

**DETERMINATION OF BIAXIAL CREEP STRENGTH
OF T-111 TANTALUM ALLOY**

SEMI-ANNUAL REPORT

Period March 8, 1968 to September 8, 1968

by

L. B. Engel, Jr.

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
Contract NAS 3-9437
Robert L. Davies, Project Manager

NUCLEAR SYSTEMS PROGRAMS
SPACE SYSTEMS
GENERAL  ELECTRIC
CINCINNATI, OHIO 45215

CASE FILE
COPY

SEMI-ANNUAL REPORT

DETERMINATION OF BIAXIAL CREEP STRENGTH
OF T-111 TANTALUM ALLOY

prepared by
L. B. Engel, Jr.

approved by
R. W. Harrison

NUCLEAR SYSTEMS PROGRAMS
MISSILE AND SPACE DIVISION
GENERAL ELECTRIC COMPANY
Cincinnati, Ohio 45215

prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Period March 8 to September 8, 1968
May 22, 1969

Contract NAS 3-9437

NASA Lewis Research Center
Cleveland, Ohio
Robert L. Davies, Project Manager
Materials Section

TABLE OF CONTENTS

	<u>PAGE NO.</u>
I. INTRODUCTION	1
II. SUMMARY	3
III. PROGRAM STATUS	5
A. T-111 Alloy Test Capsule	5
1. Design	5
2. Manufacture	16
B. Test Facility	29
C. Preliminary Uniaxial Creep Testing	30
D. Potassium Pressure Transducer	41
IV. FUTURE PLANS	49
REFERENCES	50

LIST OF ILLUSTRATIONS

<u>Figure No.</u>		<u>Page No.</u>
1	Design of Elliptical Contoured Stress Attenuating Fillets for T-111 Alloy Biaxial Creep Test Capsule.	7
2	Design Model Used for Stress Analysis of T-111 Alloy Biaxial Creep Test Capsule.	7
3	Equivalent Uniaxial Outer Surface Stresses in the Design Model of the T-111 Alloy Biaxial Creep Test Capsule, as Predicted by the Multi-Shell Analysis for Three Test Temperatures	9
4	Equivalent Uniaxial Inner and Outer Surface Stresses in the Design Model of the T-111 Alloy Biaxial Creep Test Capsule, as Predicted by the Multi-Shell Analysis at a Test Temperature of 2300°F.	10
5	Equivalent Uniaxial Stresses in the 0.020-Inch Thick x 0.200-Inch Long Test Section of the Design Model for the T-111 Alloy Biaxial Creep Test Capsule at a Test Temperature of 2127°F.	11
6	Equivalent Uniaxial Stresses in the 0.020-Inch Thick x 0.200-Inch Long Test Section of the Design Model for the T-111 Alloy Biaxial Creep Test Capsule at a Test Temperature of 2220°F.	12
7	Equivalent Uniaxial Stresses in the 0.020-Inch Thick x 0.200-Inch Long Test Section of the Design Model for the T-111 Alloy Biaxial Creep Test Capsule at a Test Temperature of 2300°F.	13
8	Equivalent Uniaxial Stresses in the 0.020-Inch Thick x 0.500-Inch Long Test Section of the Design Model for the T-111 Alloy Biaxial Creep Test Capsule at a Test Temperature of 2300°F.	15
9	Stress Attenuating Fillet Design of the T-111 Alloy Biaxial Creep Refluxing Potassium Capsule	17
10	Biaxial Creep Test Capsule Made from T-111 Alloy Seamless Tubing. (C680719171)	18
11	Seamless T-111 Alloy Biaxial Creep Test Capsule Prior to Assembly	20
12	The Seamless T-111 Alloy Biaxial Creep Capsule Prior to Filling with Potassium. (C68080508).	22
13	30KV Electron Beam Welding Chamber and Controls Used to Fill T-111 Alloy Biaxial Creep Capsule with Potassium. (C67040153).	23

LIST OF ILLUSTRATIONS

<u>Figure No.</u>		<u>Page No.</u>
14	Potassium Purification System.	24
15	External Apparatus for Filling T-111 Alloy Biaxial Creep Capsule with Potassium in the EB Welding Chamber. (C66051941)	26
16	Internal Apparatus for Filling Capsules with Potassium in the EB Welding Chamber. (C66053119) .	27
17	High-Vacuum Creep-Rupture Facility Capable of Achieving a Pressure of 10^{-10} Torr and Incorporating a 100 Liter/Sec Getter-Ion Pump. (C64051213) .	31
18	Design of Conventional T-111 Alloy Uniaxial Creep Test Specimens	32
19	Conventional T-111 Alloy Uniaxial Creep Test Specimen Prior to Testing. (C68050719)	33
20	Uniaxial Creep of T-111 Alloy Tested at 2200°F with a 15,000 psi Stress in Vacuum of $<4 \times 10^{-9}$ Torr. The Conventional Specimen was Machined from the Seamless Tube (Preliminary Uniaxial Test No. 1). .	34
21	Uniaxial Creep of T-111 Alloy Tested at 2350°F at 10,000 psi Stress in Vacuum of $<1 \times 10^{-8}$ Torr. The Conventional Specimen was Machined from the Seamless Tube (Preliminary Uniaxial Test No. 2)	35
22	Uniaxial Creep of T-111 Alloy Tested at 2300°F with a 12,500 psi Stress in a Vacuum of $<1 \times 10^{-8}$ Torr. The Conventional Specimen was Machined from the Seamless Tube (Preliminary Uniaxial Test No. 3). .	37
23	Larson-Miller Plot of One Percent Creep Data for T-111 Alloy Annealed at 3000°F for One Hour and Tested in Vacuum Environments of $<1 \times 10^{-8}$ Torr. .	38
24	Preliminary One Percent Uniaxial Creep Data for T-111 Alloy Tubing (Heat 7810) and Stress Developed in Test Capsule as a Function of Temperature. Parameters are Computed for Stress Function Using a Time of 5000 Hours	39
25	Vapor Pressure of Potassium as a Function of Temperature.	40
26	Design of Special T-111 Alloy Uniaxial Creep Test Specimen	42

LIST OF ILLUSTRATIONS

<u>Figure No.</u>		<u>Page No.</u>
27	Special Uniaxial Creep Test Specimens Made from Seamless T-111 Alloy Tubing. (C680719170).	43
28	The Potassium Pressure Transducer to be Used on the Seamless T-111 Alloy Capsule. (C68073103).	44
29	The System Used to Directly Measure Argon Gas Pressure on Potassium Side of Biaxial Creep Capsule Pressure Transducer During Calibration. (C68081306).	46
30	Instrumentation for the Calibration of the Potassium Pressure Transducer (Standard Pressure System Not Shown). (C68081307).	46
31	The Potassium Pressure Transducer Located in the Electron Beam Welding Chamber without Tantalum Heat Shields. (C68081308)	47
32	The Potassium Pressure Transducer Located in the Electron Beam Welding Chamber with Tantalum Heat Shields in Place. (C68081309).	47

LIST OF TABLES

<u>Table No.</u>		<u>Page No.</u>
I	Deviations of Stresses in 0.020-Inch Thick T-111 Alloy Biaxial Creep Capsule Test Section	14
II	Chemical Analysis of T-111 Alloy Coupons Used in Qualification of the Vacuum Furnace Used for Postweld Annealing of Seamless T-111 Alloy Biaxial Creep Test Capsule.	21
III	Spectrographic Analysis of Potassium Used in Biaxial Creep Capsule I	28
IV	Calibration Data for the Potassium Pressure Transducer T-111 Alloy Biaxial Creep Capsule Test	48

DETERMINATION OF BIAXIAL CREEP STRENGTH
OF T-111 TANTALUM ALLOY

I. INTRODUCTION

This report covers the period from March 8, 1968, to September 8, 1968, of a program to document the creep behavior of seamless and welded and reworked T-111 alloy tubing under a biaxial state of stress, and to evaluate the effects of stress on the corrosion behavior of T-111 alloy with potassium. Potassium refluxing capsules of seamless and welded and reworked T-111 alloy tubing are to be tested under conditions which will result in one to five percent equivalent uniaxial strain during a 5000-hour exposure. The capsule test temperature will be 2200°F. The capsule walls will be reduced in the potassium liquid region and in the vapor condensing region to provide the gauge sections where the extent of creep can be measured. The testing will be done in a manner similar to that developed under an earlier NASA contract.⁽¹⁾

(1) Harrison, R. W., "The Compatibility of Biaxially Stressed D-43 Alloy with Refluxing Potassium," NASA Contractor Report NASA CR-807, NASA Contract NAS 3-6012, June 1967.

II. SUMMARY

The complete analysis of the T-111 alloy test capsule design has been completed. A test capsule has been prepared from the seamless T-111 alloy tubing and is now ready for testing. Machining of test capsules from the welded and reworked T-111 alloy tube is now in progress.

All modifications to the test facility have been completed. Calibration of the W-25Re/W-3Re thermocouples has also been completed, and the test capsule is presently being installed into the test facility.

Three preliminary uniaxial creep tests have been completed, and the results of these tests were used to select the test temperature for the first biaxial creep capsule test. The test temperature will be 2200°F.

The assembly and final calibration of the potassium pressure transducer, which will be used to measure the potassium pressure in the test capsule, has been completed. Excellent performance of the transducer was observed during the calibration.

III. PROGRAM STATUS

A. T-111 Alloy Test Capsule

1. Design

The design of the test capsule for this program is very similar to that used for similar biaxial creep testing of D-43 alloy under an earlier NASA contract.⁽¹⁾ The test capsule has two 0.020-inch-thick wall x 0.200-inch-long reduced wall test sections at which creep will be measured. One of the test sections is located in the boiling liquid potassium region and the other is in the condensing potassium vapor region of the refluxing test capsule. Stress attenuating fillets are used to approach the reduced wall test sections so that the test sections can be evaluated as thin wall, infinitely long cylinders.

The design of the fillet was determined by calculating the attenuation lengths for both the test section wall thickness, 0.020 inch, and the original or thicker capsule wall thickness, which is 0.095 inch. This is accomplished by considering the cylinders for each wall thickness as "beams on an elastic foundation,"⁽²⁾ which allows the "attenuation wave length factor, " β ," to be expressed as:

$$\beta = \sqrt[4]{\frac{3(\frac{1}{2} - \mu^2)}{t^2 R^2}}$$

where: μ = Poisson's ratio
t = wall thickness, inches
R = mean radius, inches

Using $\mu = 0.35$ for T-111 alloy,⁽³⁾ β can be expressed as:

$$\beta = \frac{1.2738}{\sqrt{tR}}$$

(2) Den Hartog, J. P., Advanced Strength of Materials, p 166, McGraw Hill, New York (1952).

(3) Zimmerman, W. F., "Turbine Materials-Potassium Turboalternator Program," NASA Contract NAS 3-10933, Nuclear Systems Programs Dept., General Electric Company, March (1968).

With the selection of an attenuation length of $\beta x = 4$, the shear forces, bending moments, slopes, and deflections produced at one end of the attenuation interval, x , will have been attenuated to 0.2 to -2.6% of their maximum values (for constant wall thickness) at the opposite end of the interval. This percent attenuation is considered adequate for the biaxial creep tests which will be conducted. The required attenuation length can then be determined by using:

$$x = \frac{\beta x}{\beta}$$

where: $\beta x = 4$

which gives:

$$x = \frac{4}{\beta} = \frac{4 \sqrt{tR}}{1.2738} = 3.1403 \sqrt{tR}$$

For the thin wall test section where $t = 0.020$ inch and $R = 0.665$ inch, $x = 0.362$ inch. For the thicker capsule wall where $t = 0.095$ inch and $R = 0.7025$ inch, $x = 0.811$ inch. Therefore, an elliptical contour was selected to reduce the wall thickness from 0.095 inch to 0.020 inch with a semimajor axis, a , > 0.811 inch, say $a = 1.100$ inch, and a semiminor axis, b , $= 0.095 - 0.020 = 0.075$ inch. The design of the elliptical contour is shown in Figure 1.

The 0.200-inch length of the thin wall test sections was selected to give sufficient length to the test section for locating the probes which measure the capsule diameter during testing, and yet be short enough to assure that maximum creep will occur during testing in the region where the probes are located.

The design of the test capsule was further analyzed to determine how closely the stresses in the test section resemble those which would be predicted for an infinitely long, thin-walled cylinder. The design model used for this evaluation is shown in Figure 2. This model was analyzed using a multishell computer program⁽⁴⁾ which yields the equivalent uniaxial inner and outer surface stresses and elastic deflections at zero time in the creep test. The model was considered as 19

(4) Beitch, L., Cook, W., and Holt, R., "Computer Program for Analysis of Structures Made Up of Shells of Revolution (Multi Shell II)," General Electric Company, AEG, Report No. R59FPD889, February 29 (1960).

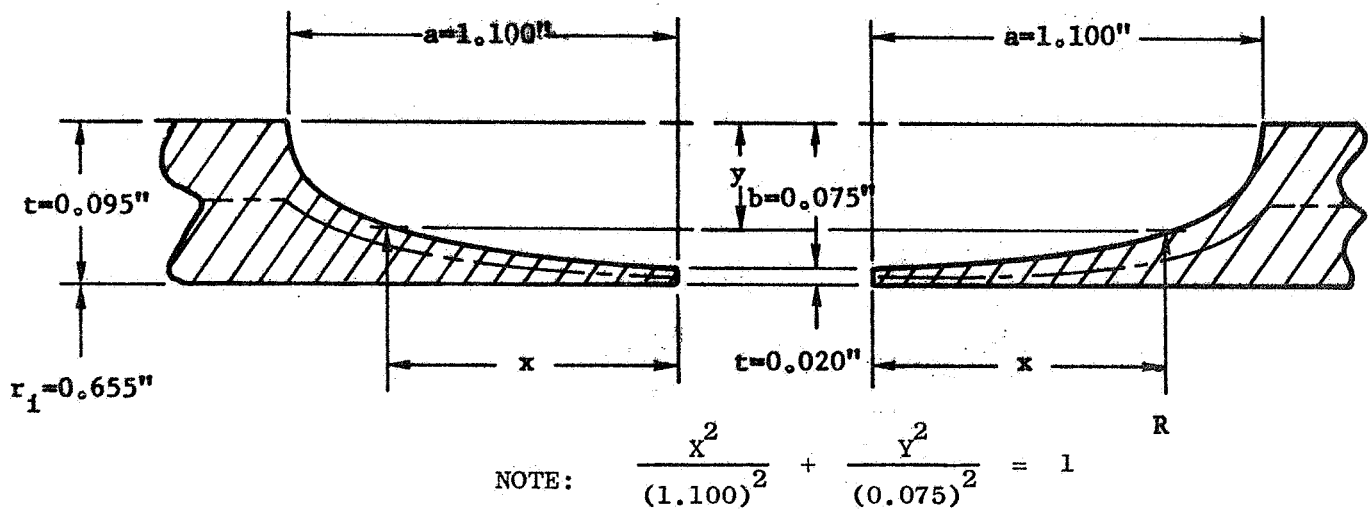


Figure 1. Design of Elliptical Contoured Stress Attenuating Fillets for T-111 Alloy Biaxial Creep Test Capsule

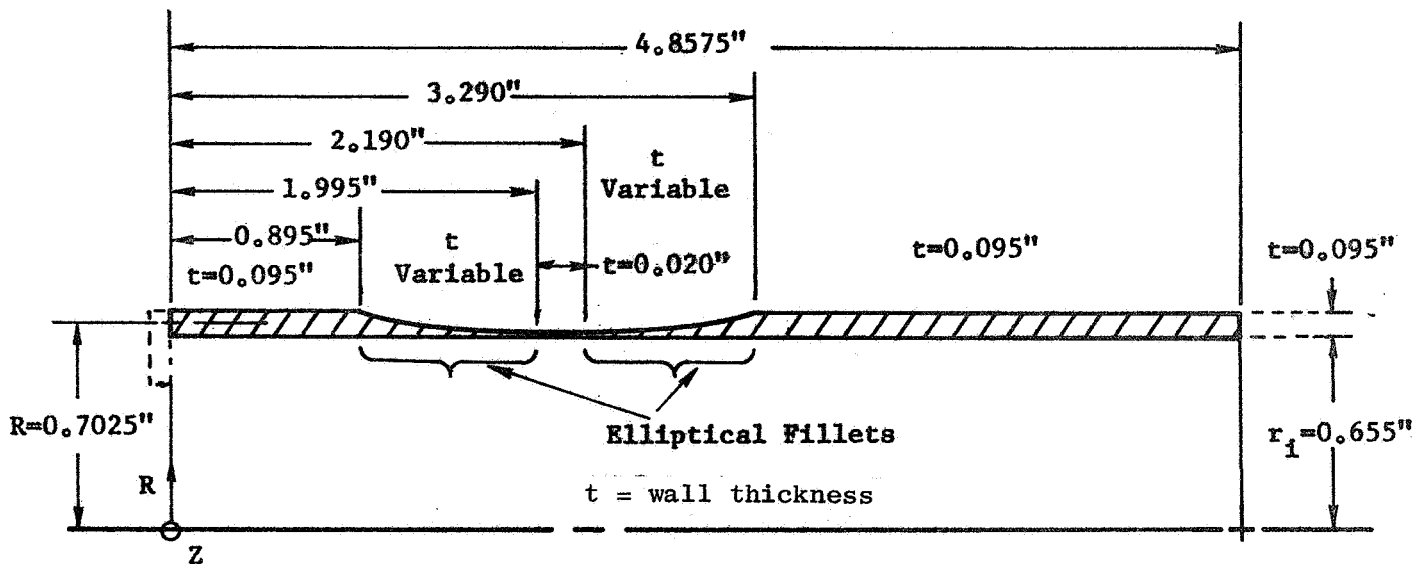


Figure 2. Design Model Used for Stress Analysis of T-111 Alloy Biaxial Creep Test Capsule.

shells with computations being made for 19 positions within each shell. The model was analyzed at 2127, 2220, and 2300°F which are in the temperature range where the actual testing is expected to be performed. The equivalent uniaxial outer surface stresses in the design model for the three temperatures of interest, and as predicted by the multishell analysis, are shown in Figure 3. A comparison of the inner and outer surface stresses in the model at 2300°F is shown in Figure 4 and is typical of the two lower temperatures. A more detailed plot of the test section inner and outer surface stresses predicted by the multishell program for the three temperatures and how they compare with the respective stresses predicted for an infinitely long, thin wall cylinder are shown in Figures 5, 6, and 7. It can be seen that the stresses in the test section which are predicted by the multishell analysis are generally higher than those predicted for infinitely long, thin wall cylinders, and the deviation becomes greater as the temperature is increased. Also the deviation between the inner and outer surface stresses increases as the temperature increases. A quantitative tabulation of these deviations for the maximum differences is given in Table I. Although the maximum deviations of the stresses predicted by the multishell analysis from those for a thin wall, infinitely long, cylinder increase as temperature increases the percentage change remains essentially constant at approximately one percent. Also, the maximum variations between the inner and outer surface stresses predicted by the multishell analysis are of almost the same magnitude as the respective deviations between the multishell analysis and the thin wall, infinitely long, cylinder analysis.

