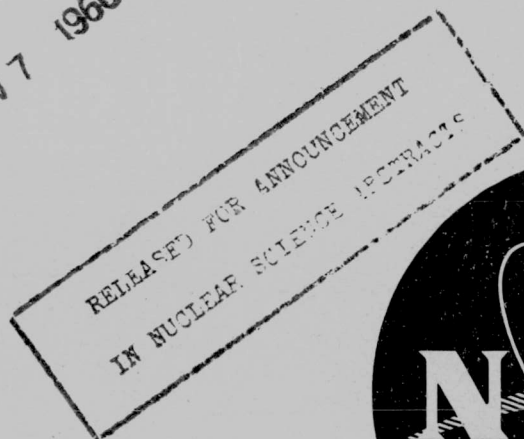
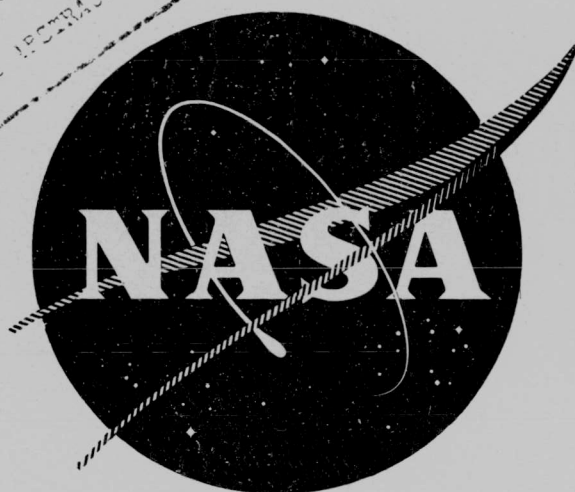


NOV 7 1966



NAS-CR-72044

MASTER



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

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the National Aeronautics and Space Administration (NASA), nor any person acting on behalf of NASA:

- A.) Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or**
- B.) Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method or process disclosed in this report.**

As used above, "person acting on behalf of NASA" includes any employee or contractor of NASA, or employee of such contractor, to the extent that such employee or contractor of NASA, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with NASA, or his employment with such contractor.

**Request for copies of this report should be referred to
National Aeronautics and Space Administration
Office of Scientific and Technical Information
Attention: AFSS-A
Washington, D. C. 20546**

NAS - CR 72044

TWELFTH QUARTERLY REPORT

for

26 March 1966 to 26 June 1966

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

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

Prepared by:

J. C. Sawyer and E. A. Steigerwald

Prepared for:

National Aeronautics and Space Administration

Contract No. NAS 3-2545

Technical Management

Paul E. Moorhead
NASA - Lewis Research Center
Space and Power Systems

July 15, 1966

Materials Research and Development Department
TRW Equipment Laboratories
TRW Inc.
23555 Euclid Avenue
Cleveland, Ohio 44117

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.

Prepared by

J. C. Sawyer
J. C. Sawyer
Sr. Research Metallurgist

Approved by

E. A. Steigerwald
E. A. Steigerwald
Research Supervisor

Approved by

G. J. Guarnieri
G. J. Guarnieri
Manager, Materials
Research & Development

TABLE OF CONTENTS

	<u>Page No.</u>
I INTRODUCTION	1
II MATERIALS AND PROCEDURE	1
III RESULTS AND DISCUSSION	9
Molybdenum Base Alloys.	9
Tantalum Base Alloys.	22
Tungsten.	22
IV RESIDUAL GAS ANALYSIS.	22
APPENDIX I.	32

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	ppm	
												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)
			1.62 (1.00)	Bal.			.06 (.015)		.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
Cbl32M	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) (Heat D-1670)	8.5				Bal.	2.30	.004	.002				55	6
	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)
W 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

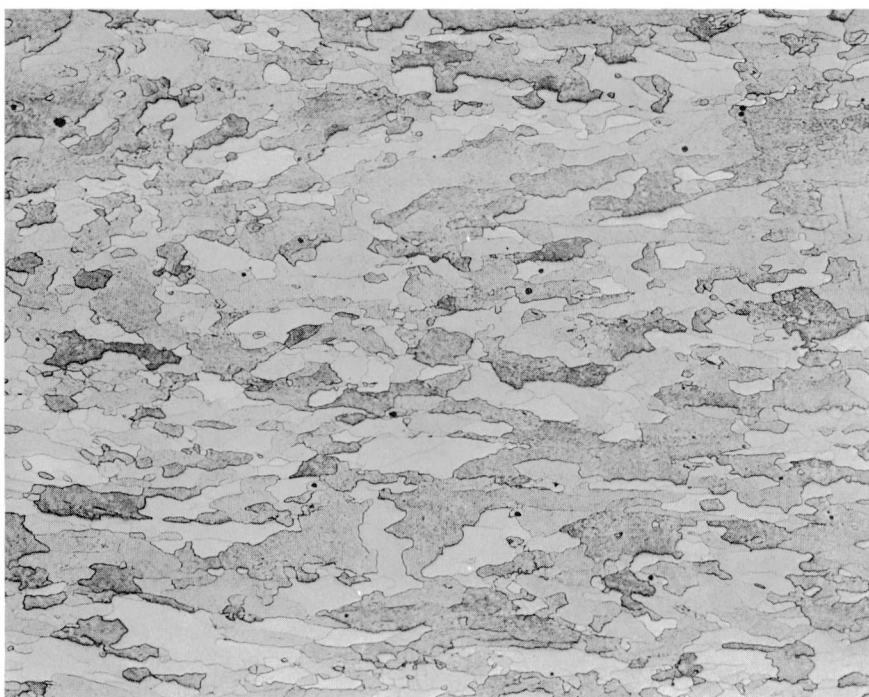
Tensile Properties of TZC Material

Heat No.	Condition	Test Temp., °F	Strength (Ksi)				Hardness DPH
			Tensile	0.2% Yield	%E	%R. A.	
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
	3092°F, 1 hr.	RT	81.8	50.3	4.4	8.6	
	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	3.1	
	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.

