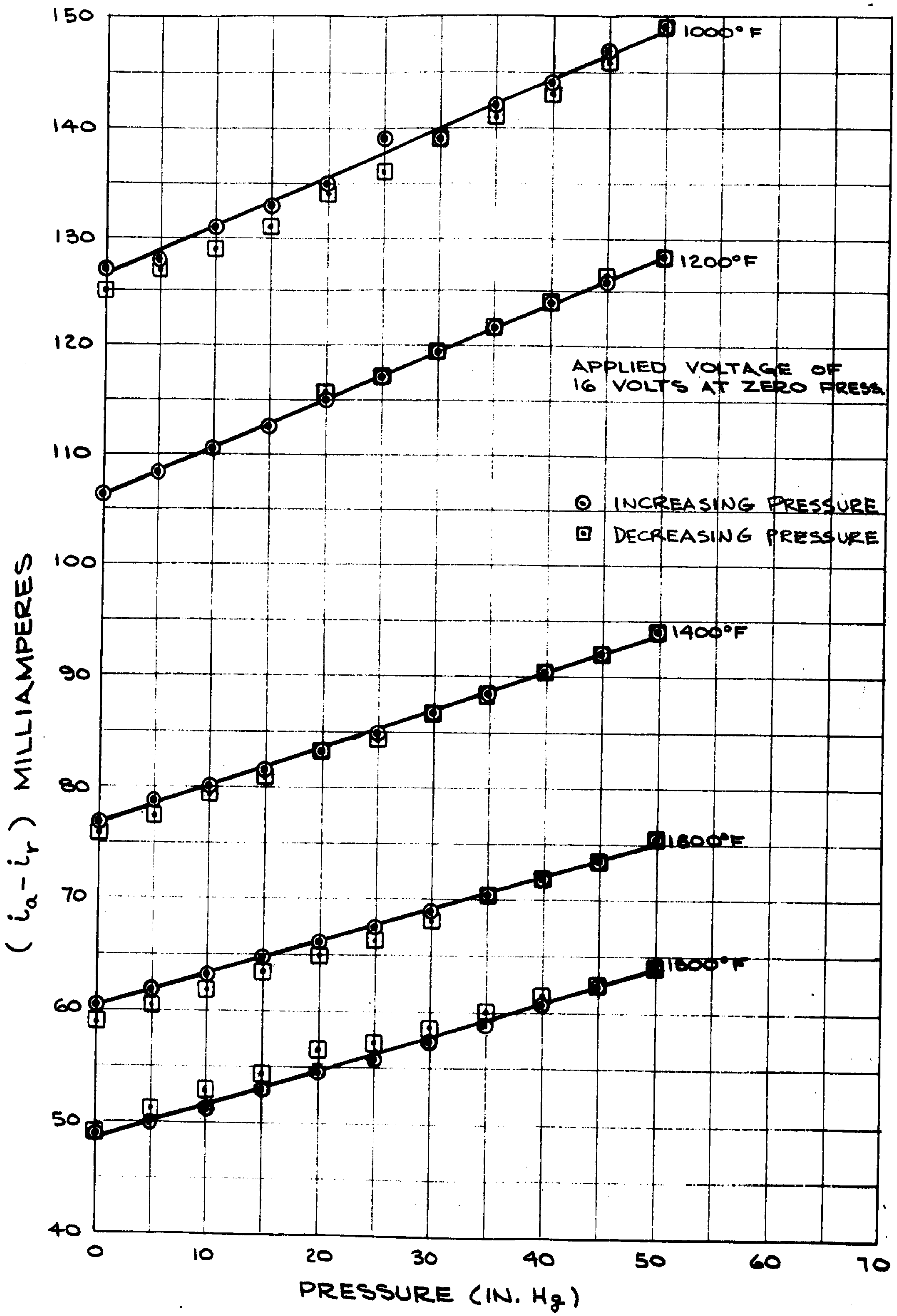


FIGURE 2

PRESSURE - OUTPUT CURRENT CHARACTERISTICS
FOR T-4

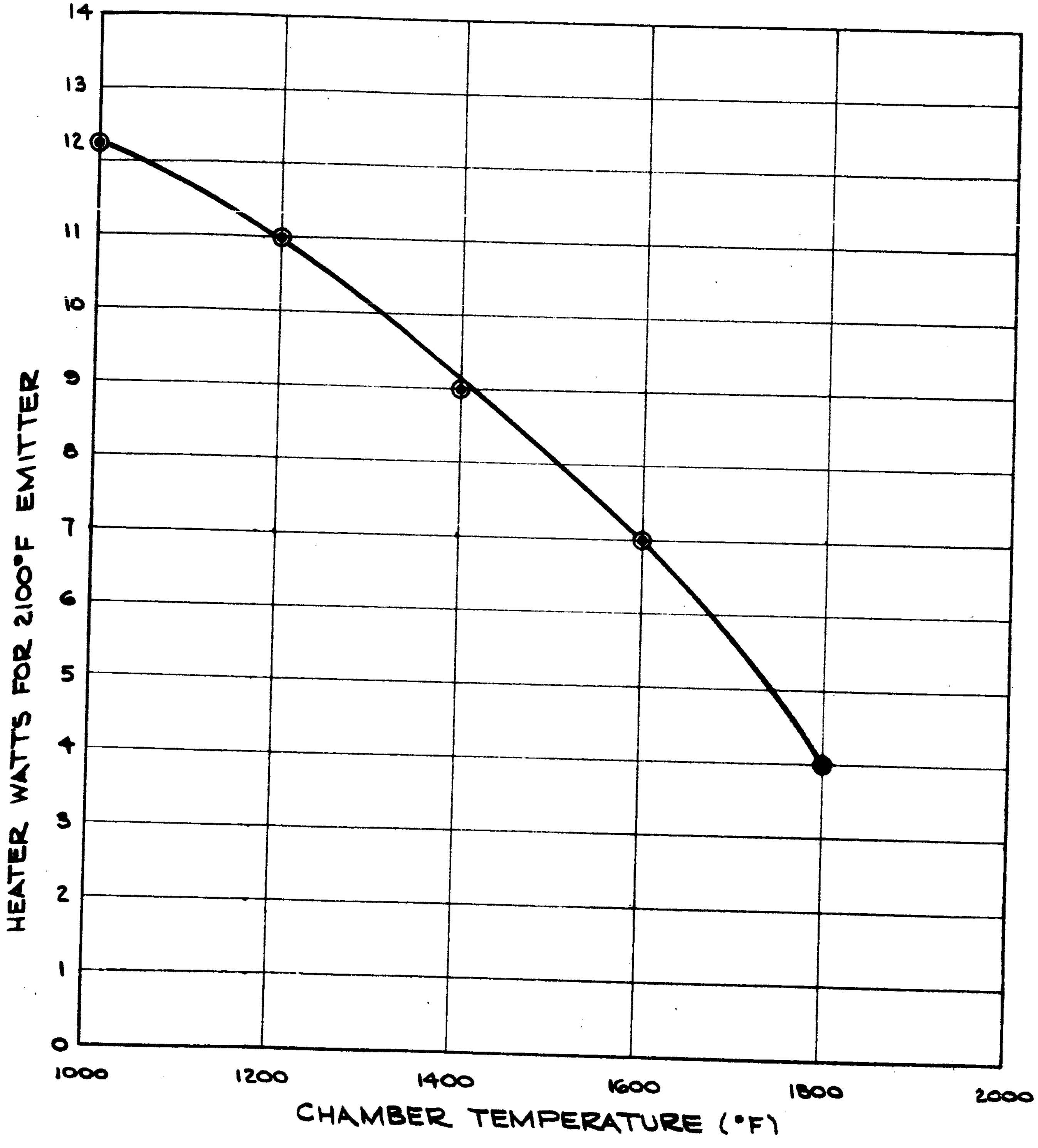


FIGURE 3

EMITTER HEATER POWER REQUIREMENTS FOR T-4

