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GENERATION OF LONG TIME CREEP DATA ON REFRACTORY ALLOYS AT ELEVATED TEMPERATURES

TWELFTH QUARTERLY REPORT

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
UNDER CONTRACT NAS 3-2545

TRW EQUIPMENT LABORATORIES
 CLEVELAND, OHIO

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TWELFTH QUARTERLY REPORT

for

26 March 1966 to 26 June 1966

GENERATION OF LONG TIME CREEP DATA
OF REFRACTORY ALLOYS AT ELEVATED TEMPERATURES

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National Aeronautics and Space Administration

Contract No. NAS 3-2545

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July 15, 1966

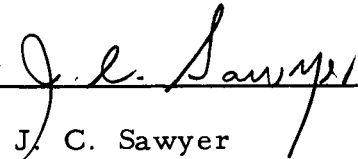
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FOREWORD

The work described herein is being performed by TRW Inc. under the sponsorship of the National Aeronautics and Space Administration under Contract NAS 3-2545. The purpose of this study is to obtain design creep data on refractory metal alloys for use in advanced space power systems.

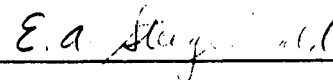
The program is administered for TRW Inc. by E. A. Steigerwald, Program Manager. J. C. Sawyer is the Principal Investigator, and R. R. Ebert contributed to the program. The NASA technical director is Paul E. Moorhead.

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I INTRODUCTION

Space electric power systems depend upon the use of refractory metals in a variety of component areas. A critical property parameter in the design of these systems is the long-time creep strength at very low pressures and elevated temperatures. Since oxygen contamination of refractory metal alloys can occur under conditions of 1×10^{-6} Torr, vacuums better than 1×10^{-8} Torr must be used to obtain meaningful creep measurements which can be employed in the design of space components. The initial work of this program was to generate 1000 hour creep data on selected refractory alloys which have potential use in advanced power systems. These alloys are in the form of rolled sheet and forged plate with the former being considered as representative of material for cladding and tubing applications and the latter for turbine components. Following the initial evaluation, primary emphasis has been placed on providing long-time creep design data for the tantalum-base alloy T-111 and the molybdenum-base alloys TZC and TZM.

This report presents creep data for vapor-deposited tungsten, TZC, TZM, columbium-modified TZM and T-111.

II MATERIALS AND PROCEDURE

The compositions of the various alloys which have been or are being tested are presented in Table 1 while the material form, the range of test temperatures, and heat treatment are given in Table 2. A detailed review of the processing history of the alloys under evaluation was presented in the Ninth Quarterly Report, NASA-CR-54772.

In the current tests vapor-deposited tungsten was evaluated as 1/8" diameter bar machined from the wall of vapor-deposited tubing.

The TZM alloy was obtained from two different sources. One lot of material, designated as Climax Heat 7502, was purchased in the form of disc forgings approximately 11 inches in diameter, while a second lot of material (Heat KDTZM-1175) consisted of a section of a disc forging obtained by NASA from AiResearch. The latter material was processed by

TABLE 1

Chemical Composition of Alloys Being Evaluated in Creep Program (Weight %)

Material	W	Re	Cb	Mo	Ta	Hf	C	N ₂	Ti	Zr	Ni	O ₂	H ₂
Tungsten (Vapor Deposited) (General Atomics)	Bal.						.0012					12-14	1-3
Tungsten (Arc-melted)	Bal.						.0058					9	4
Tungsten-25% Rhenium (Arc-Melted)	Bal.	24.9					.0050					50	1.4
Sylvania A	Bal.					0.52	.030					20	3
TZM (Climax Heat 7502)				Bal.			.013	.011	.47	.091		20	7
TZM (Climax Heat 7463) Commercial 5/8" Diameter Bar				Bal.			.016	.0003	.48	.080		2	1
TZM Heat KDTZM-1175 (AiResearch)				Bal.			.031 (.024)	.0043	.61 (.49)	.12 (.144)		34	9 ⁽¹⁾ (2)
Cb Modified TZM (Heat 4305-4)			1.62 (1.00)	Bal.			.06 (.015)	(.003)	.50 (.48)	.32 (.095)		(39)	(4) (1) (4)
TZC (Heat M-80)				Bal.			.140	.0018	1.02	.130		41	5
TZC (Heat M-91)				Bal.			.145	.003	1.17	.274		37	10
AS-30	21.0		Bal.				.090	.010	.03	1.04	.02	60	15
Cb132M	15.6		Bal.	4.73	19.5		.150	.002		2.40		4	2
T-222	9.57			Bal.			.012	.0026				35	11 ⁽³⁾
T-111 (Heat 70616)	8.5			Bal.		2.30	.004	.002				55	6
(Heat D-1670)	7.9			Bal.		2.17-2.44	.001	.002				72	5

(1) - TRW Analysis
 (2) - AiResearch Analysis
 (3) - Originally ST-222 plate, program plan revised and plate rolled to make T-222 sheet.
 (4) - Climax Analysis

TABLE 2
Summary of Material Variables Being Evaluated in the Creep Program

Material	Form	Test Temperature	Test Condition
Tungsten	Arc-Melted 0.030" Sheet	3200°F (1760°C) 2800°F (1538°C)	Recrystallized 1-2 hours, 3200°F (1760°C) Recrystallized 1 hour, 2800°F (1538°C)
Tungsten-25% Rhenium	Arc-Melted 0.030" Sheet	3200°F (1760°C)	Recrystallized 1-2 hours, 3200°F (1760°C)
Sylvania A	Powder Metallurgy 0.030" Sheet	3200°F (1760°C)	Recrystallized 1-2 hours, 3200°F (1760°C)
Tungsten	Vapor-Deposited 1/8" Dia. Bars	3200°F (1760°C) 2800°F (1538°C)	Anneal 1 hour, 3200°F (1760°C) Anneal 1 hour, 2800°F (1538°C)
AS-30	3/4" Plate	2000-2200°F (1093-1204°C)	As-Received (stress-relieved condition)
Cb132M	3/4" Plate	2056-2256°F (1124-1235°C)	Annealed 1 hour, 3092°F (1700°C)
TZM (Heat 7463)	5/8" Diameter Bar	2000°F (1093°C)	Stress relieved 2250°F (1232°C), 1/2 hour
TZM (Climax Heat 7502)	"Pancake" Forging	2000°F (1093°C)	(Cond. 1) As-received (stress-relieved condition)(Cond. 2) Annealed 1 hour, 2850°F (1566°C)
TZM Heat KDTZM-1175 (AiResearch)	"Pancake" Forging	1600-1856°F (871-1013°C)	As-received (stress relieved 2300°F (1260°C), 1 hour)
CB Modified TZM Heat 4305-4	5/8" Diameter Bar	1800-2200°F (982-1204°C)	Stress -relieved 2500°F (1371°C), 1 hour
TZC (Heat M-80) TZC (Heat M-91)	3/4" Plate	1800-2200°F (982-1204°C)	Several test conditions
T-222*	0.030" Sheet	2056-2200°F (1124-1204°C)	Recrystallized 2800°F (1538°C) and 3000°F (1649°C), 1 hour
T-111 (Heat 70616) (Heat D-1670)	0.030" Sheet	1800-2200°F (982-1204°C)	Recrystallized 2600°F (1426°C) and 3000°F (1649°C), 1 hour

* Originally scheduled to be tested as ST-222 plate material, program plan revised to include materials as T-222 grade applicable for tubing.

Universal Cyclops to produce improved creep resistance* through the development of a fine carbide dispersion. In order to produce this effect it is necessary to work with a carbon level above 0.02%. Commercial TZM bar has also been included in the studies as a means of determining the influence of material form on the creep properties.

To date two different heats of TZC have been tested. These heats obtained from the same vendor, represent a difference in processing treatment. Heat M-80 involved finishing a 2" x 4" sheet bar by rolling at 2925°F (1585°C) using small reductions per pass (approximately 4%). In contrast M-91 employed a finishing temperature of 2372°F (1300°C) and a relatively large degree of deformation per pass.

The tensile properties of the various heats of TZC material are summarized in Table 3. Included in the Table are data for Heat M-88 which was tested as 2" x 4" extruded bar and for Heat M-89 which received the same fabrication sequence as Heat M-80. The results indicate that after 3092°F (1700°C) annealing treatment Heat M-91 which had the relatively high degree of working per pass possessed a greater ductility than that present in specimens from Heat M-80. The lower yield strength in the M-91 specimens is a result of the M-91 material being completely recrystallized after annealing while specimens from Heat M-80 were not (see Figure 1). Aging treatments at 2400°F (1316°C), following recrystallization at 3092°F (1700°C), did not significantly alter the room temperature properties of the TZC from Heat M-91. Aging the as-received material at 2250°F (1371°C) produced a decrease in tensile strength of approximately 20%. The room and elevated tensile properties of the TZC from Heat M-91 after a 3092°F (1700°C) annealing treatment are summarized in Figure 2.

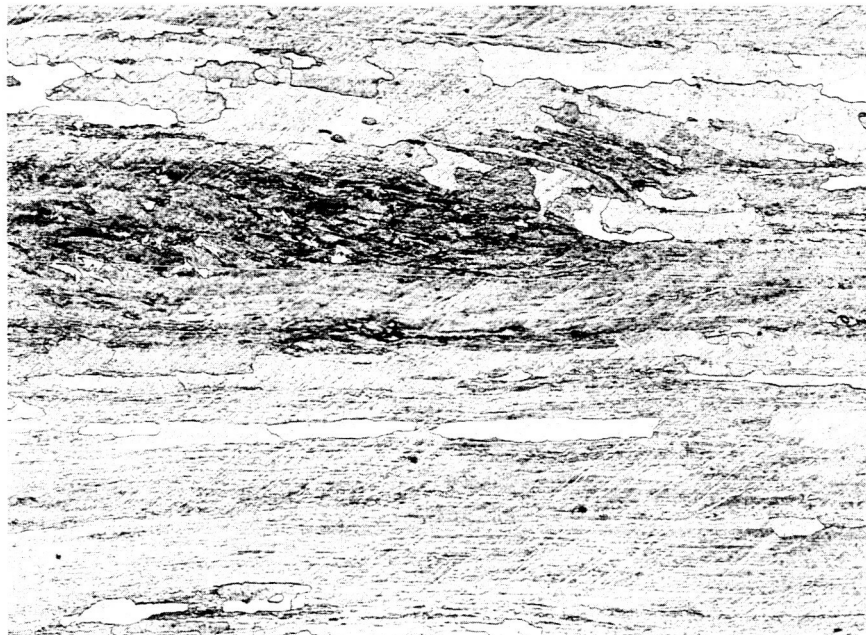
Columbium-modified TZM, a relatively new alloy produced by Climax Molybdenum, was tested as a swaged 5/8" diameter bar. Prior to testing the recrystallization behavior of the material was evaluated by aging metallographic specimens for one hour at 2500, 2800, and 3000°F (1371, 1538, 1649°C). The results summarized in Figure 3 indicate that very local recrystallization occurred at 2800°F (1538°C). However, neither complete recrystallization nor any hardness variation was noted at temperatures as high as 3000°F (1649°C).

* Technical Report AF-APL-TR-61-51, June 25, 1965.

TABLE 3

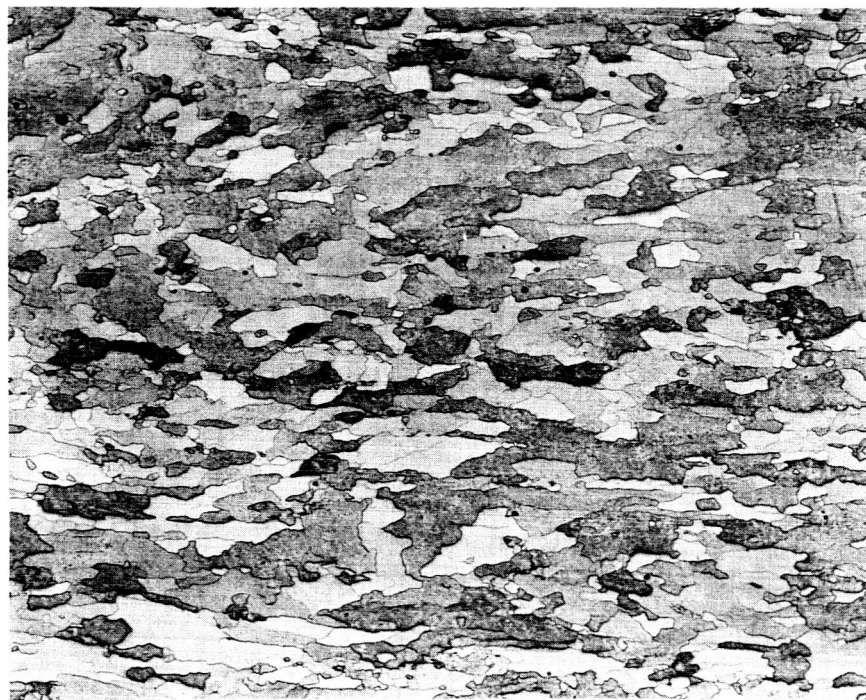
Tensile Properties of TZC Material

Heat No.	Condition	Test Temp., °F	Strength (Ksi)			%R. A.	Hardness DPH
			Tensile	0.2% Yield	%E		
M-80	As-received	-	-	-	-	-	257-317
	3092°F, 1 hr.	RT	68.6	68.5	.05	0	219-240
	{3092°F, 1 hr. 2400°F, 1 hr.}	RT	94.7	90.3	.05	0	257
	2750°F, 25 hr.	RT	99.5	67.8	7.00	10.0	-
M-88	As-extruded	RT	91.7	89.7	0.8	2.6	286
	As-extruded	2000	64.6	59.7	23.3	72.6	226
M-89	3092°F, 1 hr.	1800	55.6	29.9	31.3	67.6	317
	3092°F, 1 hr.	2000	55.5	30.8	29.4	67.8	217
M-91	As-received	RT	124.7	111.6	1.4	0.8	310
		RT	157.5	85.6	13.2	13.1	
	3092°F, 1 hr.	RT	88.2	47.8	9.0	5.6-8.0	268
		RT	81.8	50.3	4.4		
	3092°F, 1 hr.	1800	44.8	29.1	33.5	87.8	271
	3092°F, 1 hr.	2000	40.8	25.0	42.7	87.8	286
	3092°F, 1 hr.	2200	34.9	23.9	42.3	88.3	264
	{3092°F, 1 hr. 2400°F, 1 hr.}	RT	78.8	42.8	13.2	13.1	268-302
		RT	71.2	47.0	3.8		
	3092°F, 1 hr. 3092°F, 10 hr.	RT	72.3	50.3	4.3	5.5	254
2500°F, 1 hr.		RT	106.4	99.0	3.7	6.9	326



100 X

M-80



100 X

M-91

FIGURE 1 MICROSTRUCTURE OF TZC HEATS M-80 AND M-91 ANNEALED 1 HOUR AT 3092°F (1700°C). ETCHANT 15% HF, 15% H₂SO₄, 8% HNO₃, 62% H₂O. SURFACE PERPENDICULAR TO EXTRUSION.

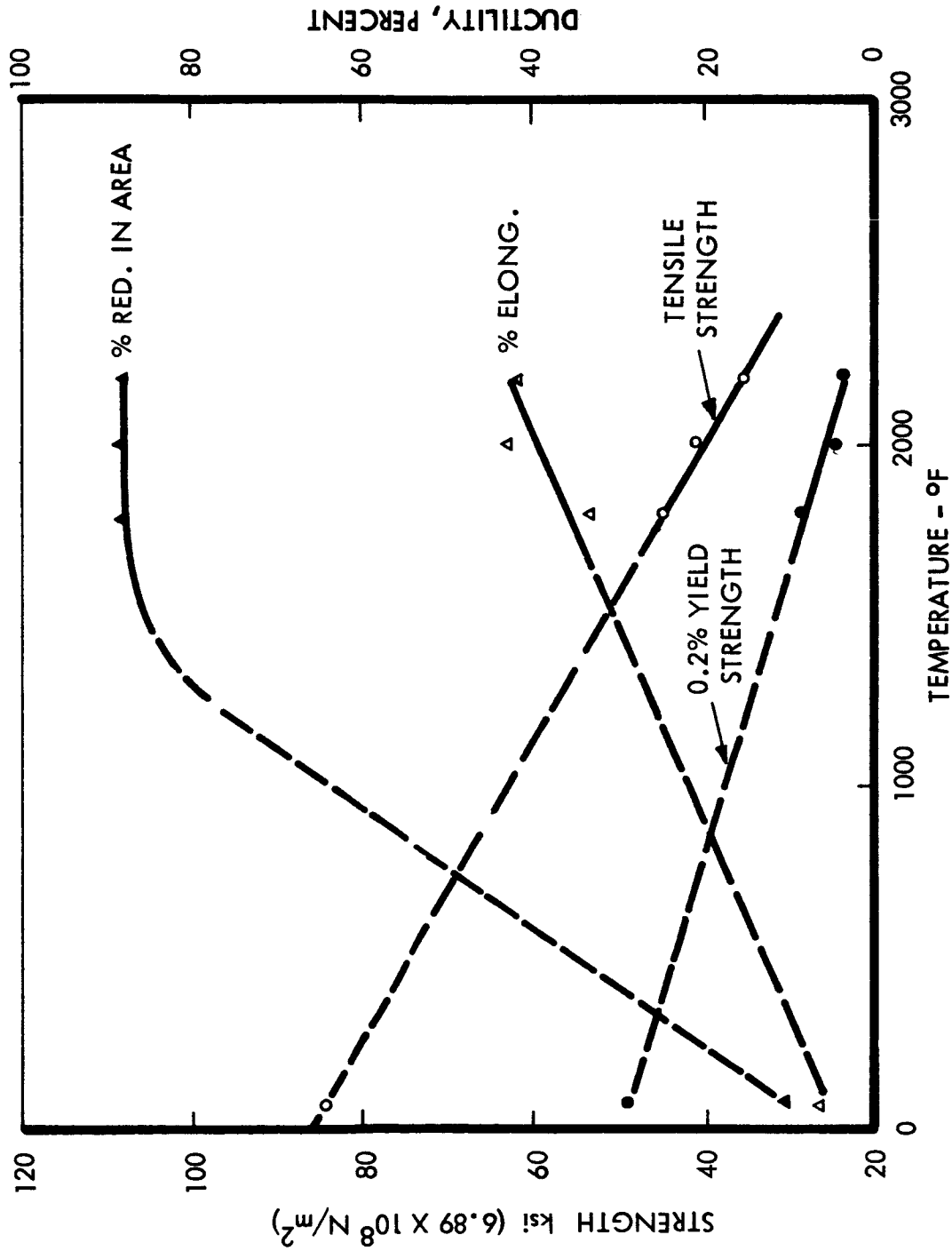
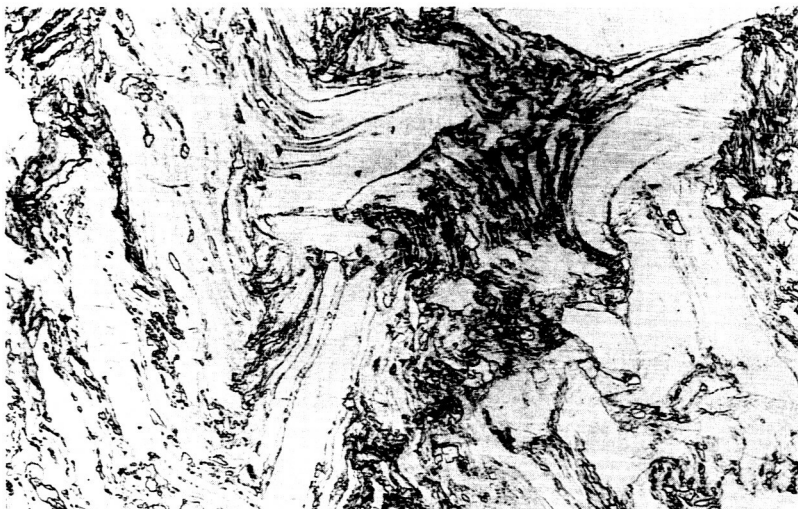


FIGURE 2: TENSILE PROPERTIES OF TZC, HEAT M-91 ANNEALED 1 HOUR AT 3092°F (1700°C).



HARDNESS: DPH 278
ANNEALED 1 HOUR AT 2500°F (1371°C)



HARDNESS: DPH 287
ANNEALED 1 HOUR AT 2800°F (1538°C)



HARDNESS: DPH 279
ANNEALED 1 HOUR AT 3000°F (1649°C)

FIGURE 3 COLUMBIUM-MODIFIED TZM ANNEALED AT VARIOUS TEMPERATURES.
SURFACE PERPENDICULAR TO AXIS OF BAR. MURAKAMIS ETCH, 100 X

The T-111 alloy was obtained from two different sources. One lot was produced by Wah Chang (Heat 70616), the other was obtained from Fansteel (Heat D-1670). Both lots were evaluated after recrystallization for one hour at 3000°F (1649°C).

The creep-test procedure involved obtaining a vacuum of 5×10^{-10} Torr or better at room temperature, then heating the specimen at a rate so that the pressure never went above 1×10^{-6} Torr. Heat treatment was performed on the materials in situ, prior to load application. After heat treatment the specimens were cooled to 600°F or lower and then reheated to the test temperature which was maintained for two hours to insure equilibrium. During testing the vacuum was less than 1×10^{-8} Torr and generally decreased with test time.

Specimen extension was measured over a two-inch gauge length with an optical extensometer that determined the distance between two scribed reference marks to an accuracy of 50μ -inches. The program plan involves testing the plate or forged alloys at temperatures between 1600 and 2250°F (871 and 1235°C) until a 1% total elongation is obtained. The tungsten materials are being tested at 2800 and 3200°F (1566 and 1760°C) for total extensions between 3 and 5% while the tantalum-base materials are being evaluated in the 1800 to 2200°F (982 to 1204°C) range to an elongation of approximately 2 to 5%. The applied stress levels have been selected with the goal of obtaining creep data over total test times between 1000 and 10,000 hours.

III RESULTS AND DISCUSSION

The creep test data are graphically presented as percent elongation in the two inch gauge section as a function of the time at the applied stress. Reference marks are placed on the curves to indicate the chamber pressure during the course of the test. The numerical creep data for each test in progress during this quarter are given in detail in Appendix I.

Molybdenum-Base Alloys

The three classes of molybdenum-base alloys being examined are TZC, TZM, and columbium-modified TZM. A summary of the materials and pretest treatments are presented below. A variety of conditions are being evaluated in an effort to determine the optimum treatment from the standpoint of creep resistance, yield strength, and room temperature ductility.

TZC (Heat M-80)

Annealed 3092°F (1700°C), 1 hour

TZC (Heat M-91)

Stress relieved 2300°F (1260°C), 1 hour

Stress relieved 2500°F (1371°C), 1 hour

Annealed 3092°F (1700°C), 1 hour

TZM (Heat 7502)

Stress relieved 2200°F (1204°C), 1 hour

TZM (Heat 7463)

Stress relieved 2250°F (1232°C), 1/2 hour

TZM (Heat KDTZM 1175)

Stress relieved 2300°F (1260°C), 1 hour

Cb-Modified TZM (Heat 4305-4)

Stress relieved 2500°F (1371°C), 1 hour

The creep data for the tests of TZC from Heat M-80 are presented in Figure 4 while the data for specimens from Heat M-91 are given in Figures 5 and 6. The creep results are summarized in Figure 7 in the form of a Larson-Miller plot using a constant of 15. The data used to develop the Larson-Miller plot are presented in Table 4. The results indicate that after the 3092°F (1700°C) treatment, material from Heat M-80 has creep resistance which is superior to Heat M-91. A large variation in slope of the Larson-Miller curve exists between the two heats as a result of the very low Larson-Miller value obtained on the specimen from Heat M-91 which was tested at 2200°F (1204°C), 14 Ksi (9.65×10^7 N/m²). Post test examination indicated no apparent reason for this variation in behavior.