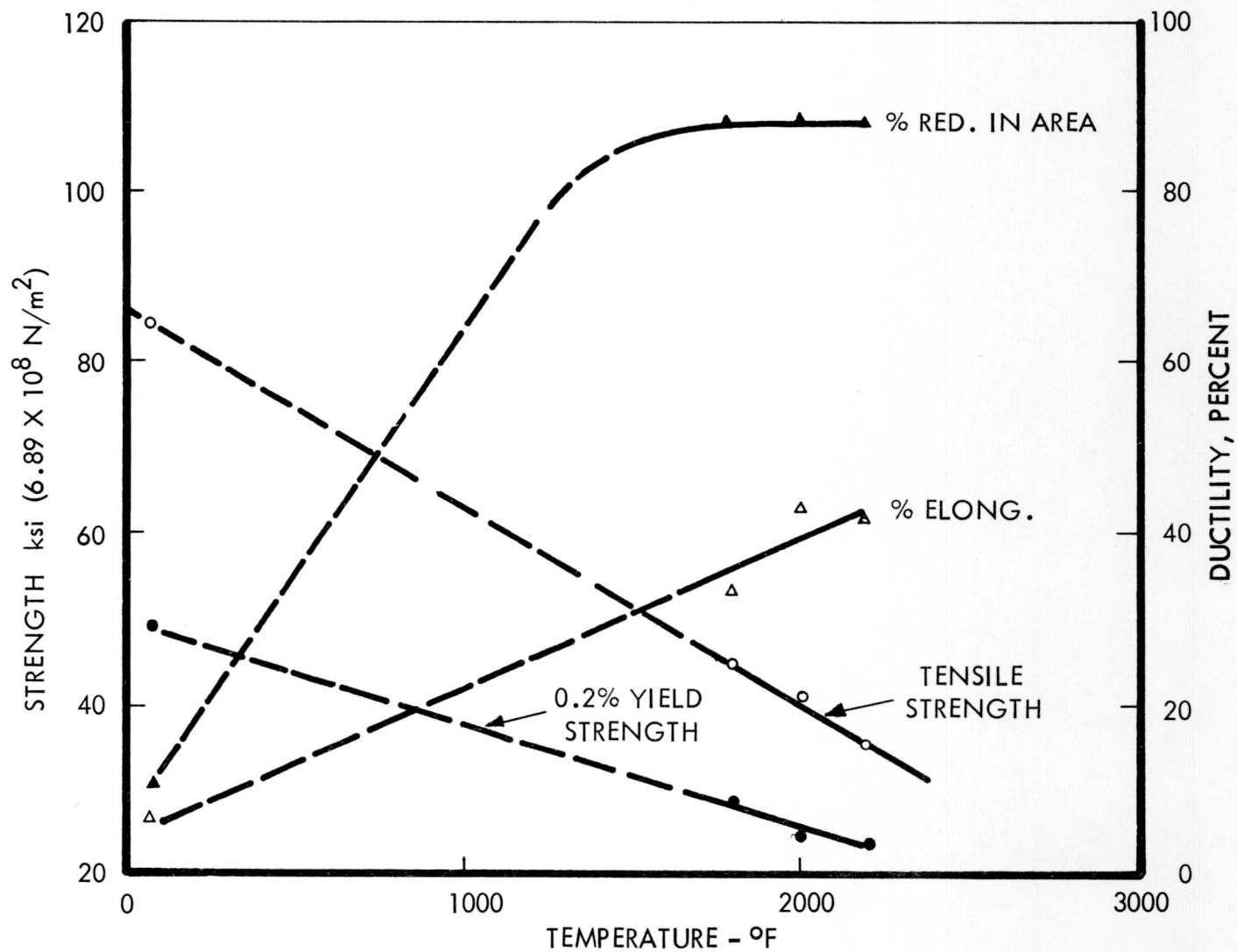


FIGURE 2: TENSILE PROPERTIES OF TZC, HEAT M-91 ANNEALED 1 HOUR AT 3092°F (1700°C).



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 ($9.65 \times 10^7 \text{ N/m}^2$). Post test examination indicated no apparent reason for this variation in behavior.