Since a longer test section would be expected to improve the correlation between the multishell analysis and the thin wall, infinitely long, cylinder analysis, a second model was analyzed with the multishell program to determine the amount of improvement in correlation which might be obtained. A test section length of 0.5 inch was evaluated at 2300°F, and a detailed plot of the stresses in the test section is shown in Figure 8. The maximum deviations for the test section are tabulated in Table I. Although the maximum deviation from a thin wall cylinder is reduced to approximately 0.5 percent, this small reduction is not considered worth the problems which are generated in manufacturing the

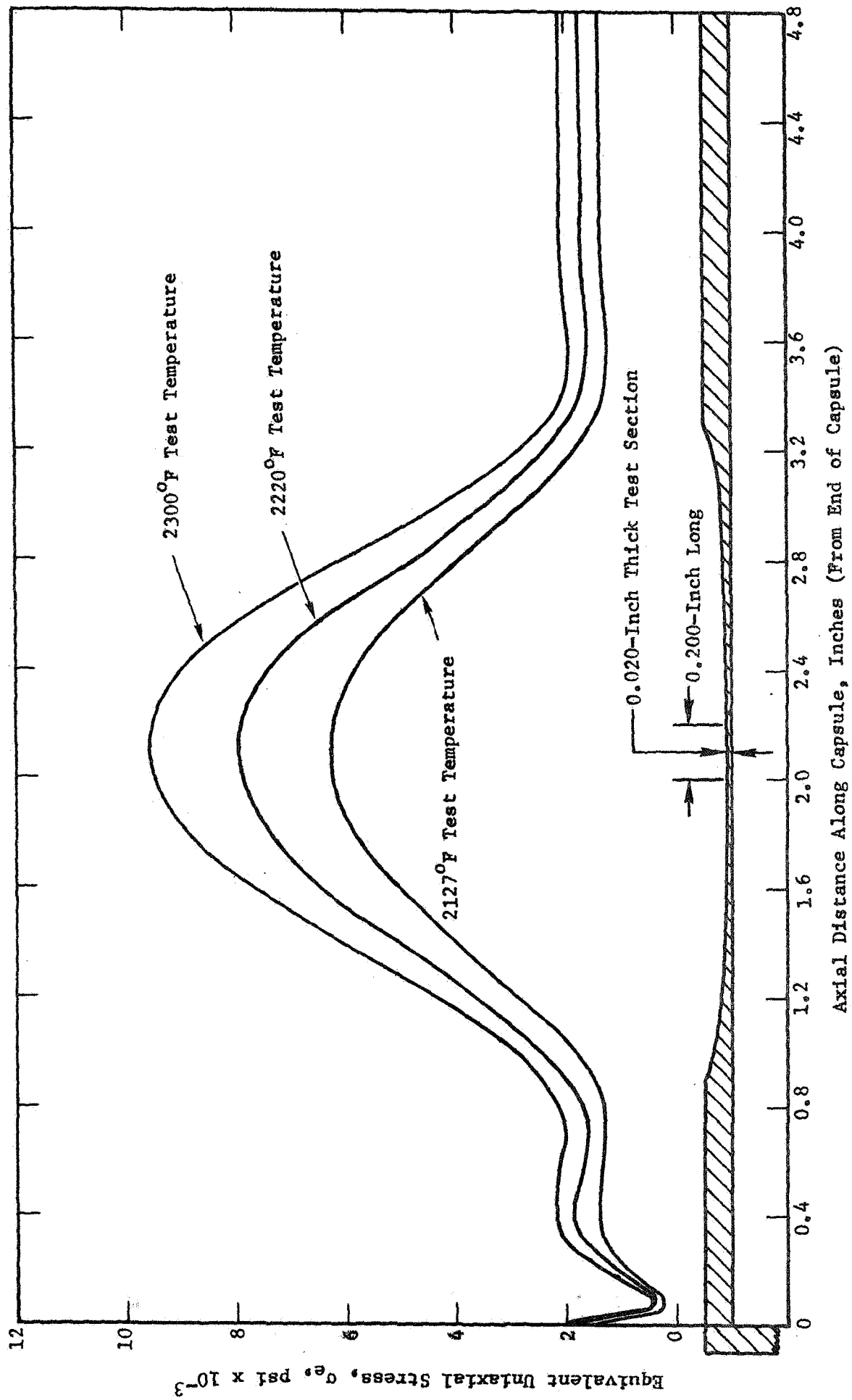


Figure 3. Equivalent Uniaxial Outer Surface Stresses in the Design Model of the T-111 Alloy Biaxial Creep Test Capsule, as Predicted by the Multi-Shell Analysis for Three Test Temperatures.

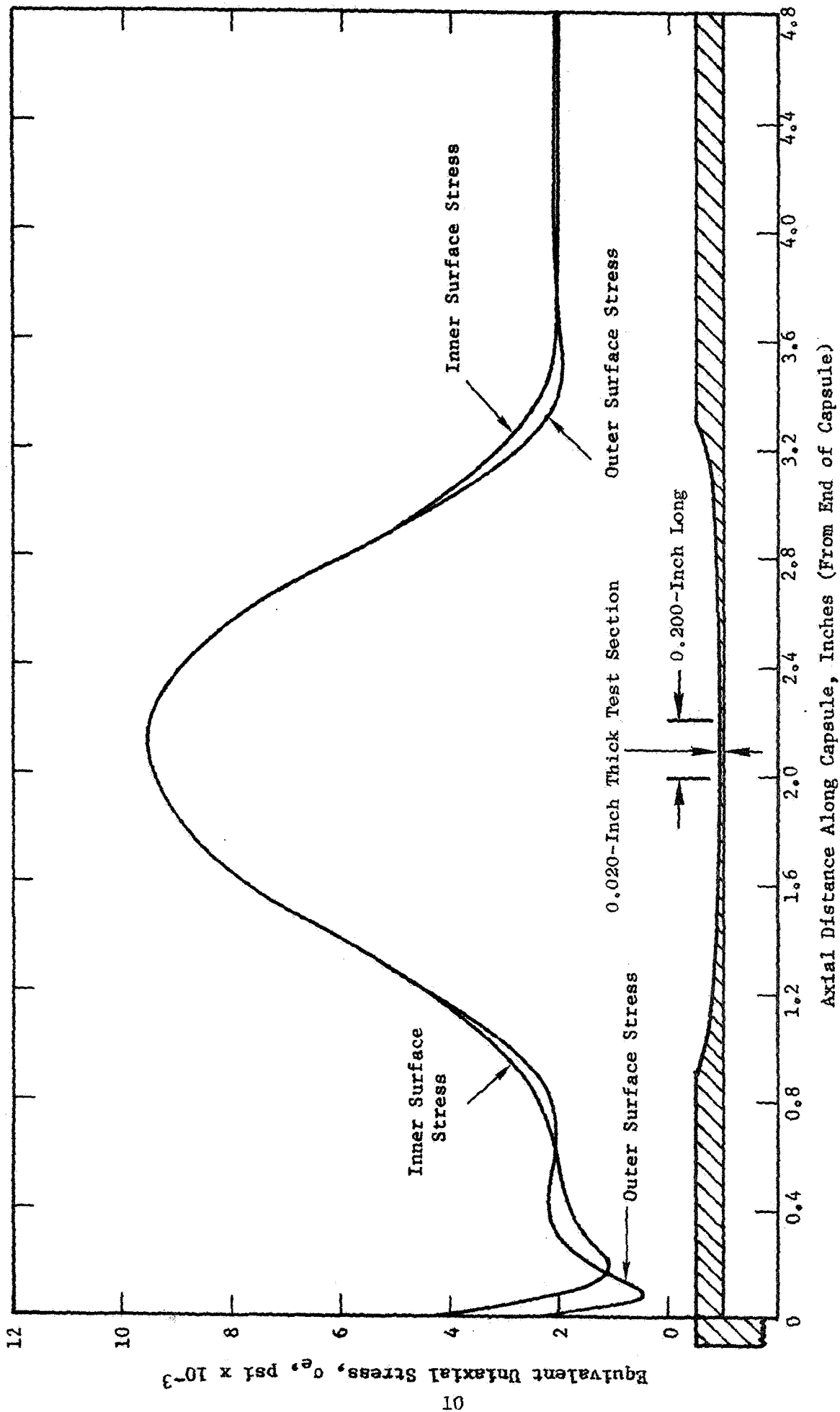


Figure 4. Equivalent Uniaxial Inner and Outer Surface Stresses in the Design Model of the T-111 Alloy Biaxial Creep Test Capsule, as Predicted by the Multi-Shell Analysis at a Test Temperature of 2300°F.

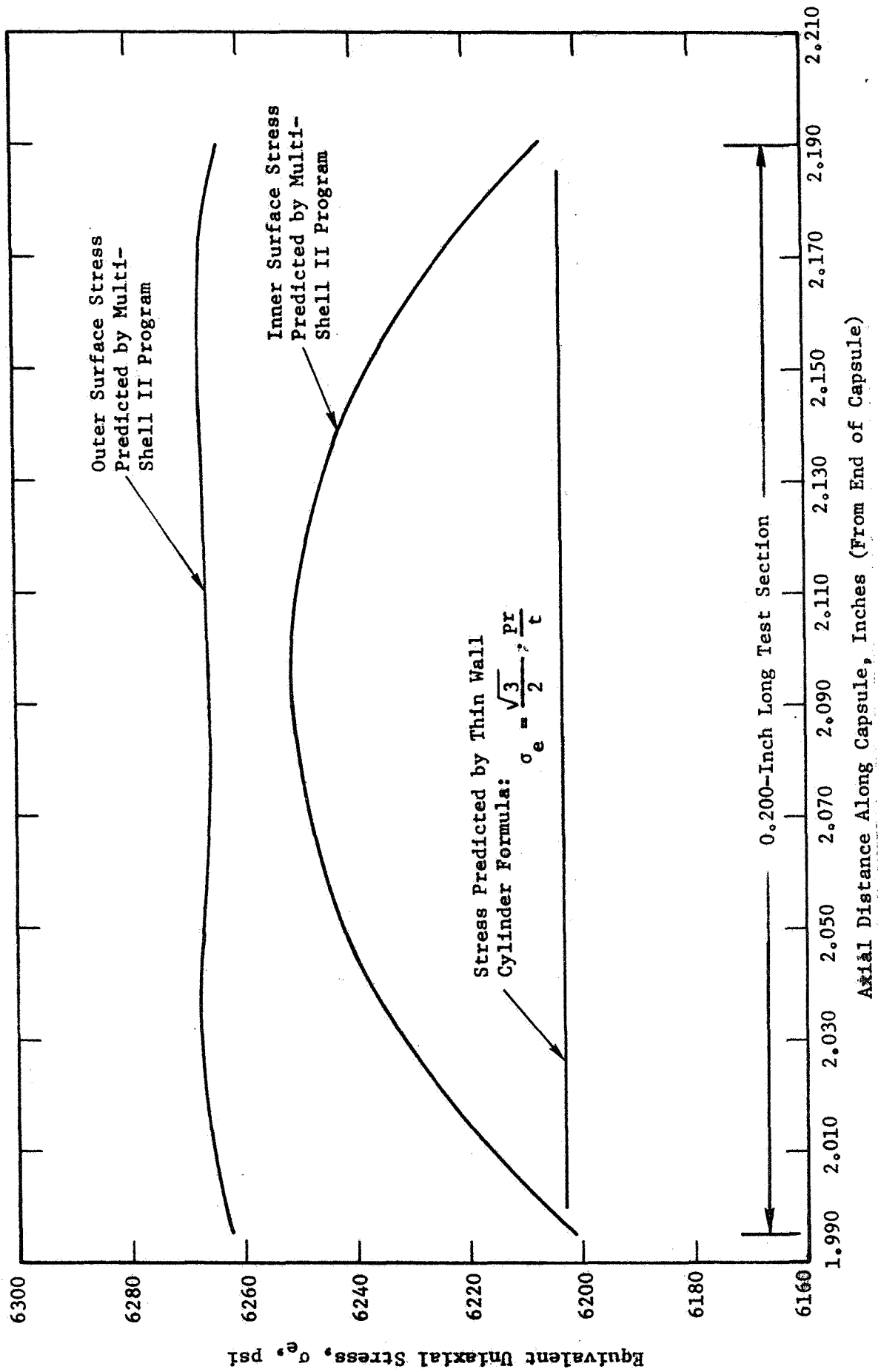


Figure 5. Equivalent Uniaxial Stresses in the 0.020-Inch Thick x 0.200-Inch Long Test Section of the Design Model for the T-111 Alloy Biaxial Creep Test Capsule at a Test Temperature of 2127°F.

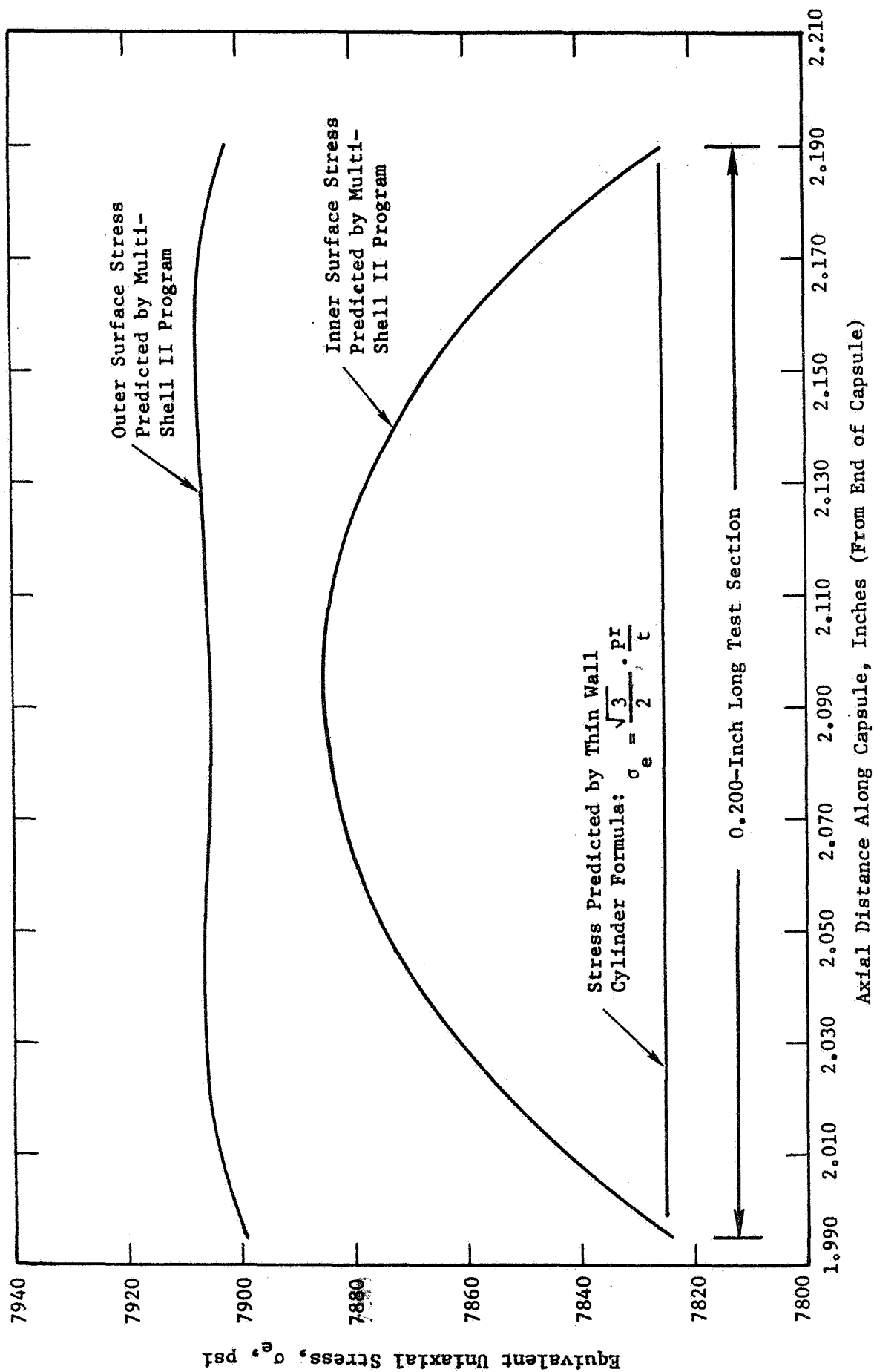


Figure 6. Equivalent Uniaxial Stresses in the 0.020-Inch Thick x 0.200-Inch Long Test Section of the Design Model for the T-111 Alloy Biaxial Creep Test Capsule at a Test Temperature of 2220°F.

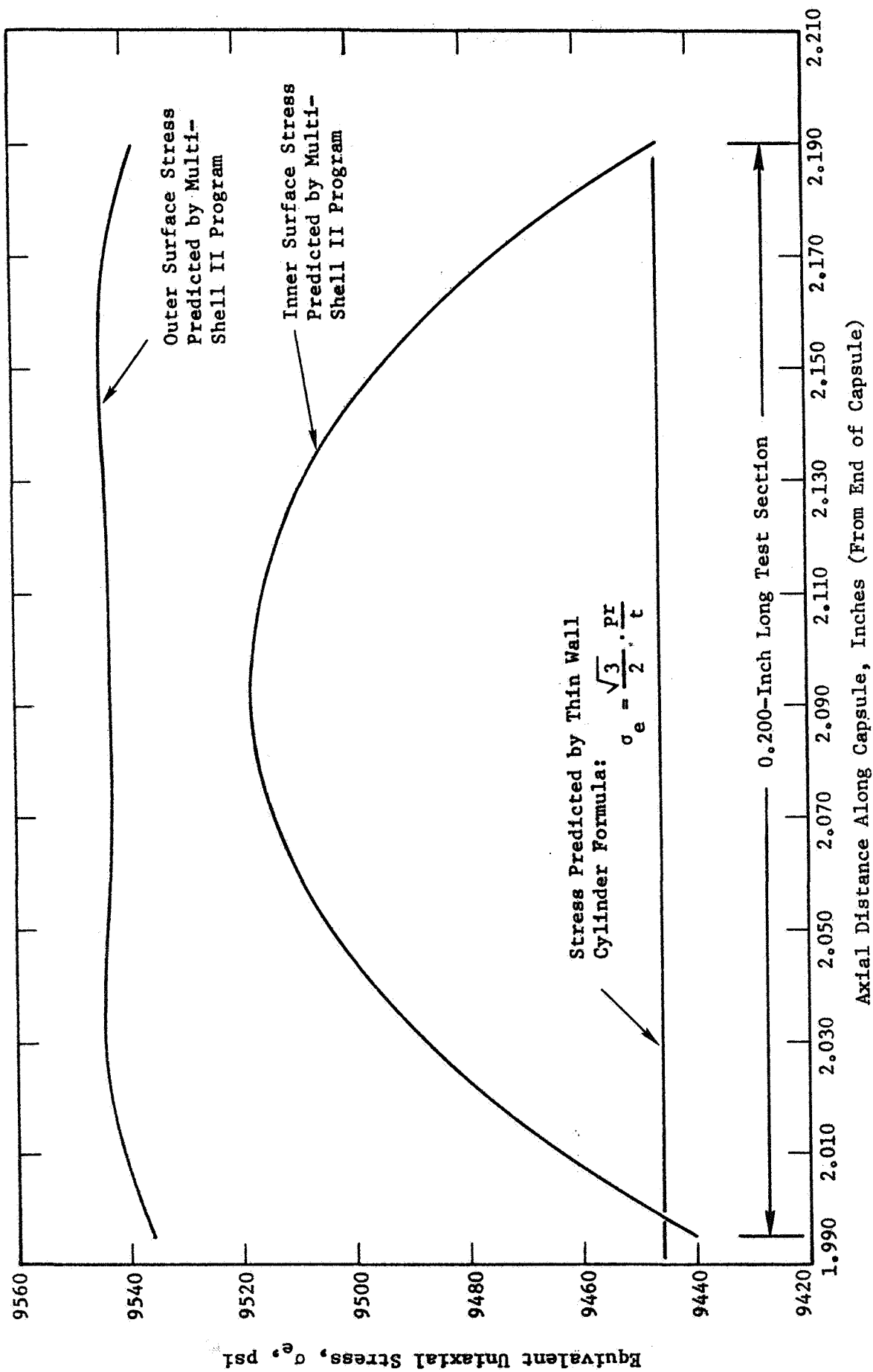


Figure 7. Equivalent Uniaxial Stresses in the 0.020-Inch Thick x 0.200-Inch Long Test Section of the Design Model for the T-111 Alloy Biaxial Creep Test Capsule at a Test Temperature of 2300°F.