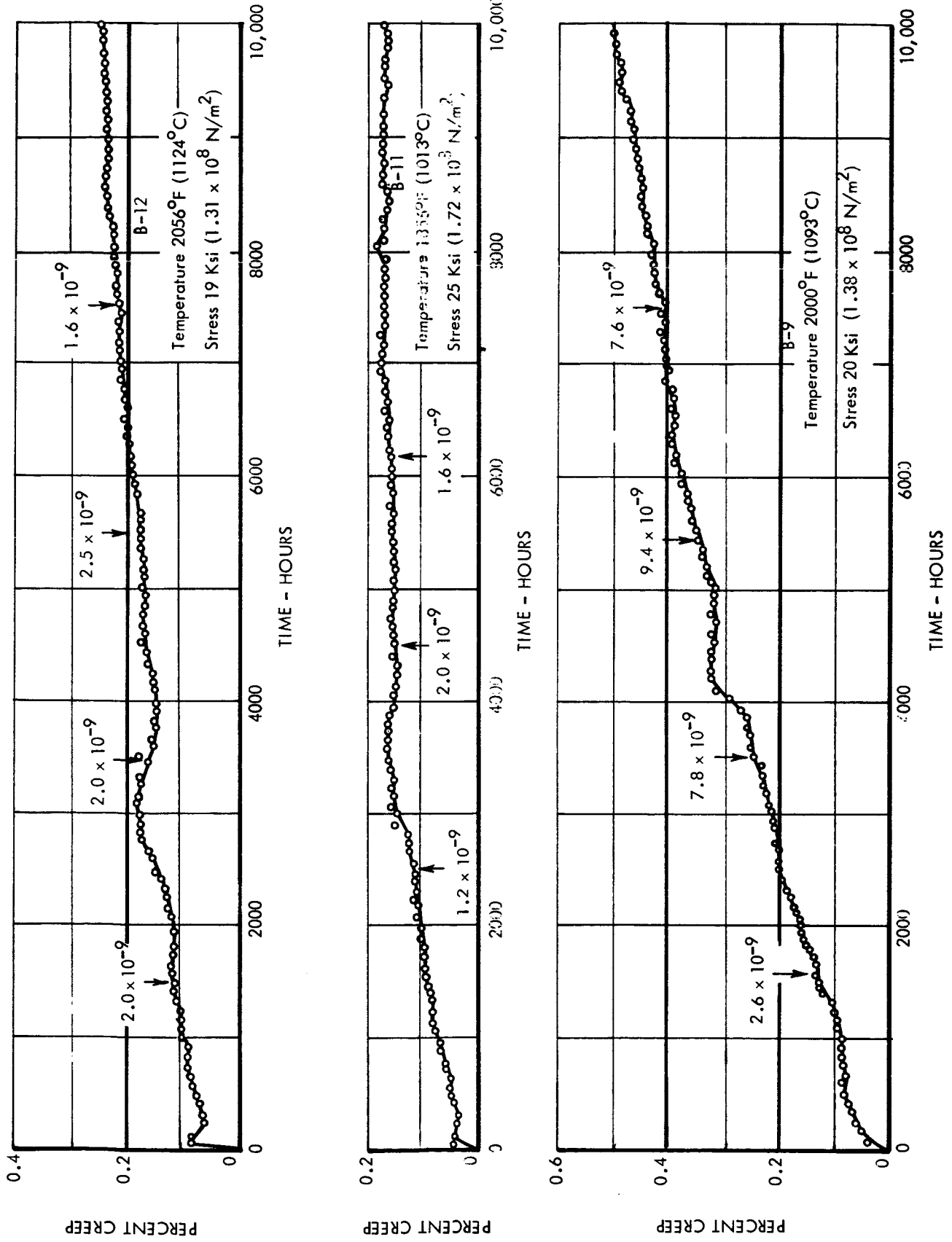


FIGURE 4 CREEP TEST DATA, TZC (HEAT M-80), ANNEALED 3092°F (1700°C) 1 HOUR TESTED IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR.

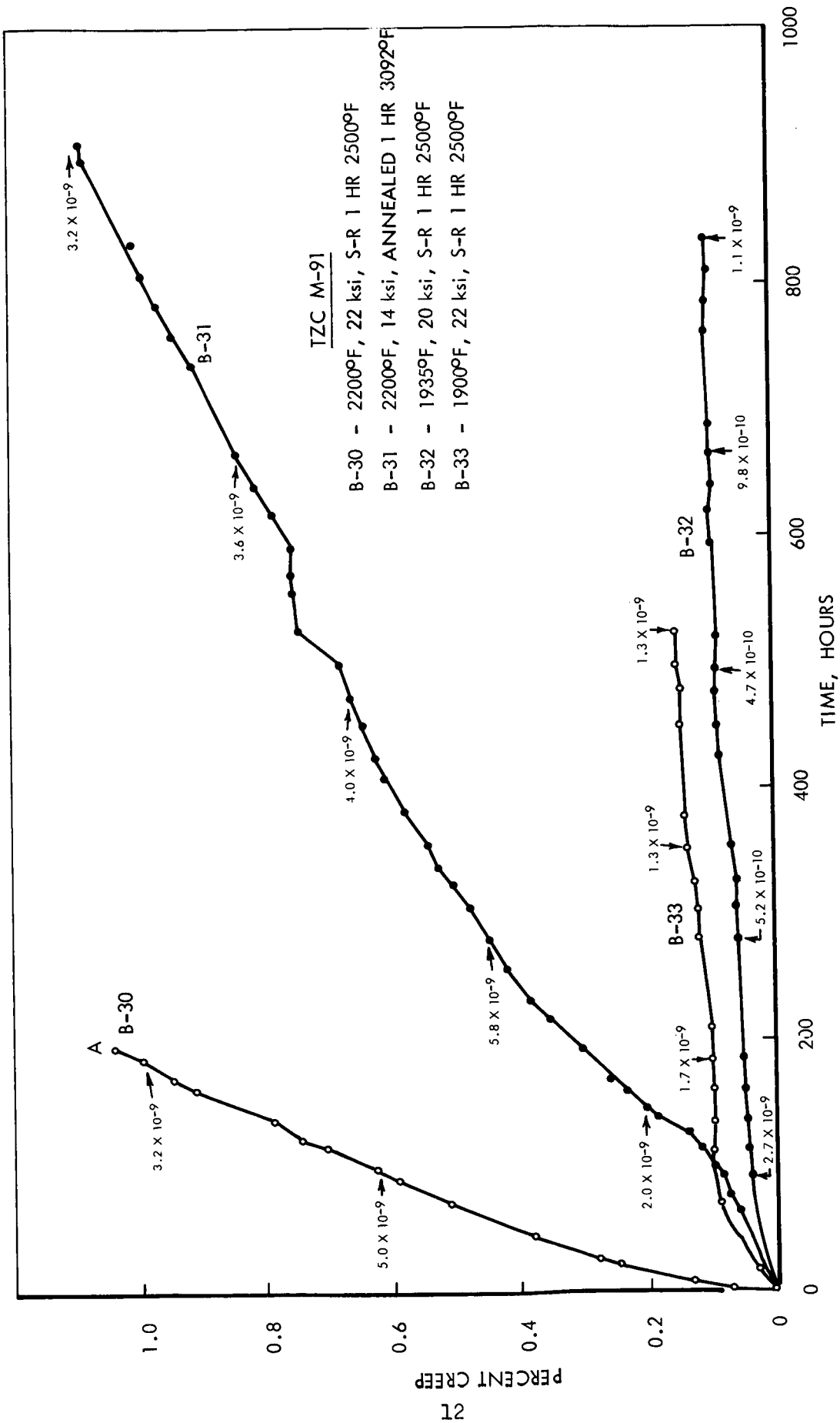


FIGURE 5 CREEP DATA FOR TZC HEAT M-91 TESTED IN VACUUM ENVIRONMENT $<1 \times 10^{-8}$ TORR

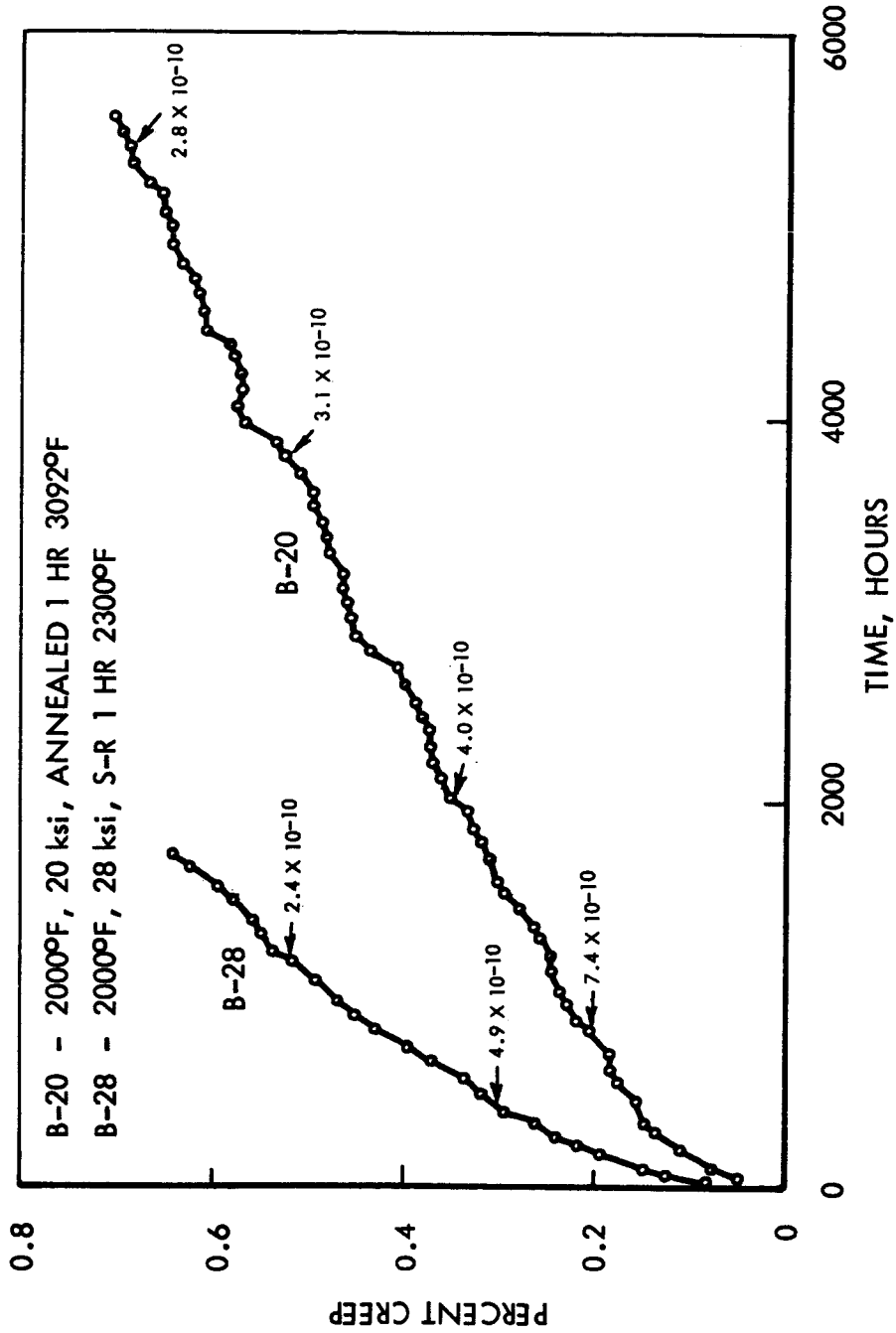


FIGURE 6: CREEP DATA FOR TZC HEAT M-91 TESTED IN VACUUM ENVIRONMENT
 $< 1 \times 10^{-8}$ TORR.

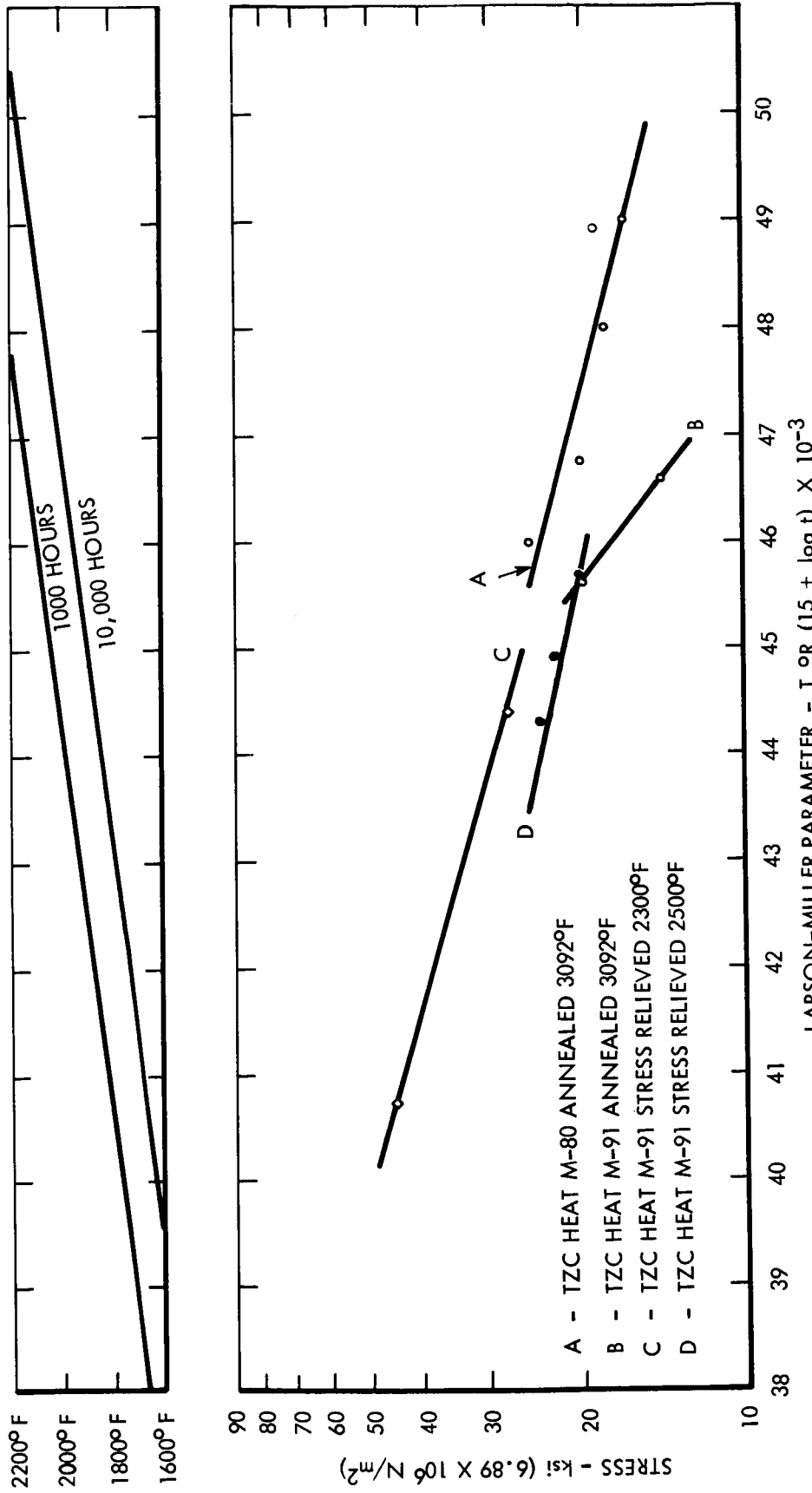


FIGURE 7 LARSON-MILLER PLOT OF DATA FOR 0.5% CREEP IN MOLYBDENUM-BASE TZC ALLOY, TESTED IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR.

TABLE 4

0.5% Creep Test Data for TZC Molybdenum-Base Alloy

Specimen No.	Test Temperature		Stress		Hours for 0.5% Creep	Larson-Miller $T^{\circ}R(15+\log t) \times 10^{-3}$ for 0.5% Creep
	$^{\circ}F$	$^{\circ}C$	Ksi	$N/m^2 \times 10^8$		
<u>Heat M-80, Annealed 3092°F (1700°C), 1 Hour</u>						
B-8A	2200	1204	18	1.24	1,100	48.0
B-10	2200	1204	17	1.17	2,500	49.0
B-9	2000	1093	20	1.38	10,400	46.8
B-12	2056	1124	19	1.31	35,000*	49.1
B-11	1856	1013	25	1.72	75,000*	46.0
<u>Heat M-91, Annealed 3092°F (1700°C), 1 Hour</u>						
B-31	2200	1204	14	0.965	320	46.6
B-20	2000	1093	20	1.38	3,600	45.6
<u>Heat M-91, Stress Relieved 2300°F (1260°C), 1 Hour</u>						
B-28	2000	1093	28	1.93	1,100	44.4
B-19	1800	982	44	3.03	1.075	40.8
<u>Heat M-91, Stress Relieved 2500°F (1371°C), 1 Hour</u>						
B-30	2200	1204	22	1.52	70	44.9
B-32	1935	1057	20	1.38	12,000*	45.7
B-33	1900	1038	22	1.52	4,000*	43.9

* Extrapolated Data

At an applied stress level of 20 Ksi ($1.38 \times 10^8 \text{N/m}^2$) the creep resistance of the M-91 material, after the 3092°F (1700°C) treatment, was comparable to that obtained with a 2500°F (1371°C) stress relief. At the 1800°F (982°C) test temperature, the material in the 2300°F (1260°C) stress relieved condition had creep resistance which was significantly better than the other conditions evaluated. In fact the 1000 hour, 0.5% creep strength of 2300°F (1260°C) stress relieved TZC at 1800°F (982°C) was significantly greater than the tensile strength of the same material in the recrystallized condition.

A comparison of the creep properties of forged TZM disc (Climax 7502), TZM in commercial bar stock form, and columbium-modified TZM bar is presented in Figure 8. The results indicate that the commercial bar stock had creep properties superior to the forged disc. In addition, when the comparison is made with the two bar materials, the columbium-modified TZM appears to have superior creep strength for the test times involved.

The creep curve for TZM forged disc (Heat KDTZM 1175), processed for high creep strength, is presented in Figure 9. At 1800°F (982°C) and 44 Ksi ($3.03 \times 10^8 \text{N/m}^2$), the material exhibited 0.128% creep after 3329 hours. These results indicate that the processing used on TZM Heat KDTZM 1175 provided a significant improvement in creep resistance.

A comparison of the creep strength of the TZM material with TZC is presented in Figure 10 on the basis of a Larson-Miller parameter. Pertinent data are given in Table 5. At the lower test temperatures, the stress relieved TZM material was superior in creep resistance to the stress relieved TZC. The specially processed TZM alloy has not been tested above 1800°F (982°C) so that no valid comparisons can be made with TZC under these conditions.

The examination of a TZM creep specimen after extended elongation (6.125%), see Figure 11, indicated that the deformation at 2000°F (1093°C), 41 Ksi ($2.82 \times 10^8 \text{N/m}^2$) proceeds principally by transgranular slip.

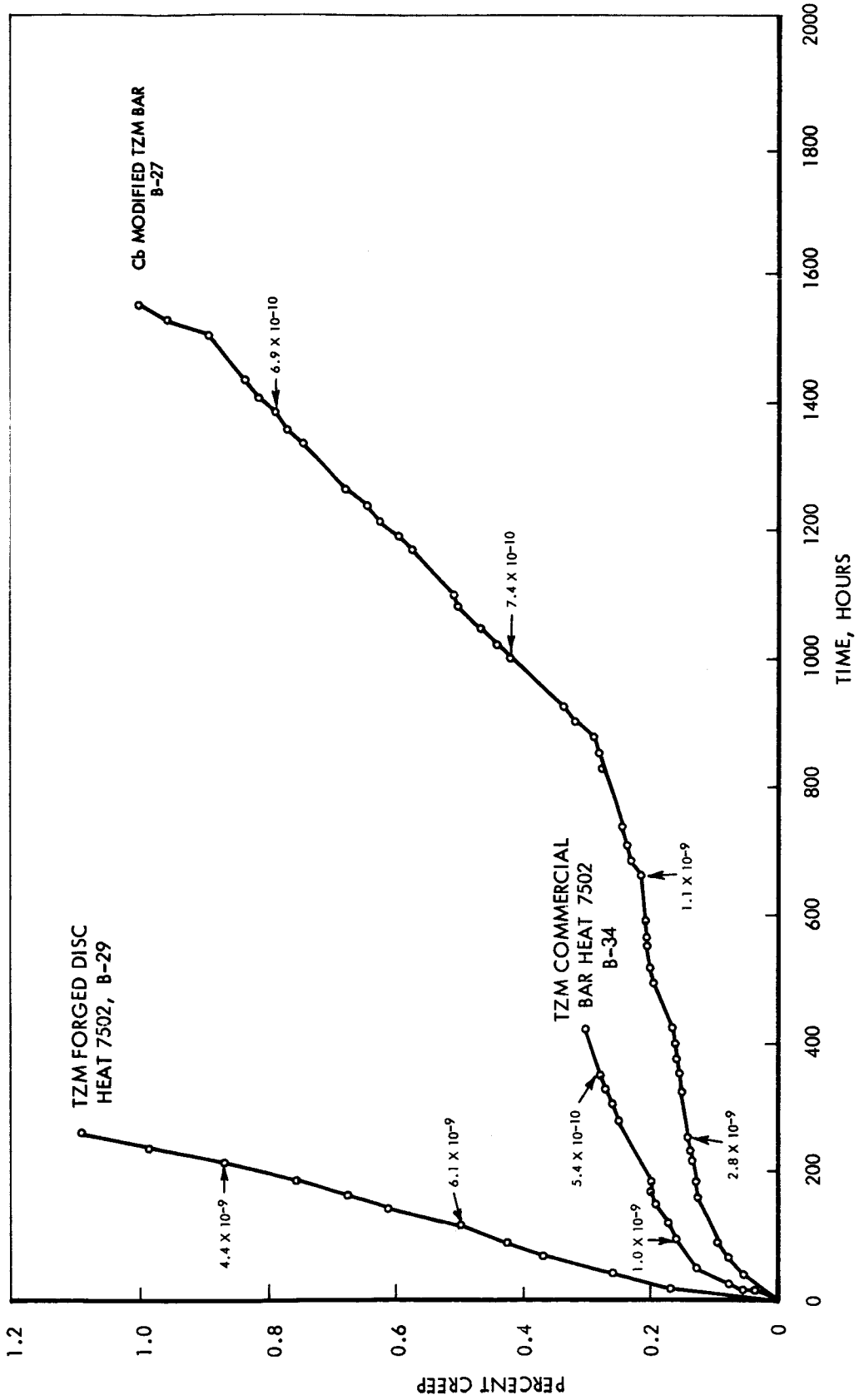


FIGURE 8: CREEP TEST DATA FOR TZM ALLOYS IN STRESS RELIEVED CONDITION. TESTED AT 2000°F (1093°C) AND 41 ksi ($2.82 \times 10^8 \text{ N/m}^2$) IN VACUUM ENVIRONMENT $\approx 1 \times 10^{-8}$ TORR.

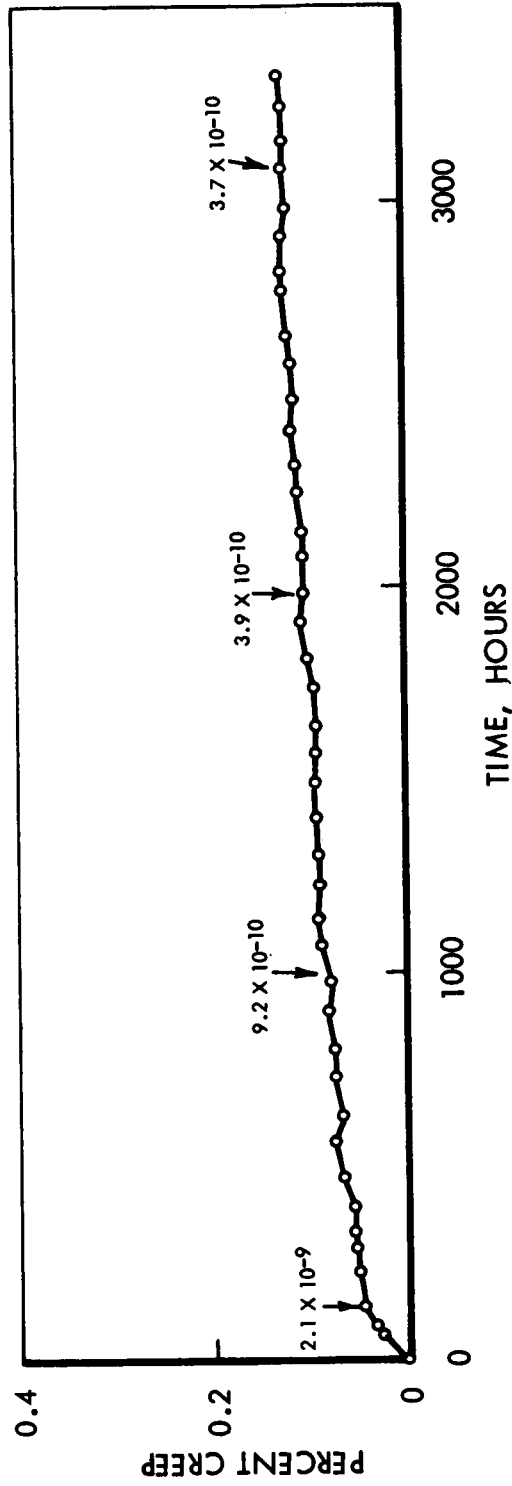


FIGURE 9: CREEP DATA FOR TZM HEAT KDTZM-1175 IN THE STRESS RELIEVED CONDITION. TESTED AT 1800 F (982 C) AT 44 ksi (3.03×10^8 N/m²) IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR.