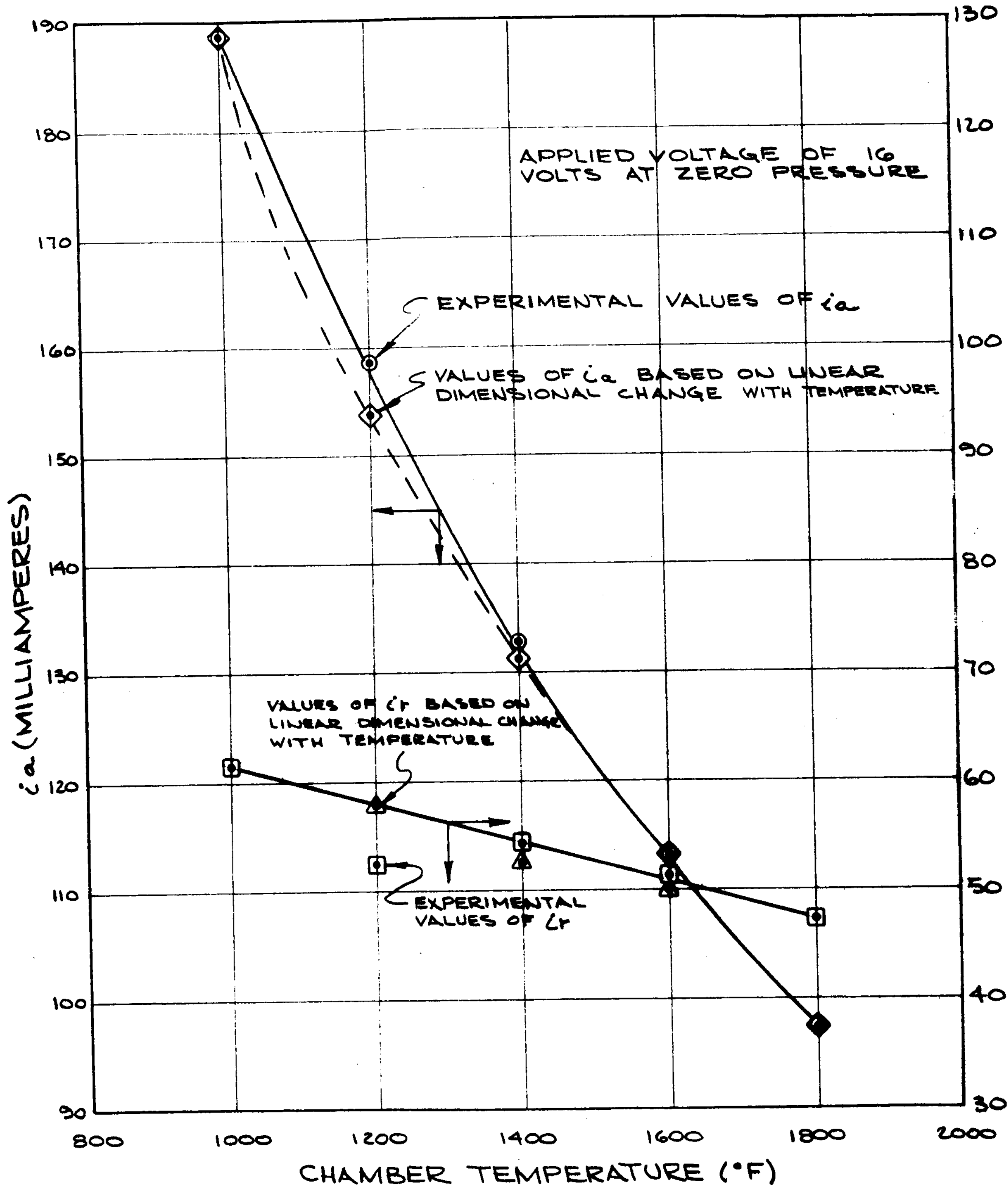


FIGURE 4

T-4 ACTIVE AND REFERENCE CURRENTS AS FUNCTIONS OF TEMPERATURE

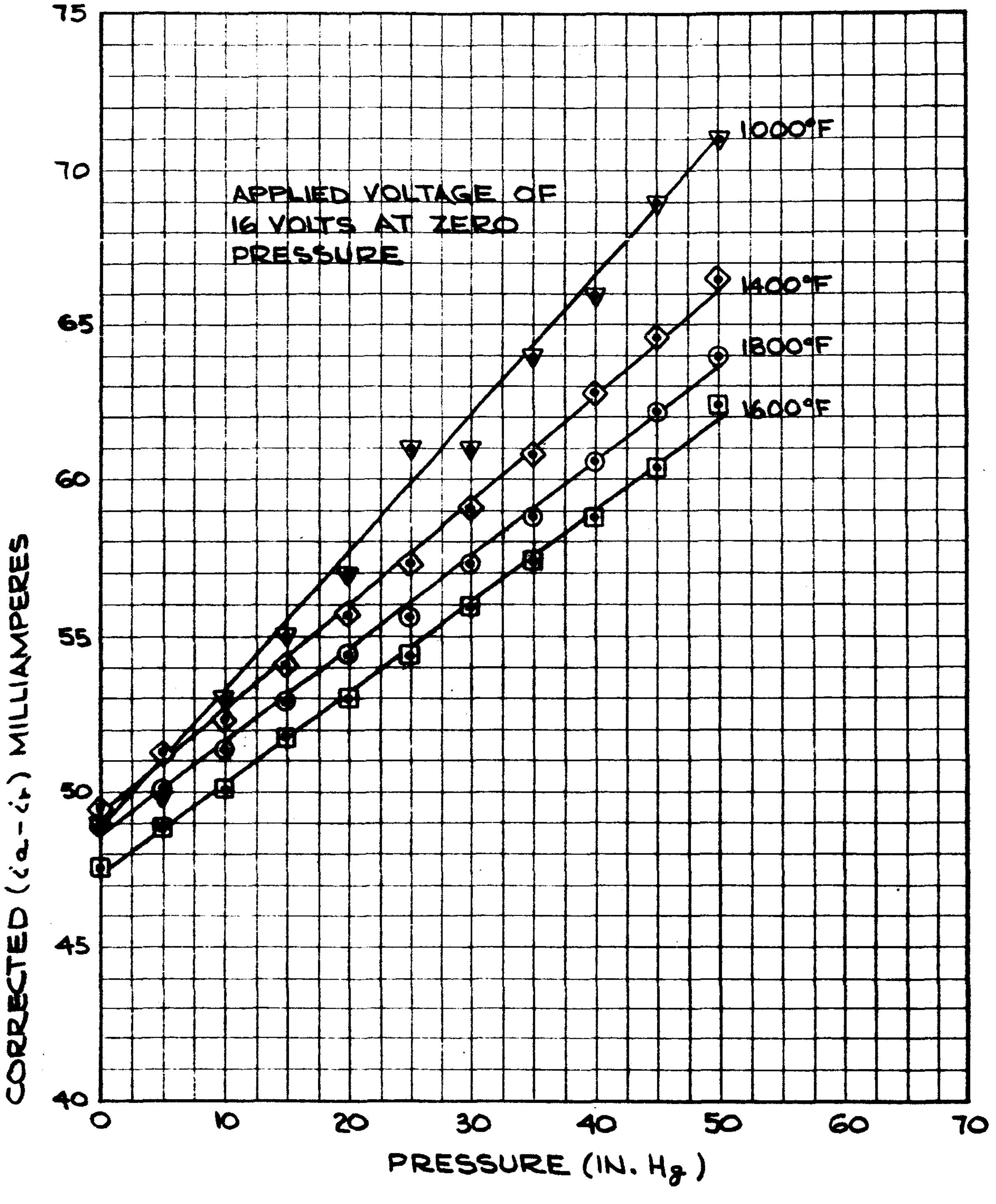
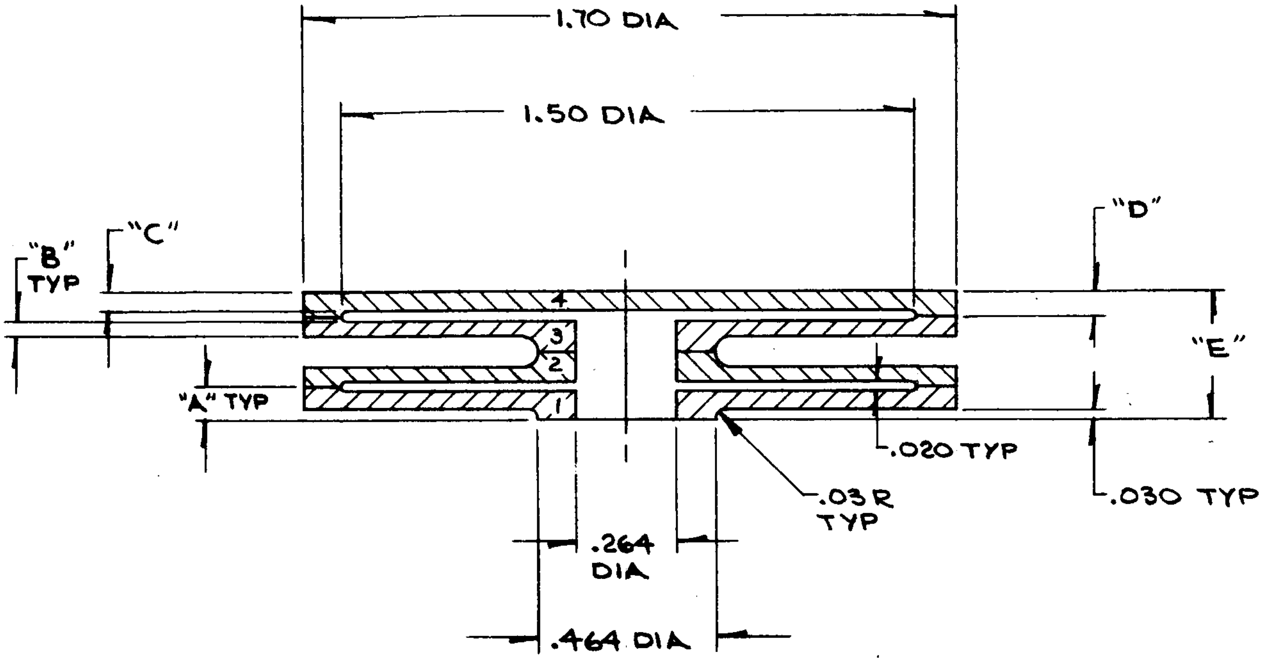