TABLE I

DEVIATIONS OF STRESSES IN 0.020-INCH-THICK T-111 ALLOY
BIAXIAL CREEP CAPSULE TEST SECTION

Test Section Length Inch	Temp. °F	Stress for Thin Wall Cylinder psi	Maximum Deviation of Multishell Analysis Stresses from Thin Wall Cylinder Stress		Maximum Spread Between Inner & Outer Surface Stresses Predicted by Multishell Analysis psi
			psi	%	
0.200	2127	6203	+64	+1.03	61
0.200	2220	7825	+82	+1.05	77
0.200	2300	9445	+99	+1.04	96
0.500	2300	9445	+46	+0.49	50

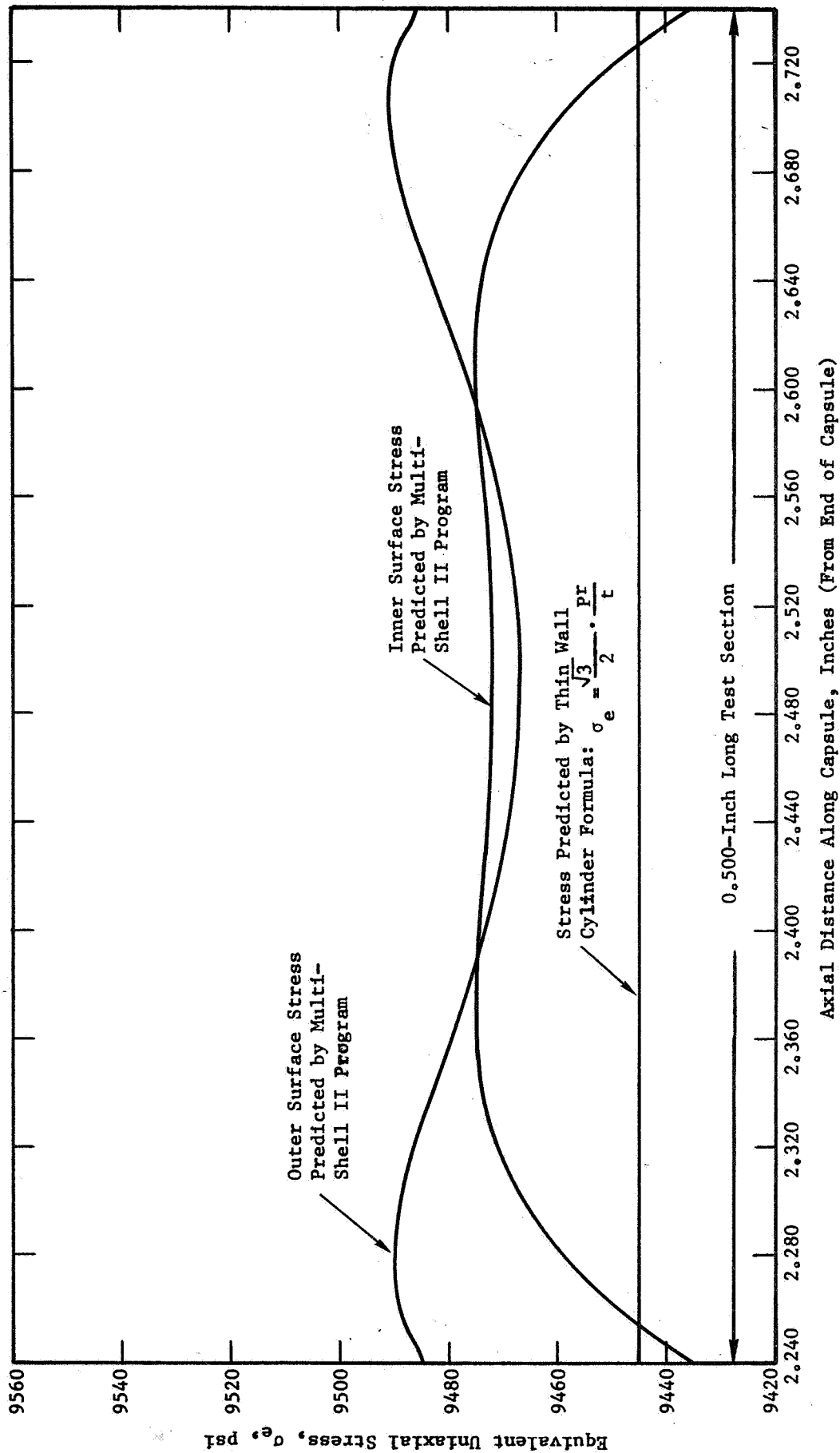


Figure 8. Equivalent Uniaxial Stresses in the 0.020-Inch Thick x 0.500-Inch Long Test Section of the Design Model for the T-111 Alloy Biaxial Creep Test Capsule at a Test Temperature of 2300°F.

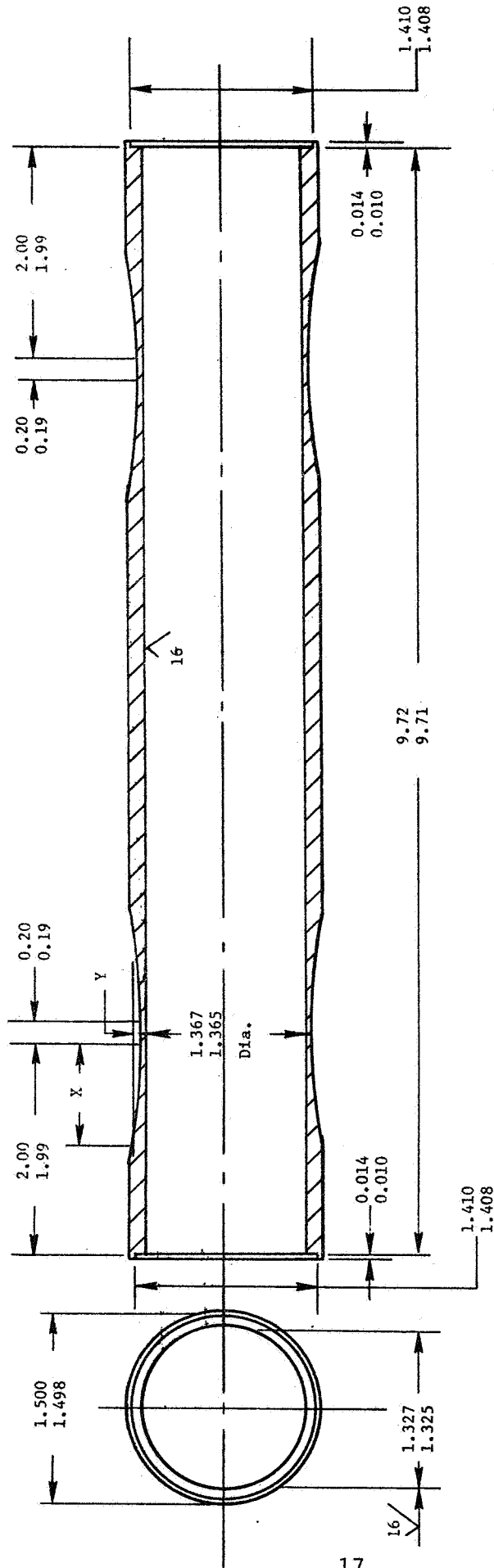
longer test section and also in confidently predicting where maximum creep will occur in the test section. The 0.200-inch-long test section was therefore selected for the final design of the test capsule as shown in Figure 9. Thermocouple wells are located in the ends of the test capsule extending into the test section region and will be used to measure the temperature of the test sections during creep testing. As discussed earlier^(5,6) a pressure transducer will be attached to the test capsule to determine the potassium pressure within the capsule during testing.

2. Manufacture

Machining of the T-111 alloy test capsules was performed by Delta Tool Inc., Warren, Michigan. A Type 304 SS test capsule containing one reduced wall section was machined and measured to assure the dimensional accuracy of the machine setup. Subsequently, four T-111 alloy special uniaxial creep test specimens, which are described in detail later in this report were machined to evaluate the actual machining techniques used on the T-111 alloy while using a minimum of material. Two T-111 alloy test capsules were then machined from the seamless tube and were received on July 8, 1968. The machined capsule is shown in Figure 10.

Pretest dimensioning of the seamless test capsules, to accurately ascertain the dimensions of the capsules in the gauge section area, has been completed. Since all of the necessary measurements, in particular internal measurements, cannot be obtained after welding and postweld annealing of the capsules, the measurements were made at this time. Prior to testing of the capsule, a portion of the dimensions will be rechecked to assure that no serious distortion of the gauge sections occurred during either the welding, postweld annealing, or filling and sealing of the capsule.

-
- (5) Engel, L. B., "Determination of Biaxial Creep Strength of T-111 Tantalum Alloy," Semi-Annual Report, NASA CR-72337, NASA Contract NAS 3-9437, Period March 8, 1967, to September 8, 1967.
- (6) Engel, L. B., "Determination of Biaxial Creep Strength of T-111 Tantalum Alloy," Semi-Annual Report, General Electric Report No. GESP-75, NASA Contract NAS 3-9437, Period September 8, 1967, to March 8, 1968.



All Dimensions shown are in inches.

Dimension Schedule of Reduced Wall Sections of Capsule

X(+0.010) Y(+0.001) Z(-0.000)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.75	0.80	0.85	0.900	0.925	0.950	0.975	1.000	1.025	1.050	1.075	1.100
	0	0.001	0.002	0.003	0.005	0.007	0.011	0.015	0.018	0.021	0.025	0.029	0.031	0.033	0.036	0.039	0.043	0.047	0.053	0.067

Figure 9. Stress Attenuating Fillet Design of the T-111 Alloy Biaxial Creep Refluxing Potassium Capsule.

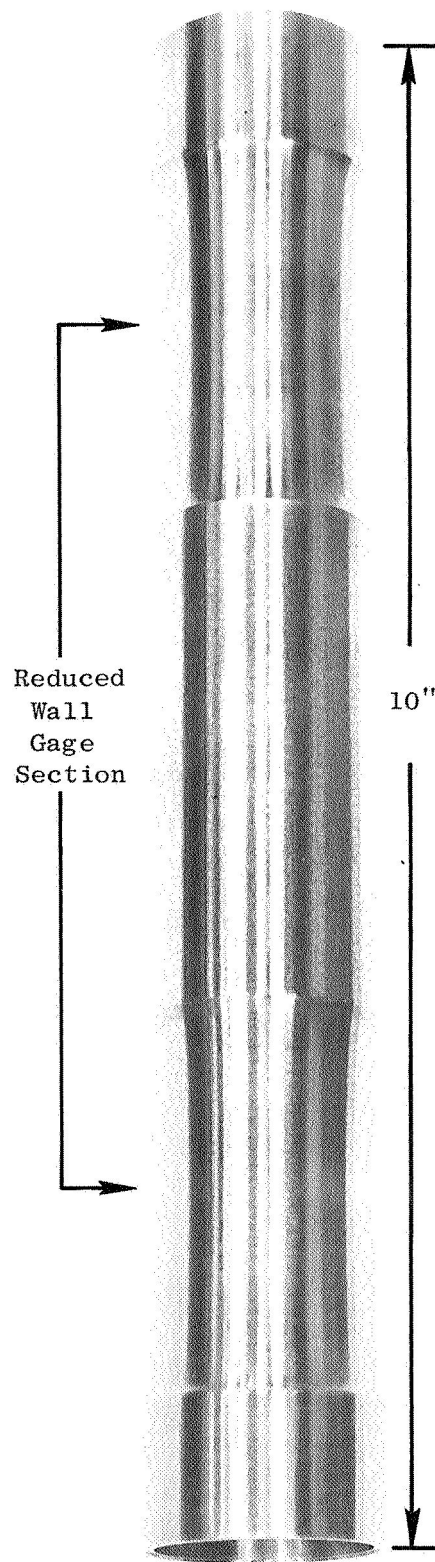


Figure 10. Biaxial Creep Test Capsule Made From T-111 Alloy Seamless Tubing. (Orig. C680719171)

Assembly of the test capsule, Figure 11, preceded initially by welding the boiling nucleator, liquid zone thermocouple well and bottom cap to the capsule. The condensing zone thermocouple well was welded to the top cap. All welding was performed in accordance with NSP Specification 03-0025-00, "Welding of Columbium, Tantalum, and Their Alloys by the Inert-Gas Tungsten Arc Process." The capsule and top cap assembly were wrapped with two layers of Cb-lZr alloy foil and postweld annealed in vacuum at 2400°F for one hour. The vacuum furnace used for the annealing was previously qualified by annealing a 0.040-inch-thick T-111 alloy coupon wrapped with two layers of Cb-lZr alloy foil and a similar unwrapped coupon for one hour at 2400°F. Chemical analysis of the coupons for oxygen, nitrogen, hydrogen, and carbon, as shown in Table II, revealed no significant contamination in the wrapped coupon and very slight contamination in the unwrapped coupon. In both cases, the concentration changes were within the limits required in NSP specification 03-0037-00-A, "Postweld Vacuum Annealing of Cb-lZr and T-111 (Ta-8W-2Hf) Alloys." During the postweld annealing of the capsule assemblies, a 0.020-inch-thick T-111 alloy coupon which had been wrapped with the capsule was annealed and subsequently analyzed for oxygen, nitrogen, hydrogen, and carbon as a further check for possible contamination. The results of this analysis given in Table II also showed no contamination.

Following postweld annealing, the pressure transducer was welded to the capsule top. This weld could not be postweld annealed since the melting point of the braze alloy used in the transducer was less than 2400°F. The capsule is shown in Figure 12 prior to filling with potassium.

The assembled capsule was then placed in the 30 KV electron beam welding chamber, shown in Figure 13, for filling with potassium. The potassium reflux capsule was filled with potassium procured from Mine Safety Appliances Research Corporation. This high-purity grade potassium was hot trapped and distilled before shipment to General Electric. The potassium was further purified at General Electric by vacuum distillation at approximately 600°F at a pressure in the 10^{-5} torr range into a titanium-lined hot trap. The purification apparatus is shown in Figure 14.

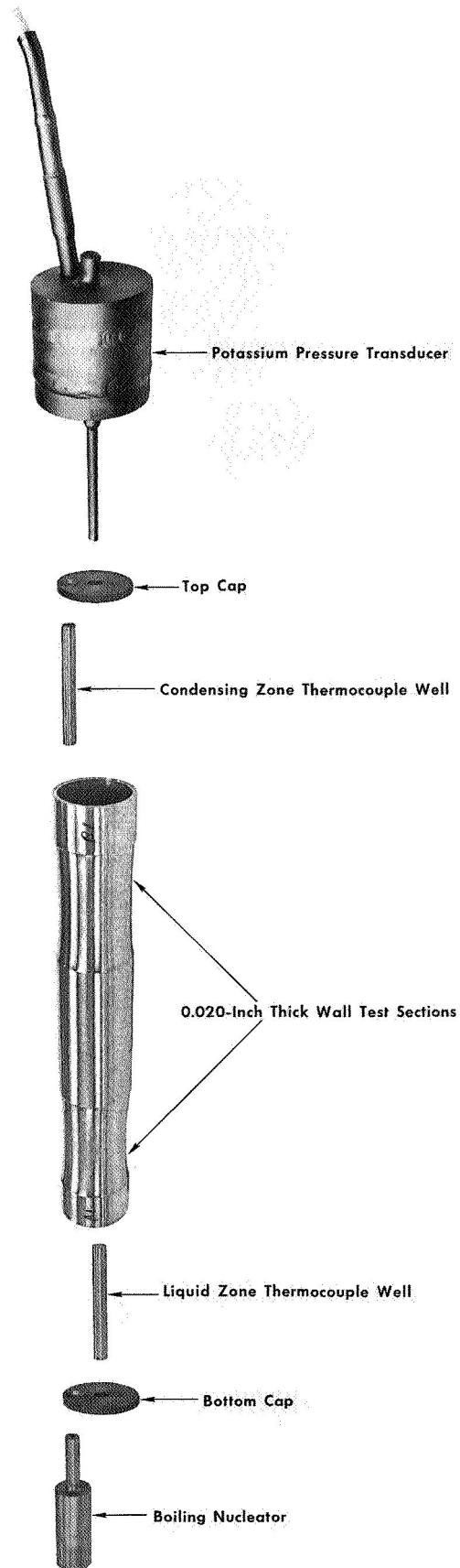


Figure 11. Seamless T-111 Alloy Biaxial Creep Test Capsule Prior to Assembly. (C68073104, C68082314, C68082315 & C68082316)

TABLE II

CHEMICAL ANALYSIS OF T-111 ALLOY COUPONS USED
IN QUALIFICATION OF THE VACUUM FURNACE USED FOR POSTWELD ANNEALING^(a)
OF SEAMLESS T-111 ALLOY BIAxIAL CREEP TEST CAPSULE

Specimen	Concentration, ppm				Average Change in Concentration, ppm			
	O	N	H	C	O	N	H	C
Maximum Change in Chemical Analysis Allowed ^(b)	-	-	-	-	+15	+15	+2	+5
0.040" thk. Qualification Coupon Before Annealing	59,61	4,7	< 1,1	20	-	-	-	-
0.040" thk. Qualification Coupon After Annealing, Unwrapped	85,89	7,7	1,2	19	+27 ^(d)	+1	+1	-1
0.040" thk. Qualification Coupon After Annealing, Wrapped ^(c)	54,56	7,5	< 1,1	12	-5	0	0	-8
0.020" thk. Coupon Before Annealing	55,50	8,12	1,2	71,63	-	-	-	-
0.020" thk. Coupon ^(c) Wrapped with Capsule, After Annealing	50,53	16,20	2,2	52,50	-1	+8	0	-16

(a) All anneals done at 2400°F for one hour.