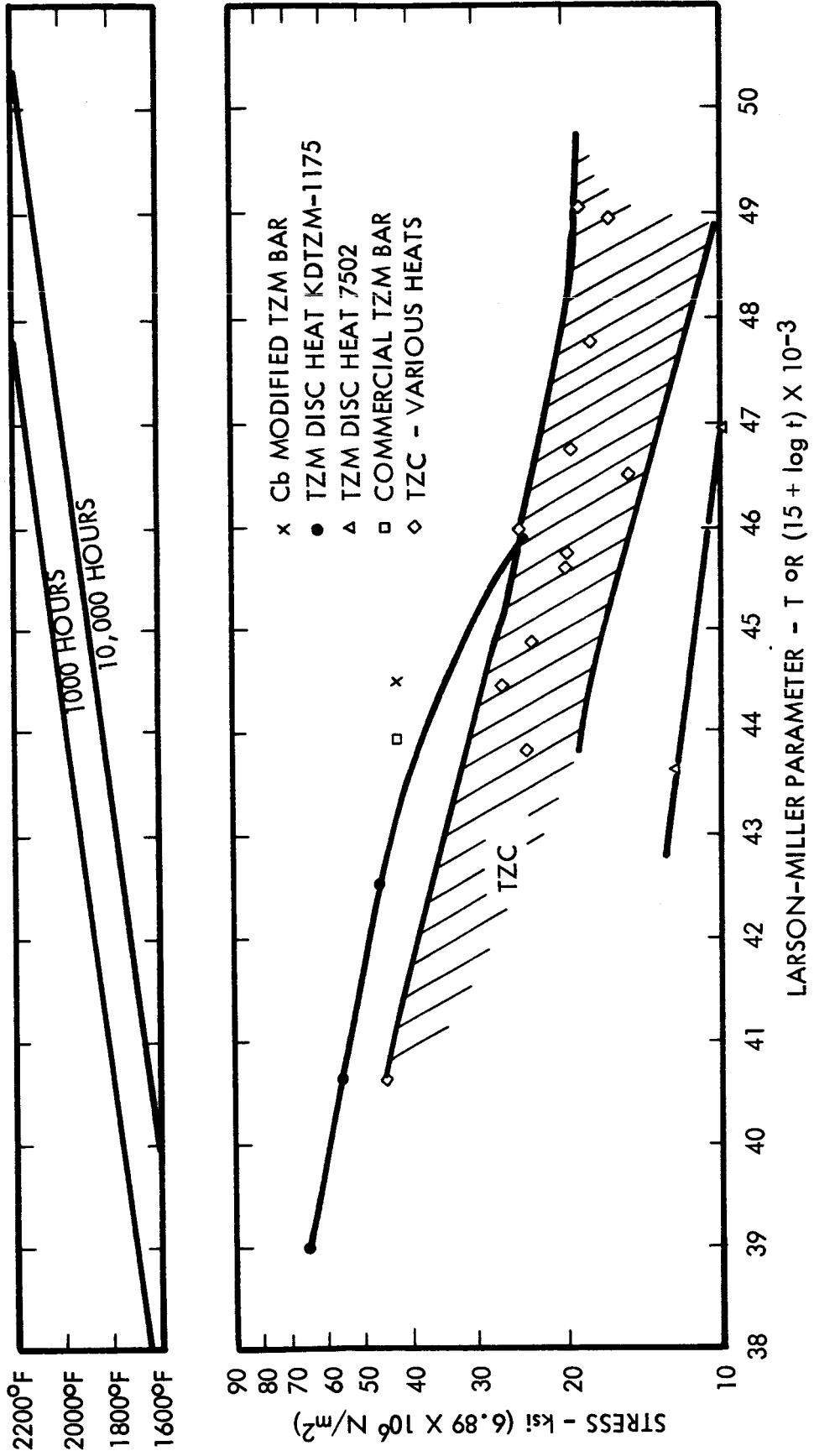


FIGURE 10 LARSON-MILLER PLOT OF DATA FOR 0.5% CREEP IN MOLYBDENUM-BASE ALLOYS, TESTED IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR

TABLE 5

0.5% Creep Test Data for TZM Molybdenum-Base Alloy

<u>Specimen No.</u>	<u>Test Temperature</u>		<u>Stress</u>		<u>Hours for 0.5% Creep</u>	<u>Larson-Miller T°R(15+logt)x 10⁻³ for 0.5% Creep</u>
	<u>°F</u>	<u>°C</u>	<u>Ksi</u>	<u>N/m² x 10⁸</u>		
<u>Heat KDTZM-1175, Stress Relieved 2300°F (1260°C), 1 Hour (Forged Disc)</u>						
B-21	1600	871	65	4.48	9,600*	39.1
B-18	1600	871	55	3.78	60,000*	40.7
B-25	1800	982	44	3.03	7,000*	42.6
B-16	1855	1013	23.4	1.61	62,500*	45.8
<u>Columbium-Modified TZM, Stress Relieved 2500°F (1371°C), 1 Hour (Bar)</u>						
B-27	2000	1093	41	2.82	1,080	44.4
<u>Heat 7502, Stress Relieved 2200°F (1204°C), 1 Hour (Cross-Rolled Plate)</u>						
B-1	2000	1093	12	0.826	605	43.7
B-3	2000	1093	10	0.689	13,000*	47.0
<u>Heat 7463, Stress Relieved 2250°F (1232°C), 1 Hour (Commercial Bar)</u>						
B-34	2000	1093	41	2.82	800*	43.9

* Extrapolated Data

TRANS GRANULAR
SLIP LINES



2.5X

FIGURE 11 CLIMAX TZM (HEAT 7502) STRESS RELIEVED 2200°F. TESTED AT 2000°F AND 41 ksi IN VACUUM ENVIRONMENT OF $<1 \times 10^{-8}$ TORR. 6.215% CREEP OBTAINED IN 664.3 HRS. NOTE THE LINES INDICATING TRANSGRANULAR SLIP.

Tantalum-Base T-111

Creep tests on specimens from two heats of tantalum-base alloy T-111 are in progress. The results of tests currently underway and completed during this quarter are presented in Figure 12. With the exception of the test on specimen S-24, the curves are characterized by an increasing creep rate with test time.

A compilation of all data for T-111 alloy sheet annealed for one hour at 3000°F (1649°C) is presented in Table 6 and Figure 13. The single value for Heat D-1670 indicated that this material had creep resistance which was significantly less than that exhibited by Heat 70616. At the completion of the test, metallographic examination will be made to determine whether variations in grain size or structure exist which could account for the difference in creep properties.

Vapor-Deposited Tungsten

The creep test results for the vapor-deposited tungsten are presented in Figure 14. The data for arc-melted material, tested at 3 ksi, are also included in the graph to provide a relative indication of the difference in creep properties between the two material conditions.

IV RESIDUAL GAS ANALYSIS

The discussion of the residual gas analysis in the Tenth Quarterly Report indicated that the recorded composition of the residual gas showed systematic variations due to filament heating. The heat from the filament was believed to produce outgassing of the components in the ionization section of the analyzer head which caused an increase in the water and CO₂ content of the residual gas. In an attempt to remedy this situation, an auxiliary power supply was used to hold the filament at approximately half-temperature thereby allowing the ionization section of the analyzer to become warm and outgas with time. Subsequent tests have shown that this does not prevent additional outgassing when the filaments are brought to full operating temperature. On the basis of these tests it was decided that the best procedure would be to turn the filament on at full power and with a minimum of delay, record the composition of the residual gas. In this way the outgassing of the ionization section would be minimized and the measured gas content would more accurately represent the composition in the chamber without the alterations produced by local heating effects.

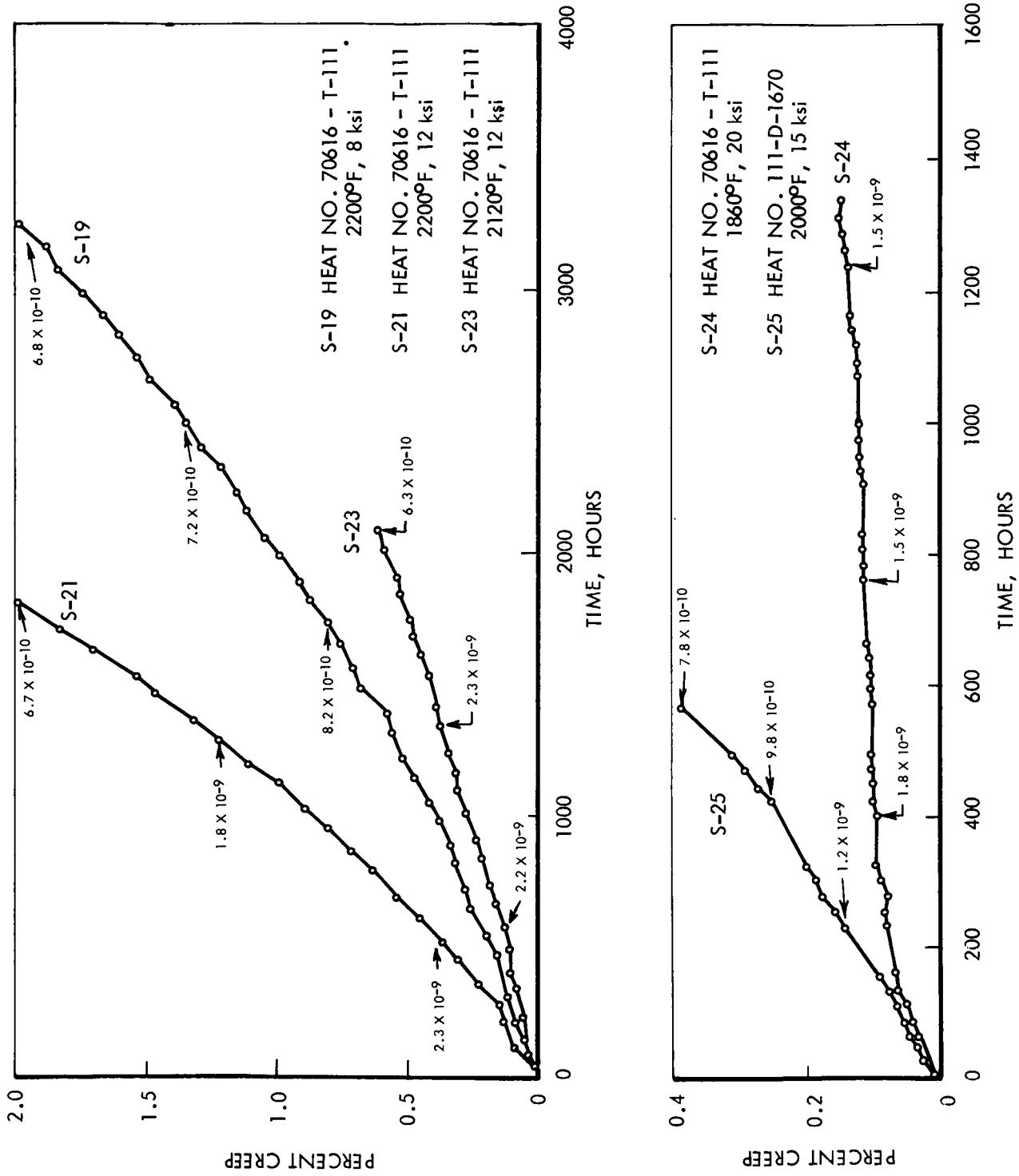


FIGURE 12: CREEP DATA FOR T-111 ALLOY ANNEALED ONE HOUR AT 3000°F (1649°C), TESTED IN VACUUM ENVIRONMENT < 1 X 10⁻⁸ TORR.

TABLE 6

1% Creep Test Data for T-111 Tantalum-Base Alloy, Annealed 3000°F (1649°C), 1 Hour

Heat No.	Specimen No.	Test Temperature		Stress		Hours for 1% Creep	Larson-Miller T°R (15+logt) x 10 ⁻³ for 1% Creep
		°F	°C	Ksi	N/m ² x 10 ⁸		
70616	S-19	2200	1204	8	0.511	2,000	48.6
70616	S-21	2200	1204	12	0.826	1,140	48.0
70616	S-23	2120	1160	12	0.826	3,000*	47.7
70616	S-22	2000	1093	20	1.38	670	43.9
70616	S-24	1860	1016	20	1.38	16,700*	44.6
D-1670	S-25	2000	1093	15	1.03	1,200*	44.5

* Extrapolated Data

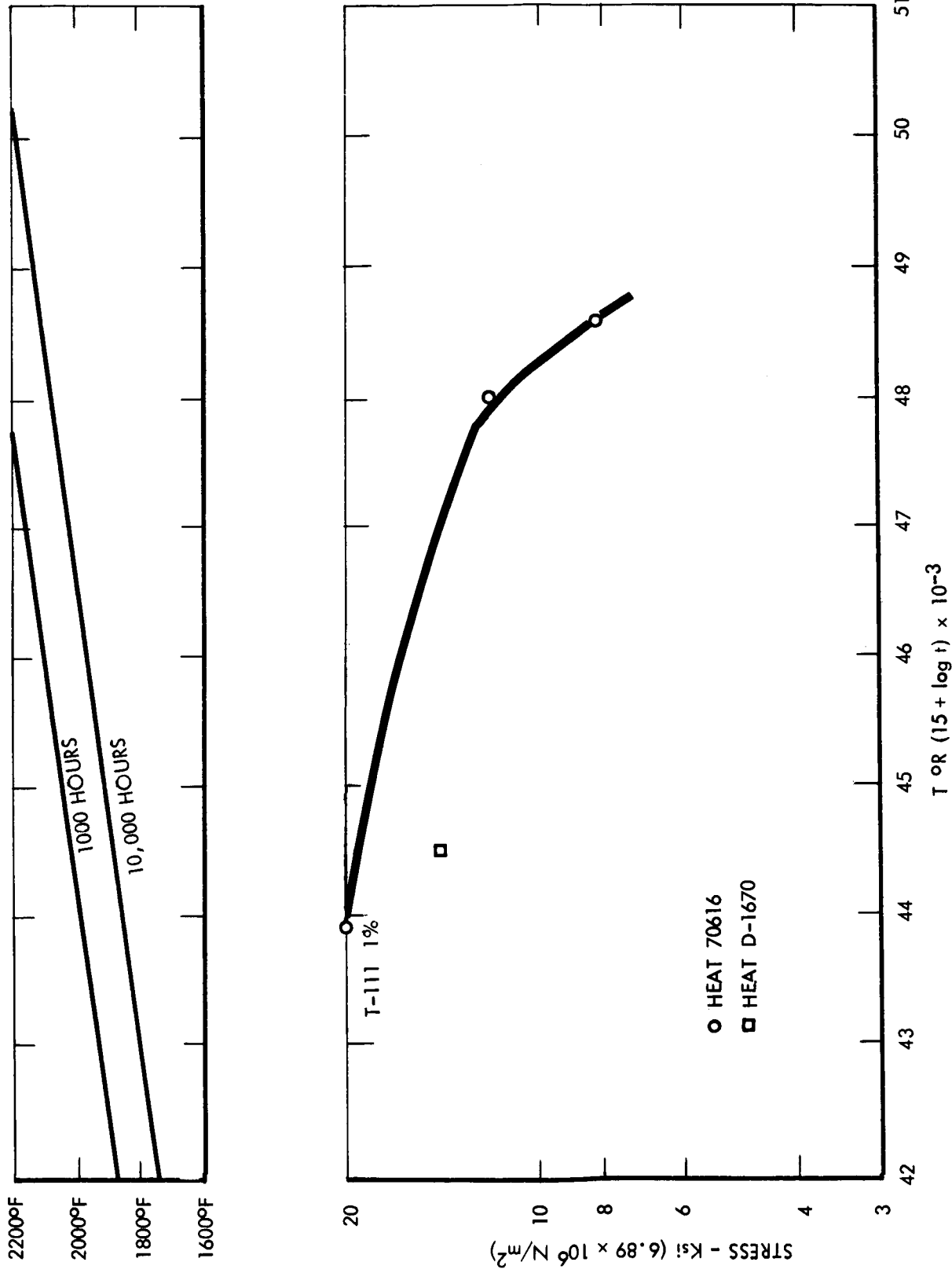


FIGURE 13: LARSON MILLER PLOT, 1% CREEP FOR T-111 ALLOY ANNEALED 1 HOUR 3000°F (1649°C)

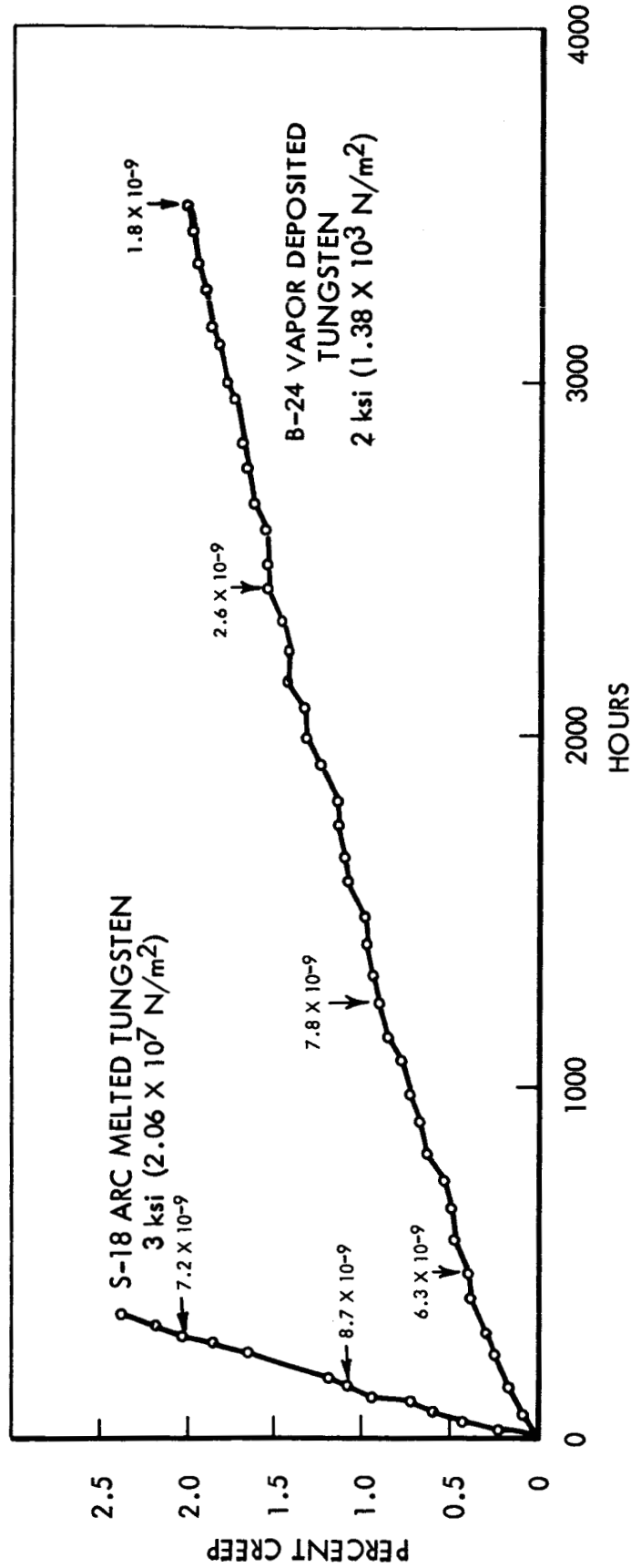


FIGURE 14: CREEP DATA FOR VAPOR-DEPOSITED AND ARC-MELTED TUNGSTEN ANNEALED 2800°F, 1 HOUR, AND TESTED AT 2800°F (1538°C) IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR.

One of the vacuum creep units which was undergoing leak testing provided an opportunity to examine the effect of various individual gases on the overall composition of the residual gas. This unit was in an unbaked condition and at a pressure of 2×10^{-8} Torr. The roughing valve was opened slightly to introduce a leak into the system and the resulting recorded residual gases are shown in Figure 15. The introduction of a leak caused an increase in nitrogen (28) (14) oxygen (32) and argon (40)(20). The identity of all the gas species can be obtained from the mass numbers given in Table 8. Other gases were then introduced into the leak. Figure 16 shows the effect of argon (40) (20) and CO_2 (44) while Figures 17 and 18 indicate the patterns when helium (4) water, or acetone are allowed to enter the system. Line 17 in Figure 18 is due to decomposition of the water to the OH ion. Acetone (58) introduced into the leak decomposes into various hydrocarbons H_2 (2), CH_4 , (16), CH_3 (15), etc. as well as CO (28) and CO_2 (44).

A general review of all the mass analyzer traces indicate that the gases which are present in the creep systems under test at 1×10^{-8} Torr are in order of decreasing intensity: carbon monoxide, water, carbon dioxide, hydrogen, small quantities of methane, argon, and helium, and on occasion traces of acetone and other contaminants which probably result from the specimen cleaning operations.