FIGURE 5

NORMALIZED PRESSURE-OUTPUT CHARACTERISTICS FOR T-4



PART NO.	A	B	C	D	E
-A	.090	.050	.058	.068	.338
-B	.060	.020	.020	.030	.210

FIGURE 6

PRESSURE CAPSULE CONFIGURATION

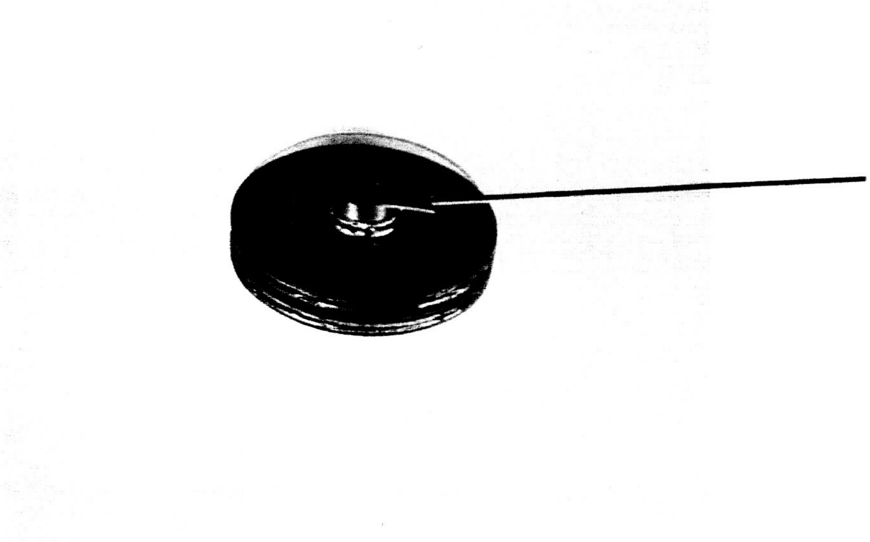


FIGURE 7