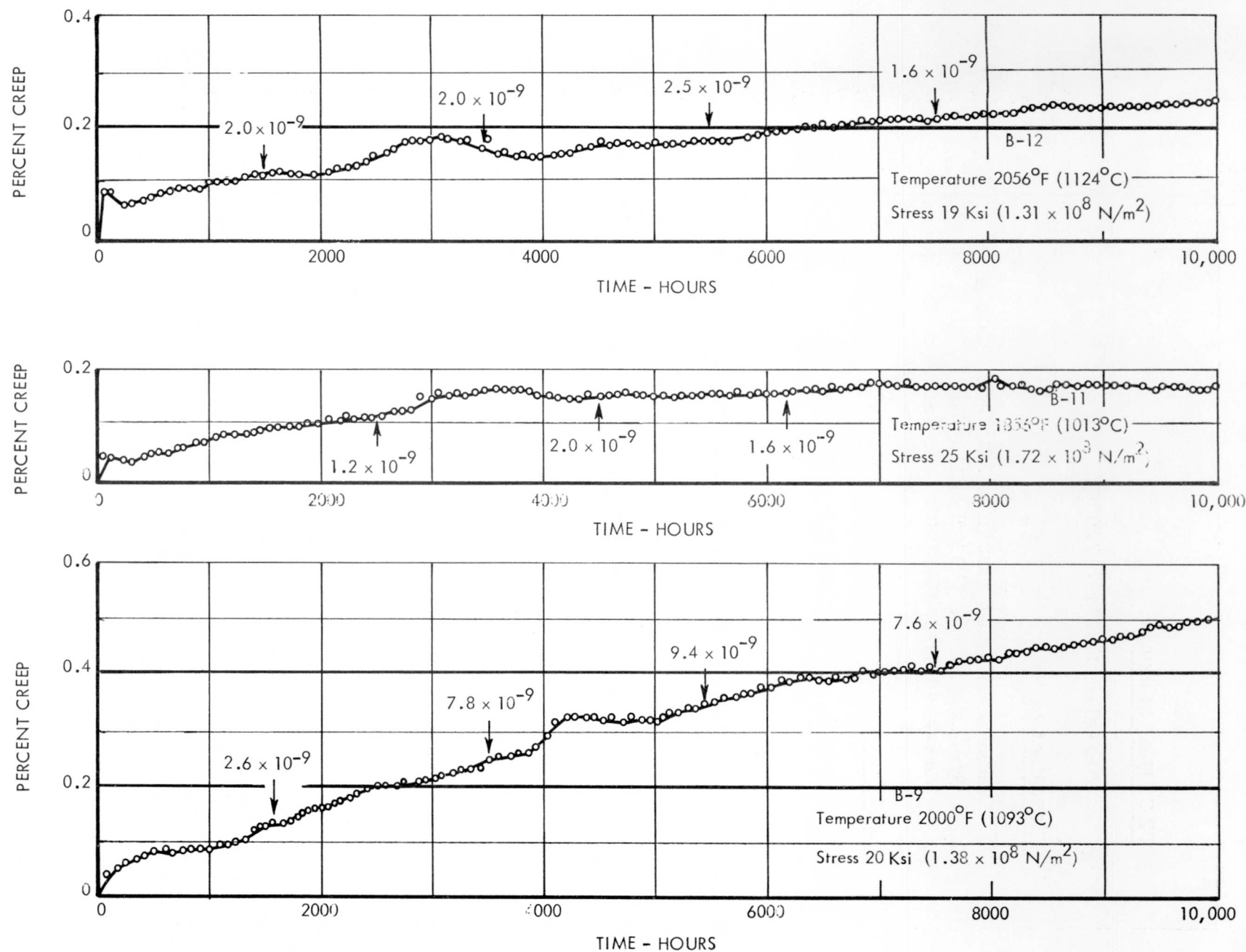


FIGURE 4 CREEP TEST DATA, TZC (HEAT M-80), ANNEALED 3092°F (1700°C) 1 HOUR TESTED IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR.