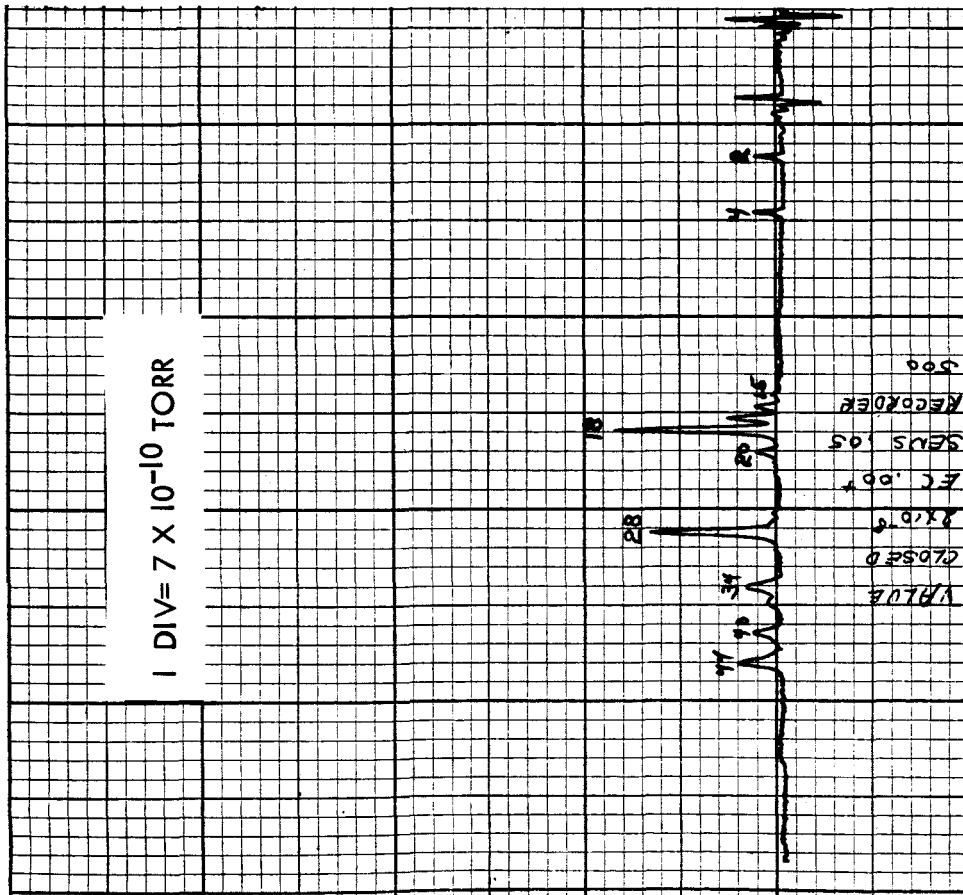
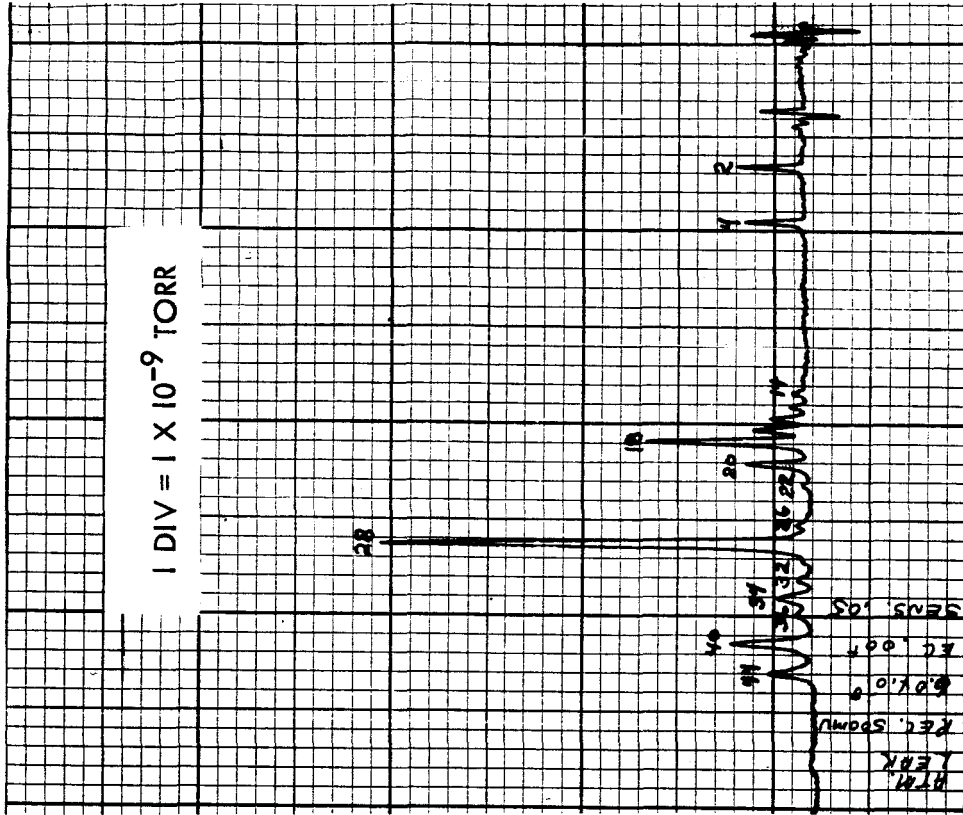


FIGURE 15 CHANGE IN COMPOSITION OF RESIDUAL GAS WHEN AN AIR LEAK IS MADE IN THE SYSTEM.

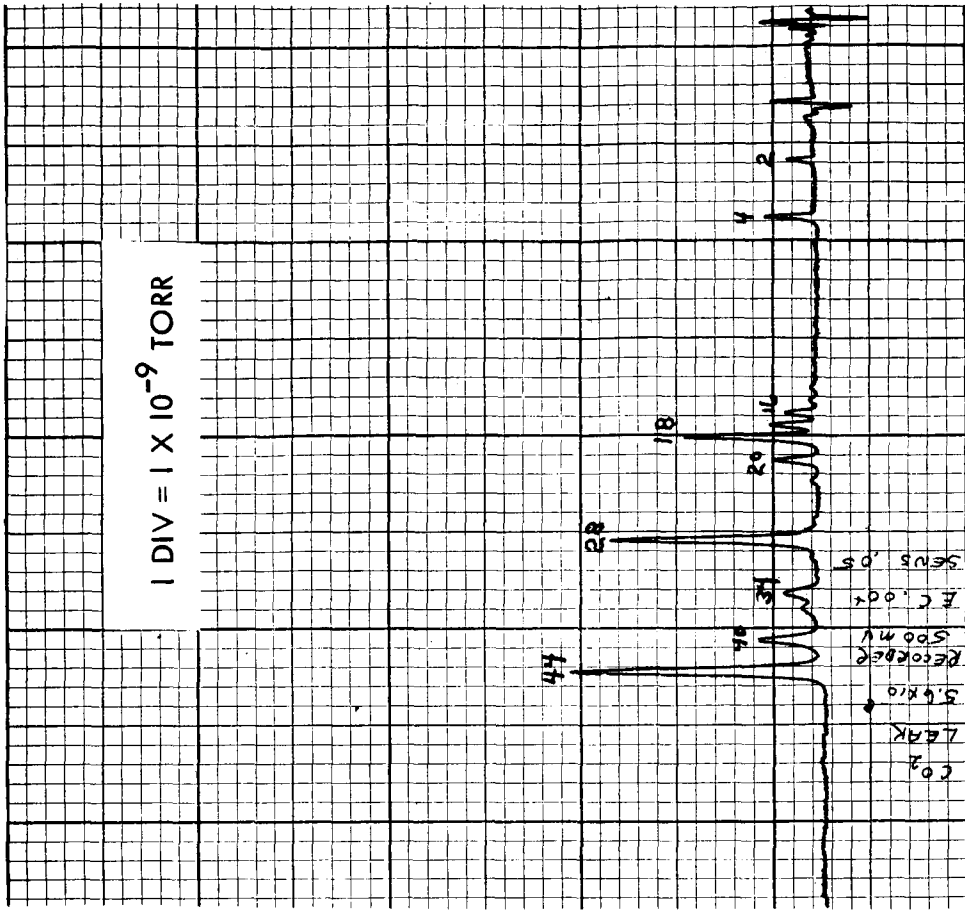
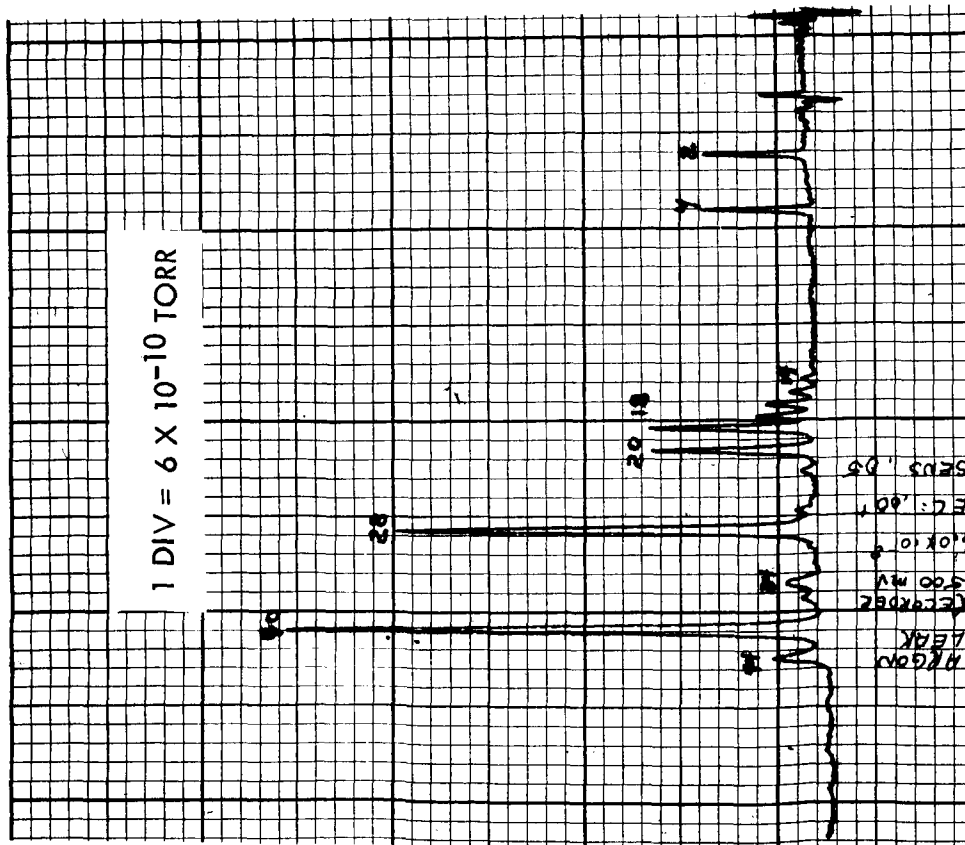


FIGURE 16 RESIDUAL GAS COMPOSITION WITH ARGON OR CO₂ INTRODUCED INTO LEAK.

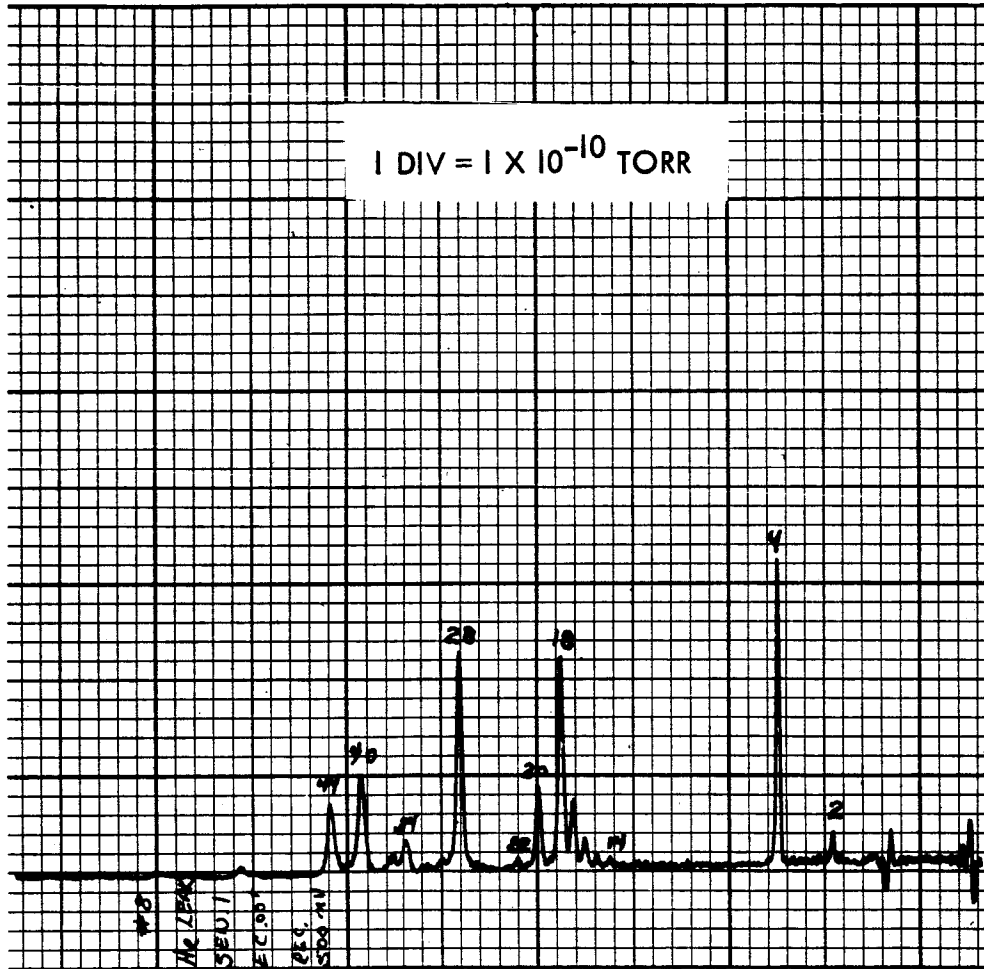


FIGURE 17 RESIDUAL GAS COMPOSITION WITH HELIUM INTRODUCED INTO THE LEAK.

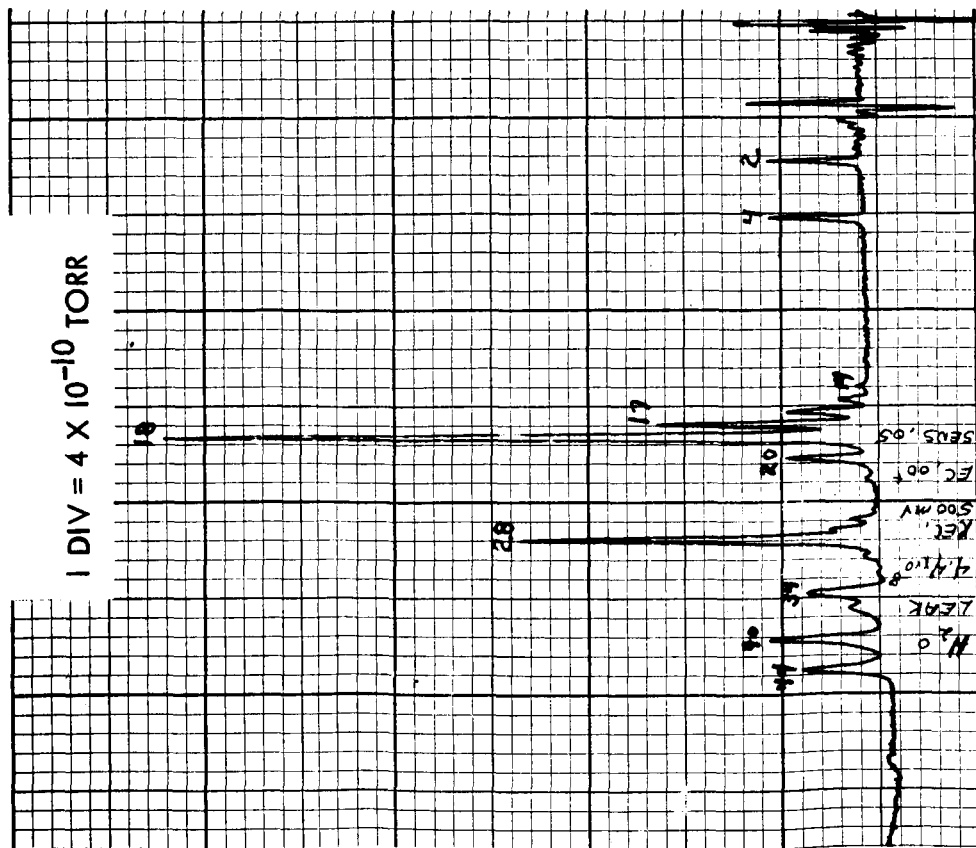
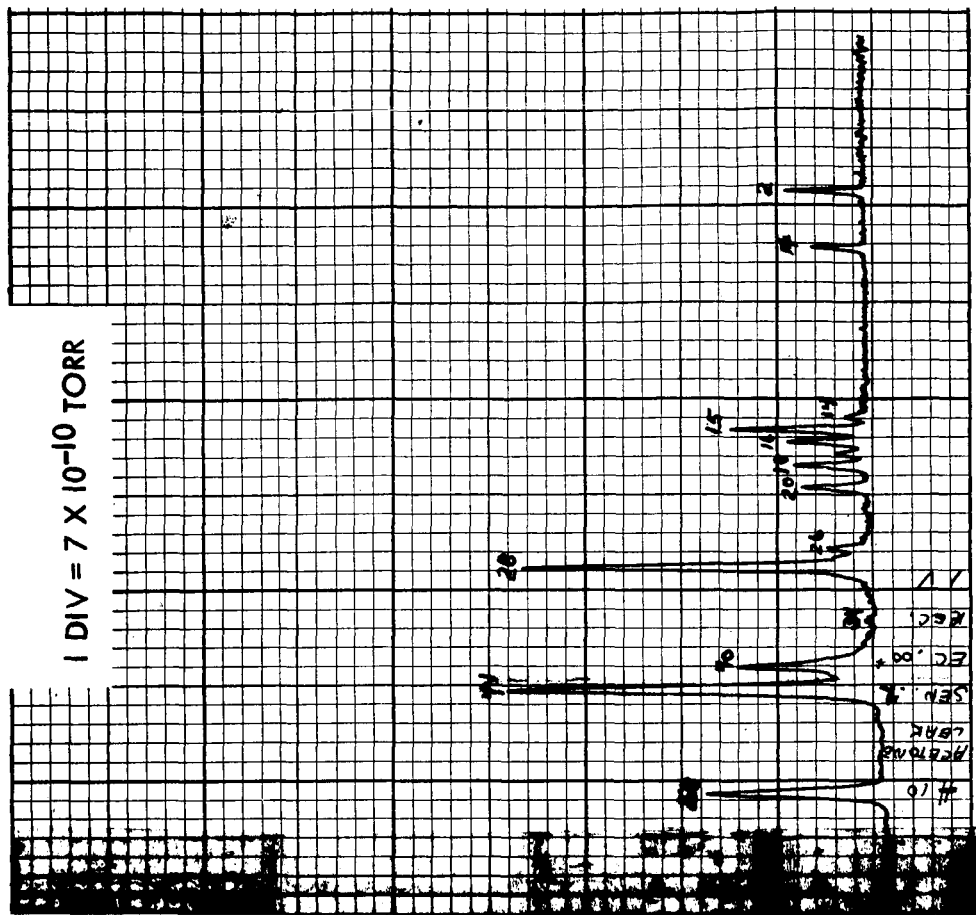


FIGURE 18 RESIDUAL GAS COMPOSITION WITH WATER OR ACETONE INTRODUCED INTO LEAK.

TABLE 8

Mass Numbers of Various Gases Found in
Vacuum Creep Systems

<u>Element or Compound</u>	<u>Mass Number</u>
Hydrogen	1
Hydrogen	2
Helium	4
Carbon	12
Methane	13
Methane	14
Nitrogen	14
Methane	15
Methane	16
Oxygen	16
Water	17
Water	18
Fluorine	19
Argon	20
Sodium	22
Carbon Monoxide	28
Nitrogen	28
Oxygen	32
Sulphur	32
Hydrogen Sulfide	34
Chlorine	35
Hydrogen Chloride	36
Chlorine	37
Hydrogen Chloride	38
Argon	40
Calcium	40
Carbon Dioxide	44
Acetone	58
Ethane	30 thru 25
Propane	44 thru 37

A P P E N D I X I

CREEP TEST DATA

TABLE I

CREEP TEST DATA, TZC PLATE, HEAT M-80, RECRYSTALLIZED AT 3092°F (1700°C) FOR 1 HOUR,

TESTED AT 2000°F (1093°C), 20,000 PSI (1.38 x 10⁸N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 minutes	.00000	.000	1.2 x 10 ⁻⁹
2	-.00020	-.010	
3	-.00040	-.020	
4	-.00030	-.015	
5	-.00030	-.015	
10	-.00005	-.002	
15	.00005	.002	
20	.00005	.002	
25	.00010	.005	
30	.00010	.005	
60	.00005	.002	
90	-.00005	-.002	
17.2 hours	.00040	.020	2.6 x 10 ⁻⁹
41.3	.00060	.030	2.2 x 10 ⁻⁹
65.2	.00080	.040	2.2 x 10 ⁻⁹
89.2	.00115	.058	2.0 x 10 ⁻⁹
161.3	.00110	.055	1.3 x 10 ⁻⁹
185.7	.00130	.065	1.7 x 10 ⁻⁹
209.1	.00125	.068	1.7 x 10 ⁻⁹
233.2	.00125	.062	1.4 x 10 ⁻⁹
257.3	.00130	.065	1.3 x 10 ⁻⁹
329.2	.00140	.070	2.0 x 10 ⁻⁹
355.9	.00145	.072	3.2 x 10 ⁻⁹
377.0	.00145	.072	3.4 x 10 ⁻⁹
401.1	.00145	.072	2.4 x 10 ⁻⁹
425.0	.00150	.075	1.5 x 10 ⁻⁹
497.2	.00170	.085	1.9 x 10 ⁻⁹
521.4	.00170	.085	3.1 x 10 ⁻⁹
545.4	.00165	.082	4.8 x 10 ⁻⁹
569.2	.00170	.085	4.5 x 10 ⁻⁹
593.1	.00170	.085	4.6 x 10 ⁻⁹
665.2	.00165	.082	5.0 x 10 ⁻⁹
713.3	.00160	.080	4.6 x 10 ⁻⁹
762.8	.00170	.085	--
833.4	.00175	.088	1.5 x 10 ⁻⁸
881.4	.00185	.092	6.1 x 10 ⁻⁹
905.2	.00175	.088	5.8 x 10 ⁻⁹

TABLE I (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1001.1 hours	.00185	.092	3.9×10^{-9}
1049.2	.00185	.092	6.4×10^{-9}
1097.3	.00190	.095	--
1168.4	.00195	.098	4.2×10^{-9}
1216.2	.00200	.100	7.5×10^{-9}
1264.3	.00195	.098	7.0×10^{-9}
1336.7	.00210	.105	7.5×10^{-9}
1389.5	.00250	.125	--
1433.4	.00255	.128	7.2×10^{-9}
1504.2	.00260	.130	1.3×10^{-8}
1552.3	.00270	.135	1.2×10^{-8}
1600.2	.00265	.132	2.6×10^{-9}
1672.4	.00270	.135	5.5×10^{-9}
1720.4	.00275	.138	3.8×10^{-9}
1768.5	.00285	.142	4.6×10^{-9}
1840.1	.00305	.152	4.4×10^{-9}
1894.6	.00310	.155	4.4×10^{-9}
1936.3	.00315	.158	3.8×10^{-9}
1985.6	.00310	.155	3.8×10^{-9}
2032.2	.00325	.162	4.0×10^{-9}
2057.0	.00330	.165	4.0×10^{-9}
2104.1	.00335	.168	3.8×10^{-9}
2176.1	.00345	.172	3.5×10^{-9}
2248.4	.00370	.185	4.2×10^{-9}
2272.2	.00360	.180	7.5×10^{-9}
2344.2	.00375	.188	2.4×10^{-9}
2396.9	.00380	.190	4.6×10^{-9}
2440.2	.00390	.195	4.4×10^{-9}
2512.0	.00400	.200	2.7×10^{-9}
2584.4	.00400	.200	2.9×10^{-9}
2680.2	.00400	.200	7.4×10^{-9}
2752.2	.00405	.202	5.4×10^{-9}
2872.4	.00415	.208	3.8×10^{-9}
2920.8	.00420	.210	6.2×10^{-9}
3016.1	.00425	.212	3.8×10^{-9}
3088.4	.00435	.218	2.6×10^{-9}
3184.6	.00440	.220	4.2×10^{-9}
3256.3	.00450	.225	4.4×10^{-9}

TABLE I (Continued)