(b) NSP specification 03-037-00-A, "Postweld Vacuum Annealing of Cb-1Zr and T-111 (Ta-8W-2Hf) Alloys" (11-26-65).

(c) Wrapped with two layers of Cb-1Zr alloy foil.

(d) Specification allows for ± 30 ppm limits in oxygen analyses.

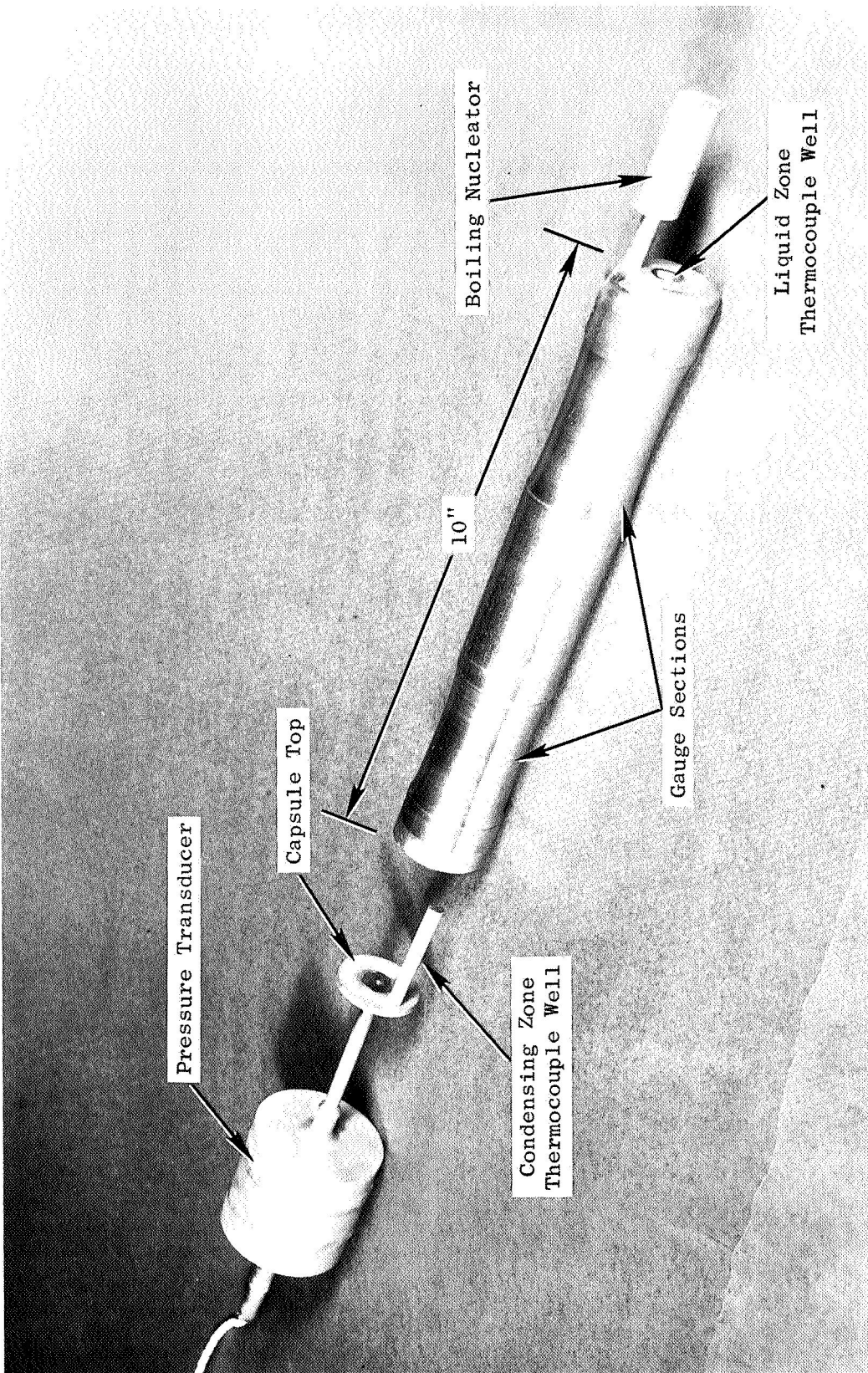


Figure 12. The Seamless T-111 Alloy Biaxial Creep Capsule Prior to Filling with Potassium. (Orig. C68080508)

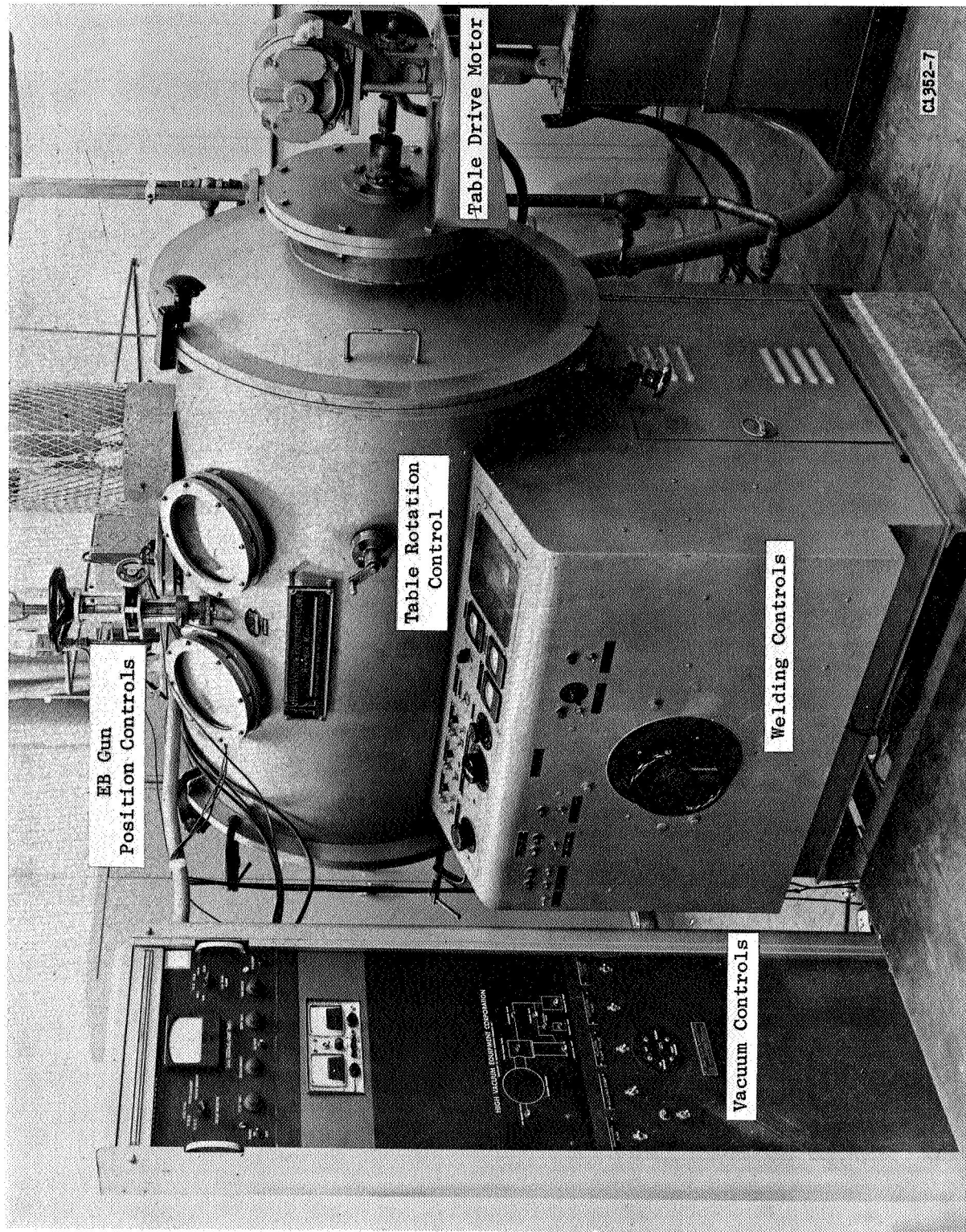


Figure 13. 30KV Electron Beam Welding Chamber and Controls Used to Fill T-111 Alloy Biaxial Creep Capsule with Potassium. (C67040153)

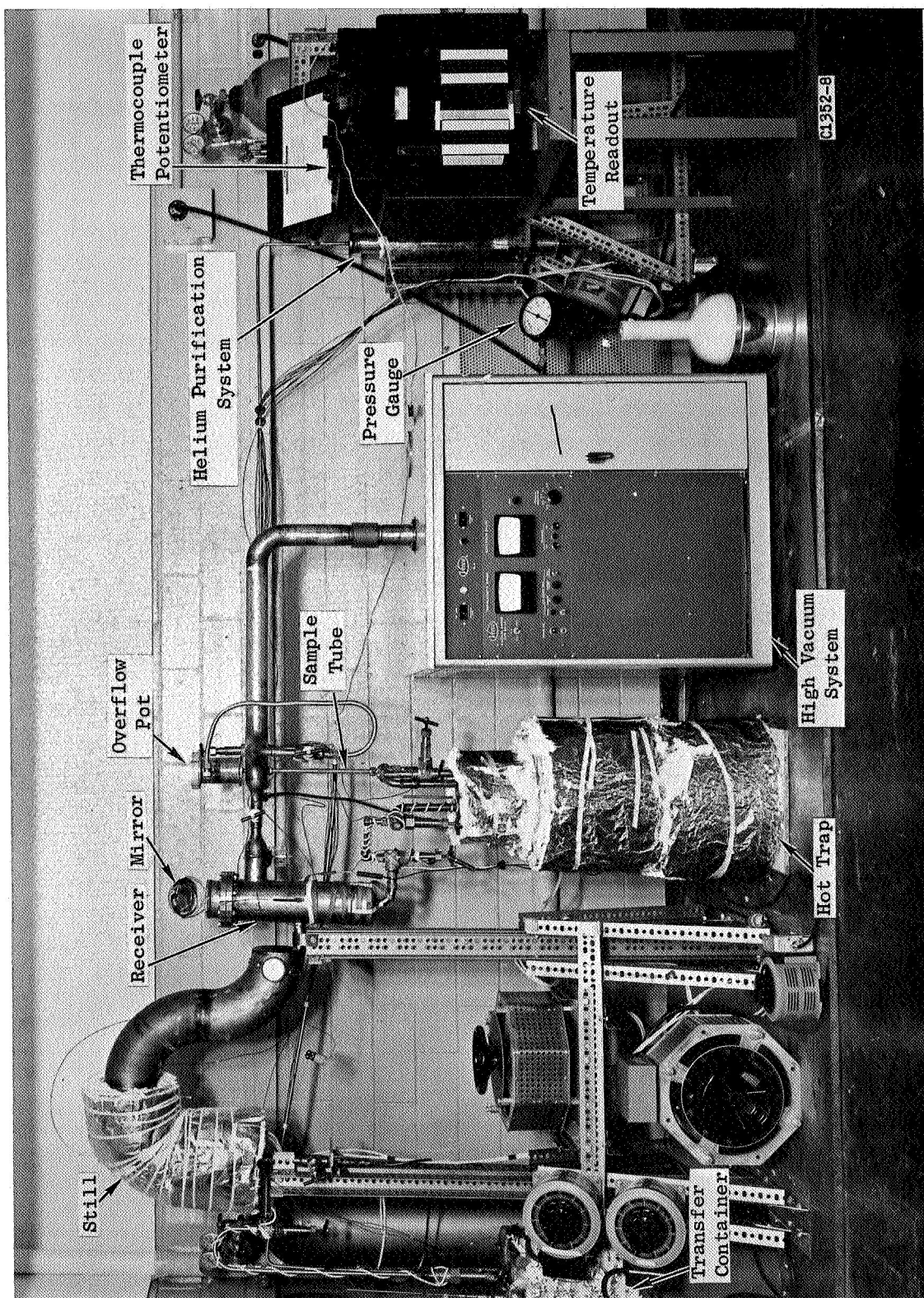


Figure 14. Potassium Purification System.

The hot trap was used in this case as a clean storage and transfer container. In the filling operation, potassium was transferred under argon pressure from the hot trap into an annular dispensing reservoir, shown in Figure 15, to a precalculated height corresponding to the volume required to result in the test capsule being half filled with liquid potassium at the test temperature. The liquid metal level was determined by means of a MSA Research Corporation Level Probe. The measured volume was then transferred under argon pressure through the bellows-sealed filling line, shown in Figure 16, into the capsule. The capsule was positioned under the fill line by means of a manipulator and a flexible cable which was attached on one end to a gear train on the turntable and on the other end to a crank outside the chamber, Figures 13 and 16. A waste container was placed on the rotating table to provide a means of initial flushing of the fill line with potassium. When filled, the capsule was rotated from under the fill line, and the capsule lid was put in place with the manipulator. The manipulator is sealed to the chamber door by means of sliding O-ring seals. The capsule was positioned under the EB welding gun by moving the table holding the capsule to the opposite end of the EB weld tank. The gear on the capsule was adjusted to mesh with the welding drive gear such that the capsule rotated around its axis during welding. This gear was controlled by a variable speed motor to rotate at the optimum welding speed. Copper chill blocks were fitted on each capsule to reduce the heat conduction along the capsule during welding, thereby, minimizing the possible vaporization of the potassium which might cause unsound welds.

Analytical samples of the potassium were obtained by filling a stainless steel tube in the same manner as the capsule was filled. The resulting oxygen analyses by the mercury amalgamation method indicated the oxygen concentration to be 10 ppm. Metallic impurities were determined by spectrographic analysis and are presented in Table III.

The OD dimensions of the capsule in the test section region were rechecked, and no significant distortion was noted. The capsule is presently being installed in the test facility prior to testing.

Machining of test capsules and special uniaxial creep test specimens from the welded and reworked T-111 alloy tube is now in progress.

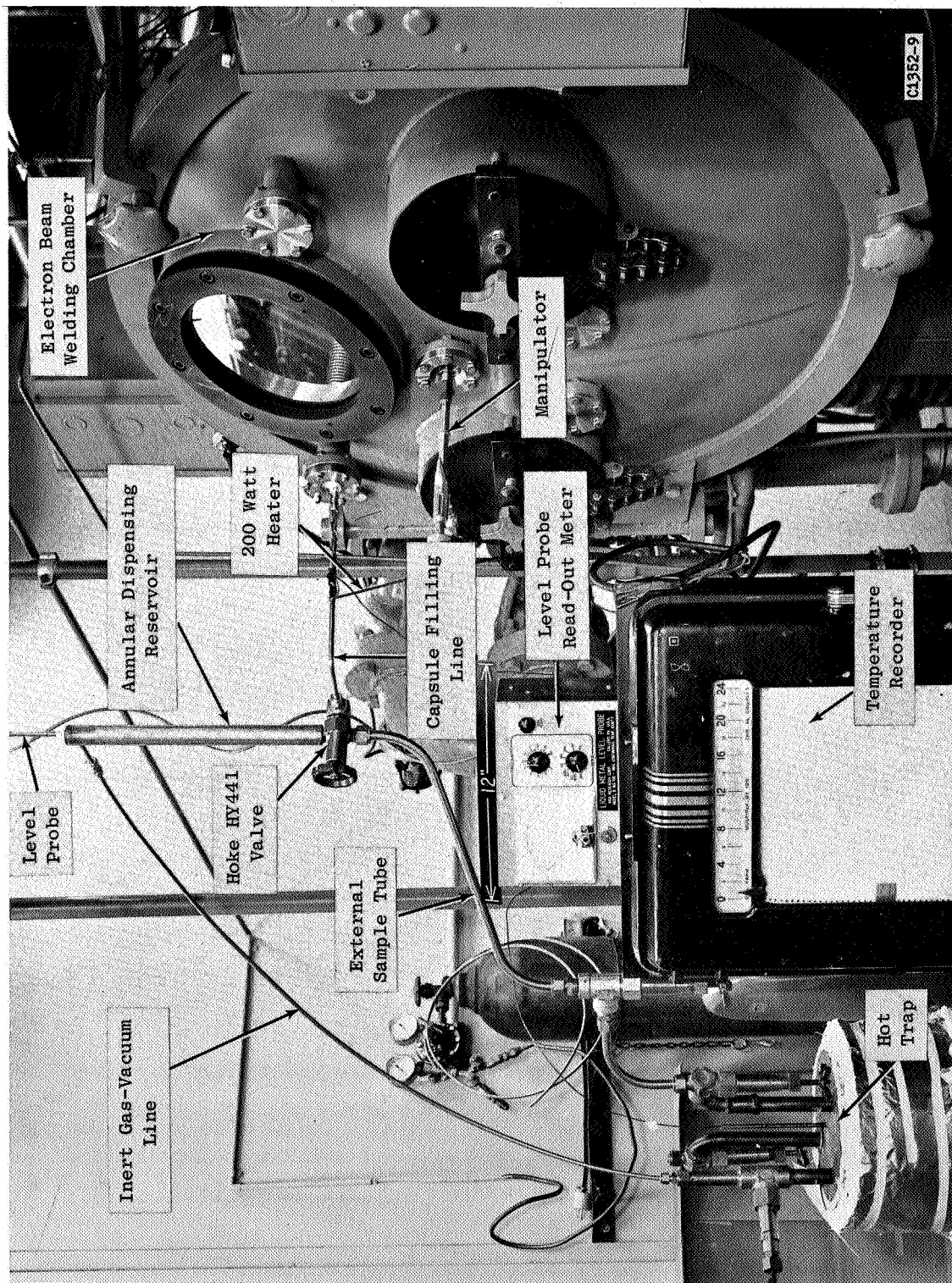


Figure 15. External Apparatus for Filling T-111 Alloy Biaxial Creep Capsule with Potassium in the EB Welding Chamber. (C66051941)