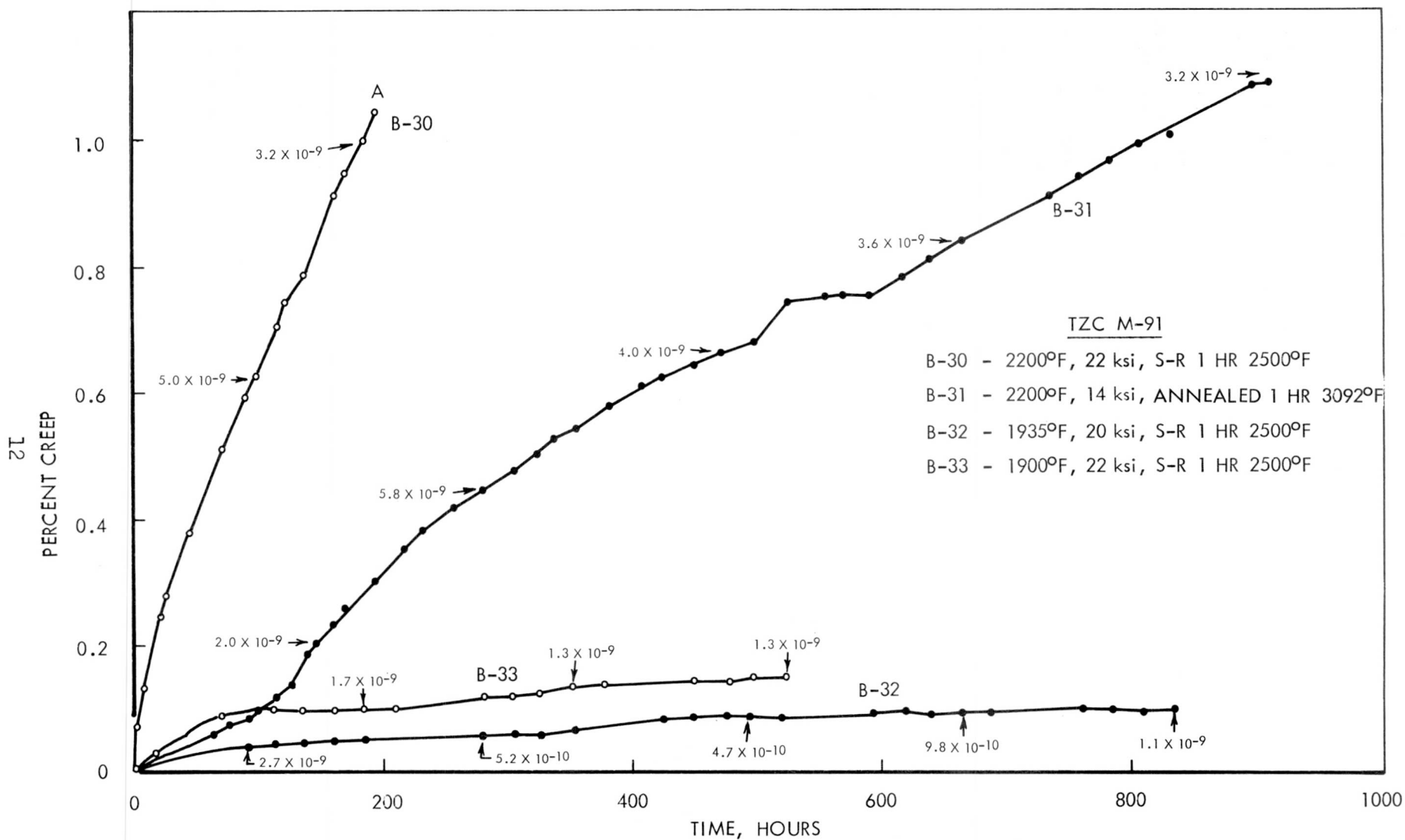


FIGURE 5 CREEP DATA FOR TZC HEAT M-91 TESTED IN VACUUM ENVIRONMENT $<1 \times 10^{-8}$ TORR

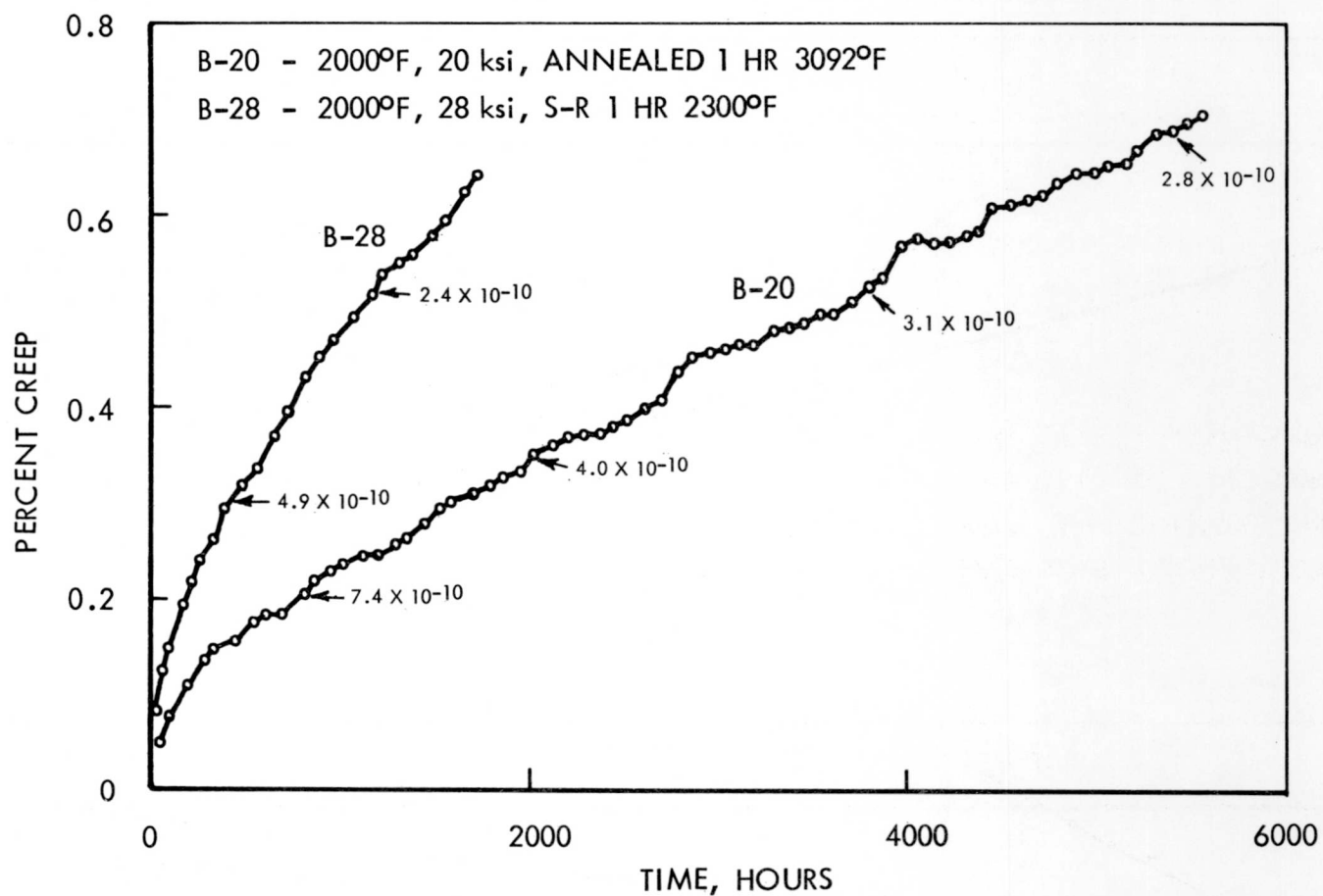


FIGURE 6: CREEP DATA FOR TZC HEAT M-91 TESTED IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR.