80 PSIA Pressure Capsule

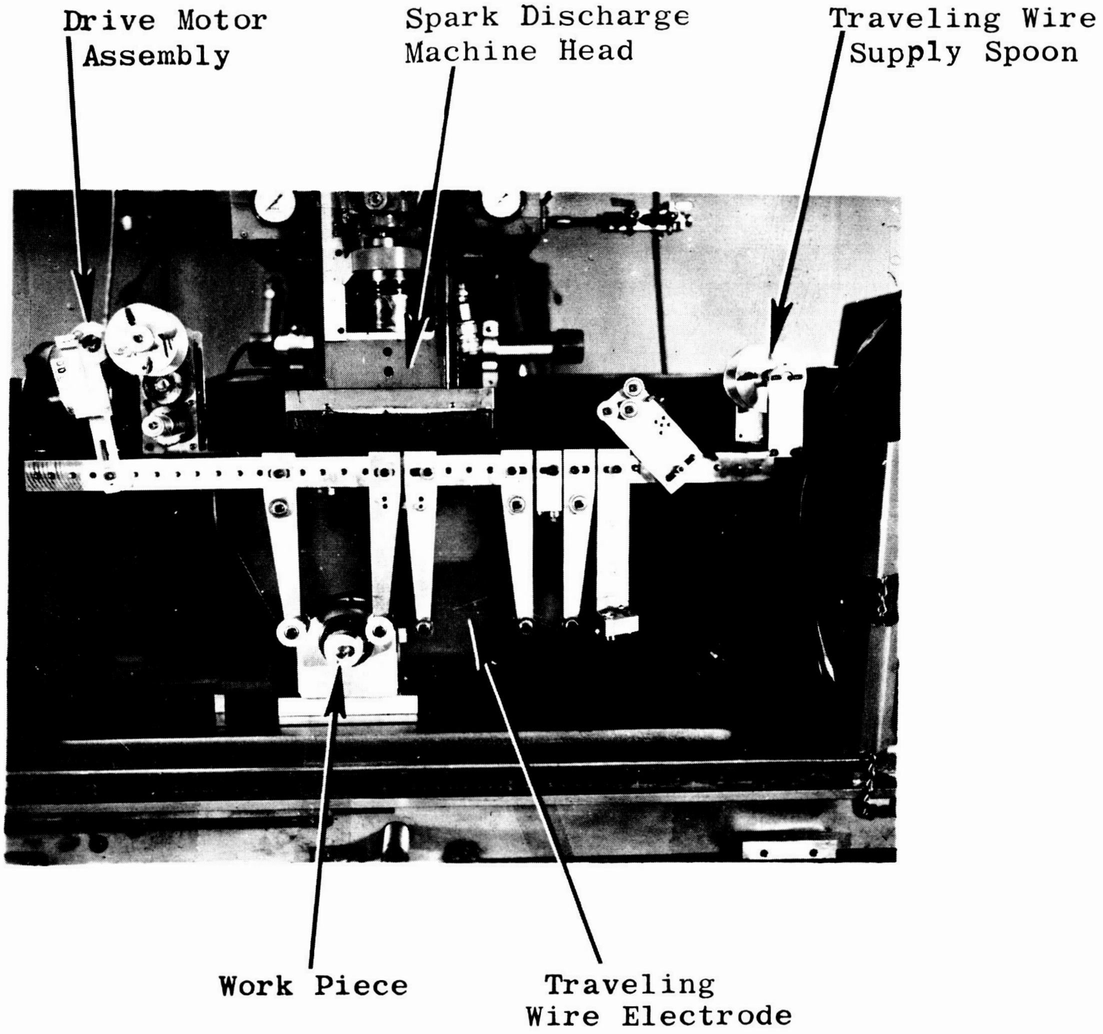


FIGURE 8

Spark Discharge Machining Set-Up

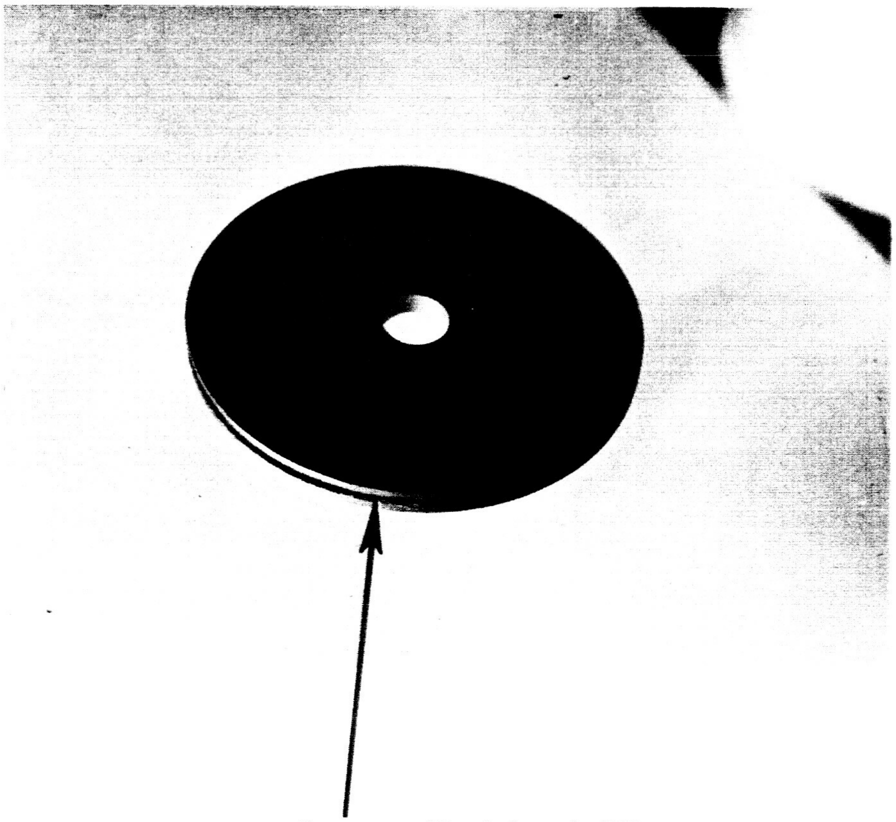


FIGURE 9

5 PSID Pressure Capsule Convolution

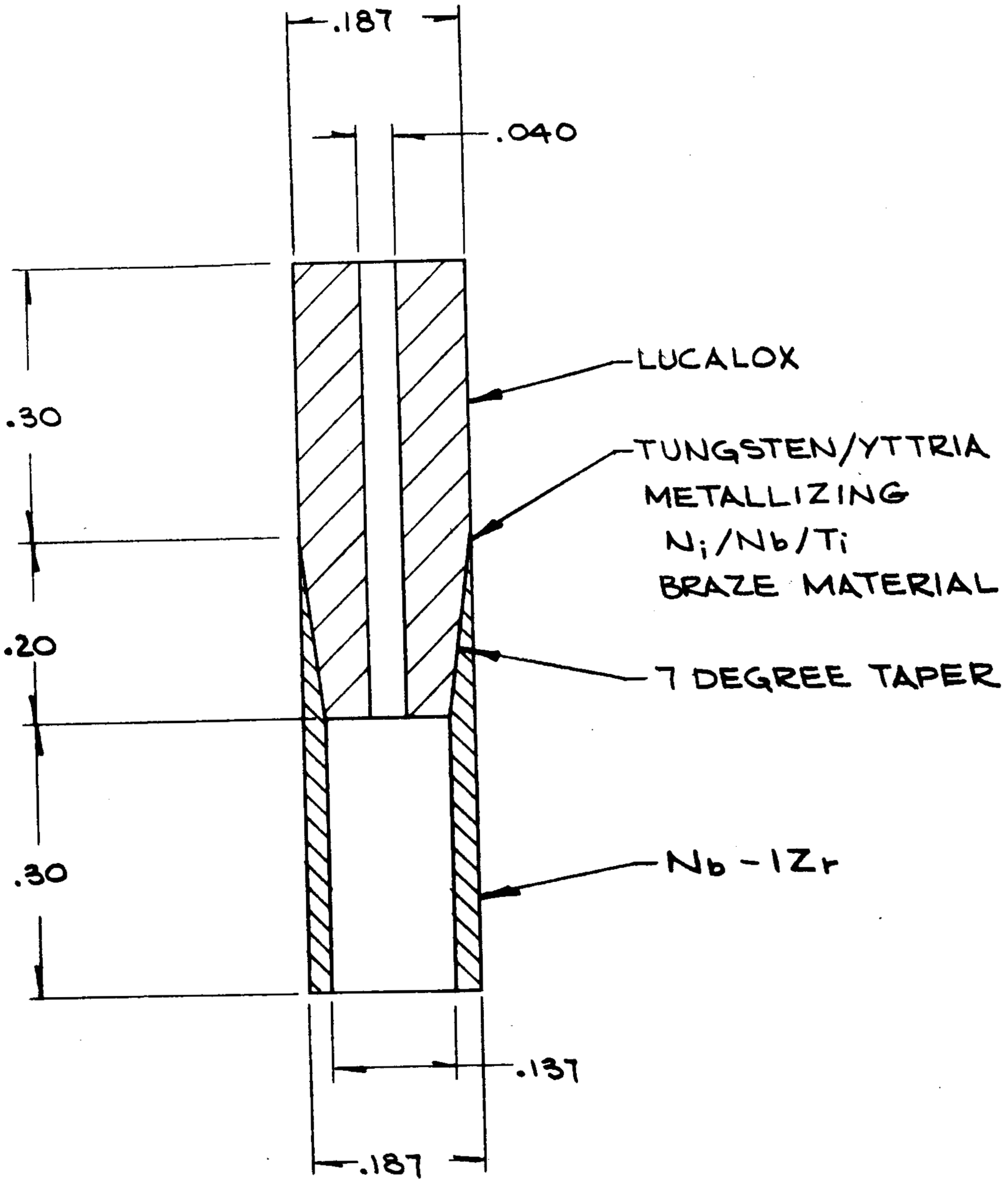


FIGURE 10