<u>Time</u>	<u>Length Change</u> <u>ΔL (inch)</u> <u>(2" G. L.)</u>	<u>Creep</u> <u>%</u>	<u>Pressure</u> <u>(Torr)</u>
3355.4 hours	.00460	.230	--
3429.1	.00460	.230	--
3530.3	.00490	.245	--
3593.5	.00495	.247	7.8 x 10 ⁻⁹
3689.9	.00500	.250	8.0 x 10 ⁻⁹
3760.5	.00510	.255	8.0 x 10 ⁻⁹
3856.2	.00515	.257	8.2 x 10 ⁻⁹
3928.5	.00525	.262	8.2 x 10 ⁻⁹
4024.1	.00575	.282	8.7 x 10 ⁻⁹
4096.3	.00620	.310	8.2 x 10 ⁻⁹
4192.3	.00640	.320	8.2 x 10 ⁻⁹
4264.1	.00640	.320	8.2 x 10 ⁻⁹
4384.3	.00640	.320	8.4 x 10 ⁻⁹
4432.3	.00640	.320	9.0 x 10 ⁻⁹
4528.3	.00630	.315	8.6 x 10 ⁻⁹
4600.5	.00640	.320	9.4 x 10 ⁻⁹
4696.7	.00625	.312	9.5 x 10 ⁻⁹
4769.2	.00640	.320	8.5 x 10 ⁻⁹
4866.4	.00635	.318	9.2 x 10 ⁻⁹
4936.5	.00630	.315	9.2 x 10 ⁻⁹
5032.5	.00635	.318	9.2 x 10 ⁻⁹
5104.4	.00660	.330	8.4 x 10 ⁻⁹
5200.9	.00660	.330	9.5 x 10 ⁻⁹
5272.3	.00670	.335	8.8 x 10 ⁻⁹
5368.8	.00675	.338	9.4 x 10 ⁻⁹
5440.3	.00685	.342	9.4 x 10 ⁻⁹
5536.2	.00700	.350	1.0 x 10 ⁻⁸
5608.0	.00705	.352	3.4 x 10 ⁻⁹
5705.8	.00715	.358	6.4 x 10 ⁻⁹
5777.0	.00720	.360	4.9 x 10 ⁻⁹
5873.3	.00730	.365	4.9 x 10 ⁻⁹
5945.1	.00745	.372	3.4 x 10 ⁻⁹
6041.2	.00750	.375	2.8 x 10 ⁻⁹
6113.2	.00770	.385	3.4 x 10 ⁻⁹
6209.9	.00770	.385	3.3 x 10 ⁻⁹
6305.5	.00775	.388	3.5 x 10 ⁻⁹
6377.5	.00780	.390	6.3 x 10 ⁻⁹
6449.2	.00775	.388	7.0 x 10 ⁻⁹
6545.7	.00770	.385	8.2 x 10 ⁻⁹
6617.2	.00780	.390	7.4 x 10 ⁻⁹
6713.2	.00780	.390	7.9 x 10 ⁻⁹
6785.3	.00780	.390	7.8 x 10 ⁻⁹
6881.6	.00810	.405	8.0 x 10 ⁻⁹
6953.4	.00790	.395	8.3 x 10 ⁻⁹
7052.7	.00805	.402	8.2 x 10 ⁻⁹
7125.5	.00810	.405	8.1 x 10 ⁻⁹

TABLE I (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
7217.2 hours	.00810	.410	8.2 x 10 ⁻⁹
7386.0	.00815	.408	7.9 x 10 ⁻⁹
7457.2	.00825	.412	7.5 x 10 ⁻⁹
7553.3	.00830	.415	7.6 x 10 ⁻⁹
7625.7	.00835	.418	7.0 x 10 ⁻⁹
7721.9	.00845	.422	7.0 x 10 ⁻⁹
7793.6	.00845	.422	7.3 x 10 ⁻⁹
7889.4	.00850	.425	6.5 x 10 ⁻⁹
7961.2	.00855	.428	7.1 x 10 ⁻⁹
8057.4	.00855	.428	7.4 x 10 ⁻⁹
8129.4	.00860	.430	7.3 x 10 ⁻⁹
8225.3	.00870	.435	5.2 x 10 ⁻⁹
8297.5	.00875	.438	4.3 x 10 ⁻⁹
8393.2	.00880	.440	1.6 x 10 ⁻⁹
8465.6	.00885	.442	4.8 x 10 ⁻⁹
8561.4	.00890	.445	4.8 x 10 ⁻⁹
8633.1	.00895	.448	4.6 x 10 ⁻⁹
8729.1	.00900	.450	5.3 x 10 ⁻⁹
8801.3	.00905	.452	5.2 x 10 ⁻⁹
8969.3	.00915	.458	6.0 x 10 ⁻⁹
9065.3	.00920	.460	7.5 x 10 ⁻⁹
9137.2	.00925	.462	9.6 x 10 ⁻⁹
9233.1	.00930	.465	1.0 x 10 ⁻⁸
9305.3	.00940	.470	1.0 x 10 ⁻⁸
9401.9	.00965	.482	1.0 x 10 ⁻⁸
9476.5	.00970	.485	1.6 x 10 ⁻⁸
9569.4	.00965	.482	2.7 x 10 ⁻⁹
9642.2	.00965	.482	5.4 x 10 ⁻⁹
9737.6	.00960	.480	3.8 x 10 ⁻⁹
9814.3	.00970	.485	5.0 x 10 ⁻⁹
9904.3	.00980	.490	7.6 x 10 ⁻⁹
9976.3	.00980	.490	4.6 x 10 ⁻¹⁰
10,000.7	.00980	.490	5.2 x 10 ⁻¹⁰
10,072.1	.00985	.492	8.5 x 10 ⁻¹⁰
10,144.3	.00985	.492	1.0 x 10 ⁻⁹
10,240.3	.00990	.495	1.5 x 10 ⁻⁹
10,312.1	.00995	.498	1.9 x 10 ⁻⁹
10,408.5	.01005	.502	2.2 x 10 ⁻⁹

TABLE I (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
10,576.5	.01010	.505	3.4×10^{-9}
10,648.2	.01010	.505	3.2×10^{-9}
10,768.7	.01020	.510	2.9×10^{-9}
10,816.2	.01020	.510	2.9×10^{-9}
10,917.0	.01020	.510	3.3×10^{-9}
10,984.1	.01025	.512	3.2×10^{-9}
11,008.1	.01025	.512	4.0×10^{-9}
11,080.2	.01030	.515	3.6×10^{-9}
11,152.5	.01035	.518	3.8×10^{-9}
11,248.2	.01030	.515	3.6×10^{-9}
11,320.3	.01030	.515	3.9×10^{-9}

Test in Progress
Specimen B-9

TABLE II

CREEP TEST DATA, TZC PLATE, RECRYSTALLIZED AT 3092°F (1700°C), FOR 1 HOUR,
 TESTED AT 1856°F (1013°C). 25,000 psi (1.72×10^8 N/m²)
 HEAT M-80

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 minute(s)	-.00005	-.002	
2	.00000	.000	
3	-.00005	-.002	
4	.00005	.002	
5	.00005	.002	
6	.00010	.005	
7	.00005	.002	
8	.00000	.000	
9	.00000	.000	
10	.00005	.002	
15	-.00005	-.002	
20	.00015	.008	
25	.00015	.008	
30	.00025	.012	
60	.00065	.032	
19.3 hours	.00085	.042	1.4×10^{-8}
42.1	.00095	.048	1.3×10^{-8}
68.2	.00095	.048	1.1×10^{-8}
138.4	.00090	.045	5.8×10^{-9}
162.8	.00085	.042	6.6×10^{-9}
186.0	.00085	.042	6.8×10^{-9}
210.3	.00080	.040	5.8×10^{-9}
306.2	.00075	.038	5.2×10^{-9}
330.2	.00090	.045	4.4×10^{-9}
354.2	.00085	.042	3.4×10^{-9}
381.6	.00095	.048	--
402.4	.00095	.048	3.6×10^{-9}
460.7	.00105	.052	2.5×10^{-9}
484.5	.00105	.052	2.8×10^{-9}
508.5	.00125	.062	3.4×10^{-9}
532.4	.00105	.052	3.8×10^{-9}
556.8	.00105	.052	3.2×10^{-9}
628.9	.00105	.052	3.0×10^{-9}
681.7	.00115	.058	--
725.6	.00125	.062	3.1×10^{-9}
796.4	.00130	.065	2.0×10^{-9}
844.8	.00145	.072	2.2×10^{-9}
892.4	.00145	.072	1.6×10^{-9}
964.6	.00140	.070	2.8×10^{-9}

TABLE II (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep %</u>	<u>Pressure (Torr)</u>
1012.6 hours	.00155	.078	2.7×10^{-9}
1060.7	.00170	.085	2.6×10^{-9}
1132.3	.00165	.082	2.4×10^{-9}
1186.9	.00165	.082	2.0×10^{-9}
1228.6	.00170	.085	1.8×10^{-9}
1277.8	.00170	.085	2.2×10^{-9}
1324.4	.00165	.082	2.3×10^{-9}
1349.2	.00175	.088	1.4×10^{-9}
1396.3	.00185	.092	1.8×10^{-9}
1468.3	.00185	.092	2.5×10^{-9}
1516.4	.00180	.090	2.6×10^{-9}
1564.4	.00185	.092	3.1×10^{-9}
1636.4	.00195	.098	2.5×10^{-9}
1689.1	.00205	.102	2.2×10^{-9}
1732.4	.00195	.098	2.8×10^{-9}
1804.3	.00200	.100	2.0×10^{-9}
1876.7	.00215	.108	2.0×10^{-9}
1972.6	.00210	.105	2.3×10^{-9}
2044.4	.00225	.112	9.6×10^{-10}
2164.7	.00225	.112	2.5×10^{-9}
2213.1	.00235	.118	1.4×10^{-9}
2308.3	.00230	.115	1.2×10^{-9}
2380.7	.00235	.118	2.5×10^{-9}
2479.4	.00235	.118	1.2×10^{-9}
2548.4	.00235	.118	2.6×10^{-9}
2647.3	.00245	.122	1.8×10^{-9}
2720.0	.00245	.122	1.1×10^{-9}
2822.6	.00260	.130	9.1×10^{-10}
2886.4	.00305	.152	2.2×10^{-9}
2982.1	.00295	.148	1.6×10^{-9}
3052.8	.00320	.160	1.6×10^{-9}
3148.7	.00315	.158	1.6×10^{-9}
3220.7	.00315	.158	1.6×10^{-9}
3316.4	.00310	.155	1.9×10^{-9}
3388.8	.00315	.158	1.8×10^{-9}
3484.6	.00335	.168	1.6×10^{-9}
3556.4	.00330	.165	1.4×10^{-9}
3676.5	.00335	.168	1.5×10^{-9}
3724.5	.00330	.165	1.9×10^{-9}
3820.7	.00330	.165	1.6×10^{-9}
3892.7	.00320	.160	1.7×10^{-9}
3988.9	.00315	.158	2.8×10^{-9}
4061.4	.00315	.158	1.3×10^{-9}
4158.8	.00300	.150	1.8×10^{-9}
4228.7	.00300	.150	6.0×10^{-10}
4325.1	.00300	.150	1.5×10^{-9}
4396.7	.00315	.158	1.8×10^{-9}
4493.1	.00315	.158	2.0×10^{-9}

TABLE II (Continued)

<u>Time</u>	<u>Length Change Δ L (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
4564.6 hours	.00310	.155	2.0 x 10 ⁻⁹
4661.2	.00315	.158	1.4 x 10 ⁻⁹
4732.6	.00320	.160	2.0 x 10 ⁻⁹
4828.5	.00305	.152	1.7 x 10 ⁻⁹
4900.3	.00310	.155	1.7 x 10 ⁻⁹
4998.1	.00305	.152	1.4 x 10 ⁻⁹
5069.3	.00305	.152	2.4 x 10 ⁻⁹
5165.5	.00305	.152	1.6 x 10 ⁻⁹
5237.4	.00310	.155	1.2 x 10 ⁻⁹
5333.5	.00310	.155	1.1 x 10 ⁻⁹
5405.5	.00305	.152	1.6 x 10 ⁻⁹
5502.2	.00305	.152	1.1 x 10 ⁻⁹
5598.0	.00310	.155	1.4 x 10 ⁻⁹
5669.8	.00310	.155	1.8 x 10 ⁻⁹
5741.4	.00320	.160	1.6 x 10 ⁻⁹
5838.0	.00315	.158	1.6 x 10 ⁻⁹
5909.4	.00325	.162	1.5 x 10 ⁻⁹
6005.6	.00315	.158	1.5 x 10 ⁻⁹
6077.5	.00315	.158	1.6 x 10 ⁻⁹
6173.9	.00315	.158	1.6 x 10 ⁻⁹
6245.7	.00320	.160	1.6 x 10 ⁻⁹
6345.0	.00325	.162	1.0 x 10 ⁻⁹
6417.7	.00335	.168	1.3 x 10 ⁻⁹
6509.4	.00335	.168	1.5 x 10 ⁻⁹
6582.0	.00340	.170	1.0 x 10 ⁻⁹
6678.2	.00335	.168	1.6 x 10 ⁻⁹
6749.4	.00340	.170	1.5 x 10 ⁻⁹
6845.6	.00345	.172	1.6 x 10 ⁻⁹
6917.9	.00350	.175	2.2 x 10 ⁻⁹
7014.1	.00355	.178	1.4 x 10 ⁻⁹
7085.9	.00350	.175	2.1 x 10 ⁻⁹
7181.9	.00345	.172	2.3 x 10 ⁻⁹
7253.6	.00355	.178	3.0 x 10 ⁻⁹
7350.0	.00345	.172	1.4 x 10 ⁻⁹
7421.6	.00345	.172	1.4 x 10 ⁻⁹
7517.6	.00345	.172	7.8 x 10 ⁻¹⁰
7589.7	.00350	.175	1.8 x 10 ⁻⁹
7685.4	.00345	.172	1.6 x 10 ⁻⁹
7757.8	.00340	.170	2.2 x 10 ⁻⁹
7853.8	.00345	.172	1.8 x 10 ⁻⁹
7925.4	.00340	.170	1.6 x 10 ⁻⁹
8021.3	.00340	.170	1.3 x 10 ⁻⁹
8093.4	.00340	.170	1.6 x 10 ⁻⁹
8189.3	.00345	.172	1.7 x 10 ⁻⁹
8261.5	.00345	.172	1.9 x 10 ⁻⁹
8357.5	.00335	.168	1.1 x 10 ⁻⁹
8429.5	.00335	.168	1.6 x 10 ⁻⁹

TABLE II (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
8525.3 hours	.00340	.170	1.7 x 10 ⁻⁹
8597.7	.00350	.175	1.8 x 10 ⁻⁹
8694.0	.00355	.178	1.6 x 10 ⁻⁹
8769.8	.00350	.175	1.7 x 10 ⁻⁹
8861.7	.00355	.178	1.7 x 10 ⁻⁹
8934.4	.00355	.178	1.7 x 10 ⁻⁹
9030.0	.00350	.175	1.7 x 10 ⁻⁹
9106.9	.00350	.175	1.6 x 10 ⁻⁹
9197.3	.00350	.175	2.2 x 10 ⁻⁹
9268.5	.00350	.175	1.5 x 10 ⁻⁹
9364.7	.00345	.172	1.6 x 10 ⁻⁹
9436.8	.00335	.168	1.7 x 10 ⁻⁹
9532.5	.00345	.172	1.7 x 10 ⁻⁹
9604.3	.00345	.172	1.6 x 10 ⁻⁹
9700.8	.00345	.172	1.6 x 10 ⁻⁹
9774.3	.00335	.168	1.7 x 10 ⁻⁹
9868.8	.00330	.165	1.6 x 10 ⁻⁹
9940.4	.00340	.170	1.6 x 10 ⁻⁹
10,060.9	.00345	.172	1.1 x 10 ⁻⁹
10,108.5	.00340	.170	1.0 x 10 ⁻⁹
10,207.3	.00335	.168	1.1 x 10 ⁻⁹
10,276.3	.00335	.168	9.9 x 10 ⁻¹⁰
10,300.4	.00340	.170	9.7 x 10 ⁻¹⁰
10,372.4	.00340	.170	1.3 x 10 ⁻⁹
10,444.8	.00335	.168	1.4 x 10 ⁻⁹
10,540.5	.00345	.172	1.0 x 10 ⁻⁹
10,612.5	.00340	.170	1.0 x 10 ⁻⁹

Test in Progress
Specimen B-11

TABLE III

CREEP TEST DATA, TZC PLATE, HEAT M-80, RECRYSTALLIZED AT 3092°F (1700°C), 1 HOUR,
TESTED AT 2056°F (1124°C), 19,000 PSI (1.31 x 10⁸N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 minutes	.00010	.005	7.0 x 10 ⁻⁸
2	.00020	.010	
3	.00030	.015	
4	.00050	.025	
5	.00055	.028	
6	.00065	.032	
7	.00085	.042	
8	.00095	.048	
9	.00105	.052	
10	.00120	.060	
12	.00130	.065	
13	.00140	.070	
14	.00150	.075	
15	.00160	.080	6.9 x 10 ⁻⁸
20	.00165	.082	
25	.00170	.085	
30	.00170	.085	6.9 x 10 ⁻⁸
40	.00175	.088	
45	.00175	.088	
60	.00180	.090	6.8 x 10 ⁻⁸
90	.00180	.090	6.7 x 10 ⁻⁸
15.7 hours	.00180	.090	3.5 x 10 ⁻⁸
87.1	.00180	.090	1.4 x 10 ⁻⁸
111.2	.00100	.050	9.8 x 10 ⁻⁹
133.4	.00140	.070	7.0 x 10 ⁻⁹
159.0	.00135	.068	3.0 x 10 ⁻⁹
181.6	.00130	.065	--
239.9	.00135	.068	4.2 x 10 ⁻⁹
263.7	.00130	.065	5.1 x 10 ⁻⁹
287.7	.00150	.075	4.5 x 10 ⁻⁹
309.9	.00140	.070	3.8 x 10 ⁻⁹
334.3	.00150	.075	3.2 x 10 ⁻⁹
406.5	.00145	.072	3.5 x 10 ⁻⁹
459.3	.00155	.078	--
503.2	.00150	.075	2.2 x 10 ⁻⁹
573.9	.00175	.088	1.2 x 10 ⁻⁹

TABLE III (Continued)

<u>Time</u>	<u>Length Change</u> <u>ΔL (inch)</u> <u>(2" G. L.)</u>	<u>Creep</u> <u>(%)</u>	<u>Pressure</u> <u>(Torr)</u>
622.5 hours	.00175	.088	1.1 x 10 ⁻⁹
669.9	.00180	.090	3.8 x 10 ⁻⁹
742.3	.00185	.092	2.8 x 10 ⁻⁹
790.2	.00190	.095	2.8 x 10 ⁻⁹
838.3	.00185	.092	1.8 x 10 ⁻⁹
909.9	.00195	.098	3.2 x 10 ⁻⁹
964.8	.00205	.102	2.6 x 10 ⁻⁹
1006.2	.00210	.105	2.6 x 10 ⁻⁹
1055.3	.00215	.108	2.7 x 10 ⁻⁹
1102.0	.00220	.110	2.9 x 10 ⁻⁹
1126.8	.00220	.110	1.7 x 10 ⁻⁹
1173.9	.00220	.110	1.0 x 10 ⁻⁹
1245.9	.00215	.108	4.2 x 10 ⁻¹⁰
1294.0	.00225	.112	2.1 x 10 ⁻⁹
1342.0	.00235	.118	2.1 x 10 ⁻¹⁰
1414.1	.00235	.118	1.4 x 10 ⁻⁹
1466.7	.00235	.118	2.5 x 10 ⁻⁹
1509.0	.00225	.112	2.0 x 10 ⁻⁹
1581.8	.00245	.122	7.5 x 10 ⁻¹⁰
1654.2	.00245	.122	1.2 x 10 ⁻⁹
1750.2	.00240	.120	1.3 x 10 ⁻⁹
1822.1	.00235	.118	7.0 x 10 ⁻¹⁰
1942.2	.00235	.118	8.4 x 10 ⁻¹⁰
1990.6	.00240	.120	7.4 x 10 ⁻¹⁰
2086.2	.00250	.125	1.6 x 10 ⁻⁹
2158.2	.00260	.130	1.4 x 10 ⁻⁹
2254.4	.00265	.132	7.2 x 10 ⁻¹⁰
2326.1	.00265	.132	2.0 x 10 ⁻⁹
2424.7	.00280	.140	1.4 x 10 ⁻⁹
2497.4	.00305	.152	1.2 x 10 ⁻⁹
2600.1	.00310	.155	8.0 x 10 ⁻¹⁰
2664.7	.00325	.162	2.4 x 10 ⁻⁹
2759.8	.00345	.172	2.6 x 10 ⁻⁹
2854.3	.00355	.178	1.5 x 10 ⁻⁹
2926.3	.00355	.178	1.5 x 10 ⁻⁹
2998.2	.00355	.178	2.1 x 10 ⁻⁹
3094.0	.00365	.182	2.1 x 10 ⁻⁹
3166.4	.00360	.180	2.2 x 10 ⁻⁹
3262.2	.00355	.178	9.2 x 10 ⁻⁹

TABLE III (Continued)

<u>Time</u>	<u>Length Change Δ L (inch) (2" G. L.)</u>	<u>Creep %</u>	<u>Pressure (Torr)</u>
3334.1 hours	.00360	.180	2.2 x 10 ⁻⁹
3454.1	.00340	.170	1.6 x 10 ⁻⁹
3502.1	.00365	.182	2.0 x 10 ⁻⁹
3598.2	.00315	.158	1.1 x 10 ⁻⁹
3670.3	.00315	.158	1.0 x 10 ⁻⁹
3766.6	.00300	.150	9.0 x 10 ⁻¹⁰
3839.0	.00305	.152	2.5 x 10 ⁻⁹
3936.4	.00300	.150	9.1 x 10 ⁻¹⁰
4006.3	.00295	.148	2.0 x 10 ⁻⁹
4102.6	.00305	.152	2.1 x 10 ⁻⁹
4174.3	.00310	.155	1.9 x 10 ⁻⁹
4270.6	.00320	.160	1.0 x 10 ⁻⁹
4342.2	.00330	.165	2.0 x 10 ⁻⁹
4438.7	.00330	.165	2.5 x 10 ⁻⁹
4510.1	.00355	.178	1.4 x 10 ⁻⁹
4606.2	.00340	.170	2.0 x 10 ⁻⁹
4677.8	.00345	.172	1.8 x 10 ⁻⁹
4775.6	.00345	.172	1.8 x 10 ⁻⁹
4846.8	.00335	.168	1.6 x 10 ⁻⁹
4943.1	.00335	.168	1.6 x 10 ⁻⁹
5015.0	.00355	.178	1.7 x 10 ⁻⁹
5111.1	.00340	.170	1.6 x 10 ⁻⁹
5183.2	.00345	.172	1.0 x 10 ⁻⁹
5279.7	.00350	.175	1.6 x 10 ⁻⁹
5375.6	.00355	.178	1.5 x 10 ⁻⁹
5447.3	.00355	.178	2.5 x 10 ⁻⁹
5518.9	.00355	.178	2.5 x 10 ⁻⁹
5615.6	.00355	.178	1.0 x 10 ⁻⁹
5687.0	.00360	.180	2.5 x 10 ⁻⁹
5783.8	.00355	.178	2.4 x 10 ⁻⁹
5855.1	.00365	.182	2.4 x 10 ⁻⁹
5951.5	.00375	.188	2.4 x 10 ⁻⁹
6023.3	.00380	.190	2.5 x 10 ⁻⁹
6122.5	.00395	.198	9.0 x 10 ⁻¹⁰
6195.3	.00390	.195	2.4 x 10 ⁻⁹
6286.9	.00400	.200	2.5 x 10 ⁻⁹

TABLE III (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
6359.5 hours	.00405	.202	1.0 x 10 ⁻⁹
6455.8	.00410	.205	1.7 x 10 ⁻⁹
6527.0	.00415	.208	2.5 x 10 ⁻⁹
6623.2	.00410	.205	1.6 x 10 ⁻⁹
6695.6	.00410	.205	2.3 x 10 ⁻⁹
6791.8	.00420	.210	1.6 x 10 ⁻⁹
6864.8	.00420	.210	1.6 x 10 ⁻⁹
6959.5	.00415	.208	1.4 x 10 ⁻⁹
7031.2	.00420	.210	2.4 x 10 ⁻⁹
7127.6	.00435	.218	1.0 x 10 ⁻⁹
7199.2	.00430	.215	2.2 x 10 ⁻⁹
7295.2	.00430	.215	7.2 x 10 ⁻¹⁰
7367.3	.00430	.215	1.1 x 10 ⁻⁹
7463.2	.00425	.212	1.0 x 10 ⁻⁹
7535.5	.00430	.215	1.6 x 10 ⁻⁹
7631.3	.00440	.220	1.6 x 10 ⁻⁹
7702.9	.00440	.220	1.6 x 10 ⁻⁹
7798.9	.00440	.220	1.5 x 10 ⁻⁹
7870.9	.00440	.220	1.7 x 10 ⁻⁹
7966.8	.00445	.222	1.6 x 10 ⁻⁹
8039.1	.00440	.220	1.6 x 10 ⁻⁹
8135.2	.00450	.225	1.4 x 10 ⁻⁹
8207.0	.00455	.228	1.4 x 10 ⁻⁹
8302.8	.00465	.232	1.4 x 10 ⁻⁹
8375.2	.00470	.235	1.4 x 10 ⁻⁹
8471.6	.00475	.238	1.3 x 10 ⁻⁹
8546.4	.00480	.240	1.4 x 10 ⁻⁹
8639.3	.00480	.240	1.4 x 10 ⁻⁹
8712.3	.00480	.240	1.3 x 10 ⁻⁹
8807.6	.00470	.235	1.3 x 10 ⁻⁹
8885.0	.00470	.235	1.4 x 10 ⁻⁹
8975.7	.00470	.235	1.3 x 10 ⁻⁹
9046.1	.00475	.238	1.4 x 10 ⁻⁹
9142.2	.00475	.238	1.3 x 10 ⁻⁹
9214.3	.00475	.238	1.4 x 10 ⁻⁹
9310.0	.00475	.238	1.3 x 10 ⁻⁹
9381.9	.00480	.240	1.4 x 10 ⁻⁹
9478.8	.00480	.240	1.4 x 10 ⁻⁹
9551.8	.00485	.242	1.3 x 10 ⁻⁹
9646.4	.00485	.242	1.3 x 10 ⁻⁹
9718.0	.00485	.242	1.4 x 10 ⁻⁹
9838.4	.00490	.245	1.4 x 10 ⁻⁹
9886.2	.00495	.248	1.4 x 10 ⁻⁹
9985.1	.00500	.250	1.4 x 10 ⁻⁹