14

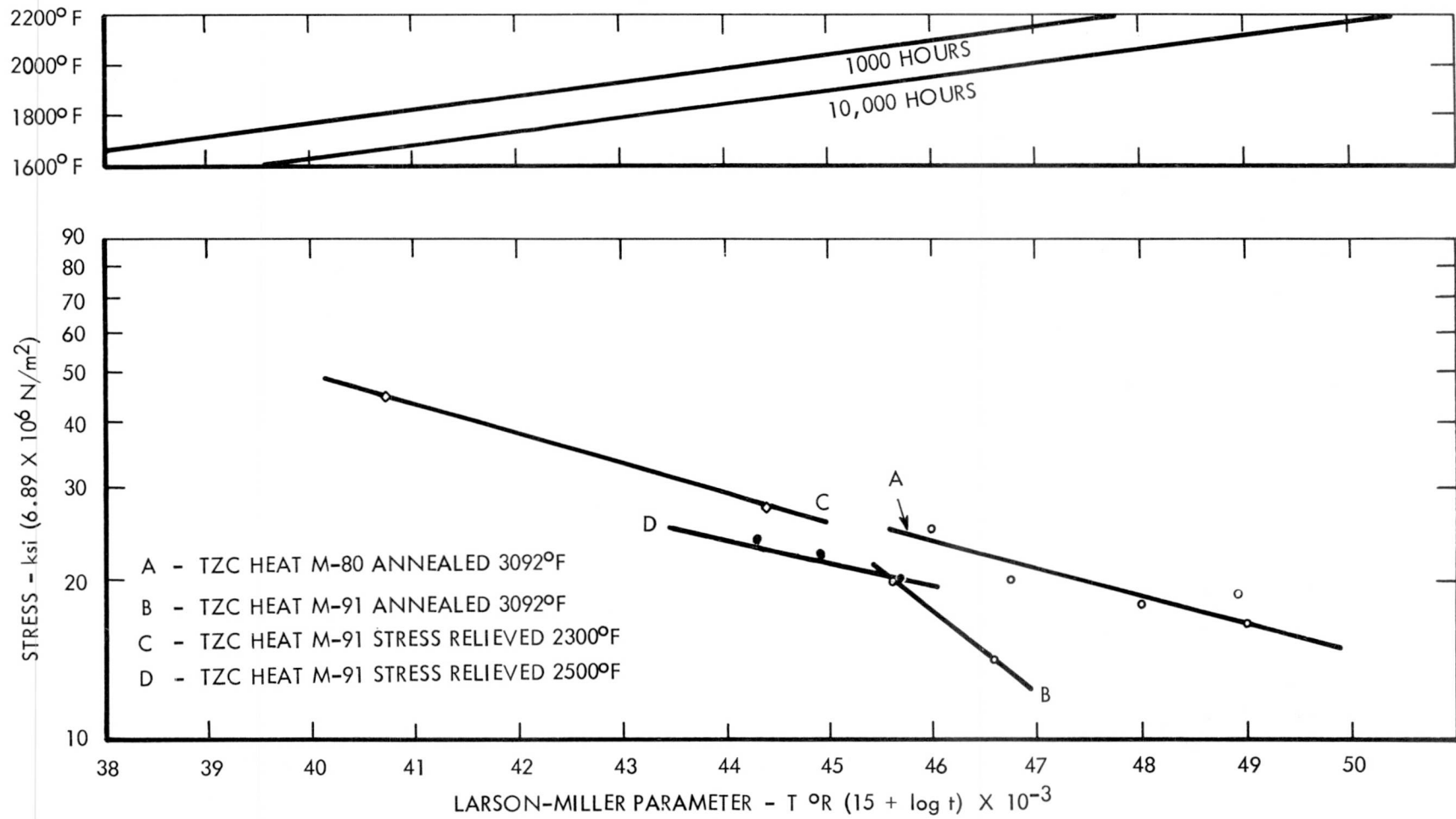


FIGURE 7 LARSON-MILLER PLOT OF DATA FOR 0.5% CREEP IN MOLYBDENUM-BASE TZC ALLOY, TESTED IN VACUUM ENVIRONMENT $<1 \times 10^{-8}$ TORR.

TABLE 4
0.5% Creep Test Data for TZC Molybdenum-Base Alloy

Specimen No.	Test Temperature		Stress		Hours for 0.5% Creep	Larson-Miller
	°F	°C	Ksi	N/m ² x 10 ⁸		T°R(15+logt) x 10 ⁻³ for 0.5% Creep
<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.

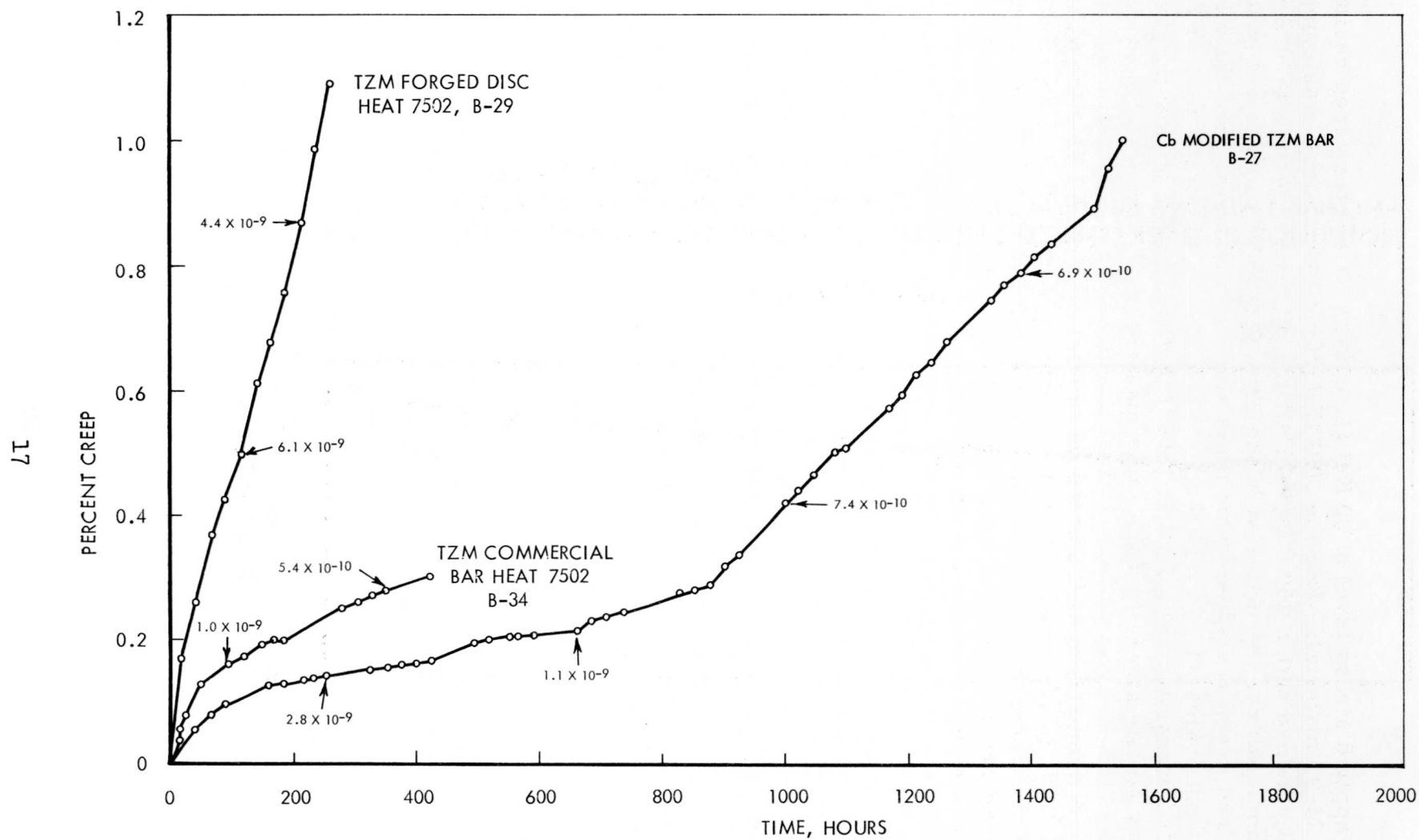


FIGURE 8: CREEP TEST DATA FOR TZM ALLOYS IN STRESS RELIEVED CONDITION. TESTED AT 2000°F (1093°C) AND 41 ksi (2.82×10^8 N/m²) IN VACUUM ENVIRONMENT $\leq 1 \times 10^{-8}$ TORR.