REPRESENTATIVE Nb-1Zr/LUCALOX SEAL

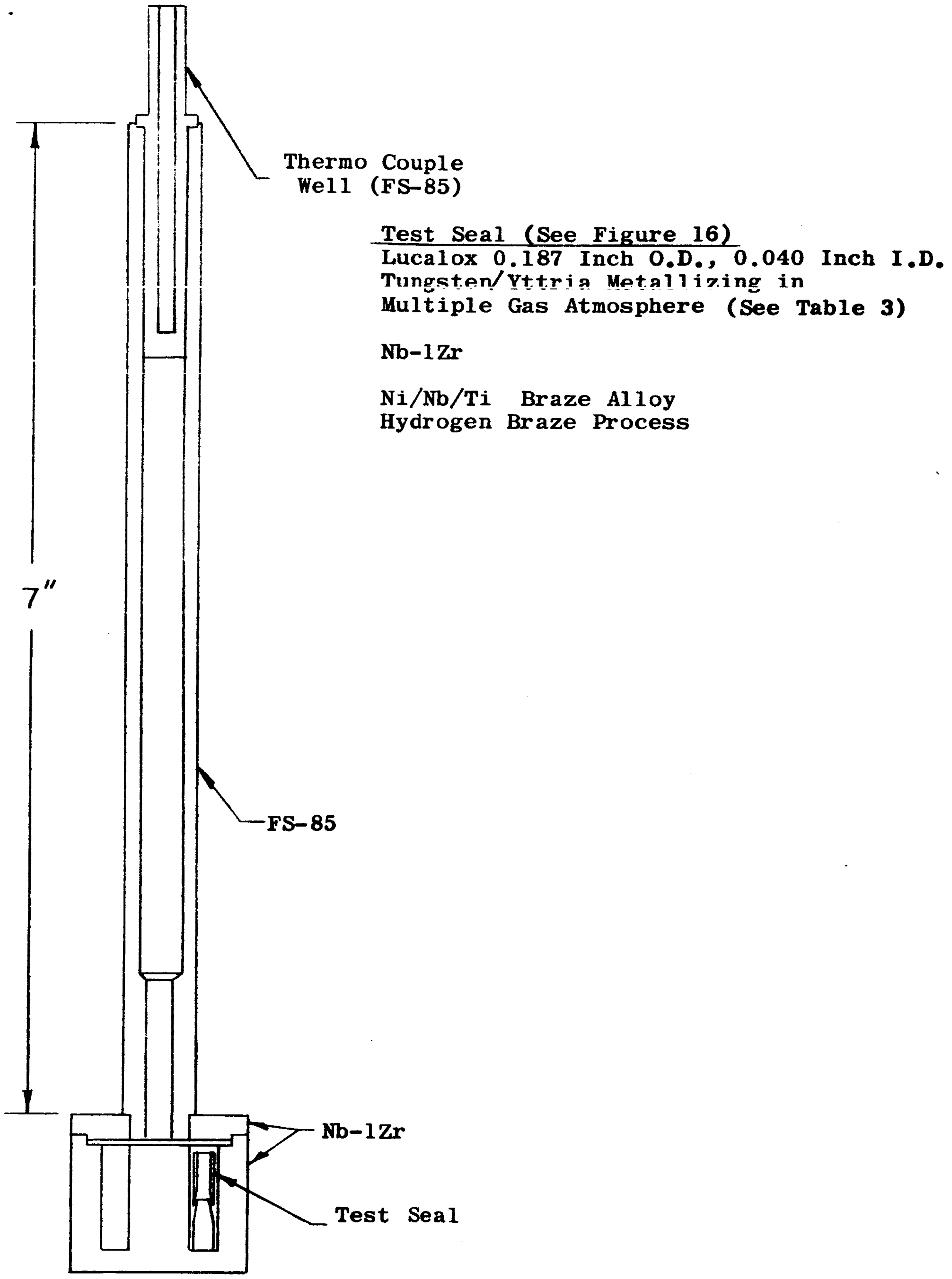
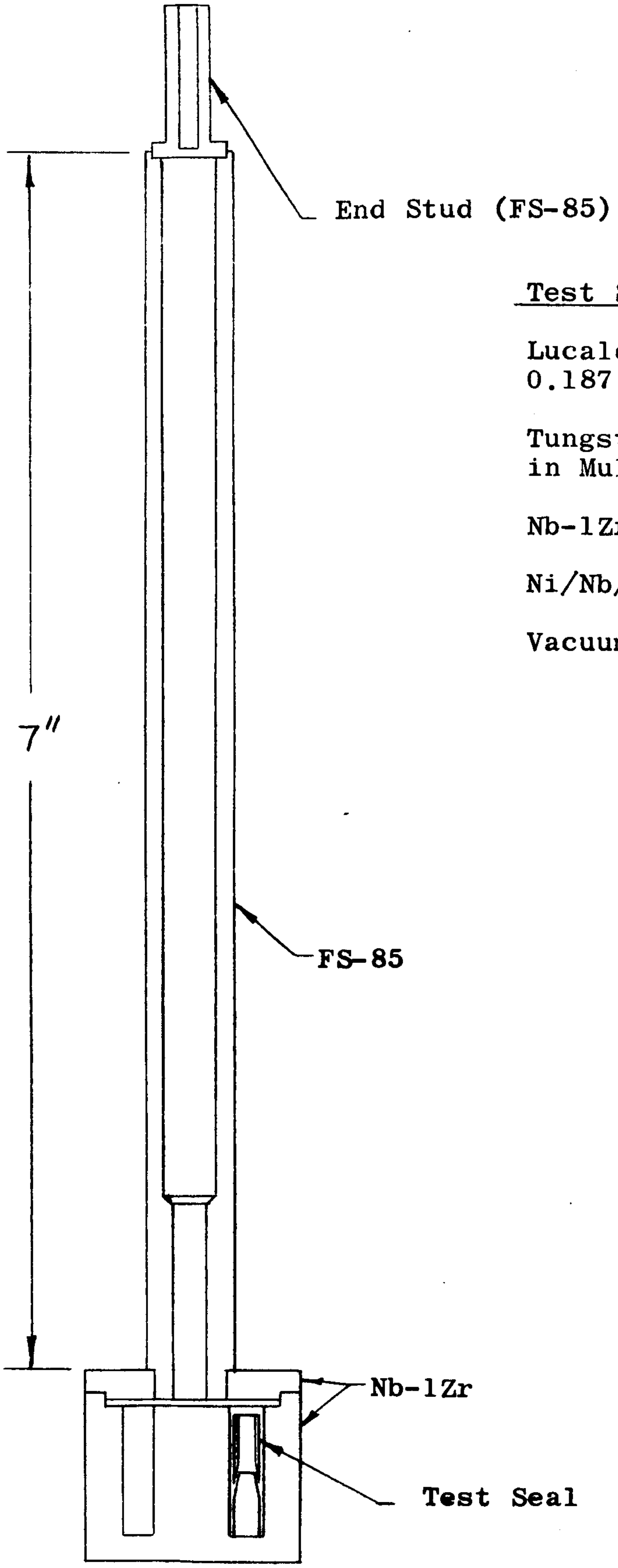


FIGURE 11
Metal-Ceramic Seal Compatibility
Test Capsule I



Test Seal (See Figure 16)

Lucalox
0.187 Inch O.D., 0.040 Inch I.D.