TABLE III (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
10,053.9	.00500	.250	1.3 x 10 ⁻⁹
10,077.9	.00500	.250	1.3 x 10 ⁻⁹
10,150.1	.00500	.250	1.4 x 10 ⁻⁹
10,222.5	.00505	.252	1.3 x 10 ⁻⁹
10,318.1	.00510	.255	1.3 x 10 ⁻⁹
10,390.8	.00510	.255	1.3 x 10 ⁻⁹

Test in Progress
Specimen B-12

TABLE IV

CREEP TEST DATA, T-111 SHEET, HEAT NO. 70616, ANNEALED AT 3000°F (1649°C)

FOR 1 HOUR, TESTED AT 2100°F (1149°C), 12,000 PSI (8.28 x 10⁷ N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 Minute(s)	.00000	.000	3.0 x 10 ⁻⁹
2	.00005	.002	3.0 x 10 ⁻⁹
3	.00010	.005	3.0 x 10 ⁻⁹
4	.00015	.008	3.0 x 10 ⁻⁹
5	.00015	.008	3.0 x 10 ⁻⁹
6	.00010	.005	3.0 x 10 ⁻⁹
7	.00010	.005	3.0 x 10 ⁻⁹
8	.00005	.002	3.0 x 10 ⁻⁹
9	.00010	.005	3.0 x 10 ⁻⁹
10	.00005	.002	3.0 x 10 ⁻⁹
15	.00000	.000	3.0 x 10 ⁻⁹
30	-.00005	-.002	3.0 x 10 ⁻⁹
45	.00010	.005	3.0 x 10 ⁻⁹
60	.00010	.005	3.0 x 10 ⁻⁹
19.6 Hours	.00025	.012	3.1 x 10 ⁻⁹
50.1	.00060	.030	2.4 x 10 ⁻⁹
67.5	.00070	.035	2.3 x 10 ⁻⁹
91.5	.00080	.040	2.4 x 10 ⁻⁹
164.0	.00100	.050	2.1 x 10 ⁻⁹
187.5	.00115	.058	2.1 x 10 ⁻⁹
211.3	.00125	.062	2.2 x 10 ⁻⁹
238.7	.00140	.070	2.2 x 10 ⁻⁹
331.5	.00190	.095	1.7 x 10 ⁻⁹
355.6	.00195	.098	1.8 x 10 ⁻⁹
379.3	.00205	.102	2.3 x 10 ⁻⁹
404.3	.00205	.102	2.3 x 10 ⁻⁹
427.4	.00215	.108	1.9 x 10 ⁻⁹
499.8	.00245	.122	2.2 x 10 ⁻⁹
523.3	.00240	.120	2.2 x 10 ⁻⁹
547.5	.00250	.125	2.2 x 10 ⁻⁹
576.4	.00270	.135	2.2 x 10 ⁻⁹
595.3	.00275	.138	2.4 x 10 ⁻⁹
667.2	.00340	.170	2.5 x 10 ⁻⁹
690.6	.00370	.185	2.4 x 10 ⁻⁹

TABLE IV (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
714.4	.00380	.190	2.3 x 10 ⁻⁹
738.5	.00385	.192	2.4 x 10 ⁻⁹
762.9	.00385	.192	2.4 x 10 ⁻⁹
834.3	.00440	.220	2.4 x 10 ⁻⁹
858.4	.00445	.222	2.3 x 10 ⁻⁹
882.5	.00455	.228	2.3 x 10 ⁻⁹
906.7	.00480	.240	2.3 x 10 ⁻⁹
930.3	.00515	.258	2.3 x 10 ⁻⁹
1002.4	.00560	.280	2.2 x 10 ⁻⁹
1026.2	.00575	.288	2.2 x 10 ⁻⁹
1050.4	.00620	.310	2.2 x 10 ⁻⁹
1074.2	.00630	.315	2.2 x 10 ⁻⁹
1098.6	.00620	.310	2.2 x 10 ⁻⁹
1170.7	.00640	.320	2.2 x 10 ⁻⁹
1194.3	.00655	.328	2.2 x 10 ⁻⁹
1218.3	.00665	.332	2.2 x 10 ⁻⁹
1242.5	.00690	.345	2.2 x 10 ⁻⁹
1266.3	.00715	.358	2.3 x 10 ⁻⁹
1338.7	.00750	.375	2.3 x 10 ⁻⁹
1362.5	.00760	.380	2.3 x 10 ⁻⁹
1386.3	.00775	.388	2.2 x 10 ⁻⁹
1410.4	.00785	.392	2.2 x 10 ⁻⁹
1434.3	.00795	.398	2.2 x 10 ⁻⁹
1530.8	.00850	.425	6.7 x 10 ⁻¹⁰
1554.5	.00880	.440	6.8 x 10 ⁻¹⁰
1578.4	.00890	.445	6.8 x 10 ⁻¹⁰
1602.4	.00905	.452	2.2 x 10 ⁻⁹
1677.5	.00955	.478	2.2 x 10 ⁻⁹
1698.3	.00965	.482	6.7 x 10 ⁻⁹
1722.3	.00980	.490	2.1 x 10 ⁻⁹
1746.2	.00990	.495	6.6 x 10 ⁻¹⁰
1770.2	.00995	.498	6.9 x 10 ⁻¹⁰
1842.3	.01055	.528	2.0 x 10 ⁻⁹
1866.3	.01070	.535	2.0 x 10 ⁻⁹
1890.4	.01100	.550	6.3 x 10 ⁻¹⁰
1914.6	.01095	.548	2.2 x 10 ⁻⁹
1938.3	.01145	.572	6.4 x 10 ⁻¹⁰
2010.4	.01190	.595	2.1 x 10 ⁻⁹
2034.3	.01210	.605	6.3 x 10 ⁻¹⁰
2058.4	.01220	.610	6.4 x 10 ⁻¹⁰
2082.4	.01235	.618	6.3 x 10 ⁻¹⁰

Test in Progress
Specimen S-23

TABLE V

CREEP TEST DATA, TZC PLATE, HEAT M-91, ANNEALED AT 3092°F (1700°C) FOR 1 HOUR,

TESTED AT 2000°F (1093°C), 20,000 PSI (1.38 x 10⁸N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 Minutes	.00000	.000	8.2 x 10 ⁻⁹
2	.00005	.002	8.2 x 10 ⁻⁹
3	.00010	.005	8.2 x 10 ⁻⁹
4	.00010	.005	8.2 x 10 ⁻⁹
5	.00015	.008	8.2 x 10 ⁻⁹
6	.00020	.010	8.2 x 10 ⁻⁹
7	.00020	.010	8.2 x 10 ⁻⁹
8	.00020	.010	8.2 x 10 ⁻⁹
9	.00015	.008	8.2 x 10 ⁻⁹
10	.00020	.010	8.2 x 10 ⁻⁹
15	.00025	.012	8.2 x 10 ⁻⁹
20	.00020	.010	8.2 x 10 ⁻⁹
25	.00025	.012	8.2 x 10 ⁻⁹
30	.00025	.012	8.2 x 10 ⁻⁹
60	.00020	.010	8.2 x 10 ⁻⁹
1.7 Hours	.00030	.015	8.2 x 10 ⁻⁹
19.0	.00075	.038	8.4 x 10 ⁻⁹
43.9	.00100	.050	7.2 x 10 ⁻⁹
115.2	.00155	.078	4.0 x 10 ⁻⁹
139.2	.00185	.092	3.2 x 10 ⁻⁹
163.6	.00210	.105	2.6 x 10 ⁻⁹
187.1	.00220	.110	2.4 x 10 ⁻⁹
211.4	.00240	.120	2.1 x 10 ⁻⁹
283.2	.00270	.135	1.4 x 10 ⁻⁹
307.3	.00290	.145	1.2 x 10 ⁻⁹
331.2	.00300	.150	1.1 x 10 ⁻⁹
355.2	.00295	.148	9.7 x 10 ⁻¹⁰
379.3	.00295	.148	9.6 x 10 ⁻¹⁰
451.9	.00310	.155	7.9 x 10 ⁻¹⁰
499.6	.00350	.175	6.7 x 10 ⁻¹⁰
547.7	.00355	.178	6.1 x 10 ⁻¹⁰
619.5	.00360	.180	9.2 x 10 ⁻¹⁰
643.4	.00365	.182	6.3 x 10 ⁻¹⁰
667.4	.00365	.182	8.1 x 10 ⁻¹⁰
691.1	.00365	.182	8.2 x 10 ⁻¹⁰
715.5	.00375	.188	7.8 x 10 ⁻¹⁰

TABLE V (Continued)

<u>Time</u>	<u>Length Change Δ L (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
787.7 Hours	.00410	.205	7.4 x 10 ⁻¹⁰
811.6	.00420	.210	7.1 x 10 ⁻¹⁰
835.3	.00435	.218	7.2 x 10 ⁻¹⁰
859.2	.00440	.220	7.0 x 10 ⁻¹⁰
883.2	.00445	.222	7.0 x 10 ⁻¹⁰
956.3	.00460	.230	6.6 x 10 ⁻¹⁰
980.0	.00470	.235	6.4 x 10 ⁻¹⁰
1003.4	.00455	.228	6.4 x 10 ⁻¹⁰
1027.2	.00465	.232	6.2 x 10 ⁻¹⁰
1123.7	.00485	.242	6.0 x 10 ⁻¹⁰
1195.5	.00490	.245	5.7 x 10 ⁻¹⁰
1294.7	.00515	.258	6.0 x 10 ⁻¹⁰
1367.4	.00525	.262	5.8 x 10 ⁻¹⁰
1459.1	.00560	.280	5.6 x 10 ⁻¹⁰
1531.7	.00585	.292	5.4 x 10 ⁻¹⁰
1627.9	.00600	.300	5.4 x 10 ⁻¹⁰
1699.2	.00620	.310	5.4 x 10 ⁻¹⁰
1795.3	.00640	.320	5.4 x 10 ⁻¹⁰
1867.8	.00655	.328	5.1 x 10 ⁻¹⁰
1963.9	.00665	.332	5.1 x 10 ⁻¹⁰
2035.6	.00695	.348	4.7 x 10 ⁻¹⁰
2131.6	.00720	.360	4.8 x 10 ⁻¹⁰
2203.3	.00740	.370	4.9 x 10 ⁻¹⁰
2299.8	.00745	.372	4.9 x 10 ⁻¹⁰
2371.4	.00755	.378	4.8 x 10 ⁻¹⁰
2467.3	.00760	.380	3.6 x 10 ⁻¹⁰
2539.5	.00770	.385	2.6 x 10 ⁻¹⁰
2635.2	.00800	.400	3.8 x 10 ⁻¹⁰
2707.6	.00820	.410	3.4 x 10 ⁻¹⁰
2803.4	.00880	.440	3.4 x 10 ⁻¹⁰
2875.1	.00900	.450	3.4 x 10 ⁻¹⁰
2971.0	.00910	.455	3.1 x 10 ⁻¹⁰
3043.1	.00920	.460	3.6 x 10 ⁻¹⁰
3139.0	.00935	.468	3.3 x 10 ⁻¹⁰
3211.3	.00930	.465	3.4 x 10 ⁻¹⁰
3307.3	.00960	.480	3.3 x 10 ⁻¹⁰
3379.2	.00965	.482	3.2 x 10 ⁻¹⁰

TABLE V (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
3475.0	.00980	.490	3.4 x 10 ⁻¹⁰
3547.4	.00990	.495	3.2 x 10 ⁻¹⁰
3643.8	.00995	.498	3.2 x 10 ⁻¹⁰
3718.6	.01020	.510	3.1 x 10 ⁻¹⁰
3811.5	.01050	.525	3.1 x 10 ⁻¹⁰
3884.2	.01070	.535	3.4 x 10 ⁻¹⁰
3979.7	.01140	.570	3.1 x 10 ⁻¹⁰
4051.3	.01145	.572	2.9 x 10 ⁻¹⁰
4147.1	.01145	.572	2.9 x 10 ⁻¹⁰
4218.3	.01145	.572	3.2 x 10 ⁻¹⁰
4314.4	.01160	.580	3.1 x 10 ⁻¹⁰
4386.5	.01165	.582	3.0 x 10 ⁻¹⁰
4482.2	.01230	.615	2.9 x 10 ⁻¹⁰
4554.1	.01225	.612	3.0 x 10 ⁻¹⁰
4650.5	.01235	.618	3.2 x 10 ⁻¹⁰
4724.0	.01240	.620	3.0 x 10 ⁻¹⁰
4818.5	.01270	.635	3.3 x 10 ⁻¹⁰
4890.2	.01290	.645	3.0 x 10 ⁻¹⁰
5010.6	.01290	.645	3.2 x 10 ⁻¹⁰
5058.3	.01300	.650	4.4 x 10 ⁻¹⁰
5157.1	.01310	.655	3.0 x 10 ⁻¹⁰
5226.0	.01340	.670	2.9 x 10 ⁻¹⁰
5250.1	.01370	.685	2.8 x 10 ⁻¹⁰
5324.2	.01375	.688	2.8 x 10 ⁻¹⁰
5394.5	.01380	.690	2.8 x 10 ⁻¹⁰
5490.3	.01395	.698	2.7 x 10 ⁻¹⁰
5562.2	.01405	.702	2.8 x 10 ⁻¹⁰

Test in Progress
Specimen B-20

TABLE VI

CREEP TEST DATA, T-111 SHEET, HEAT NO. 70616, ANNEALED 3000°F (1649°C)

FOR 1 HOUR, TESTED AT 1860°F (1016°C), 20,000 PSI (1.38 x 10⁸N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 Minute(s)	.00010	.005	3.2 x 10 ⁻⁹
2	.00000	.000	3.2 x 10 ⁻⁹
3	.00000	.000	3.2 x 10 ⁻⁹
4	.00010	.005	3.2 x 10 ⁻⁹
5	.00015	.008	3.2 x 10 ⁻⁹
6	.00010	.005	3.2 x 10 ⁻⁹
7	.00020	.010	3.2 x 10 ⁻⁹
8	.00015	.008	3.2 x 10 ⁻⁹
9	.00015	.008	3.2 x 10 ⁻⁹
10	.00020	.010	3.2 x 10 ⁻⁹
15	.00020	.010	3.2 x 10 ⁻⁹
30	.00015	.008	3.2 x 10 ⁻⁹
45	.00015	.008	3.2 x 10 ⁻⁹
60	.00020	.010	3.2 x 10 ⁻⁹
65.2 Hours	.00070	.035	2.6 x 10 ⁻⁹
89.1	.00085	.042	2.2 x 10 ⁻⁹
113.2	.00110	.055	2.1 x 10 ⁻⁹
137.4	.00135	.068	1.9 x 10 ⁻⁹
161.0	.00140	.070	2.0 x 10 ⁻⁹
233.1	.00160	.080	1.8 x 10 ⁻⁹
256.9	.00165	.082	1.8 x 10 ⁻⁹
281.1	.00160	.080	1.8 x 10 ⁻⁹
305.0	.00180	.090	1.8 x 10 ⁻⁹
329.3	.00195	.098	1.7 x 10 ⁻⁹
401.4	.00195	.098	1.8 x 10 ⁻⁹
425.0	.00200	.100	1.6 x 10 ⁻⁹
449.1	.00200	.100	1.6 x 10 ⁻⁹
473.3	.00210	.105	1.7 x 10 ⁻⁹
497.0	.00205	.102	1.9 x 10 ⁻⁹
571.4	.00205	.102	1.7 x 10 ⁻⁹
593.3	.00210	.105	1.7 x 10 ⁻⁹

TABLE VI (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
617.0	.00210	.105	1.7 x 10 ⁻⁹
641.1	.00215	.108	1.7 x 10 ⁻⁹
665.1	.00220	.110	1.5 x 10 ⁻⁹
761.5	.00230	.115	1.5 x 10 ⁻⁹
785.3	.00230	.115	1.6 x 10 ⁻⁹
809.1	.00235	.118	1.6 x 10 ⁻⁹
833.2	.00235	.118	1.6 x 10 ⁻⁹
908.2	.00235	.118	1.7 x 10 ⁻⁹
929.1	.00240	.120	1.6 x 10 ⁻⁹
953.1	.00240	.120	1.6 x 10 ⁻⁹
976.9	.00245	.122	1.5 x 10 ⁻⁹
1001.0	.00240	.120	1.4 x 10 ⁻⁹
1073.1	.00250	.125	1.6 x 10 ⁻⁹
1097.0	.00250	.125	1.6 x 10 ⁻⁹
1121.1	.00255	.128	1.5 x 10 ⁻⁹
1145.4	.00265	.132	1.6 x 10 ⁻⁹
1169.0	.00275	.138	1.5 x 10 ⁻⁹
1241.2	.00280	.140	1.5 x 10 ⁻⁹
1265.0	.00290	.145	1.5 x 10 ⁻⁹
1289.1	.00300	.150	1.6 x 10 ⁻⁹
1313.2	.00305	.152	1.7 x 10 ⁻⁹

Test in Progress
Specimen S-24

TABLE VII

CREEP TEST DATA, TZC PLATE, HEAT M-91, ANNEALED AT 2300°F (1260°C), FOR

1 HOUR, TESTED AT 2000°F (1093°C), 28,000 PSI (1.93 x 10⁸ N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 Minute(s)	.00005	.002	9.0 x 10 ⁻⁹
2	.00005	.002	9.0 x 10 ⁻⁹
3	.00000	.000	9.0 x 10 ⁻⁹
4	.00000	.000	9.0 x 10 ⁻⁹
5	.00005	.002	9.0 x 10 ⁻⁹
6	.00005	.002	9.0 x 10 ⁻⁹
7	.00000	.000	9.0 x 10 ⁻⁹
8	.00005	.002	9.0 x 10 ⁻⁹
9	.00010	.005	9.0 x 10 ⁻⁹
10	.00005	.002	9.0 x 10 ⁻⁹
15	.00005	.002	9.0 x 10 ⁻⁹
30	.00000	.000	9.0 x 10 ⁻⁹
45	.00000	.000	9.0 x 10 ⁻⁹
60	.00000	.000	9.0 x 10 ⁻⁹
17.3 Hours	.00155	.078	3.4 x 10 ⁻⁹
25.2	.00170	.085	3.3 x 10 ⁻⁹
40.8	.00175	.088	1.5 x 10 ⁻⁹
65.9	.00245	.122	1.1 x 10 ⁻⁹
88.9	.00290	.145	1.0 x 10 ⁻⁹
161.5	.00390	.195	6.4 x 10 ⁻¹⁰
185.0	.00410	.205	6.4 x 10 ⁻¹⁰
209.1	.00425	.212	6.0 x 10 ⁻¹⁰
238.5	.00480	.240	5.5 x 10 ⁻¹⁰
257.0	.00485	.242	5.2 x 10 ⁻¹⁰
329.6	.00530	.265	4.6 x 10 ⁻¹⁰
352.2	.00555	.278	4.6 x 10 ⁻¹⁰
376.0	.00580	.290	4.6 x 10 ⁻¹⁰
400.0	.00590	.295	4.9 x 10 ⁻¹⁰
424.4	.00600	.300	4.8 x 10 ⁻¹⁰
496.2	.00635	.318	4.2 x 10 ⁻¹⁰
520.1	.00645	.322	4.2 x 10 ⁻¹⁰
544.6	.00660	.330	4.1 x 10 ⁻¹⁰
568.3	.00670	.335	4.2 x 10 ⁻¹⁰
591.9	.00685	.342	4.2 x 10 ⁻¹⁰

TABLE VII (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
663.9	.00745	.372	3.7 x 10 ⁻¹⁰
687.9	.00765	.382	3.7 x 10 ⁻¹⁰
711.9	.00780	.390	3.8 x 10 ⁻¹⁰
735.8	.00785	.392	3.6 x 10 ⁻¹⁰
760.2	.00800	.400	3.4 x 10 ⁻¹⁰
832.2	.00860	.430	3.6 x 10 ⁻¹⁰
855.9	.00885	.442	3.9 x 10 ⁻¹⁰
879.8	.00890	.445	3.6 x 10 ⁻¹⁰
905.8	.00895	.448	3.6 x 10 ⁻¹⁰
928.6	.00890	.445	4.8 x 10 ⁻¹⁰
990.3	.00940	.470	3.2 x 10 ⁻¹⁰
1014.1	.00955	.478	3.1 x 10 ⁻¹⁰
1037.9	.00970	.485	3.6 x 10 ⁻¹⁰
1061.9	.00980	.490	3.4 x 10 ⁻¹⁰
1085.9	.00975	.488	3.0 x 10 ⁻¹⁰
1182.3	.01030	.515	2.4 x 10 ⁻¹⁰
1206.3	.01075	.538	2.1 x 10 ⁻¹⁰
1230.0	.01075	.538	2.8 x 10 ⁻¹⁰
1254.1	.01070	.535	2.0 x 10 ⁻¹⁰
1328.9	.01100	.550	2.1 x 10 ⁻¹⁰
1350.0	.01100	.550	2.0 x 10 ⁻¹⁰
1373.9	.01110	.555	2.0 x 10 ⁻¹⁰
1397.7	.01115	.558	2.0 x 10 ⁻¹⁰
1421.8	.01135	.568	1.9 x 10 ⁻¹⁰
1493.9	.01165	.582	1.8 x 10 ⁻¹⁰
1517.8	.01170	.585	1.6 x 10 ⁻¹⁰
1542.0	.01175	.588	1.8 x 10 ⁻¹⁰
1566.3	.01190	.595	1.6 x 10 ⁻¹⁰
1589.8	.01200	.600	1.6 x 10 ⁻¹⁰
1662.0	.01250	.625	1.4 x 10 ⁻¹⁰
1685.9	.01260	.630	1.4 x 10 ⁻¹⁰
1710.0	.01265	.632	1.8 x 10 ⁻¹⁰
1734.0	.01280	.640	1.3 x 10 ⁻¹⁰