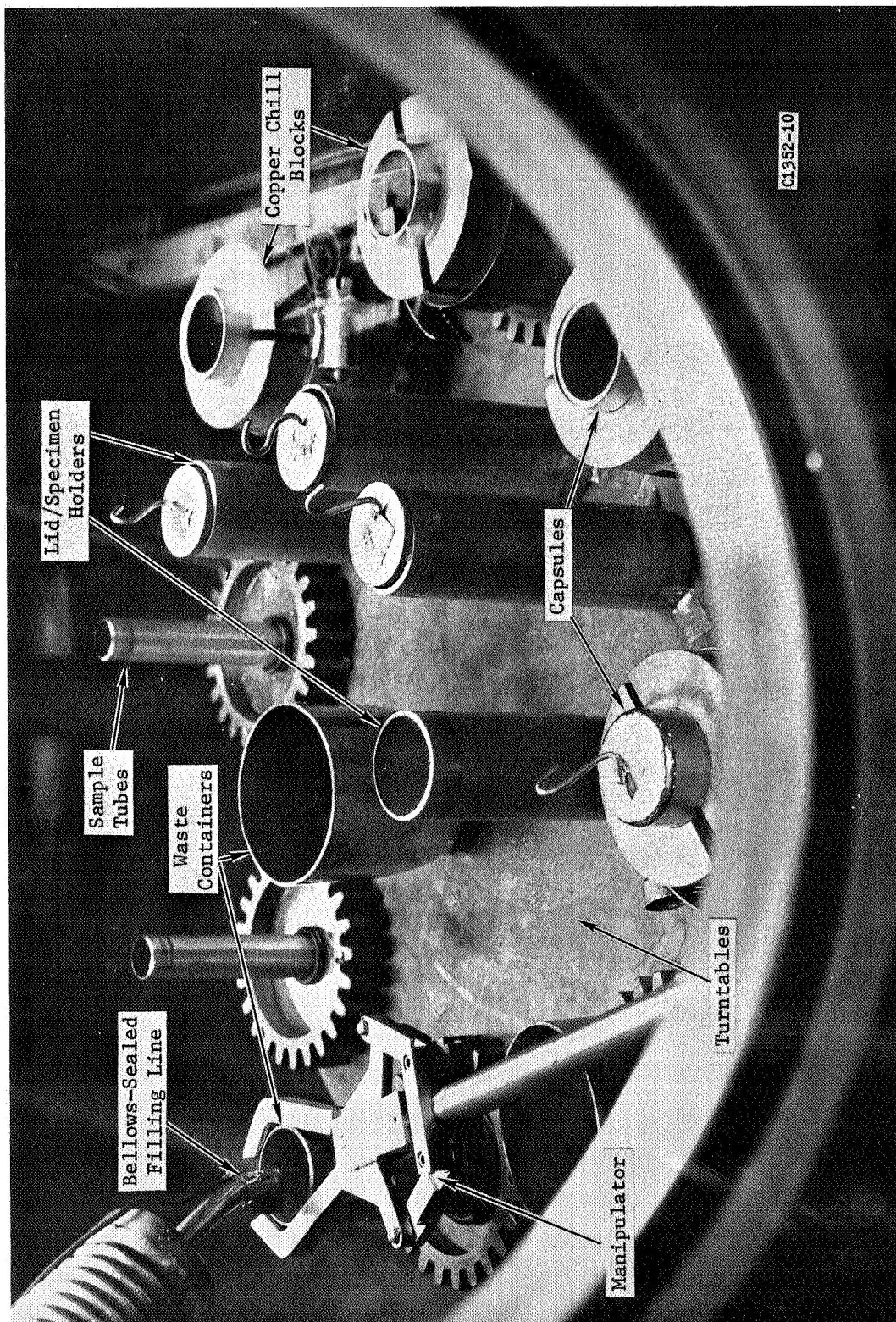


Figure 16. Internal Apparatus for Filling Capsules with Potassium in the EB Welding Chamber. (Orig. C66053119)

TABLE III

SPECTROGRAPHIC ANALYSIS OF POTASSIUM USED IN
BIAXIAL CREEP CAPSULE I

<u>Element</u>	<u>Concentration, ppm</u>
Ag	< 2
Al	< 2
B	< 10
Ba	< 10
Be	< 10
Ca	< 2
Cb	< 10
Co	< 2
Cr	< 2
Cu	< 2
Fe	< 2
Mg	< 2
Mn	< 2
Mo	< 2
Na	< 2
Ni	< 2
Pb	< 2
Si	< 2
Sn	< 2
Sr	< 2
Ti	< 2
V	< 10
Zr	< 2

B. Test Facility

The same test facility which was used for testing the D-43 alloy capsules on NASA Contract NAS 3-6012⁽¹⁾ will be used for the testing of the T-111 alloy capsules. Various minor design changes have been completed and are discussed in earlier reports.^(5,6)

All of the W-25Re/W-3Re thermocouples to be used for the first capsule test were calibrated against a new Pt/Pt - 10Rh thermocouple at temperatures between 1700°F and 2300°F. The Pt/Pt - 10Rh thermocouple was previously calibrated against the melting points of silver and copper. The calibration of the W-Re thermocouples was accomplished by placing the W-Re and Pt-Rh thermocouples in a 0.25-inch-diameter well within a 1.25-inch-diameter x 4-inch-long molybdenum cylinder. The molybdenum cylinder was placed in the capsule test facility in the same location as that for the test capsule and the facility evacuated and baked out. The cylinder was then heated with the tantalum strip heater which will be used for the capsule test. A 32°F reference junction was utilized, and the calibration was done in accordance with ASTM Specification, "Calibration of Thermocouples by Comparison Techniques," ASTM Designation: E220-64.

This calibration will be repeated at the end of the capsule testing to evaluate any changes during testing.

The test facility is now ready for installation of the test capsule. The calibration of the linear variable differential transformers (LVDT's), which remains to be done, will be completed after installation of the test capsule.

- (1) Harrison, R. W., "The Compatibility of Biaxially Stressed D-43 Alloy with Refluxing Potassium," NASA Contractor Report NASA CR-807, NASA Contract NAS 3-6012, June 1967.
- (5) Engel, L. B., "Determination of Biaxial Creep Strength of T-111 Tantalum Alloy," Semi-Annual Report, NASA CR-72337, NASA Contract NAS 3-9437, Period March 8, 1967, to September 8, 1967.
- (6) Engel, L. B., "Determination of Biaxial Creep Strength of T-111 Tantalum Alloy," Semi-Annual Report, General Electric Report No. GESP-75, NASA Contract NAS 3-9437, Period September 8, 1967, to March 8, 1968.

C. Preliminary Uniaxial Creep Testing

Preliminary uniaxial creep tests are being used to obtain baseline creep data for the final selection of test conditions for the 5000 hour tests and to evaluate a special uniaxial creep test specimen design which more closely resembles the biaxial capsule test section design.

Test conditions for the preliminary uniaxial creep tests were selected such that 1% creep would be obtained in approximately 100 hours. The uniaxial creep testing has been performed in the bakeable, getter-ion pumped creep facility capable of a 10^{-10} torr vacuum shown in Figure 17. The elongation during testing is measured optically from fiducial marks on the gauge length of the test specimen and recorded continuously from the output of a linear variable differential transformer located on the external portion of the load train.

The more conventional uniaxial creep test specimen which is being used is shown in Figures 18 and 19. The specimens are machined directly from the wall of the tubing and are not flattened. The actual test section of this type of specimen utilizes the entire wall thickness of the as-received T-111 alloy tube. Three preliminary uniaxial creep tests using conventional test specimens were planned and have been completed.

The first preliminary uniaxial creep test was conducted at 2200°F at a stress of 15,000 psi in a vacuum of $< 4 \times 10^{-9}$ torr. From the least squares linear correlation of the data plotted in Figure 20, one percent creep was found to occur in 156.5 hours. The scatter observed in the data was found to be a result of inaccuracies in the optical extensometer. The optical extensometer was repaired and recalibrated prior to initiation of the second test.

The second preliminary uniaxial creep test was conducted at 2350°F at a stress of 10,000 psi in a vacuum of $< 1 \times 10^{-8}$ torr. From the least squares linear correlation of the data plotted in Figure 21, one percent creep was found to occur in 181 hours. The two test interruptions shown in Figure 21 were the result of power failures caused by major substations repairs. There was no apparent effect of these interruptions on the test data.

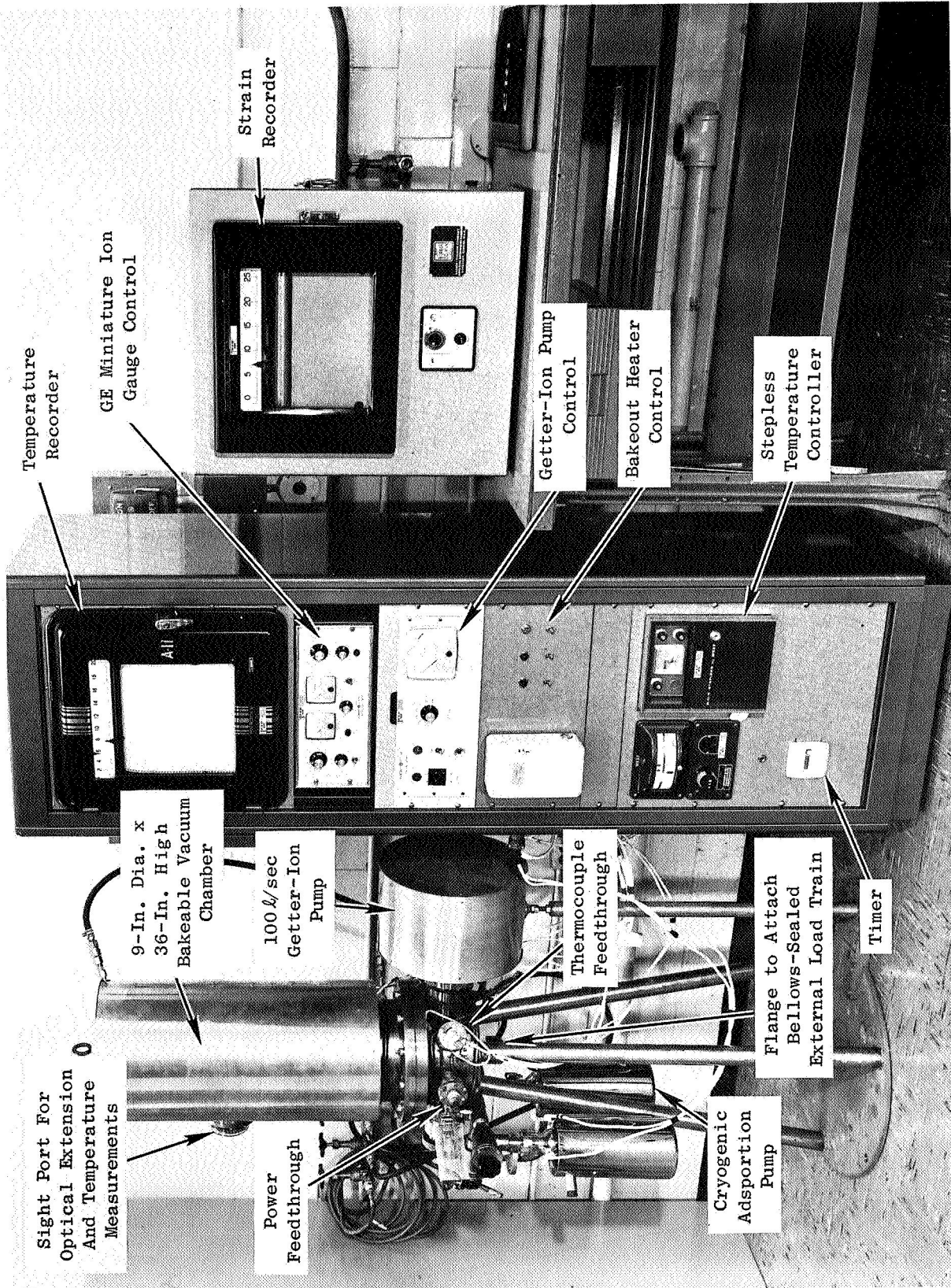
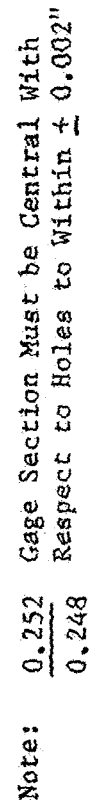


Figure 17. High-Vacuum Creep-Rupture Facility Capable of Achieving a Pressure of 10^{-10} Torr and Incorporating a 100 Liter/Sec Getter-Ion Pump. (C64051213)



32

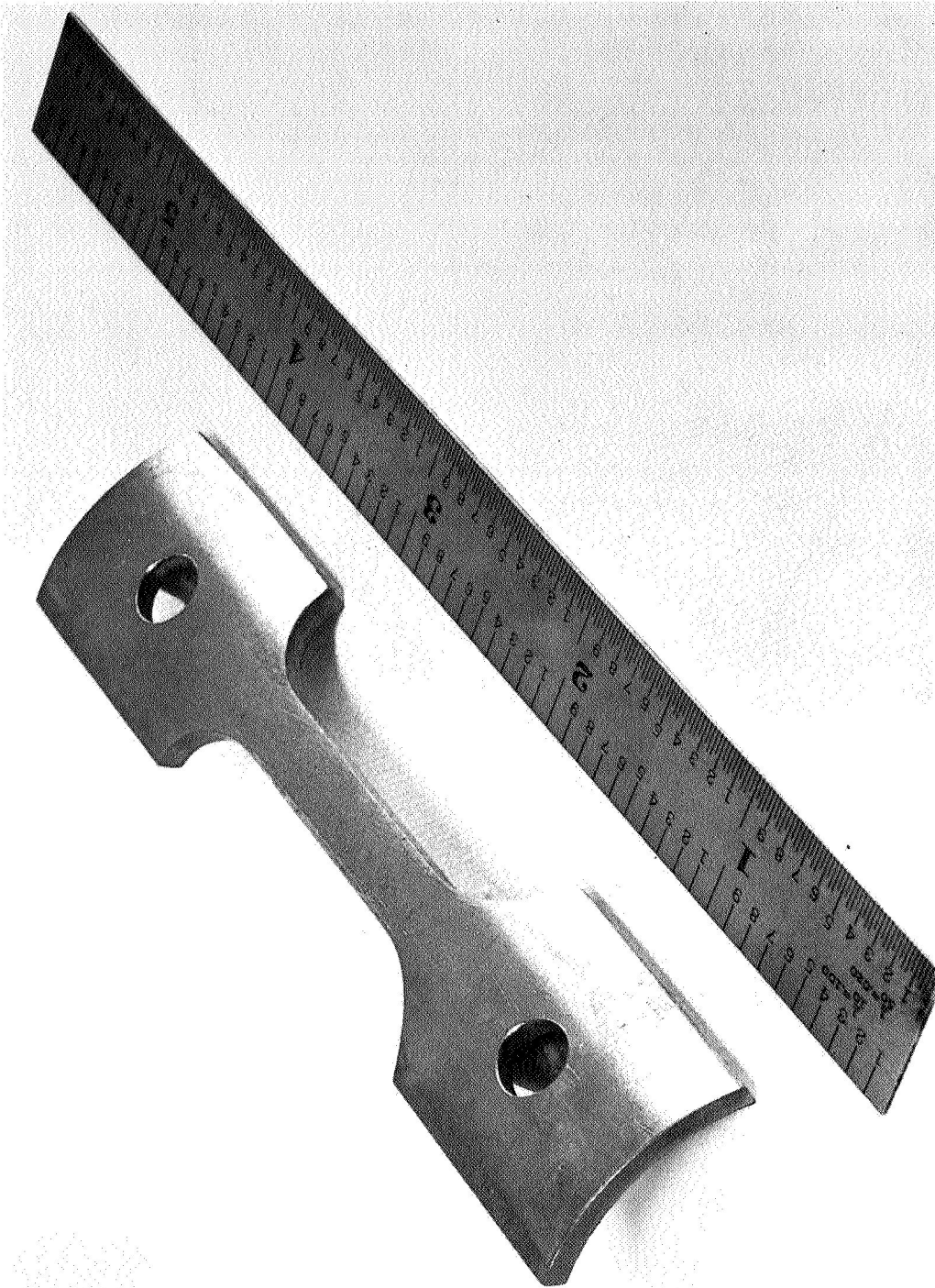


Figure 19. Conventional T-111 Alloy Uniaxial Creep Test Specimen Prior To Testing. (Orig. C68050719)

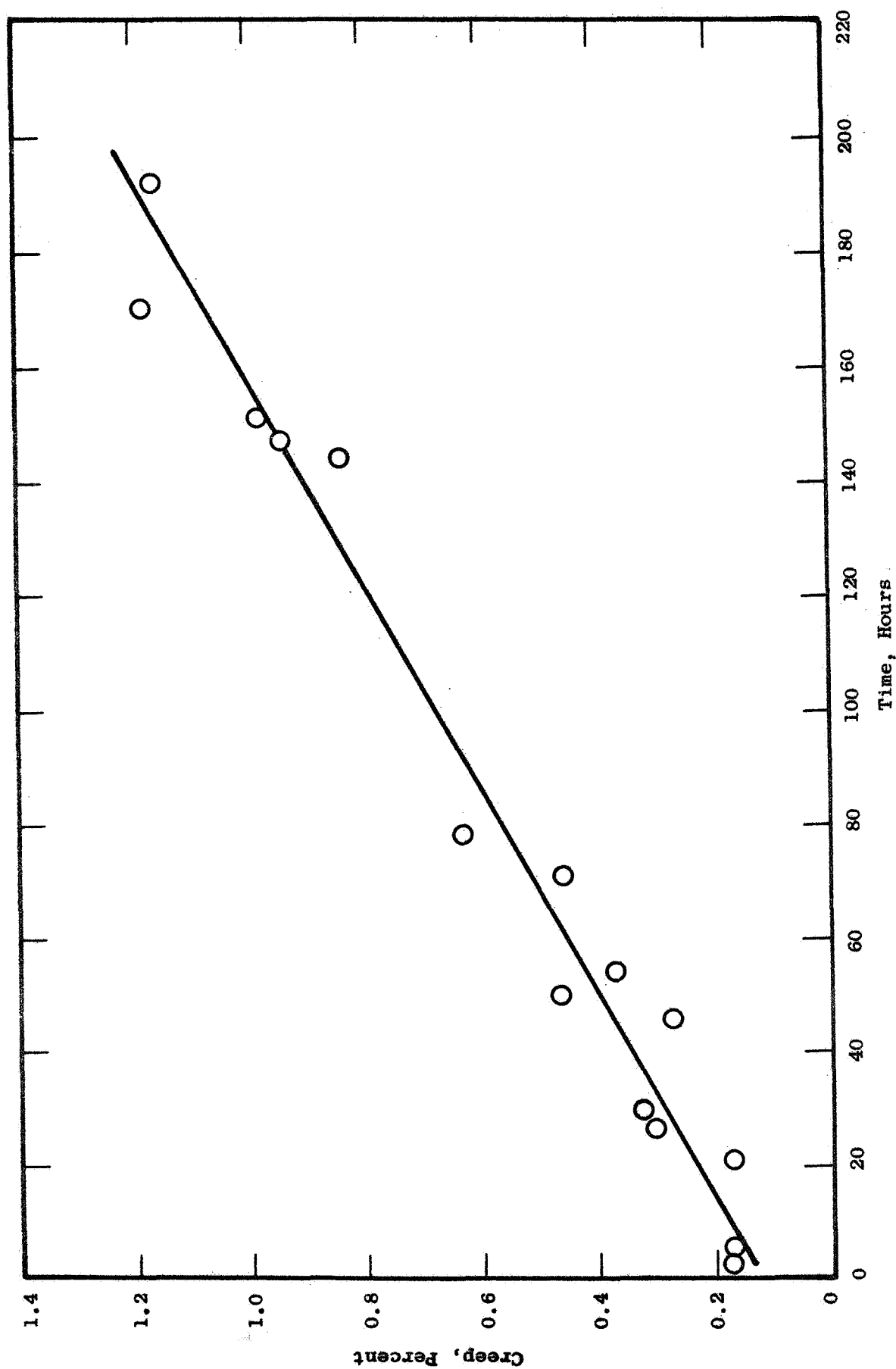


Figure 20. Uniaxial Creep of T-111 Alloy Tested at 2200° F with a 15,000 psi Stress in Vacuum of $<4 \times 10^{-9}$ torr. The Conventional Specimen was Machined from the Seamless Tube (Preliminary Uniaxial Test No. 1).