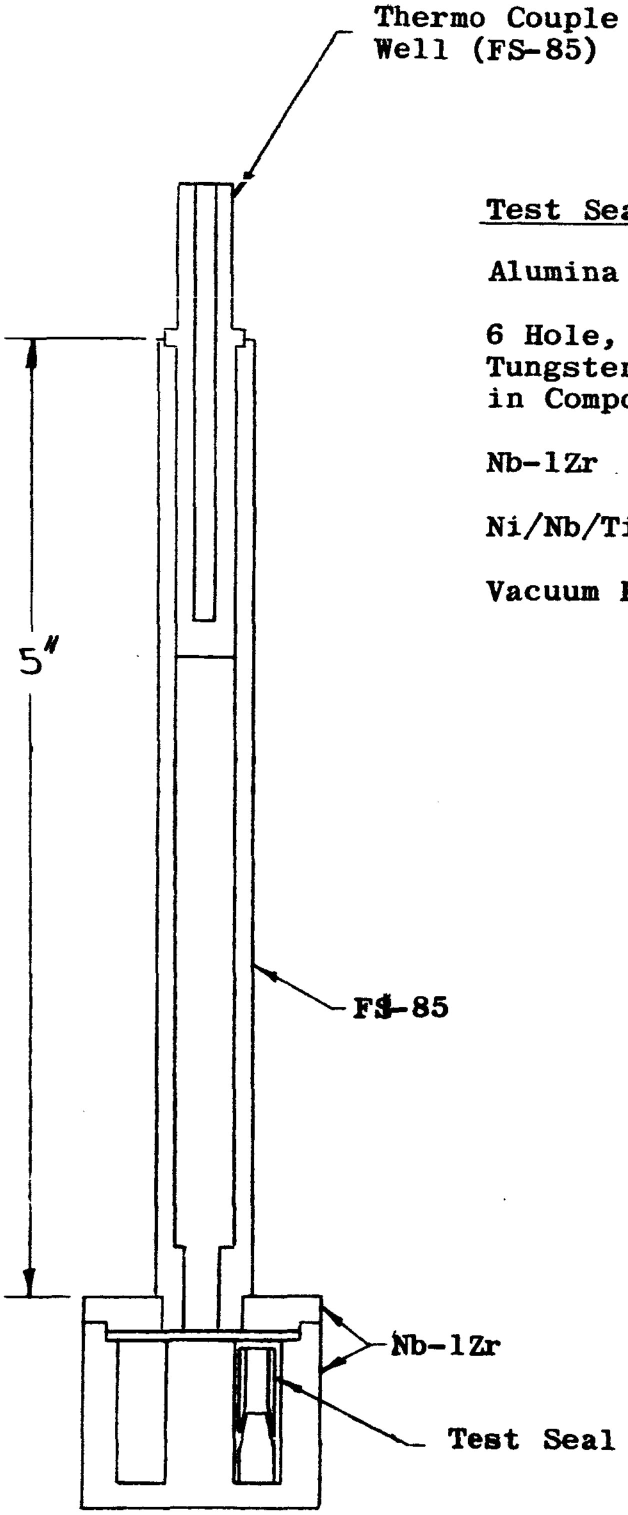
Tungsten/Yttria Metallizing
in Multiple Gas Atmosphere (See Table 3)

Nb-1Zr Metal Parts

Ni/Nb/Ti Braze Alloy

Vacuum Braze Process

FIGURE 12
Metal-Ceramic Seal Compatibility
Test Capsule II



Test Seal (See Figure 17)

Alumina Ceramic

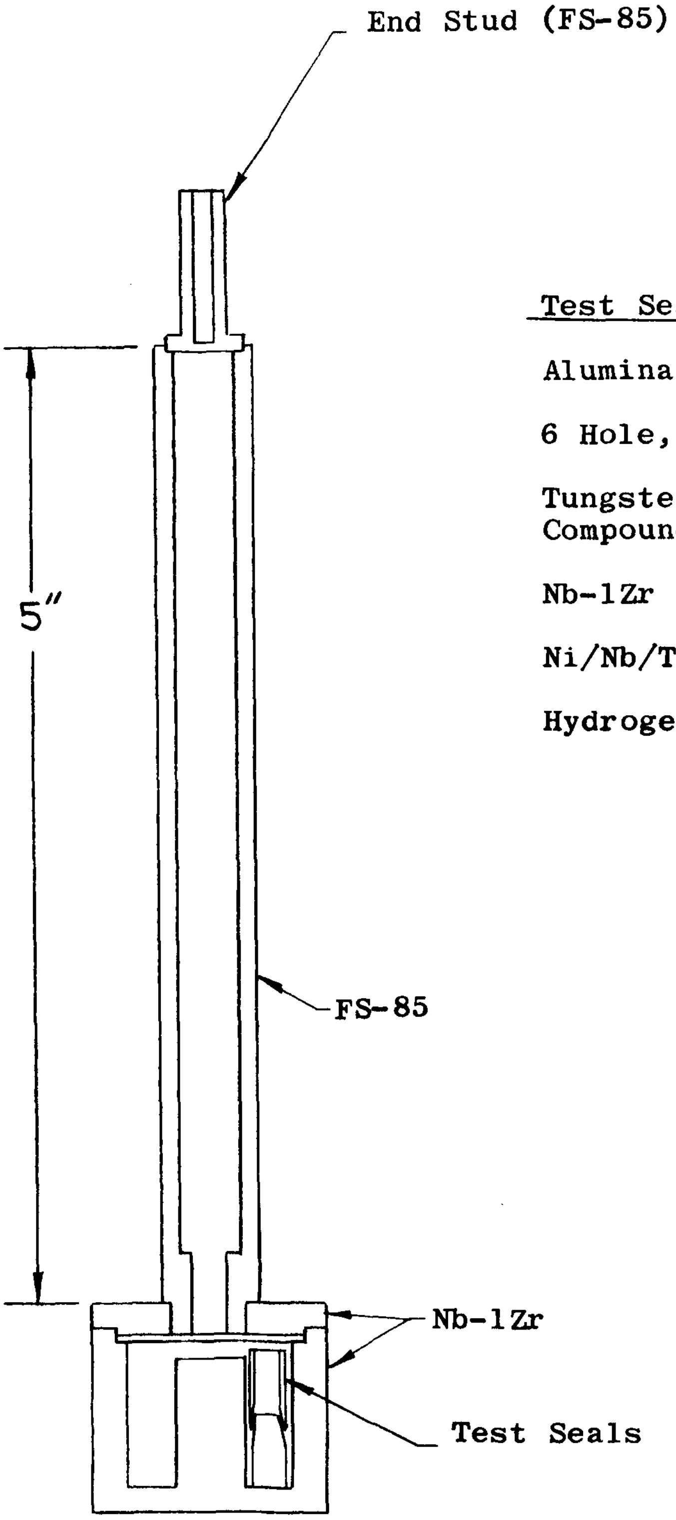
6 Hole, 0.236 Inch O.D.
Tungsten/Yttria Metallizing
in Compound Gas Atmosphere (See Table 3)

Nb-1Zr Metal Parts

Ni/Nb/Ti Braze Alloy

Vacuum Braze Process

FIGURE 13
Metal-Ceramic Seal Compatibility
Test Capsule III



Test Seal (See Figure 17)