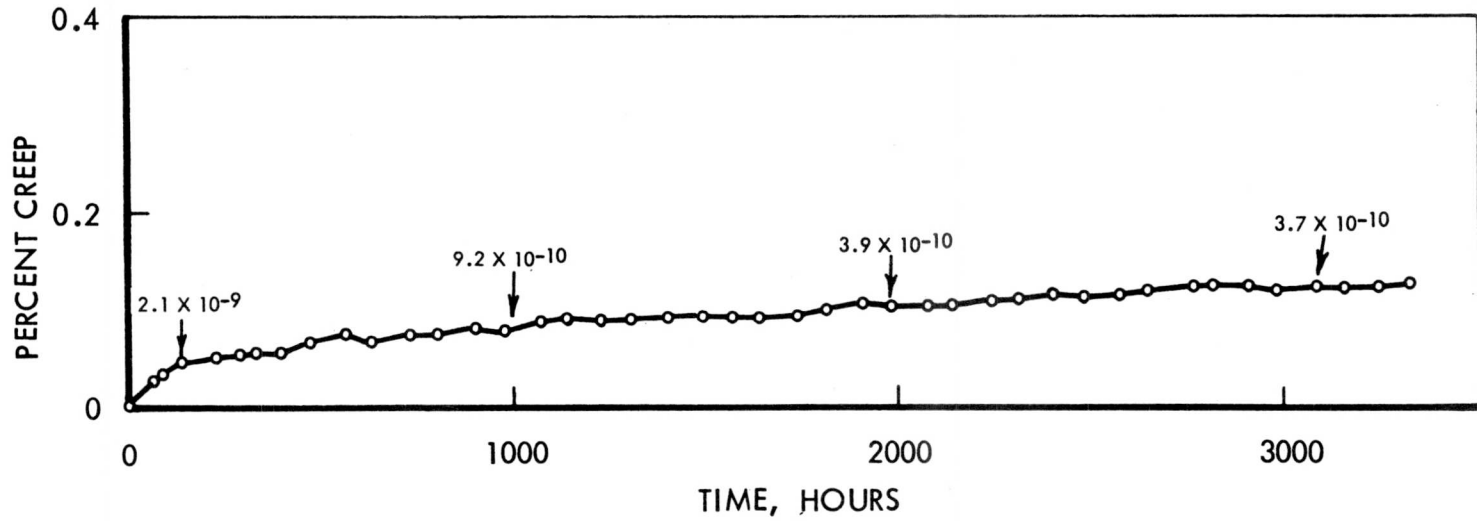


FIGURE 9: CREEP DATA FOR TZM HEAT KDTZM-1175 IN THE STRESS RELIEVED CONDITION. TESTED AT 1800 F (982 C) AT 44 ksi (3.03×10^8 N/m²) IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR.