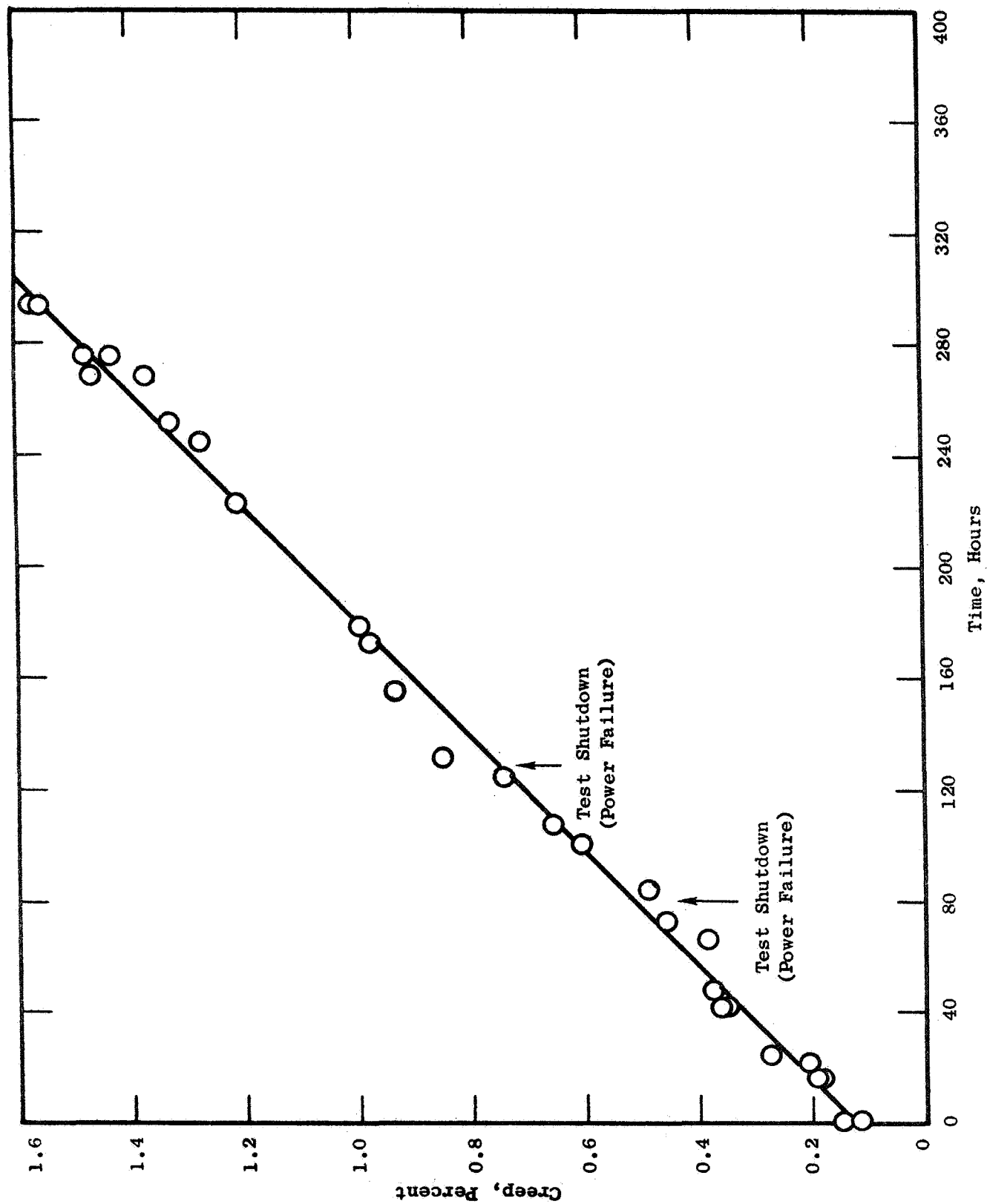


Figure 21. Uniaxial Creep of T-111 Alloy Tested at 2350°F at 10,000 psi Stress in Vacuum of $<1 \times 10^{-8}$ Torr. The Conventional Specimen was Machined From the Seamless Tube. (Preliminary Uniaxial Test No. 2).

The third preliminary uniaxial creep test was conducted at 2300°F at a stress of 12,500 psi in a vacuum of $< 1 \times 10^{-8}$ torr. From the least squares linear correlation of the data plotted in Figure 22, one percent creep was found to occur in 84.1 hours. The data from the first three uniaxial tests compare favorably with similar 1% creep data reported by Sheffler and Steigerwald⁽⁷⁾ in Figure 23.

The previously discussed preliminary uniaxial creep test results were then used in selecting the test temperature for the first biaxial capsule test. Since the capsule is filled with potassium and sealed under vacuum, the stress generated in the thin wall test section is directly dependent for any given mean capsule radius and wall thickness, on the potassium vapor pressure developed within the capsule at the test temperature. Thus for a fixed mean capsule radius and wall thickness, the stress developed in the test section is directly determined by the capsule temperature. Also, to obtain some specified amount of creep in the capsule in a specified time, the necessary stress and test temperature are again interrelated. This relationship is dependent on the basic creep properties of the T-111 alloy and is dependent of the stress - temperature relationship from the potassium pressure discussed earlier. Therefore, it is obvious that to obtain a certain amount of creep in a specified time and in a capsule of fixed dimensions, only one test temperature exists.

The desired test temperature can be readily determined by the use of a Larson-Miller parameter plot. The preliminary uniaxial 1% creep data can be plotted on the parameter plot in the normal way as shown in Figure 24. This data will allow an approximate extrapolation for the temperature and stress levels needed to obtain the desired 1% creep over the planned test period of 5000 hours. Next using the temperature - vapor pressure data for potassium shown in Figure 25, and the relationship for determining the stress in a thin wall cylinder:

$$\sigma_e = \frac{\sqrt{3}}{2} \cdot \frac{pr}{t_1}$$

(7) Sheffler, K. D. and Steigerwald, E. A., "Generation of Long Time Creep Data on Refractory Alloys at Elevated Temperatures," Fifteenth Quarterly Report, NAS-CR-72431, NASA Contract NAS 3-9439, Period December 14, 1967 to March 27, 1968, April 14 (1968).

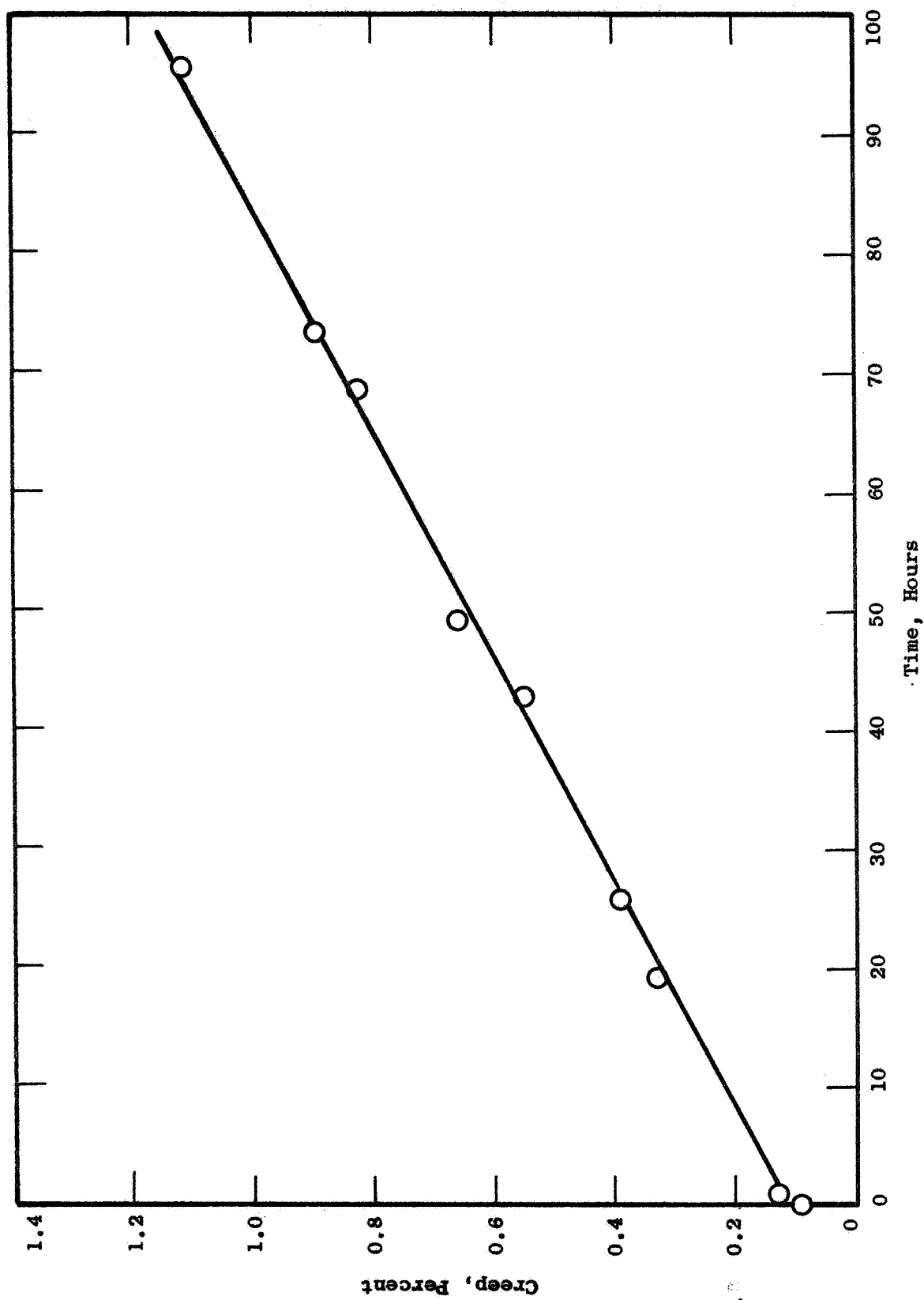


Figure 22. Uniaxial Creep of T-111 Alloy Tested at 2300°F with a 12,500 psi Stress in a Vacuum of $<1 \times 10^{-8}$ torr. The Conventional Specimen was Machined from the Seamless Tube (Preliminary Uniaxial Test No. 3).

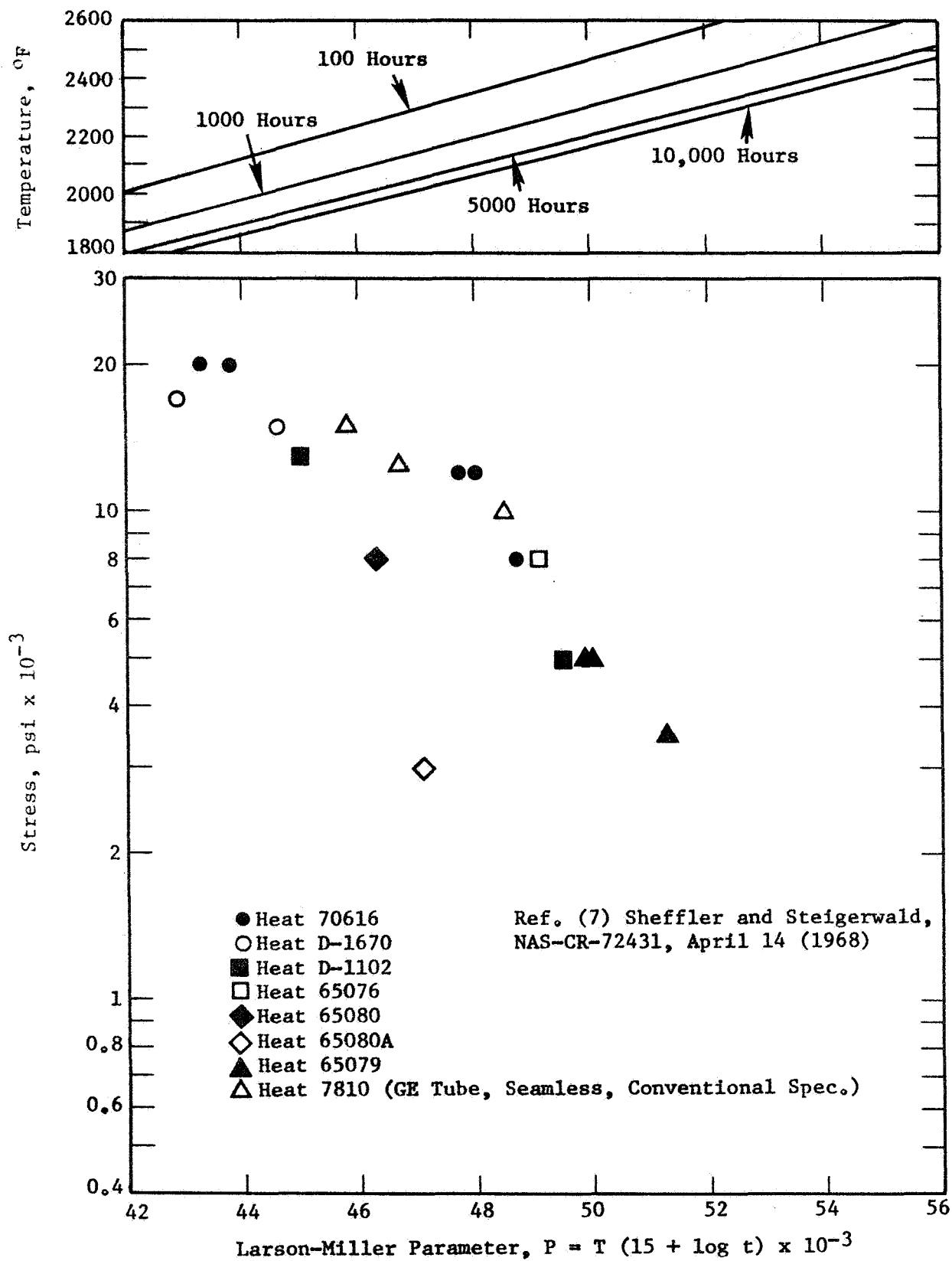


Figure 23. Larson-Miller Plot of One Percent Creep Data for T-111 Alloy Annealed at 3000°F for One Hour and Tested in Vacuum Environments of $<1 \times 10^{-8}$ Torr.

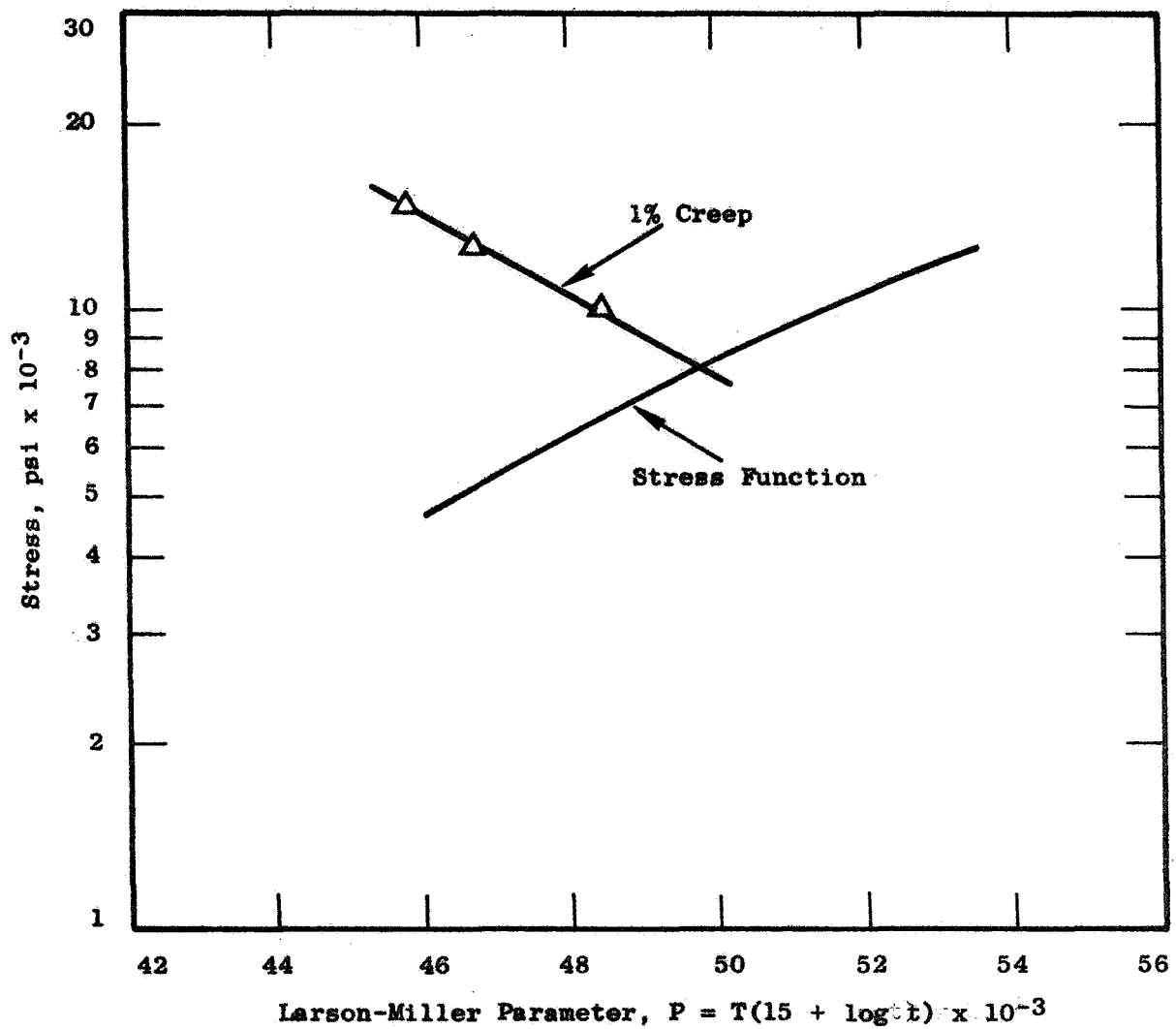


Figure 24. Preliminary One Percent Uniaxial Creep Data for T-111 Alloy Tubing (Heat 7810) and Stress Developed in Test Capsule as a Function of Temperature. Parameters are Computed for Stress Function Using a Time of 5000 Hours.