Test in Progress
Specimen B-28

TABLE VIII

CREEP TEST DATA, STRESS RELIEVED TZM FORGED DISC, CLIMAX HEAT NO. 7502,

TESTED AT 2000°F (1093°C), 41,000PSI (2.82×10^8 N/m²)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 Minute(s)	-.00005	-.002	1.4×10^{-7}
2	-.00005	-.002	1.4×10^{-7}
3	-.00005	-.002	1.4×10^{-7}
4	.00005	.002	1.4×10^{-7}
5	.00005	.002	1.4×10^{-7}
6	.00010	.005	1.4×10^{-7}
7	.00010	.005	1.4×10^{-7}
8	.00010	.005	1.4×10^{-7}
9	.00020	.010	1.4×10^{-7}
10	.00045	.012	1.4×10^{-7}
15	.00040	.010	1.4×10^{-7}
30	.00050	.025	1.4×10^{-7}
45	.00065	.032	1.4×10^{-7}
60	.00075	.038	1.4×10^{-7}
17.2 Hours	.00345	.172	1.9×10^{-8}
41.1	.00515	.258	1.0×10^{-8}
68.4	.00735	.368	6.8×10^{-9}
92.4	.00850	.425	7.2×10^{-9}
115.1	.01005	.502	6.1×10^{-9}
143.6	.01220	.610	5.2×10^{-9}
161.4	.01350	.675	4.8×10^{-9}
185.5	.01510	.755	4.4×10^{-9}
209.0	.01730	.865	4.4×10^{-9}
234.4	.01970	.985	2.9×10^{-9}
257.1	.02195	1.098	4.3×10^{-9}
329.6	.03105	1.552	3.3×10^{-9}
353.2	.03370	1.685	3.5×10^{-9}
377.2	.03770	1.885	2.2×10^{-9}
407.2	.04255	2.128	3.2×10^{-9}
425.2	.04580	2.290	3.2×10^{-9}
497.8	.06080	3.040	3.0×10^{-9}
520.4	.06650	3.325	2.8×10^{-9}
544.1	.07275	3.638	2.8×10^{-9}
568.2	.07940	3.970	2.0×10^{-9}
592.6	.08810	4.405	1.8×10^{-9}
600.4	.09070	4.535	-
617.7	.09760	4.880	2.9×10^{-9}
644.2	.11090	5.545	2.8×10^{-9}
664.3	.12430	6.215	2.6×10^{-9}

Test Terminated - 5% Creep
Specimen B-29

TABLE IX

CREEP TEST DATA, TZC PLATE, HEAT M-91, ANNEALED AT 2500°F (1371°C), FOR
1 HOUR, TESTED AT 2200°F (1204°C), 22,000 PSI (1.52 x 10⁸N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 Minute(s)	.00005	.002	3.1 x 10 ⁻⁸
2	.00000	.000	3.1 x 10 ⁻⁸
3	.00000	.000	3.1 x 10 ⁻⁸
4	.00000	.000	3.1 x 10 ⁻⁸
5	-.00005	-.002	3.1 x 10 ⁻⁸
6	.00000	.000	3.1 x 10 ⁻⁸
7	.00010	.005	3.1 x 10 ⁻⁸
8	.00005	.002	3.1 x 10 ⁻⁸
9	.00015	.008	3.1 x 10 ⁻⁸
10	.00015	.008	3.1 x 10 ⁻⁸
15	.00015	.008	3.1 x 10 ⁻⁸
30	.00030	.015	3.1 x 10 ⁻⁸
45	.00050	.025	3.1 x 10 ⁻⁸
60	.00060	.030	3.1 x 10 ⁻⁸
3.0 Hours	.00150	.075	4.5 x 10 ⁻⁸
4.0	.00165	.082	4.5 x 10 ⁻⁸
18.9	.00465	.232	1.2 x 10 ⁻⁸
22.4	.00500	.250	1.2 x 10 ⁻⁸
27.1	.00565	.282	1.2 x 10 ⁻⁸
46.8	.00765	.382	-
72.0	.01025	.512	-
90.9	.01190	.595	5.4 x 10 ⁻⁹
98.9	.01255	.628	5.0 x 10 ⁻⁹
114.9	.01410	.705	4.9 x 10 ⁻⁹
122.9	.01490	.745	4.8 x 10 ⁻⁹
138.8	.01570	.785	4.2 x 10 ⁻⁹
162.7	.01825	.912	3.9 x 10 ⁻⁹
170.9	.01885	.942	3.7 x 10 ⁻⁹
187.1	.01995	.998	3.2 x 10 ⁻⁹
195.3	.02080	1.040	3.2 x 10 ⁻⁹
238.7	.02465	1.232	3.4 x 10 ⁻⁹
259.2	.02560	1.280	3.2 x 10 ⁻⁹

Test Terminated - 1% Creep
Specimen B-30

TABLE X

CREEP TEST DATA, TZM FORGED DISC, HEAT NO. 1175, TESTED AT 1800°F (982°C)

44,000 PSI ($3.03 \times 10^8 \text{N/m}^2$)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 minute(s)	.00000	.000	4.8×10^{-7}
2	.00010	.005	4.8×10^{-7}
3	.00020	.010	4.8×10^{-7}
4	.00025	.012	4.8×10^{-7}
5	.00015	.008	4.8×10^{-7}
6	.00015	.008	4.8×10^{-7}
7	.00010	.005	4.8×10^{-7}
8	.00015	.008	4.8×10^{-7}
9	.00020	.010	4.8×10^{-7}
10	.00020	.010	4.8×10^{-7}
15	.00020	.010	4.8×10^{-7}
30	.00025	.012	4.8×10^{-7}
45	.00025	.012	4.8×10^{-7}
60	.00030	.015	4.8×10^{-7}
65.5 hours	.00055	.028	3.0×10^{-7}
89.1	.00070	.035	2.8×10^{-7}
113.1	.00095	.048	1.1×10^{-8}
137.1	.00100	.050	2.1×10^{-8}
161.1	.00100	.050	1.7×10^{-9}
233.0	.00100	.050	1.0×10^{-9}
257.3	.00105	.052	8.4×10^{-10}
280.9	.00105	.052	1.3×10^{-9}
305.2	.00110	.055	1.6×10^{-9}
329.4	.00110	.055	1.4×10^{-9}
401.0	.00115	.058	1.4×10^{-9}
426.7	.00115	.058	4.0×10^{-10}
449.2	.00120	.060	5.8×10^{-10}
473.4	.00130	.065	7.6×10^{-10}
497.0	.00135	.068	3.8×10^{-10}
569.2	.00145	.072	3.9×10^{-10}
593.1	.00140	.070	5.5×10^{-10}
616.9	.00145	.072	8.4×10^{-10}
640.8	.00140	.070	7.8×10^{-10}
664.8	.00150	.075	5.0×10^{-10}

TABLE X (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure</u>
736.8	.00150	.075	8.8 x 10 ⁻¹⁰
761.7	.00150	.075	8.6 x 10 ⁻¹⁰
785.0	.00150	.075	5.0 x 10 ⁻¹⁰
808.8	.00155	.078	9.0 x 10 ⁻¹⁰
833.8	.00155	.078	5.0 x 10 ⁻¹⁰
904.7	.00160	.080	8.4 x 10 ⁻¹⁰
928.8	.00160	.080	8.9 x 10 ⁻¹⁰
953.1	.00160	.080	7.0 x 10 ⁻¹⁰
977.0	.00165	.082	6.0 x 10 ⁻¹⁰
1001.0	.00180	.090	9.2 x 10 ⁻¹⁰
1073.0	.00180	.090	9.1 x 10 ⁻¹⁰
1114.9	.00175	.088	8.2 x 10 ⁻¹⁰
1240.7	.00175	.088	7.5 x 10 ⁻¹⁰
1313.2	.00180	.090	9.0 x 10 ⁻¹⁰
1409.5	.00180	.090	5.8 x 10 ⁻¹⁰
1484.2	.00180	.090	4.4 x 10 ⁻¹⁰
1577.2	.00185	.092	4.0 x 10 ⁻¹⁰
1650.2	.00185	.092	3.5 x 10 ⁻¹⁰
1715.9	.00190	.095	4.5 x 10 ⁻¹⁰
1822.5	.00200	.100	4.0 x 10 ⁻¹⁰
1913.6	.00215	.108	4.9 x 10 ⁻¹⁰
1984.0	.00210	.105	3.5 x 10 ⁻¹⁰
2080.1	.00215	.108	3.0 x 10 ⁻¹⁰
2152.2	.00215	.108	4.0 x 10 ⁻¹⁰
2247.9	.00220	.110	3.5 x 10 ⁻¹⁰
2319.8	.00225	.112	2.8 x 10 ⁻¹⁰
2416.7	.00235	.118	3.5 x 10 ⁻¹⁰
2489.7	.00230	.115	2.4 x 10 ⁻¹⁰
2584.3	.00235	.118	2.2 x 10 ⁻¹⁰
2655.9	.00240	.120	2.4 x 10 ⁻¹⁰
2776.3	.00250	.125	3.8 x 10 ⁻¹⁰
2824.0	.00250	.125	4.6 x 10 ⁻¹⁰
2922.9	.00250	.125	4.4 x 10 ⁻¹⁰
2991.8	.00245	.122	4.0 x 10 ⁻¹⁰
3015.8	.00245	.122	4.0 x 10 ⁻¹⁰
3088.0	.00245	.122	3.7 x 10 ⁻¹⁰
3160.4	.00245	.122	4.0 x 10 ⁻¹⁰
3256.0	.00250	.125	4.4 x 10 ⁻¹⁰
3328.7	.00255	.128	4.1 x 10 ⁻¹⁰

Test in Progress
Specimen B-25

TABLE XI

CREEP TEST DATA, TZC PLATE, HEAT M-91, ANNEALED AT 3092°F (1700°C) FOR 1 HOUR,
TESTED AT 220°F (1204°C), 14,000 PSI (9.65 x 10⁷N/m²)

<u>Time</u>	<u>Length Change ΔL(inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 Minute(s)	-.00010	-.005	2.0 x 10 ⁻⁷
2	-.00005	-.002	2.0 x 10 ⁻⁷
3	-.00010	-.005	2.0 x 10 ⁻⁷
4	-.00010	-.005	2.0 x 10 ⁻⁷
5	-.00015	-.008	2.0 x 10 ⁻⁷
6	-.00015	-.008	2.0 x 10 ⁻⁷
7	-.00005	-.002	2.0 x 10 ⁻⁷
8	-.00015	-.008	2.0 x 10 ⁻⁷
9	-.00020	-.010	2.0 x 10 ⁻⁷
10	-.00015	-.008	2.0 x 10 ⁻⁷
15	-.00010	-.005	2.0 x 10 ⁻⁷
30	.00005	.002	2.0 x 10 ⁻⁷
45	.00000	.000	2.0 x 10 ⁻⁷
60	.00005	.002	2.0 x 10 ⁻⁷
65.6 Hours	.00130	.065	1.1 x 10 ⁻⁸
72.7	.00155	.078	1.0 x 10 ⁻⁸
88.7	.00170	.085	9.0 x 10 ⁻⁹
112.7	.00245	.122	7.8 x 10 ⁻⁹
120.7	.00295	.148	7.9 x 10 ⁻⁹
136.3	.00385	.192	7.2 x 10 ⁻⁹
145.0	.00410	.205	7.0 x 10 ⁻⁹
160.7	.00470	.235	7.1 x 10 ⁻⁹
166.3	.00530	.265	7.0 x 10 ⁻⁹
193.1	.00620	.310	- - - -
217.8	.00710	.355	5.8 x 10 ⁻⁹
233.1	.00775	.388	6.0 x 10 ⁻⁹
257.0	.00840	.420	5.9 x 10 ⁻⁹
280.8	.00890	.445	5.8 x 10 ⁻⁹
304.8	.00960	.480	5.6 x 10 ⁻⁹
328.8	.01000	.500	5.3 x 10 ⁻⁹
336.7	.01050	.525	5.3 x 10 ⁻⁹
356.0	.01080	.540	4.1 x 10 ⁻⁹
381.7	.01160	.580	3.8 x 10 ⁻⁹
409.0	.01215	.608	3.8 x 10 ⁻⁹
425.2	.01255	.628	4.0 x 10 ⁻⁹
449.2	.01280	.640	4.0 x 10 ⁻⁹
473.0	.01320	.660	4.0 x 10 ⁻⁹
497.0	.01365	.682	3.9 x 10 ⁻⁹
525.8	.01490	.745	3.7 x 10 ⁻⁹
554.2	.01510	.755	3.9 x 10 ⁻⁹
571.8	.01505	.752	3.5 x 10 ⁻⁹

TABLE XI (Continued)

<u>Time</u>	<u>Length Change ΔL(inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
592.9 Hours	.01510	.755	3.5 x 10 ⁻⁹
616.8	.01570	.785	3.2 x 10 ⁻⁹
640.7	.01630	.815	3.6 x 10 ⁻⁹
664.7	.01685	.842	3.5 x 10 ⁻⁹
736.8	.01825	.912	3.4 x 10 ⁻⁹
760.7	.01885	.942	3.3 x 10 ⁻⁹
784.9	.01930	.965	3.2 x 10 ⁻⁹
809.2	.01980	.990	3.6 x 10 ⁻⁹
832.8	.02040	1.020	3.3 x 10 ⁻⁹
904.9	.02175	1.088	3.2 x 10 ⁻⁹
912.0	.02185	1.092	3.2 x 10 ⁻⁹

Test Terminated 1% Creep
Specimen B-31

TABLE XII

CREEP TEST DATA, TZC PLATE, HEAT M-91, ANNEALED AT 2500°F (1371°C) FOR 1 HOUR
TESTED AT 1935°F (1057°C), 20,000 PSI (1.38 x 10⁸ N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 Minute(s)	.00000	.000	2.0 x 10 ⁻⁸
2	-.00005	-.002	2.0 x 10 ⁻⁸
3	-.00010	-.005	2.0 x 10 ⁻⁸
4	-.00010	-.005	2.0 x 10 ⁻⁸
5	-.00010	-.005	2.0 x 10 ⁻⁸
6	-.00015	-.008	2.0 x 10 ⁻⁸
7	-.00015	-.008	2.0 x 10 ⁻⁸
8	-.00020	-.010	2.0 x 10 ⁻⁸
9	-.00015	-.008	2.0 x 10 ⁻⁸
10	-.00015	-.008	2.0 x 10 ⁻⁸
15	-.00010	-.005	2.0 x 10 ⁻⁸
30	-.00030	-.015	2.0 x 10 ⁻⁸
45	-.00030	-.015	2.0 x 10 ⁻⁸
60	-.00025	-.012	2.0 x 10 ⁻⁸
16.8 Hours	.00015	.008	1.1 x 10 ⁻⁸
91.2	.00080	.040	2.7 x 10 ⁻⁹
113.1	.00100	.050	2.2 x 10 ⁻⁹
136.1	.00105	.052	2.0 x 10 ⁻⁹
160.9	.00105	.052	1.7 x 10 ⁻⁹
184.9	.00115	.058	1.6 x 10 ⁻⁹
281.3	.00120	.060	5.2 x 10 ⁻¹⁰
305.1	.00120	.060	5.1 x 10 ⁻¹⁰
328.9	.00125	.062	5.1 x 10 ⁻¹⁰
353.0	.00130	.065	5.3 x 10 ⁻¹⁰
428.0	.00170	.085	4.8 x 10 ⁻¹⁰
448.9	.00180	.090	4.6 x 10 ⁻¹⁰
472.8	.00185	.092	1.2 x 10 ⁻⁹
496.7	.00185	.092	4.7 x 10 ⁻¹⁰
520.7	.00185	.092	1.1 x 10 ⁻⁹
592.9	.00190	.095	9.5 x 10 ⁻¹⁰
616.8	.00190	.095	9.8 x 10 ⁻¹⁰
640.9	.00190	.095	9.5 x 10 ⁻¹⁰
665.2	.00195	.098	9.8 x 10 ⁻¹⁰
688.8	.00190	.095	9.8 x 10 ⁻¹⁰
761.0	.00200	.100	9.2 x 10 ⁻¹⁰
784.8	.00195	.098	9.2 x 10 ⁻¹⁰
808.9	.00195	.098	9.8 x 10 ⁻¹⁰
833.0	.00200	.100	1.1 x 10 ⁻⁹

Test In Progress
Specimen B-32

TABLE XIII

CREEP TEST DATA, TZC PLATE, HEAT NO. M-91, ANNEALED AT 2500°F (1371°C) FOR 1 HOUR, TESTED AT 1900°F (1038°C), 22,000 PSI (1.52 x 10⁸ N/m²)

<u>Time</u>	<u>Length Change ΔL(inch) (2"G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 Minute(s)	-.00005	-.002	9.7 x 10 ⁻⁹
2	-.00005	-.002	9.7 x 10 ⁻⁹
3	-.00010	-.005	9.7 x 10 ⁻⁹
4	.00005	.002	9.7 x 10 ⁻⁹
5	.00005	.002	9.7 x 10 ⁻⁹
6	.00005	.002	9.7 x 10 ⁻⁹
7	.00005	.002	9.7 x 10 ⁻⁹
8	.00010	.005	9.7 x 10 ⁻⁹
9	.00010	.005	9.7 x 10 ⁻⁹
10	.00010	.005	9.7 x 10 ⁻⁹
15	.00015	.008	9.7 x 10 ⁻⁹
30	.00020	.010	9.7 x 10 ⁻⁹
45	.00020	.010	9.7 x 10 ⁻⁹
60	.00030	.015	9.7 x 10 ⁻⁹
17.2 Hours	.00065	.032	5.2 x 10 ⁻⁹
41.3	.00115	.058	3.7 x 10 ⁻⁹
44.2	.00120	.060	3.7 x 10 ⁻⁹
70.1	.00180	.090	3.2 x 10 ⁻⁹
98.5	.00195	.098	2.6 x 10 ⁻⁹
116.1	.00200	.100	2.5 x 10 ⁻⁹
137.2	.00200	.100	2.2 x 10 ⁻⁹
161.1	.00205	.102	1.8 x 10 ⁻⁹
184.9	.00210	.105	1.7 x 10 ⁻⁹
209.0	.00205	.102	1.7 x 10 ⁻⁹
281.1	.00240	.120	1.6 x 10 ⁻⁹
305.0	.00245	.122	1.5 x 10 ⁻⁹
329.2	.00250	.125	1.4 x 10 ⁻⁹
353.4	.00270	.135	1.3 x 10 ⁻⁹
377.0	.00275	.138	1.1 x 10 ⁻⁹
449.1	.00285	.142	1.0 x 10 ⁻⁹
473.0	.00295	.148	1.0 x 10 ⁻⁹
497.1	.00300	.150	1.2 x 10 ⁻⁹
521.9	.00310	.155	1.3 x 10 ⁻⁹

Test In Progress
Specimen B-33

TABLE XIV

CREEP TEST DATA, TZM COMMERCIAL BAR, HEAT NO. 7463, STRESS RELIEVED 0.5 HOUR AT 2250°F (1232°C) TESTED AT 2000°F(1093°C), 41,000 PSI (2.82 x 10⁻⁸ N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 Minute(s)	-.00005	-.002	2.4 x 10 ⁻⁸
2	-.00010	-.005	2.4 x 10 ⁻⁸
3	-.00015	-.008	2.4 x 10 ⁻⁸
4	-.00010	-.005	2.4 x 10 ⁻⁸
5	-.00010	-.005	2.4 x 10 ⁻⁸
6	-.00010	-.005	2.4 x 10 ⁻⁸
7	-.00010	-.005	2.4 x 10 ⁻⁸
8	-.00015	-.008	2.4 x 10 ⁻⁸
9	-.00015	-.008	2.4 x 10 ⁻⁸
10	-.00010	-.005	2.4 x 10 ⁻⁸
15	-.00015	-.008	2.4 x 10 ⁻⁸
30	-.00005	-.002	2.4 x 10 ⁻⁸
45	-.00005	-.002	2.4 x 10 ⁻⁸
60	.00005	.002	2.4 x 10 ⁻⁸
18.5 Hours	.00110	.055	2.7 x 10 ⁻⁹
24.8	.00160	.080	3.0 x 10 ⁻⁹
50.9	.00260	.130	1.4 x 10 ⁻⁹
74.7	.00235	.118	9.7 x 10 ⁻¹⁰
88.6	.00285	.142	1.0 x 10 ⁻⁹
96.7	.00320	.160	1.0 x 10 ⁻⁹
113.0	.00335	.168	9.4 x 10 ⁻¹⁰
120.5	.00340	.170	9.5 x 10 ⁻¹⁰
136.5	.00365	.182	8.8 x 10 ⁻¹⁰
144.8	.00375	.188	8.0 x 10 ⁻¹⁰
160.7	.00400	.200	6.4 x 10 ⁻¹⁰
168.0	.00405	.202	6.3 x 10 ⁻¹⁰
184.7	.00410	.205	8.0 x 10 ⁻¹⁰
280.7	.00495	.248	5.5 x 10 ⁻¹⁰
305.1	.00520	.260	5.5 x 10 ⁻¹⁰
329.7	.00540	.270	5.4 x 10 ⁻¹⁰
352.8	.00565	.282	5.4 x 10 ⁻¹⁰
425.2	.00600	.300	5.9 x 10 ⁻¹⁰

Test In Progress
Specimen B-34

TABLE XV

CREEP TEST DATA, T-111 SHEET, HEAT NO. 111-D-1670, ANNEALED 3000°F (1649°C) FOR 1 HOUR TESTED AT 2000°F (1093°C), 15,000 PSI (1.03 x 10⁸ N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 Minute(s)	.00010	.005	1.7 x 10 ⁻⁸
2	.00020	.010	1.7 x 10 ⁻⁸
3	.00030	.015	1.7 x 10 ⁻⁸
4	.00035	.018	1.7 x 10 ⁻⁸
5	.00040	.020	1.7 x 10 ⁻⁸
6	.00035	.018	1.7 x 10 ⁻⁸
7	.00040	.020	1.7 x 10 ⁻⁸
8	.00035	.018	1.7 x 10 ⁻⁸
9	.00035	.018	1.7 x 10 ⁻⁸
10	.00030	.015	1.7 x 10 ⁻⁸
15	.00040	.020	1.7 x 10 ⁻⁸
30	.00030	.015	1.7 x 10 ⁻⁸
45	.00035	.018	1.7 x 10 ⁻⁸
60	.00035	.018	1.7 x 10 ⁻⁸
26.2 Hours	.00055	.028	4.8 x 10 ⁻⁹
49.7	.00065	.032	2.2 x 10 ⁻⁹
63.4	.00095	.048	2.0 x 10 ⁻⁹
87.3	.00110	.055	1.3 x 10 ⁻⁹
111.4	.00130	.065	1.5 x 10 ⁻⁹
135.4	.00155	.078	2.0 x 10 ⁻⁹

Test In Progress
Specimen S-25

TABLE XVI

CREEP TEST DATA, Cb MODIFIED TZM WROUGHT BAR, HEAT NO. 4305-4, TESTED AT
2000°F (1093°C), 41,000 PSI (2.82 x 10⁸N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 Minute(s)	.00005	.002	2.5 x 10 ⁻⁷
2	.00005	.002	2.5 x 10 ⁻⁷
3	.00000	.000	2.5 x 10 ⁻⁷
4	.00005	.002	2.5 x 10 ⁻⁷
5	.00010	.005	2.5 x 10 ⁻⁷
6	.00010	.005	2.5 x 10 ⁻⁷
7	.00010	.005	2.5 x 10 ⁻⁷
8	.00015	.008	2.5 x 10 ⁻⁷
9	.00010	.005	2.5 x 10 ⁻⁷
10	.00010	.005	2.5 x 10 ⁻⁷
15	.00015	.008	2.5 x 10 ⁻⁷
30	.00015	.008	2.5 x 10 ⁻⁷
45	.00020	.010	2.5 x 10 ⁻⁷
60	.00025	.012	2.5 x 10 ⁻⁷
17.7 Hours	.00070	.035	2.0 x 10 ⁻⁸
40.8	.00110	.055	9.9 x 10 ⁻⁹
64.9	.00155	.078	6.4 x 10 ⁻⁹
89.9	.00195	.098	3.9 x 10 ⁻⁹
160.7	.00250	.125	2.3 x 10 ⁻⁹
184.8	.00255	.128	2.3 x 10 ⁻⁹
208.9	.00265	.132	2.0 x 10 ⁻⁹
233.0	.00275	.138	1.7 x 10 ⁻⁹
256.9	.00285	.142	2.8 x 10 ⁻⁹
329.0	.00305	.152	2.5 x 10 ⁻⁹
352.8	.00310	.155	1.3 x 10 ⁻⁹
376.7	.00315	.158	1.1 x 10 ⁻⁹
400.9	.00325	.162	1.2 x 10 ⁻⁹
424.9	.00335	.168	1.3 x 10 ⁻⁹
496.7	.00390	.195	1.1 x 10 ⁻⁹
521.1	.00400	.200	1.1 x 10 ⁻⁹
551.6	.00410	.205	1.2 x 10 ⁻⁹
569.1	.00415	.208	1.6 x 10 ⁻⁹
593.1	.00420	.210	1.0 x 10 ⁻⁹
665.5	.00430	.215	1.1 x 10 ⁻⁹
689.0	.00465	.232	7.8 x 10 ⁻¹⁰
712.8	.00475	.238	8.7 x 10 ⁻¹⁰
740.2	.00490	.245	9.4 x 10 ⁻¹⁰
833.1	.00550	.275	8.6 x 10 ⁻¹⁰
857.1	.00560	.280	8.9 x 10 ⁻¹⁰
880.8	.00575	.288	1.0 x 10 ⁻⁹
905.9	.00640	.320	8.2 x 10 ⁻¹⁰