Alumina Ceramic

6 Hole, 0.236 Inch O.D.

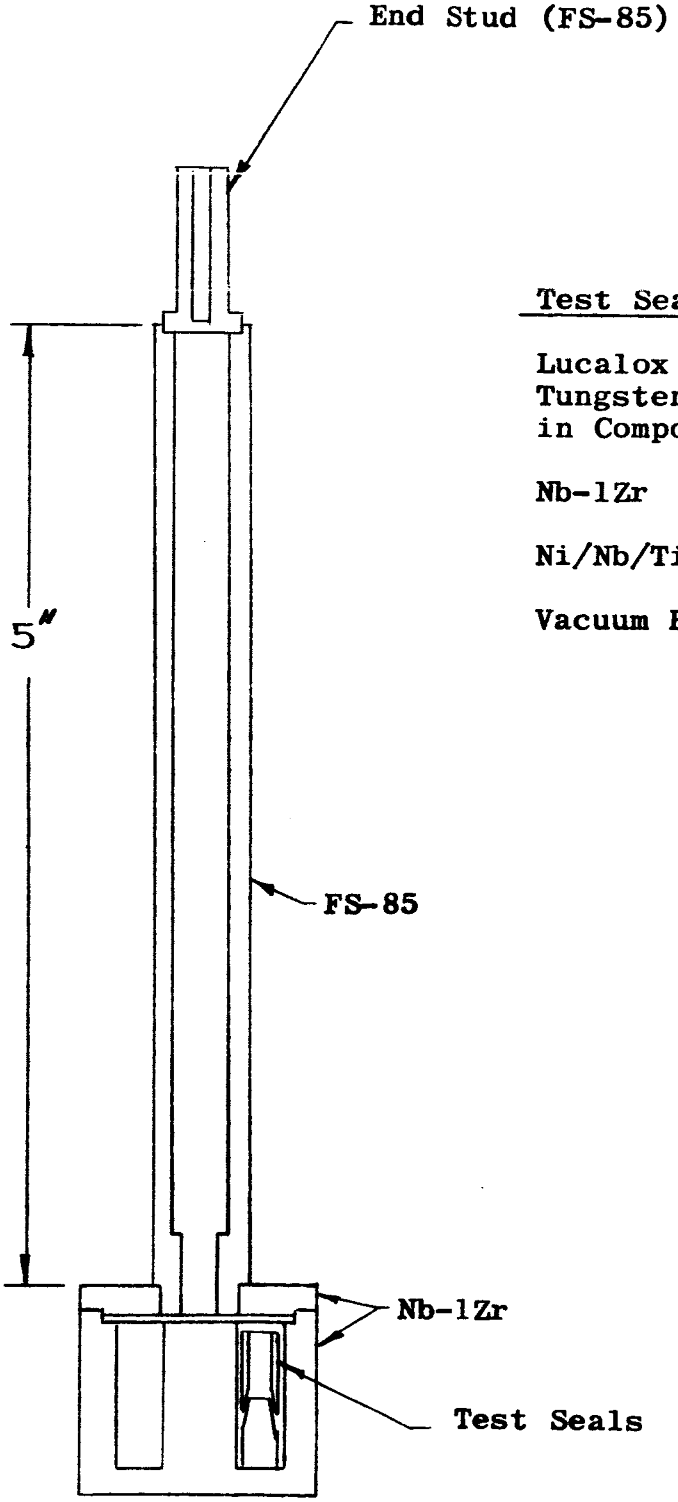
Tungsten/Yttria Metallizing in Compound Gas Atmosphere **(See Table 3)**

Nb-1Zr Metal Parts

Ni/Nb/Ti Braze Alloy

Hydrogen Braze Process

FIGURE 14
Metal-Ceramic Seal Compatibility
Test Capsule IV



Test Seal (See Figure 18)

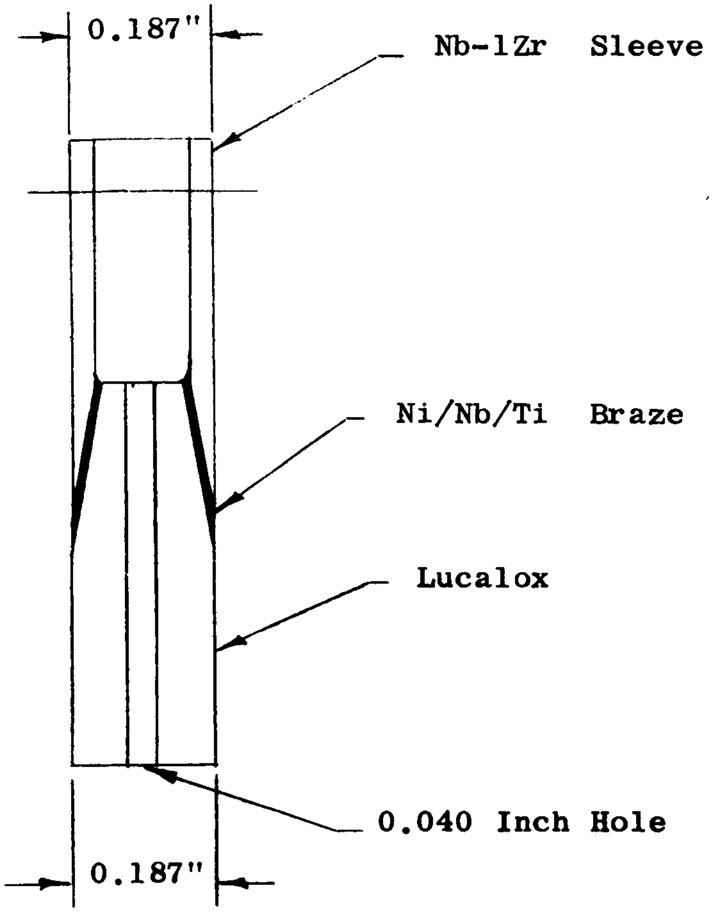
Lucalox 0.236 Inch O.D.
Tungsten/Yttria Metallizing
in Compound Gas Atmosphere (See Table 3)

Nb-1Zr Metal Parts

Ni/Nb/Ti Braze Alloy

Vacuum Braze Process

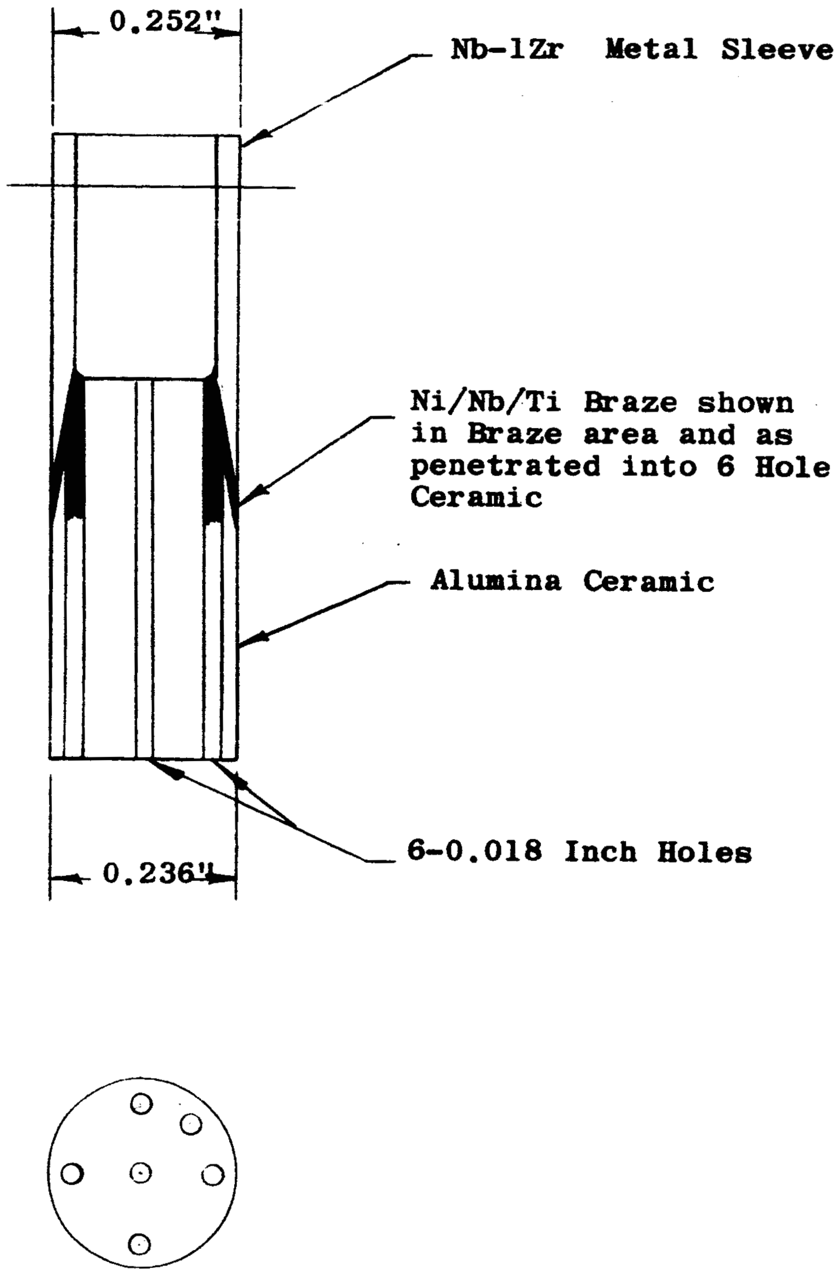
FIGURE 15
Metal-Ceramic Seal Compatibility
Test Capsule V