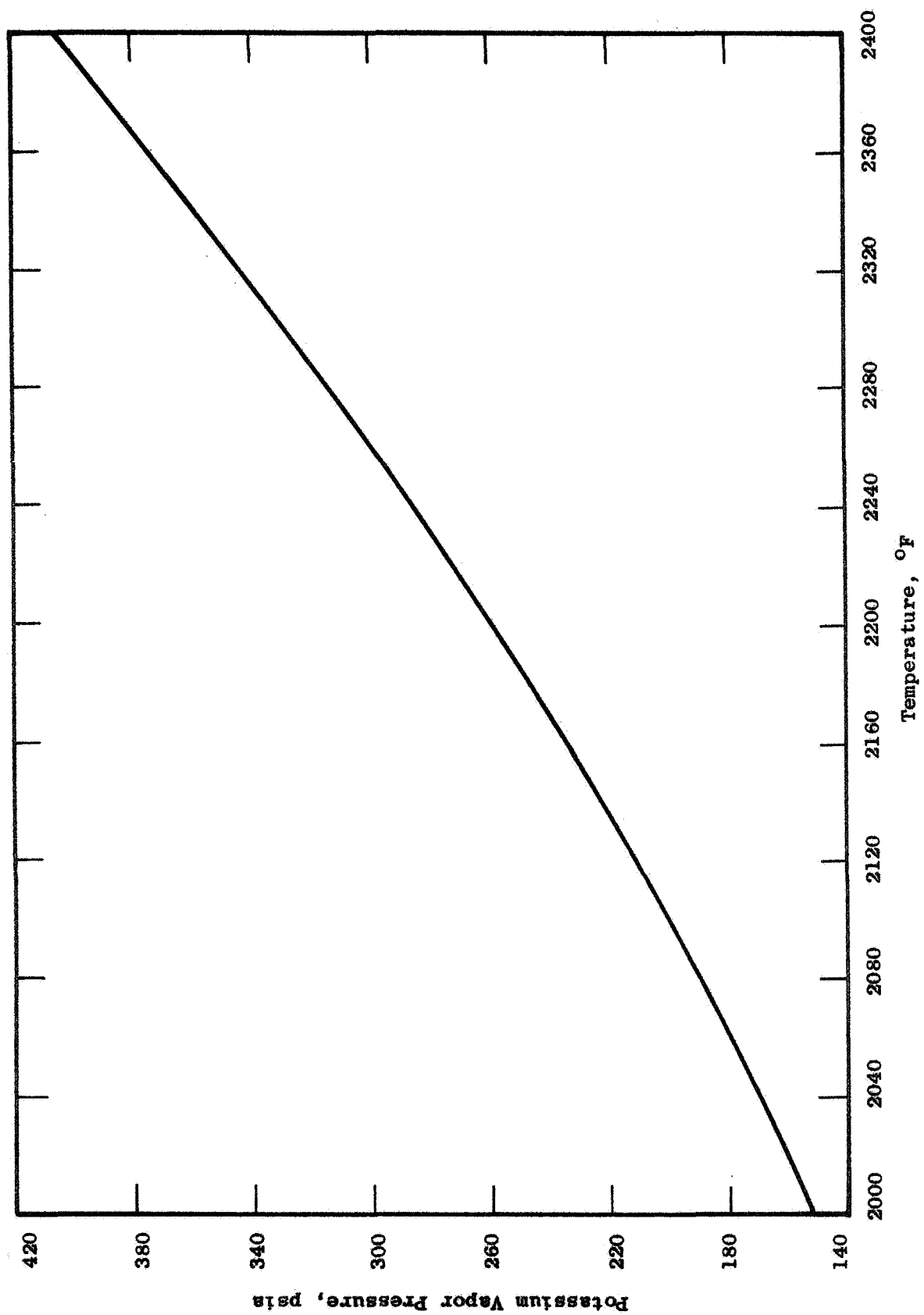


Figure 25. Vapor Pressure of Potassium as a Function of Temperature. (Reference 8).

where,

p = internal pressure in capsule (potassium vapor pressure)

r = mean radius of capsule (0.6734 in.)

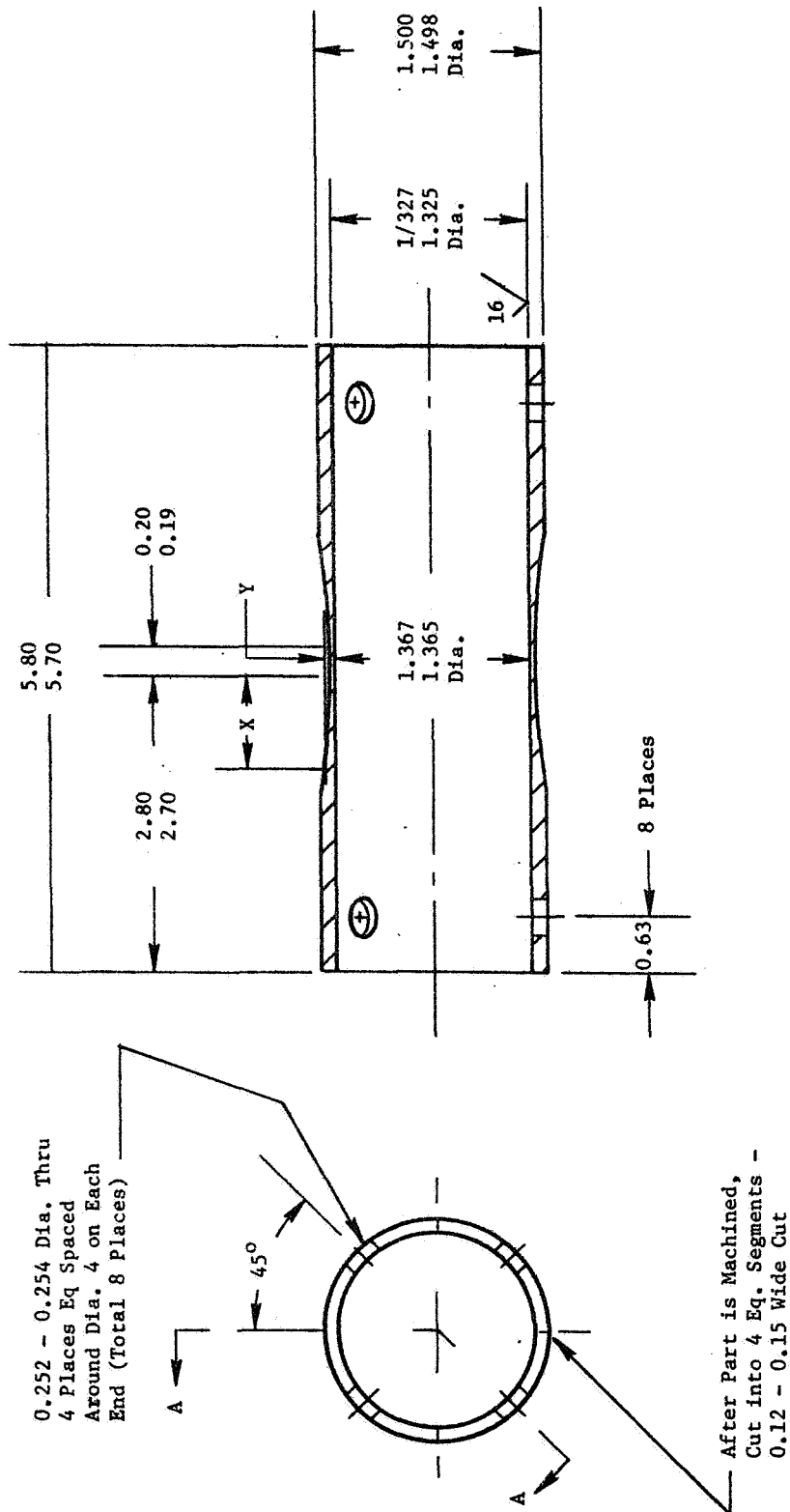
t_1 = thickness of capsule wall in test section (0.0191 in.)

the stress generated in the capsule test section as a result of the potassium pressure can be computed at various temperatures. This relationship can be shown on the same Larson-Miller parameter plot as the 1% creep data shown in Figure 24 by using the planned test time of 5000 hours in computing the parameter P . The two curves represent the two stress - temperature relationships discussed earlier and their intersection yields the desired test temperature for the 5000 hour test. The indicated parameter of 49.8 results in a test temperature of 2203°F for the 5000 hour test. A test temperature of 2200°F was then selected which should result in approximately the 1% creep which is desired.

The special uniaxial creep test specimen is shown in Figures 26 and 27. The specimens were made by machining a reduced wall test section in the T-111 alloy tubing which is identical to that in the biaxial test capsules, drilling appropriate holes in the ends of the tube for gripping during uniaxial testing, and then longitudinally sectioning the tube to form four test specimens. The test specimen gage section consists of the inner 0.020 inch of the tubing wall similar to the reduced wall section in the biaxial capsule test and has been machined in the same manner. One of these specimens will be tested under the same conditions as preliminary uniaxial test No. 3 (2300°F, 12,500 psi stress, conventional specimen design) to allow a comparison between the two specimen designs. If the uniaxial creep test results for the special test specimen design are acceptable, this type of specimen will be used for the 5000 hour uniaxial tests to be run concurrently with the capsule tests.

D. Potassium Pressure Transducer

The assembly and final calibration of the potassium pressure transducer, shown in Figure 28, which will be used to measure the potassium pressure in the seamless T-111 alloy refluxing capsule during testing



All Dimensions Shown are in Inches.

Dimension Schedule of Reduced Wall Sections of Specimen

X (+0.10)	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.75	0.80	0.85	0.90	0.925	0.950	0.975	1.000	1.025	1.050	1.075	1.100
Y (+0.001)	0	0.001	0.002	0.003	0.005	0.007	0.011	0.015	0.018	0.021	0.025	0.029	0.031	0.033	0.036	0.039	0.043	0.047	0.053	0.067
Y (-0.000)																				

Figure 26. Design of Special T-111 Alloy Uniaxial Creep Test Specimen.

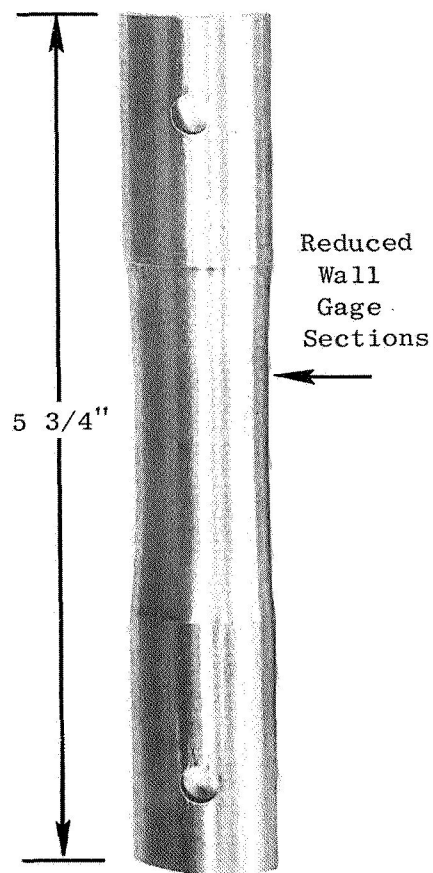


Figure 27. Special Uniaxial Creep Test Specimens Made From Seamless T-111 Alloy Tubing. (C680719170)

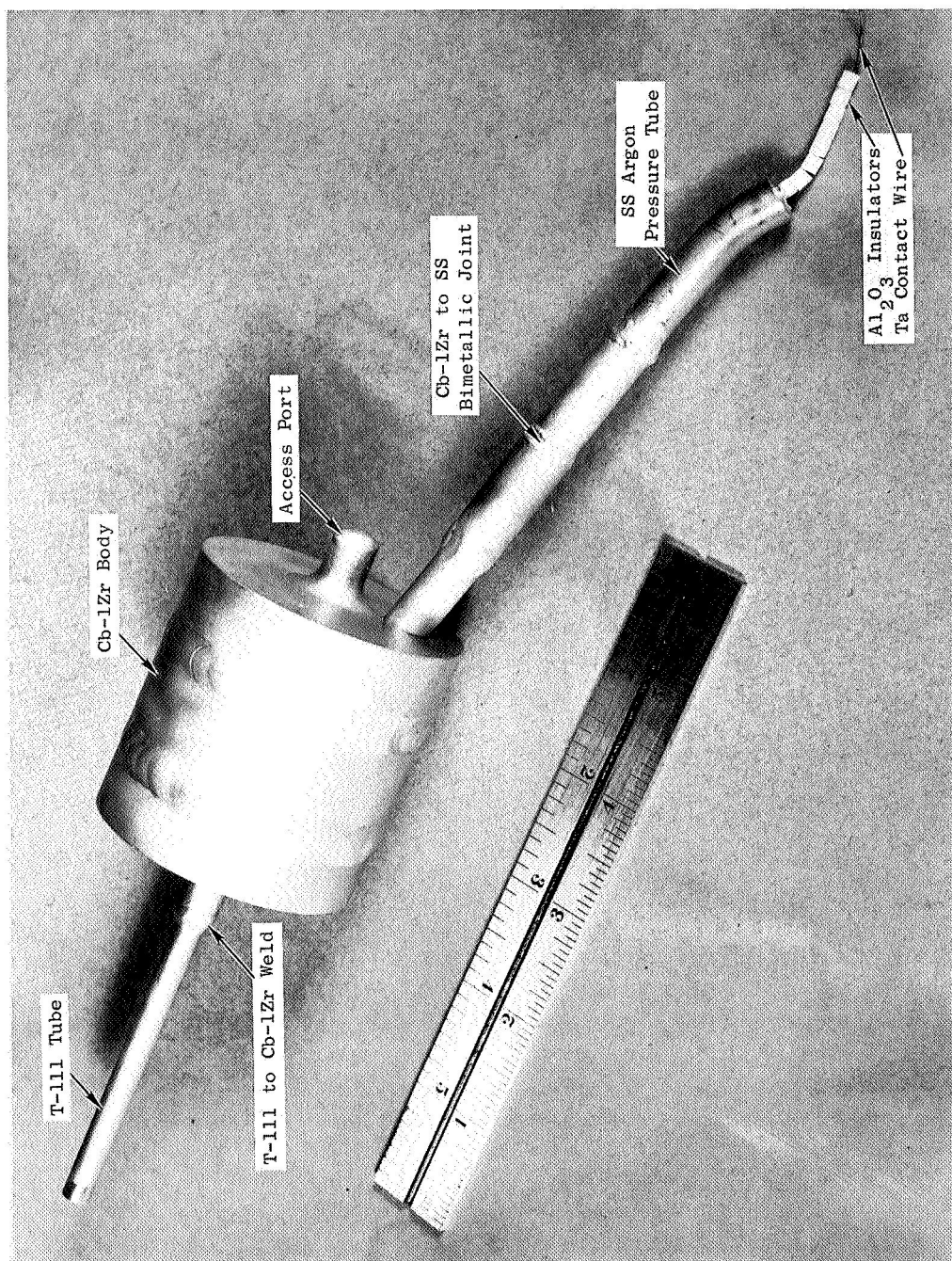


Figure 28. The Potassium Pressure Transducer to be Used on the Seamless T-111 Alloy Capsule. (Orig. C68073103)

has been completed. The calibration of the transducer was accomplished by applying an argon gas pressure to the potassium side of the transducer to simulate the potassium vapor pressure. This pressure was determined with a previously calibrated standard pressure system, shown in Figure 29. The previously described pressure system,⁽⁶⁾ which will be used during the actual test operation, was then used to determine the pressure previously applied to the potassium side of the transducer as shown in Figure 30. The capsule was contained in an evacuated EB weld tank and heated with a sheathed resistance heater shown in Figure 31 during the calibration at elevated temperatures. The temperature of the transducer was measured with Pt/Pt - 10 Rh thermocouples attached to the transducer body. The transducer was insulated with tantalum heat shields as shown in Figure 32. The calibration was performed at room temperature, 450°F, 600°F, and 800°F at pressures in the range from 0 to 400 psia. The results of the calibration are shown in Table IV. Excellent performance of the transducer was observed. At various times during the calibration the diaphragm was over pressured by as much as 100 psi with no detrimental effects on the transducer's operation or accuracy. The very small random errors observed are not attributed to the sensitivity of the transducer but are a result of the inability to accurately adjust the pressure to obtain an exact null point. In any case, the accuracy of the transducer is considered good and since the transducer is a direct reading instrument at all temperatures and pressures no calibration corrections are needed.

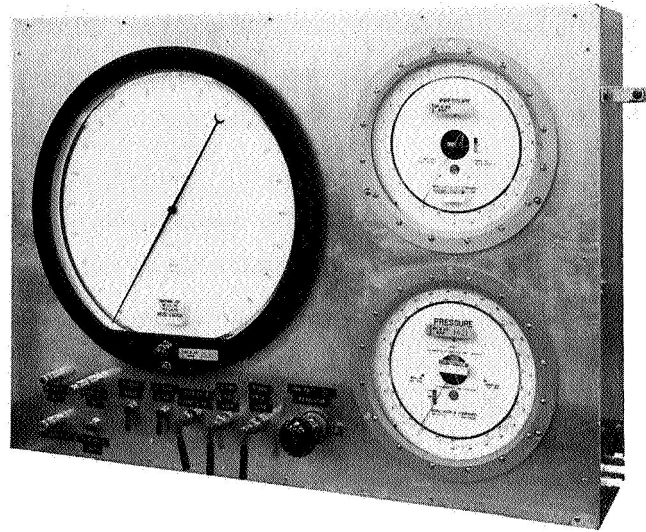


Figure 29. The System Used to Directly Measure Argon Gas Pressure on Potassium Side of Biaxial Creep Capsule Pressure Transducer During Calibration (Orig. C68081306).

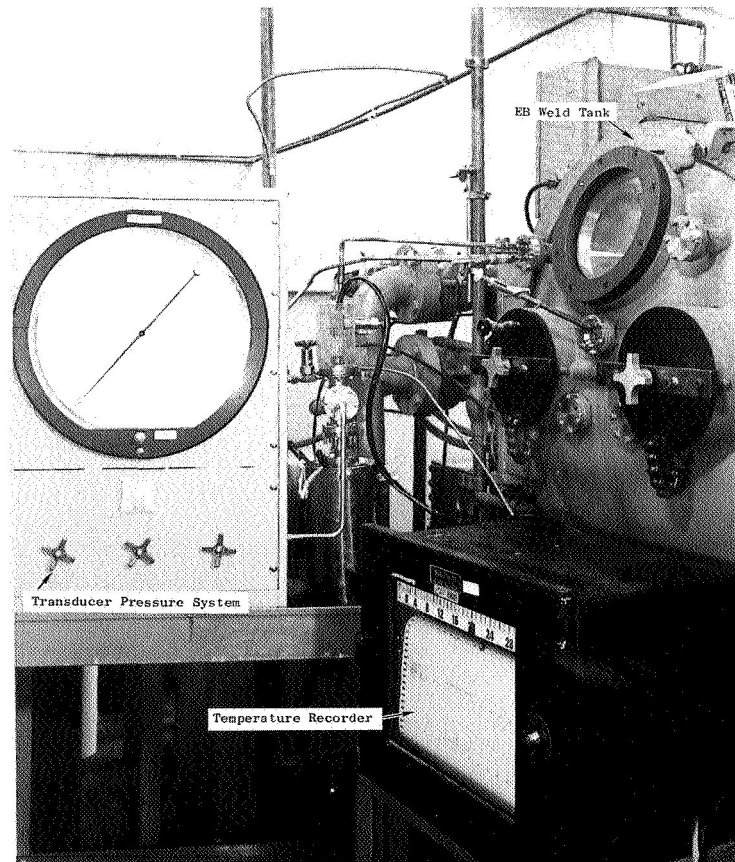


Figure 30. Instrumentation for the Calibration of the Potassium Pressure Transducer (Standard Pressure System Not Shown) (Orig. C68081307).