TABLE XVI (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2"G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
928.9 Hours	.00675	.338	9.7 x 10 ⁻¹⁰
1001.3	.00845	.422	7.4 x 10 ⁻¹⁰
1024.8	.00880	.440	7.9 x 10 ⁻¹⁰
1049.0	.00930	.465	7.7 x 10 ⁻¹⁰
1081.1	.01005	.502	7.2 x 10 ⁻¹⁰
1097.0	.01015	.508	7.5 x 10 ⁻¹⁰
1168.7	.01150	.575	1.0 x 10 ⁻⁹
1192.1	.01190	.595	9.0 x 10 ⁻¹⁰
1215.9	.01250	.625	7.5 x 10 ⁻¹⁰
1240.0	.01290	.645	7.2 x 10 ⁻¹⁰
1264.4	.01360	.680	7.1 x 10 ⁻¹⁰
1336.0	.01490	.745	7.0 x 10 ⁻¹⁰
1359.8	.01540	.770	6.6 x 10 ⁻¹⁰
1384.0	.01580	.790	6.9 x 10 ⁻¹⁰
1408.2	.01625	.812	7.9 x 10 ⁻¹⁰
1431.8	.01670	.835	6.4 x 10 ⁻¹⁰
1503.9	.01785	.892	6.4 x 10 ⁻¹⁰
1527.9	.01915	.958	6.0 x 10 ⁻¹⁰
1551.9	.02000	1.000	6.0 x 10 ⁻¹⁰
1575.8	.02050	1.025	5.8 x 10 ⁻¹⁰
1583.9	.02080	1.040	5.8

Test Terminated - 1% Creep
Specimen #B-27

TABLE XVII

CREEP TEST DATA, T-111 SHEET, HEAT NO. 70616, ANNEALED 3000°F (1649°C) FOR 1 HOUR

TESTED AT 2200°F (1204°C), 8,000 PSI (5.52 x 10⁷N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 minute(s)	.00005	.002	2.6 x 10 ⁻⁹
2	.00010	.005	2.6 x 10 ⁻⁹
3	.00015	.008	2.6 x 10 ⁻⁹
4	.00010	.005	2.6 x 10 ⁻⁹
5	.00005	.002	2.6 x 10 ⁻⁹
6	.00005	.002	2.6 x 10 ⁻⁹
7	.00005	.002	2.6 x 10 ⁻⁹
8	.00000	.000	2.6 x 10 ⁻⁹
9	.00005	.002	2.6 x 10 ⁻⁹
10	.00005	.002	2.6 x 10 ⁻⁹
15	.00000	.000	2.6 x 10 ⁻⁹
30	.00010	.005	2.6 x 10 ⁻⁹
45	.00010	.005	2.6 x 10 ⁻⁹
60	.00005	.002	2.6 x 10 ⁻⁹
2.4 hours	.00005	.002	2.6 x 10 ⁻⁹
19.2	.00010	.005	2.0 x 10 ⁻⁹
43.1	.00010	.005	1.6 x 10 ⁻⁹
48.3	.00035	.018	1.6 x 10 ⁻⁹
67.1	.00060	.030	1.5 x 10 ⁻⁹
139.4	.00135	.068	1.4 x 10 ⁻⁹
163.0	.00155	.078	1.4 x 10 ⁻⁹
187.0	.00175	.088	1.2 x 10 ⁻⁹
211.3	.00190	.095	1.3 x 10 ⁻⁹
310.5	.00215	.108	1.2 x 10 ⁻⁹
383.3	.00245	.122	1.3 x 10 ⁻⁹
474.9	.00320	.160	1.3 x 10 ⁻⁹
499.3	.00370	.185	1.2 x 10 ⁻⁹
523.1	.00390	.195	1.3 x 10 ⁻⁹
547.6	.00405	.202	1.2 x 10 ⁻⁹
572.0	.00470	.235	1.3 x 10 ⁻⁹
643.8	.00530	.265	1.4 x 10 ⁻⁹
691.2	.00545	.272	1.3 x 10 ⁻⁹
714.9	.00560	.280	1.2 x 10 ⁻⁹
739.2	.00565	.282	1.2 x 10 ⁻⁹
811.1	.00625	.312	1.3 x 10 ⁻⁹
835.0	.00640	.320	1.2 x 10 ⁻⁹
859.1	.00655	.328	1.4 x 10 ⁻⁹
883.5	.00675	.338	1.3 x 10 ⁻⁹

TABLE XVII (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
907.3 Hours	.00685	.342	1.3 x 10 ⁻⁹
979.7	.00750	.375	1.3 x 10 ⁻⁹
1051.4	.00835	.418	1.2 x 10 ⁻⁹
1147.3	.00975	.488	1.3 x 10 ⁻⁹
1219.0	.01050	.525	1.3 x 10 ⁻⁹
1315.7	.01125	.562	1.1 x 10 ⁻⁹
1387.2	.01150	.575	1.1 x 10 ⁻⁹
1483.1	.01375	.688	8.3 x 10 ⁻⁹
1555.3	.01410	.705	1.3 x 10 ⁻⁹
1651.0	.01515	.758	7.0 x 10 ⁻¹⁰
1723.4	.01615	.808	8.2 x 10 ⁻¹⁰
1819.2	.01755	.878	9.0 x 10 ⁻¹⁰
1890.9	.01830	.915	7.4 x 10 ⁻¹⁰
1986.9	.01980	.990	7.9 x 10 ⁻¹⁰
2059.0	.02080	1.040	8.3 x 10 ⁻¹⁰
2154.8	.02230	1.115	7.0 x 10 ⁻¹⁰
2227.1	.02315	1.158	6.9 x 10 ⁻¹⁰
2323.1	.02445	1.222	7.5 x 10 ⁻¹⁰
2395.0	.02580	1.290	7.0 x 10 ⁻¹⁰
2490.8	.02700	1.350	7.2 x 10 ⁻¹⁰
2563.3	.02780	1.390	7.0 x 10 ⁻¹⁰
2659.6	.02970	1.485	7.3 x 10 ⁻¹⁰
2734.4	.03080	1.540	7.4 x 10 ⁻¹⁰
2827.3	.03205	1.602	6.6 x 10 ⁻¹⁰
2900.0	.03320	1.660	6.5 x 10 ⁻¹⁰
2923.0	.03345	1.672	6.7 x 10 ⁻¹⁰
2995.6	.03505	1.752	6.5 x 10 ⁻¹⁰
3018.9	.03530	1.765	6.6 x 10 ⁻¹⁰
3043.2	.03560	1.780	6.6 x 10 ⁻¹⁰
3072.1	.03670	1.835	6.6 x 10 ⁻¹⁰
3091.1	.03635	1.818	6.8 x 10 ⁻¹⁰
3162.9	.03745	1.872	6.5 x 10 ⁻¹⁰
3186.2	.03750	1.875	6.4 x 10 ⁻¹⁰
3210.1	.03820	1.910	6.5 x 10 ⁻¹⁰
3234.1	.03910	1.955	6.8 x 10 ⁻¹⁰
3258.5	.03940	1.970	6.8 x 10 ⁻¹⁰
3330.3	.04025	2.012	6.4 x 10 ⁻¹⁰
3354.0	.04050	2.025	6.6 x 10 ⁻¹⁰
3378.7	.04085	2.042	6.6 x 10 ⁻¹⁰
3402.3	.04120	2.060	6.4 x 10 ⁻¹⁰
3426.0	.04155	2.078	6.4 x 10 ⁻¹⁰
3498.0	.04300	2.150	6.6 x 10 ⁻¹⁰
3522.0	.04320	2.160	6.7 x 10 ⁻¹⁰
3546.0	.04350	2.175	7.0 x 10 ⁻¹⁰
3569.0	.04420	2.210	6.6 x 10 ⁻¹⁰
3594.3	.04465	2.232	6.2 x 10 ⁻¹⁰
3666.3	.04585	2.292	7.0 x 10 ⁻¹⁰

TABLE XVII (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
3689.9 Hours	.04620	2.310	6.4×10^{-10}
3713.9	.04660	2.330	6.8×10^{-10}
3738.2	.04710	2.355	6.6×10^{-10}
3762.0	.04750	2.375	6.8×10^{-10}
3834.4	.04870	2.435	6.6×10^{-10}
3858.2	.04905	2.452	6.4×10^{-10}
3882.0	.04935	2.468	6.5×10^{-10}
3906.0	.04985	2.492	6.4×10^{-10}
3930.0	.05040	2.520	6.3×10^{-10}
4026.4	.05215	2.608	6.2×10^{-10}
4050.2	.05230	2.615	6.5×10^{-10}
4074.1	.05295	2.648	6.2×10^{-10}
4098.1	.05330	2.665	6.4×10^{-10}
4173.0	.05430	2.715	6.3×10^{-10}
4194.0	.05495	2.748	6.2×10^{-10}
4218.0	.05540	2.770	6.1×10^{-10}
4241.9	.05580	2.790	6.2×10^{-10}
4265.9	.05625	2.812	6.4×10^{-10}
4338.0	.05745	2.872	6.0×10^{-10}
4362.0	.05790	2.895	5.9×10^{-10}
4386.1	.05860	2.930	5.9×10^{-10}
4410.3	.05905	2.952	6.3×10^{-10}
4433.9	.05935	2.968	6.1×10^{-10}
4506.1	.06045	3.022	6.2×10^{-10}
4530.0	.06100	3.050	6.1×10^{-10}
4554.0	.06160	3.080	6.2×10^{-10}
4578.1	.06195	3.098	6.2×10^{-10}

Test in Progress
Specimen S-19

TABLE XVIII

CREEP TEST DATA, T-111 SHEET, HEAT NO. 70616, ANNEALED 3000°F (1649°C) FOR 1 HOUR,

TESTED AT 2200°F (1204°C), 12,000 PSI (8.27 x 10⁷N/m²)

Time	Length Change ΔL (Inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 minute(s)	.00000	.000	2.9 x 10 ⁻⁷
2	.00005	.002	2.9 x 10 ⁻⁷
3	.00010	.005	2.9 x 10 ⁻⁷
4	.00010	.005	2.9 x 10 ⁻⁷
5	.00010	.005	2.9 x 10 ⁻⁷
6	.00015	.008	2.9 x 10 ⁻⁷
7	.00020	.010	2.9 x 10 ⁻⁷
8	.00015	.008	2.9 x 10 ⁻⁷
9	.00020	.010	2.9 x 10 ⁻⁷
10	.00020	.010	2.9 x 10 ⁻⁷
15	.00015	.008	2.9 x 10 ⁻⁷
30	.00020	.010	2.9 x 10 ⁻⁷
45	.00015	.008	2.9 x 10 ⁻⁷
60	.00015	.008	2.9 x 10 ⁻⁷
17.7 hours	.00045	.022	2.1 x 10 ⁻⁸
42.1	.00085	.042	1.1 x 10 ⁻⁸
113.9	.00180	.090	6.4 x 10 ⁻⁹
161.3	.00220	.110	4.9 x 10 ⁻⁹
185.1	.00270	.135	4.4 x 10 ⁻⁹
209.3	.00280	.140	4.4 x 10 ⁻⁹
281.3	.00300	.150	3.9 x 10 ⁻⁹
305.1	.00370	.185	3.8 x 10 ⁻⁹
329.2	.00435	.218	3.2 x 10 ⁻⁹
353.6	.00480	.240	2.6 x 10 ⁻⁹
377.5	.00510	.255	2.1 x 10 ⁻⁹
449.8	.00625	.312	2.8 x 10 ⁻⁹
473.3	.00660	.330	3.2 x 10 ⁻⁹
497.1	.00700	.350	3.1 x 10 ⁻⁹
521.5	.00735	.368	2.3 x 10 ⁻⁹
545.4	.00775	.388	2.2 x 10 ⁻⁹
617.3	.00905	.452	2.0 x 10 ⁻⁹
641.4	.00960	.480	2.1 x 10 ⁻⁹
665.2	.01040	.520	2.0 x 10 ⁻⁹
689.1	.01080	.540	2.1 x 10 ⁻⁹
713.4	.01125	.562	1.9 x 10 ⁻⁹
785.3	.01270	.635	2.5 x 10 ⁻⁹
809.2	.01300	.650	2.5 x 10 ⁻⁹
833.3	.01340	.670	1.8 x 10 ⁻⁹
857.3	.01420	.710	2.0 x 10 ⁻⁹

TABLE XVIII (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
881.1 Hours	.01435	.718	2.0×10^{-9}
953.2	.01615	.807	5.1×10^{-10}
977.5	.01680	.840	1.0×10^{-9}
1001.1	.01740	.870	1.4×10^{-9}
1025.4	.01790	.895	1.0×10^{-9}
1049.2	.01840	.920	1.5×10^{-9}
1121.1	.01985	.992	1.6×10^{-9}
1193.5	.02205	1.102	1.8×10^{-9}
1289.3	.02460	1.230	1.8×10^{-9}
1361.0	.02635	1.318	8.0×10^{-10}
1457.0	.02920	1.460	1.8×10^{-9}
1529.2	.03070	1.535	1.9×10^{-9}
1624.9	.03415	1.708	7.2×10^{-10}
1697.2	.03660	1.830	8.1×10^{-10}
1793.2	.03985	1.992	6.7×10^{-10}
1865.1	.04185	2.092	1.8×10^{-9}
1961.0	.04570	2.285	1.8×10^{-9}
2033.2	.04855	2.428	1.6×10^{-9}
2129.8	.05185	2.592	1.7×10^{-9}
2204.5	.05505	2.752	1.8×10^{-9}
2297.3	.05790	2.895	6.6×10^{-9}
2370.1	.06175	3.088	1.0×10^{-9}
2393.1	.06215	3.108	1.4×10^{-9}
2465.5	.06505	3.252	1.6×10^{-9}
2489.0	.06600	3.300	1.7×10^{-9}
2513.3	.06690	3.345	1.6×10^{-9}
2542.2	.06815	3.408	1.5×10^{-9}
2561.0	.06900	3.450	1.6×10^{-9}
2632.2	.07220	3.610	1.7×10^{-9}
2656.4	.07295	3.648	1.4×10^{-9}
2680.2	.07390	3.695	1.7×10^{-9}
2704.2	.07495	3.748	1.7×10^{-9}
2728.6	.07605	3.802	1.8×10^{-9}
2800.0	.07925	3.962	1.7×10^{-9}
2824.1	.08020	4.010	1.6×10^{-9}
2848.2	.08120	4.060	6.4×10^{-10}
2872.4	.08220	4.110	6.8×10^{-10}
2896.0	.08330	4.165	6.0×10^{-10}
2968.2	.08715	4.358	6.7×10^{-10}
2992.0	.08815	4.408	6.6×10^{-10}
3016.2	.08925	4.462	6.7×10^{-10}
3040.0	.09020	4.510	6.7×10^{-10}
3064.3	.09150	4.575	6.0×10^{-10}
3136.5	.09530	4.765	1.6×10^{-9}
3160.1	.09615	4.808	6.1×10^{-9}

TABLE XVIII (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
3184.0	.09755	4.878	1.6 x 10 ⁻⁹
3208.1	.09910	4.955	1.6 x 10 ⁻⁹
3232.1	.09995	4.998	1.6 x 10 ⁻⁹
3304.5	.10360	5.180	1.7 x 10 ⁻⁹
3328.3	.10455	5.228	6.5 x 10 ⁻¹⁰
3352.1	.10570	5.285	6.8 x 10 ⁻¹⁰
3376.2	.10725	5.362	6.3 x 10 ⁻¹⁰
3400.1	.10810	5.405	5.5 x 10 ⁻¹⁰
3496.8	.11265	5.632	8.0 x 10 ⁻¹⁰
3520.2	.11380	5.690	8.4 x 10 ⁻¹⁰
3544.1	.11535	5.768	7.0 x 10 ⁻¹⁰
3568.1	.11640	5.820	6.8 x 10 ⁻¹⁰
3644.9	.12035	6.018	8.2 x 10 ⁻¹⁰
3664.1	.12125	6.062	8.0 x 10 ⁻¹⁰
3688.1	.12265	6.132	1.2 x 10 ⁻⁹
3712.0	.12395	6.198	1.2 x 10 ⁻⁹
3736.0	.12610	6.305	6.9 x 10 ⁻⁹
3808.1	.12945	6.472	8.3 x 10 ⁻¹⁰
3832.0	.13040	6.520	8.0 x 10 ⁻¹⁰
3840.1	.13095	6.548	1.0 x 10 ⁻¹⁰

Test Terminated 6% Creep
Specimen S-21

TABLE XIX

CREEP TEST DATA, ARC-MELTED TUNGSTEN SHEET, ANNEALED 2800°F (1538°C)
1 HOUR, TESTED AT 2800°F (1538°C, 3,000 PSI (2.07 x 10⁷ N/m²))

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 Minute(s)	.00010	.005	2.4 x 10 ⁻⁷
2	.00000	.000	2.4 x 10 ⁻⁷
3	.00005	.002	2.4 x 10 ⁻⁷
4	.00000	.000	2.4 x 10 ⁻⁷
5	.00000	.000	2.4 x 10 ⁻⁷
6	.00010	.005	2.4 x 10 ⁻⁷
7	.00015	.008	2.4 x 10 ⁻⁷
8	.00005	.002	2.4 x 10 ⁻⁷
9	.00010	.005	2.4 x 10 ⁻⁷
10	.00010	.005	2.4 x 10 ⁻⁷
15	.00005	.002	2.4 x 10 ⁻⁷
30	.00010	.005	2.4 x 10 ⁻⁷
45	.00015	.008	2.4 x 10 ⁻⁷
60	.00010	.005	2.4 x 10 ⁻⁷
3.1 Hours	.00060	.030	2.4 x 10 ⁻⁷
23.95	.00535	.218	1.0 x 10 ⁻⁷
46.95	.00830	.415	2.9 x 10 ⁻⁸
67.4	.01205	.602	2.0 x 10 ⁻⁸
91.2	.01435	.718	1.7 x 10 ⁻⁸
114.9	.01835	.918	1.0 x 10 ⁻⁸
138.8	.02190	1.095	8.7 x 10 ⁻⁹
162.8	.02355	1.178	8.9 x 10 ⁻⁹
234.8	.03280	1.640	7.2 x 10 ⁻⁹
259.0	.03665	1.832	7.4 x 10 ⁻⁹
282.9	.04075	2.038	7.2 x 10 ⁻⁹
306.8	.04340	2.170	6.8 x 10 ⁻⁹
330.8	.04750	2.375	6.4 x 10 ⁻⁹
403.2	.05605	2.802	3.8 x 10 ⁻⁹
426.8	.05845	2.922	3.9 x 10 ⁻⁹
450.8	.06065	3.032	4.1 x 10 ⁻⁹
479.9	.06370	3.185	4.0 x 10 ⁻⁹
574.3	.07495	3.748	3.0 x 10 ⁻⁹
647.0	.08195	4.098	1.7 x 10 ⁻⁹
738.7	.09155	4.578	1.5 x 10 ⁻⁹
763.1	.09445	4.722	1.6 x 10 ⁻⁹
786.9	.09690	4.845	3.1 x 10 ⁻⁹
811.3	.09880	4.940	1.6 x 10 ⁻⁹
835.8	.10160	5.080	1.5 x 10 ⁻⁹
907.5	.11070	5.535	3.0 x 10 ⁻⁹

Test Terminated 5% Creep
Specimen S-18

TABLE XX

CREEP TEST DATA, VAPOR DEPOSITED TUNGSTEN, RECRYSTALLIZED 1 HOUR 2800°F (1538°C)

TESTED AT 2800°F (1538°C), 2000 PSI ($1.38 \times 10^7 \text{N/m}^2$)

Time	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
1 minute(s)	.00020	.010	3.5×10^{-7}
2	.00025	.012	3.5×10^{-7}
3	.00025	.012	3.5×10^{-7}
4	.00025	.012	3.5×10^{-7}
5	.00025	.012	3.5×10^{-7}
6	.00030	.015	3.5×10^{-7}
7	.00040	.020	3.5×10^{-7}
8	.00035	.018	3.5×10^{-7}
9	.00040	.020	3.5×10^{-7}
10	.00035	.018	3.5×10^{-7}
15	.00000	.000	3.5×10^{-7}
30	-.00005	-.002	3.5×10^{-7}
45	.00000	.000	3.5×10^{-7}
60	-.00005	-.002	3.5×10^{-7}
64.9 hours	.00175	.088	8.0×10^{-8}
88.9	.00210	.105	6.4×10^{-8}
112.8	.00260	.130	4.6×10^{-8}
136.7	.00310	.155	4.1×10^{-8}
161.0	.00370	.185	3.8×10^{-8}
232.8	.00480	.240	3.4×10^{-8}
256.8	.00525	.262	3.1×10^{-8}
280.8	.00550	.275	2.9×10^{-8}
304.8	.00570	.285	2.7×10^{-8}
328.7	.00635	.318	2.6×10^{-8}
400.8	.00750	.375	1.6×10^{-8}
425.0	.00760	.380	1.3×10^{-8}
448.6	.00775	.388	7.8×10^{-9}
472.8	.00795	.398	6.3×10^{-9}
496.8	.00830	.415	5.6×10^{-9}
568.7	.00930	.465	5.0×10^{-9}
600.1	.00990	.495	1.1×10^{-9}
616.7	.01040	.520	1.2×10^{-8}
641.1	.01015	.508	1.1×10^{-8}
664.7	.00980	.490	1.0×10^{-8}
736.8	.01150	.575	9.9×10^{-9}
760.7	.01190	.595	8.6×10^{-9}
784.7	.01310	.655	9.7×10^{-9}

TABLE XX (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
808.5 Hours	.01235	.618	9.4×10^{-9}
832.5	.01270	.635	9.4×10^{-9}
904.5	.01350	.675	9.2×10^{-9}
929.4	.01370	.685	8.6×10^{-9}
952.6	.01410	.705	8.5×10^{-9}
976.8	.01445	.722	7.0×10^{-9}
1001.8	.01460	.730	8.2×10^{-9}
1072.5	.01540	.770	8.0×10^{-9}
1144.8	.01660	.830	7.8×10^{-9}
1240.7	.01775	.888	7.8×10^{-9}
1312.7	.01830	.915	5.6×10^{-9}
1408.5	.01925	.962	5.0×10^{-9}
1480.7	.01960	.980	4.0×10^{-9}
1577.3	.02150	1.075	4.0×10^{-9}
1652.0	.02190	1.095	4.2×10^{-9}
1744.9	.02265	1.132	2.7×10^{-9}
1817.7	.02295	1.148	3.6×10^{-9}
1912.9	.02475	1.238	3.8×10^{-9}
1989.8	.02630	1.315	3.1×10^{-9}
2079.7	.02660	1.330	2.3×10^{-9}
2151.8	.02835	1.418	3.8×10^{-9}
2247.6	.02825	1.412	3.4×10^{-9}
2319.8	.02925	1.462	2.8×10^{-9}
2415.7	.03100	1.550	2.6×10^{-9}
2487.6	.03110	1.555	3.5×10^{-9}
2584.0	.03135	1.568	3.0×10^{-9}
2655.7	.03265	1.632	2.6×10^{-9}
2752.0	.03315	1.658	2.6×10^{-9}
2823.7	.03380	1.690	2.3×10^{-9}
2944.2	.03465	1.732	2.2×10^{-9}
2991.7	.03580	1.790	2.0×10^{-9}
3099.2	.03665	1.832	2.1×10^{-9}
3159.4	.03785	1.892	1.8×10^{-9}
3183.4	.03815	1.908	1.6×10^{-9}
3255.5	.03785	1.892	2.0×10^{-9}
3327.9	.03905	1.952	2.1×10^{-9}
3423.6	.3975	1.988	1.8×10^{-9}
3495.7	.04005	2.002	1.8×10^{-9}

Test In Progress
Specimen B-24

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