Seals used in Capsules I and II (See Figures 11 and 12)

FIGURE 16

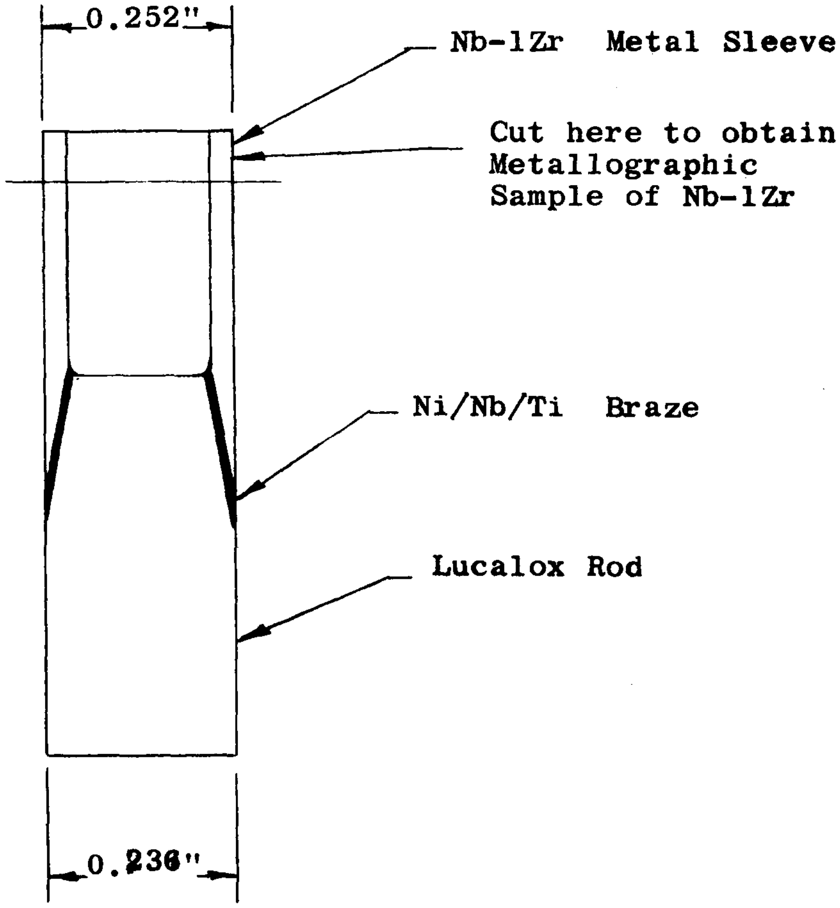
Metal-Ceramic Test Seal



Seals used in Capsules III and IV (See Figures 13 and 14)

FIGURE 17

Metal-Ceramic Test Seal



Seals used In Capsule V (See Figure 15)

FIGURE 18
Metal-Ceramic Test Seal

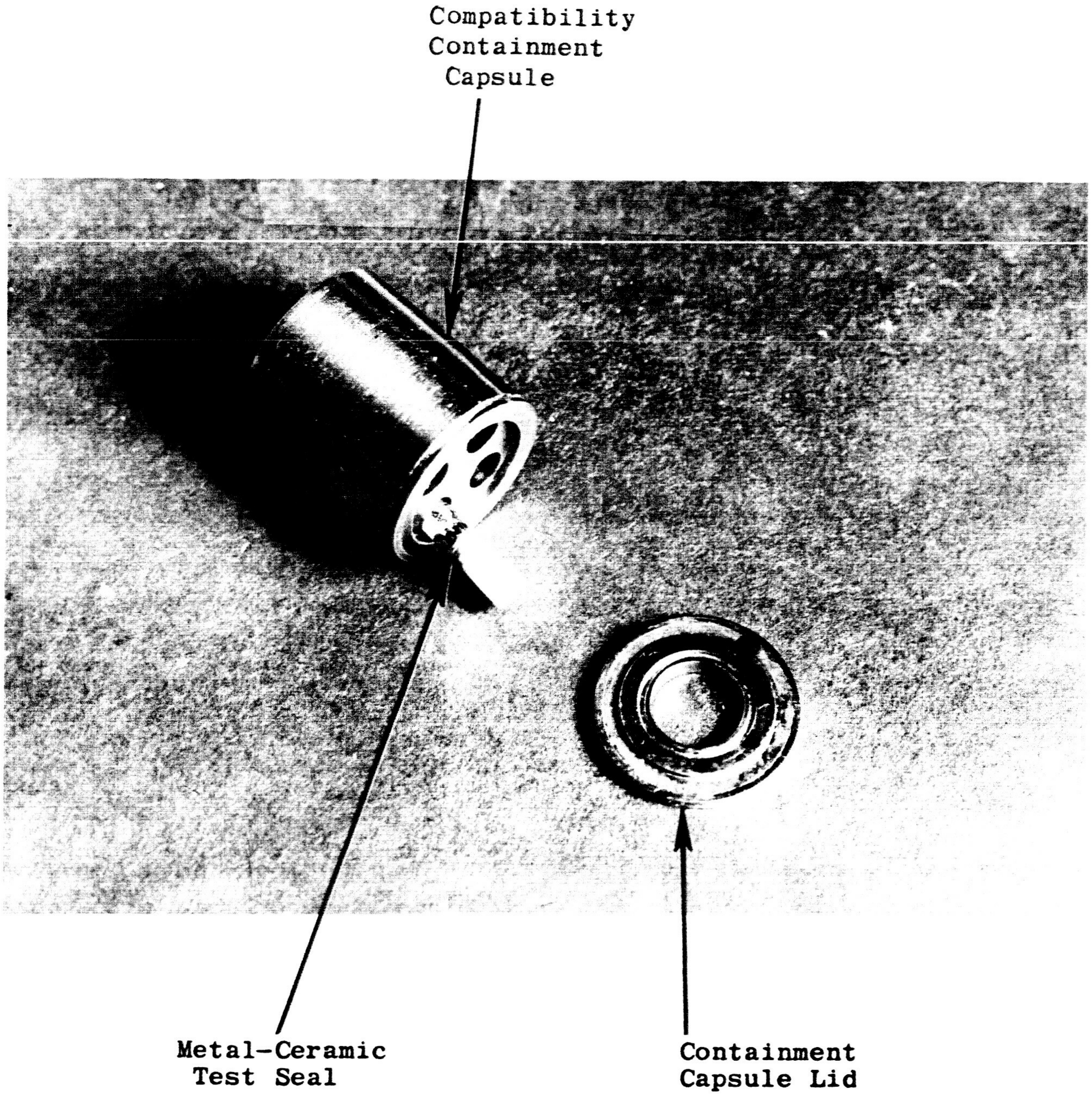


FIGURE 19

Compatibility Test Capsule Assembly

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5. Roark, Raymond J.: Formulas for Stress and Strain, Third ed., McGraw-Hill Book Co.,Inc., 1954, p. 192-231.

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