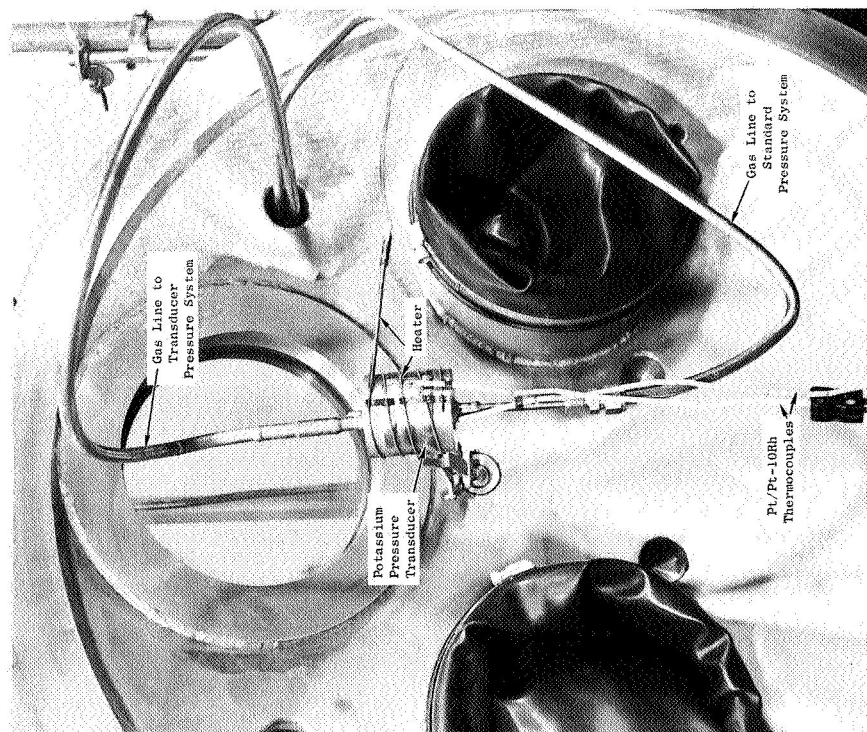


Figure 31. The Potassium Pressure Transducer Located in the Electron Beam Welding Chamber Without Tantalum Heat Shields. (Orig. C68081308)

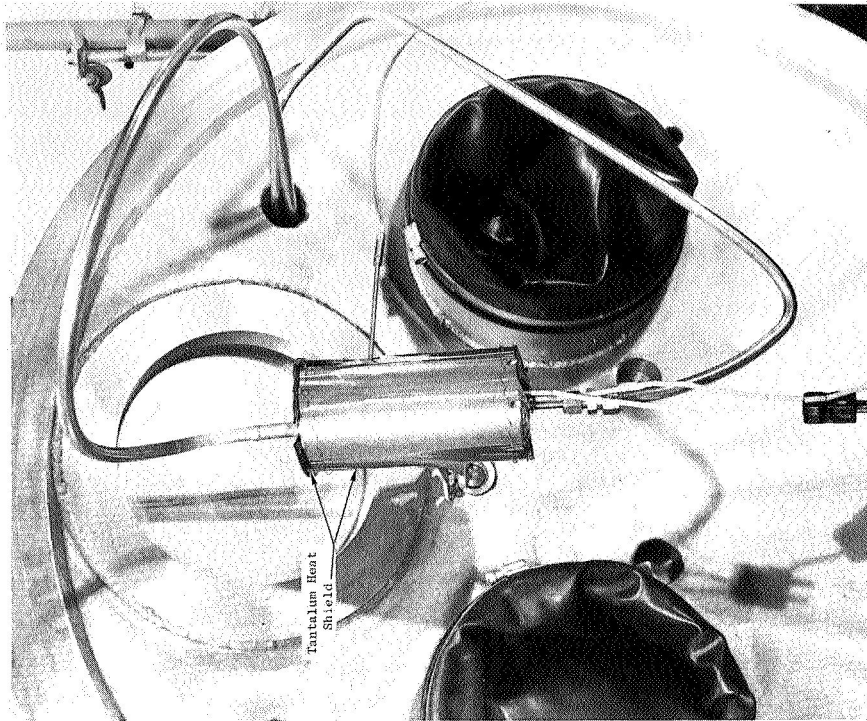


Figure 32. The Potassium Pressure Transducer Located in the Electron Beam Welding Chamber with Tantalum Heat Shields in Place. (Orig. C68081309)

TABLE IV

CALIBRATION DATA FOR THE POTASSIUM PRESSURE TRANSDUCER-
T-111 ALLOY BIAXIAL CREEP CAPSULE TEST

Transducer Temperature	Standard Reference Pressure, psia	Transducer Pressure(a), psia	Error psia
RT	25.1	26.3	+ 1.2
	104.0	104.5	+ 0.5
	172.0	172.8	+ 0.8
	200.0	201.2	+ 1.2
	254.0	254.2	+ 0.2
	300.0	300.6	+ 0.6
	350.5	350.6	+ 0.1
	398.0	398.5	+ 0.5
	304.0	303.2	- 0.8
	249.5	249.5	0.0
	197.5	197.8	+ 0.3
	149.0	149.0	0.0
	98.7	98.3	- 0.4
	52.5	52.6	+ 0.1
450°F	100.5	100.3	- 0.2
	200.5	200.5	0.0
	300.5	300.6	+ 0.1
	350.0	350.3	+ 0.3
600°F	109.5	108.8	- 0.7
	199.5	199.2	- 0.3
	300.5	299.7	- 0.8
	349.0	349.0	0.0
800°F	100.3	100.3	0.0
	199.5	199.2	- 0.3
	300.0	300.0	0.0
	349.5	349.8	+ 0.3

(a) Determined with transducer pressure system.

IV. FUTURE PLANS

- A. The T-111 alloy test capsule made from the seamless tube will be installed into the test facility and testing of the capsule will be initiated.
- B. Uniaxial creep testing of specimens from the T-111 alloy tubing will continue.

REFERENCES

- (1) Harrison, R. W., "The Compatibility of Biaxially Stressed D-43 Alloy with Refluxing Potassium," NASA Contractor Report NASA CR-807, NASA Contract NAS 3-6012, June 1967.
- (2) Den Hartog, J. P., Advanced Strength of Materials, p 166, McGraw Hill, New York (1952).
- (3) Zimmerman, W. F., "Turbine Materials-Potassium Turboalternator Program," NASA Contract NAS 3-10933, Nuclear Systems Programs Dept., General Electric Co., March (1968).
- (4) Beitch, L., Cook, W. and Holt, R., "Computer Program for Analysis of Structures Made up of Shells of Revolution (Multi Shell II)," General Electric Company, AEG, Report No. R59FPD889, February 29 (1960).
- (5) Engel, L. B., "Determination of Biaxial Creep Strength of T-111 Tantalum Alloy," Semi-Annual Report, NASA CR-72337, NASA Contract NAS 3-9437, Period March 8, 1967 to September 8, 1967.
- (6) Engel, L. B., "Determination of Biaxial Creep Strength of T-111 Tantalum Alloy," Semi-Annual Report, General Electric Report No. GES-75, NASA Contract NAS 3-9437, Period September 8, 1967 to March 8, 1968.
- (7) Sheffler, K. D. and Steigerwald, E. A., "Generation of Long Time Creep Data on Refractory Alloys at Elevated Temperatures," Fifteenth Quarterly Report, NAS-CR-72431, NASA Contract NAS 3-9439, Period December 14, 1967 to March 27, 1968, April 14 (1968).
- (8) Ewing, C. T., Stone, J. P., Spann, J. R., Steinkuller, E. W., Williams, D. D., and Miller, R. R., "High-Temperature Properties of Potassium," September 24, 1965, NRL Report 6233, U. S. Naval Research Laboratory.

DISTRIBUTION LIST - SEMI-ANNUAL REPORT

CONTRACT NAS 3-9437

NASA Washington, D. C. 20546 ATTN: Arvin Smith (RNW) S. V. Manson (RNP) George C. Deutsch (RR) Dr. Fred Schulman (RNP)	Jet Propulsion Laboratory California Institute of Technology 4800 Oak Grove Drive Pasadena, California 91103 ATTN: Librarian
NASA - Lewis Research Center 21000 Brookpark Road Cleveland, Ohio 44135 ATTN: Librarian MS 3-7 Dr. B. Lubarsky MS 500-201 G. M. Ault MS 105-1 R. L. Davies MS 500-201 J. E. Dilley MS 500-309 M. Sabala MS 3-19 T. A. Moss MS 500-201 Coulson Scheuermann (106-1) Report Control Office MS 5-5 V. F. Hlavin MS 3-14	National Bureau of Standards Washington, D. C. 20225 ATTN: Librarian Flight Vehicle Power Branch Air Force Aero-Propulsion Lab Wright Patterson AFB, Ohio 45433 ATTN: Charles Armbruster ASRPP-10 T. Cooper Librarian George E. Thompson APIP-1 George Sherman API George Glenn
NASA Scientific & Technical Infor. Fac. P. O. Box 33 College Park, Maryland 20740 ATTN: Acquisitions Branch (SQT-34054) (2 + Repro.)	Army Ordnance Frankford Arsenal Bridesburg Station Philadelphia, Pennsylvania 19137 ATTN: Librarian Bureau of Mines Albany, Oregon ATTN: Librarian
NASA Goddard Space Flight Center Greenbelt, Maryland 20771 ATTN: Librarian	Bureau of Ships Department of the Navy Washington, D. C. 20225 ATTN: Librarian
NASA Langley Research Center Hampton, Virginia 23365 ATTN: Librarian	Bureau of Weapons Research and Engineering Materials Division Washington, D. C. 20225 ATTN: Librarian
NASA Manned Spacecraft Center Houston, Texas 77001 ATTN: Librarian	U.S. Atomic Energy Commission Technical Reports Library Washington, D. C. 20545 ATTN: J. M. O'Leary (2)
NASA George C. Marshall Space Flight Center Huntsville, Alabama 35812 ATTN: Librarian	U. S. Atomic Energy Commission Germantown, Maryland 20767 ATTN: K. E. Horton

U. S. Atomic Energy Commission
Technical Information Service Ext.
P. O. Box 62
Oak Ridge, Tennessee 27831 (3)

U. S. Atomic Energy Commission
Washington, D. C. 20545
ATTN: M. J. Whitman

Office of Naval Research
Power Division
Washington, D. C. 20225
ATTN: Librarian

U. S. Naval Research Laboratory
Washington, D. C. 20225
ATTN: Librarian

AiResearch Manufacturing Company
Sky Harbor Airport
402 South 36th Street
Phoenix, Arizona 85034
ATTN: Librarian
E. A. Kovacevich
John Dannan

AiResearch Manufacturing Company
9851-9951 Sepulveda Boulevard
Los Angeles, California 90045
ATTN: Librarian

Argonne National Laboratory
9700 South Cross Avenue
Argonne, Illinois 60440
ATTN: Librarian

Atomics International
8900 DeSoto Avenue
Canoga Park, California 91303
ATTN: Librarian
Harry Pearlman

AVCO
Research & Advanced Development Prog.
201 Lowell Street
Wilmington, Massachusetts 01800
ATTN: Librarian

Babcock & Wilcox Company
Research Center
Alliance, Ohio 44601
ATTN: Librarian

Battelle Memorial Institute
505 King Avenue
Columbus, Ohio 43201
ATTN: Dr. E. M. Simmons
Librarian

The Bendix Corporation
Research Laboratories Division
Southfield, Michigan 48200
ATTN: Librarian

The Boeing Company
Seattle, Washington 98100
ATTN: Librarian

Brookhaven National Laboratory
Upton, Long Island, New York 11973
ATTN: Librarian

Chance Vought Aircraft, Inc.
P. O. Box 5907
Dallas, Texas 75222
ATTN: Librarian

Clevite Corporation
Mechanical Research Division
540 East 105th Street
Cleveland, Ohio 44108
ATTN: N. C. Beerli

Convair Astronautics
5001 Kerrny Villa Road
San Diego, California 92111
ATTN: Librarian

Curtiss-Wright Corporation
Research Division
Quehanna, Pennsylvania
ATTN: Librarian

Eitel McCullough, Inc.
301 Industrial Way
San Carlos, California
ATTN: M. Parkman

Electro-Optical Systems, Inc.
Advanced Power Systems Division
Pasadena, California 91100
ATTN: Librarian

NAS 3-9437

Ford Motor Company
Aeronutronics
Newport Beach, California 92660
ATTN: Librarian

General Atomics
John Jay Hopkins Laboratory
P. O. Box 608
San Diego, California 92112
ATTN: Librarian
Dr. Ling Yang

General Electric Company
Atomic Power Equipment Division
P. O. Box 1131
San Jose, California

General Electric Company
Missile & Space Division
3198 Chestnut Street
Philadelphia, Pennsylvania 19104
ATTN: Librarian

General Electric Company
Vallecitos Atomic Lab
Pleasanton, California 93566
ATTN: Librarian

General Dynamics/Fort Worth
P. O. Box 748
Fort Worth, Texas 76100
ATTN: Librarian

General Motors Corporation
Allison Division
Indianapolis, Indiana 46206
ATTN: Librarian

Hamilton Standard
Division of United Aircraft Corp.
Windsor Locks, Connecticut
ATTN: Librarian

Hughes Aircraft Company
Engineering Division
Culver City, California 90230
ATTN: Librarian

IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616
ATTN: Librarian

Lockheed Missiles & Space Division
Lockheed Aircraft Corporation
Sunnyvale, California
ATTN: Librarian
John N. Cox

Marquardt Aircraft Company
P. O. Box 2013
Van Nuys, California
ATTN: Librarian

The Martin Company
Baltimore, Maryland 21203
ATTN: Librarian

The Martin Company
Nuclear Division
P. O. Box 5042
Baltimore, Maryland 21220
ATTN: Librarian

Martin Marietta Corporation
Metals Technology Laboratory
Wheeling, Illinois

Materials Research and Development
Manlabs, Incorporated
21 Erie Street
Cambridge, Massachusetts 02139

Materials Research Corporation
Orangeburg, New York
ATTN: Librarian

McDonnell Aircraft
St. Louis, Missouri 63100
ATTN: Librarian

MSA Research Corporation
Callery, Pennsylvania 16024
ATTN: Librarian

North American Aviation, Inc.
Los Angeles Division
Los Angeles, California 90009
ATTN: Librarian

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
ATTN: W. H. Cook
W. O. Harms
Librarian
J. H. DeVan

Pratt & Whitney Aircraft
400 Main Street
East Hartford, Connecticut 06108
ATTN: Librarian

Engineering Library
Fairchild Hiller
Republic Aviation Corporation
Farmingdale, Long Island, New York
ATTN: Librarian

Rocketdyne
Canoga Park, California 91303
ATTN: Librarian

Solar
2200 Pacific Highway
San Diego, California 92112
ATTN: Librarian

Southwest Research Institute
8500 Culebra Road
San Antonio, Texas 78206

Superior Tube Company
Norristown, Pennsylvania
ATTN: Mr. A. Bound

Sylvania Electrics Products, Inc.
Chem. & Metallurgical
Towanda, Pennsylvania
ATTN: Librarian

TRW, Inc.
Caldwell Research Center
23555 Euclid Avenue
Cleveland, Ohio 44117
ATTN: Librarian
E. Steigerwald

Union Carbide Corporation
Stellite Division
Kokomo, Indiana
ATTN: Librarian

Union Carbide Nuclear Company
P. O. Box X
Oak Ridge, Tennessee 37831
ATTN: Records Department (2)

Union Carbide Metals
Niagara Falls, New York 14300
ATTN: Librarian

United Aircraft Corporation
Pratt & Whitney Division
400 W. Main Street
Hartford, Connecticut 06108
ATTN: W. H. Podolny

United Nuclear Corporation
Five New Street
White Plains, New York 10600
ATTN: Librarian

Union Carbide Corporation
Parma Research Center
P. O. Box 6115
Cleveland, Ohio 44101
ATTN: Technical Information Serv.

Wah Chang Corporation
Albany, Oregon
ATTN: Librarian

Westinghouse Electric Corporation
Astronuclear Laboratory
P. O. Box 10864
Pittsburgh, Pennsylvania 15236
ATTN: Librarian
R. T. Begley

Westinghouse Electric Corporation
Materials Manufacturing Division
RD #2 Box 25
Blairsville, Pennsylvania
ATTN: Librarian

Westinghouse Electric Corporation
Aerospace Electrical Division
Lima, Ohio
ATTN: P. W. Kueser

Westinghouse Electric Corporation
Research & Development Center
Pittsburgh, Pennsylvania 15235
ATTN: Librarian

Wyman-Gordon Company
North Grafton, Massachusetts
ATTN: Librarian

Grumman Aircraft
Bethpage, New York
ATTN: Librarian

NAS 3-9437

Lawrence Radiation Laboratory
Livermore, California
ATTN: Librarian (2)

Allis Chalmers
Atomic Energy Division
Milwaukee, Wisconsin
ATTN: Librarian

Allison-General Motors
Energy Conversion Division
Indianapolis, Indiana
ATTN: Librarian

AMF Atomics
140 Greenwich Avenue
Greenwich, Connecticut
ATTN: Librarian

American Machine And Foundry Company
Alexandria Division
1025 North Royal Street
Alexandria, Virginia
ATTN: Librarian

Douglas Aircraft Company, Inc.
Missile & Space Systems Division
3000 Ocean Park Boulevard
Santa Monica, California
ATTN: Librarian

Climax Molybdenum Company of Michigan
1600 Huron Parkway
Ann Arbor, Michigan 48105
ATTN: Librarian
Dr. M. Semchyshen

Fansteel Metallurgical Corporation
North Chicago, Illinois
ATTN: Librarian

National Research Corporation
405 Industrial Place
Newton, Massachusetts
ATTN: Librarian

Universal Cyclops Steel Corporation
Refractomet Division
Bridgeville, Pennsylvania
ATTN: C. P. Mueller

Los Alamos Scientific Laboratory
University of California
Los Alamos, New Mexico
ATTN: Librarian

Lockheed Georgia Company
Division, Lockheed Aircraft Company
Marietta, Georgia
ATTN: Librarian

Sandia Corporation
Div. 9333
P. O. Box 5800
Albuquerque, New Mexico 87115
ATTN: James Jacobs