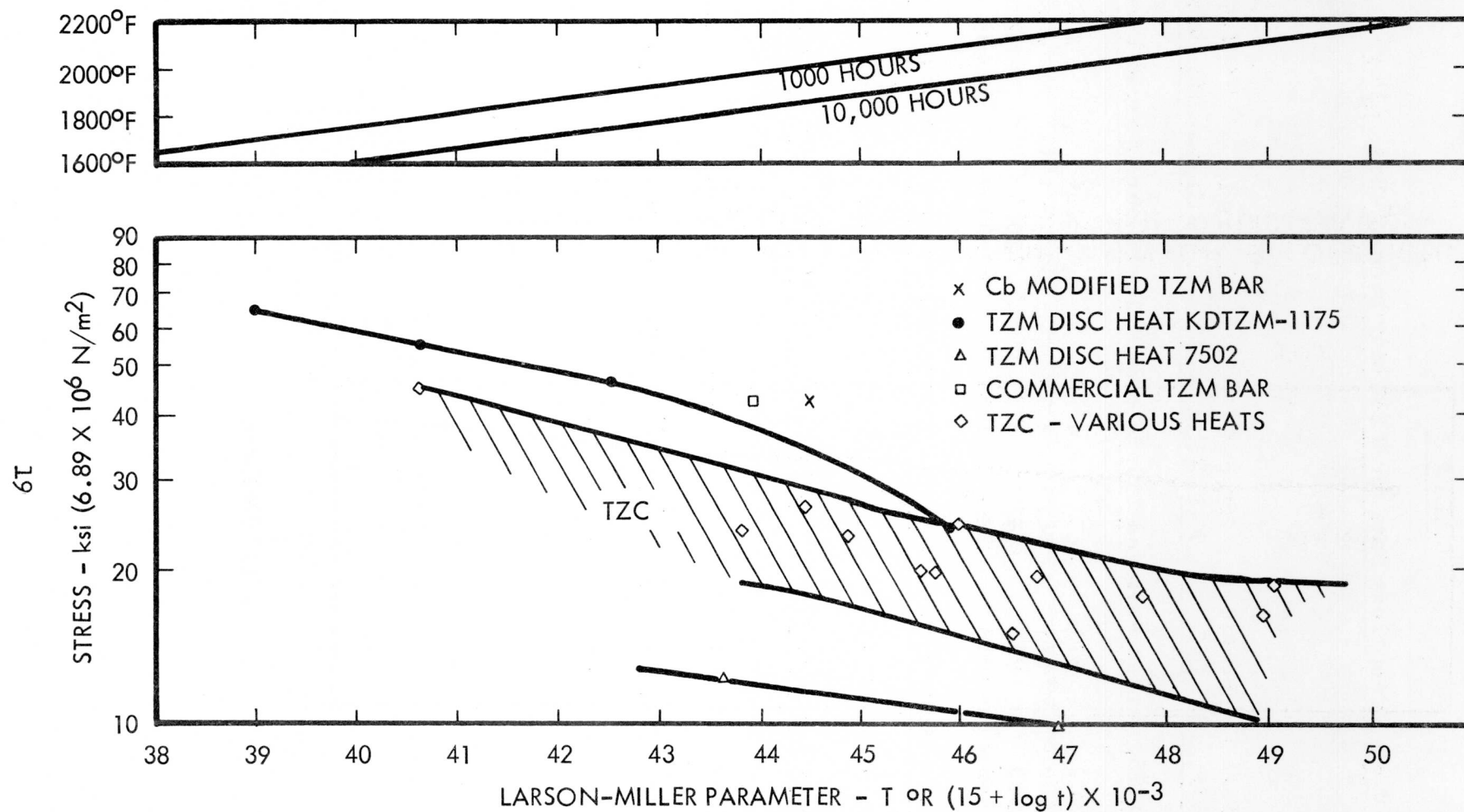


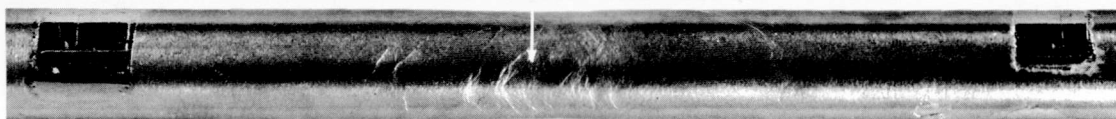
FIGURE 10 LARSON-MILLER PLOT OF DATA FOR 0.5% CREEP IN MOLYBDENUM-BASE ALLOYS, TESTED IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR

TABLE 5
0.5% Creep Test Data for TZM Molybdenum-Base Alloy

Specimen No.	Test Temperature		Stress		Hours for 0.5% Creep	Larson-Miller
	°F	°C	Ksi	N/m ² x 10 ⁸		T°R(15+logt)x 10 ⁻³ for 0.5% Creep
<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.

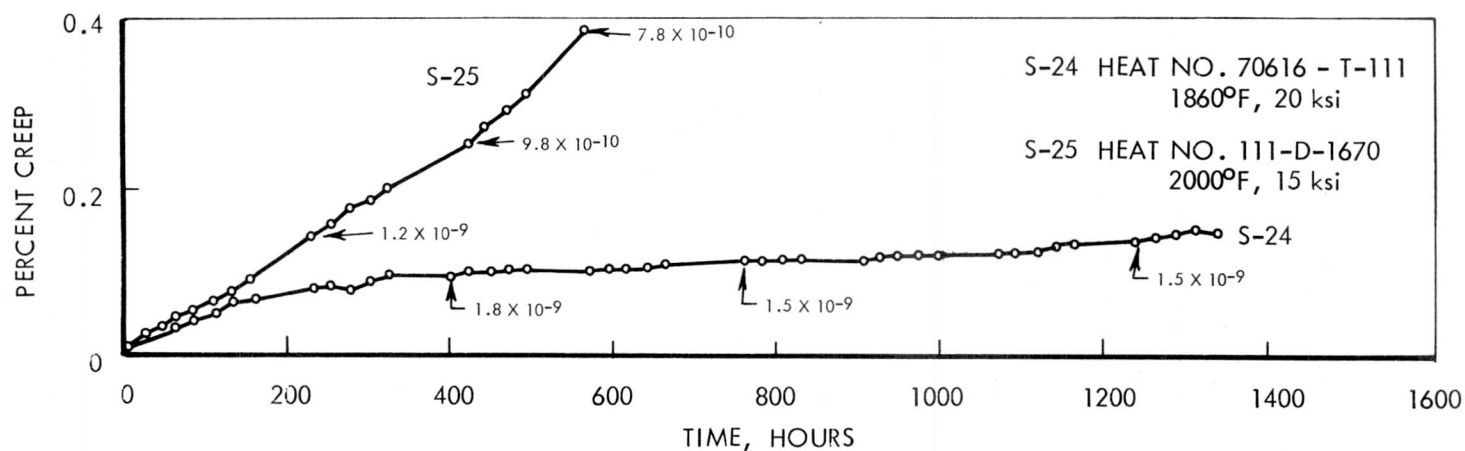
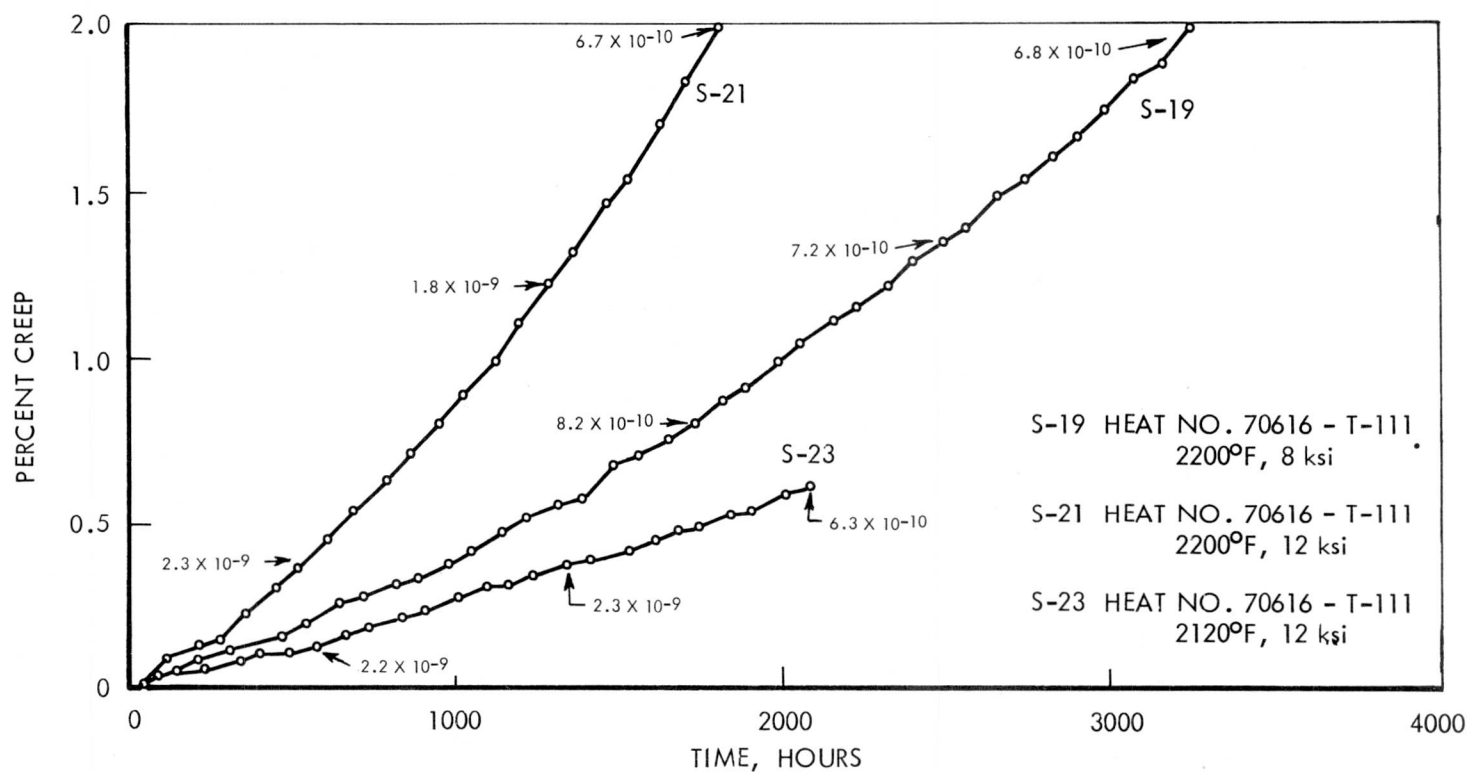


FIGURE 12: CREEP DATA FOR T-111 ALLOY ANNEALED ONE HOUR AT 3000°F (1649°C), TESTED IN VACUUM ENVIRONMENT $<1 \times 10^{-8}$ TORR.

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

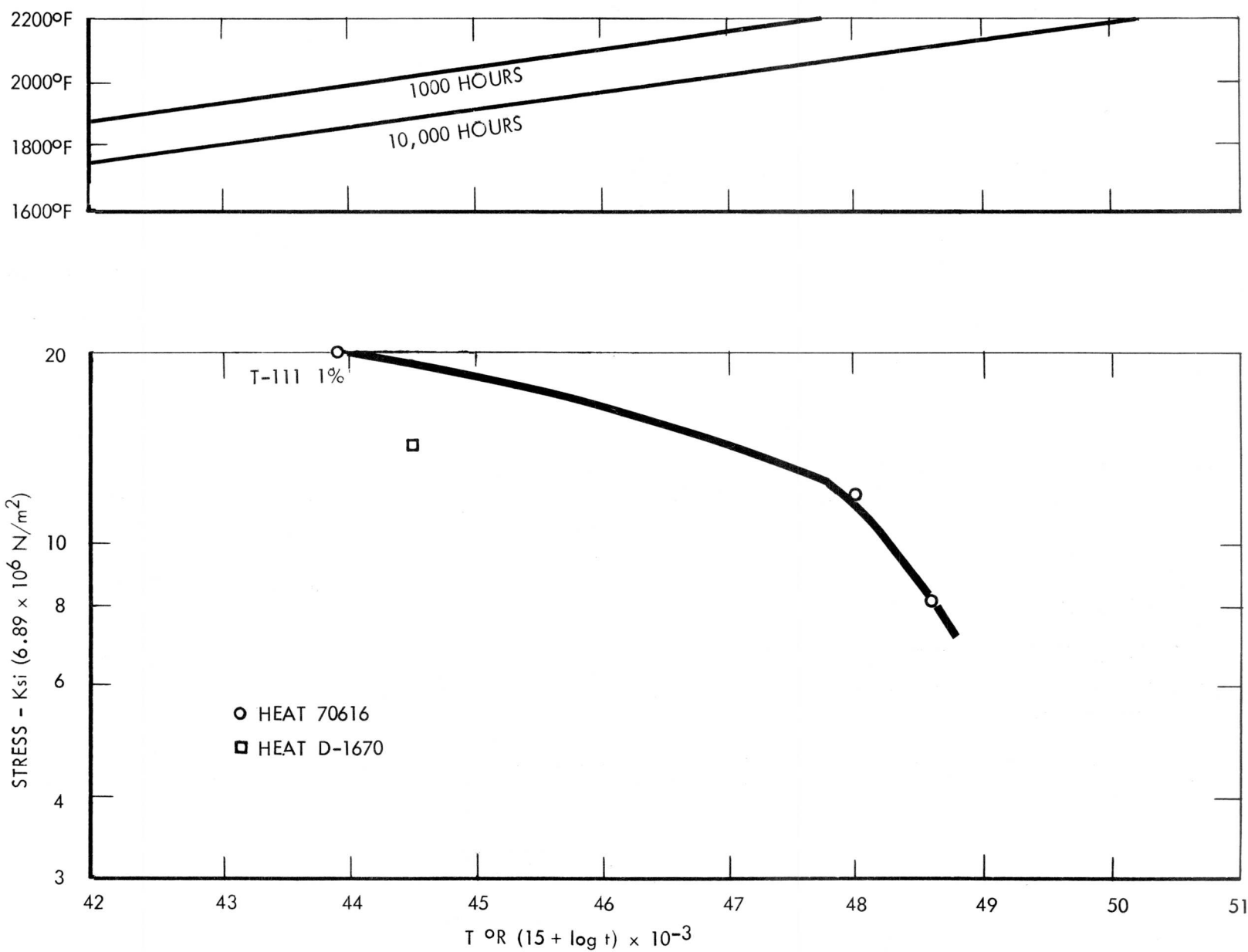


FIGURE 13: LARSON MILLER PLOT, 1% CREEP FOR T-111 ALLOY ANNEALED 1 HOUR
3000°F (1649°C)

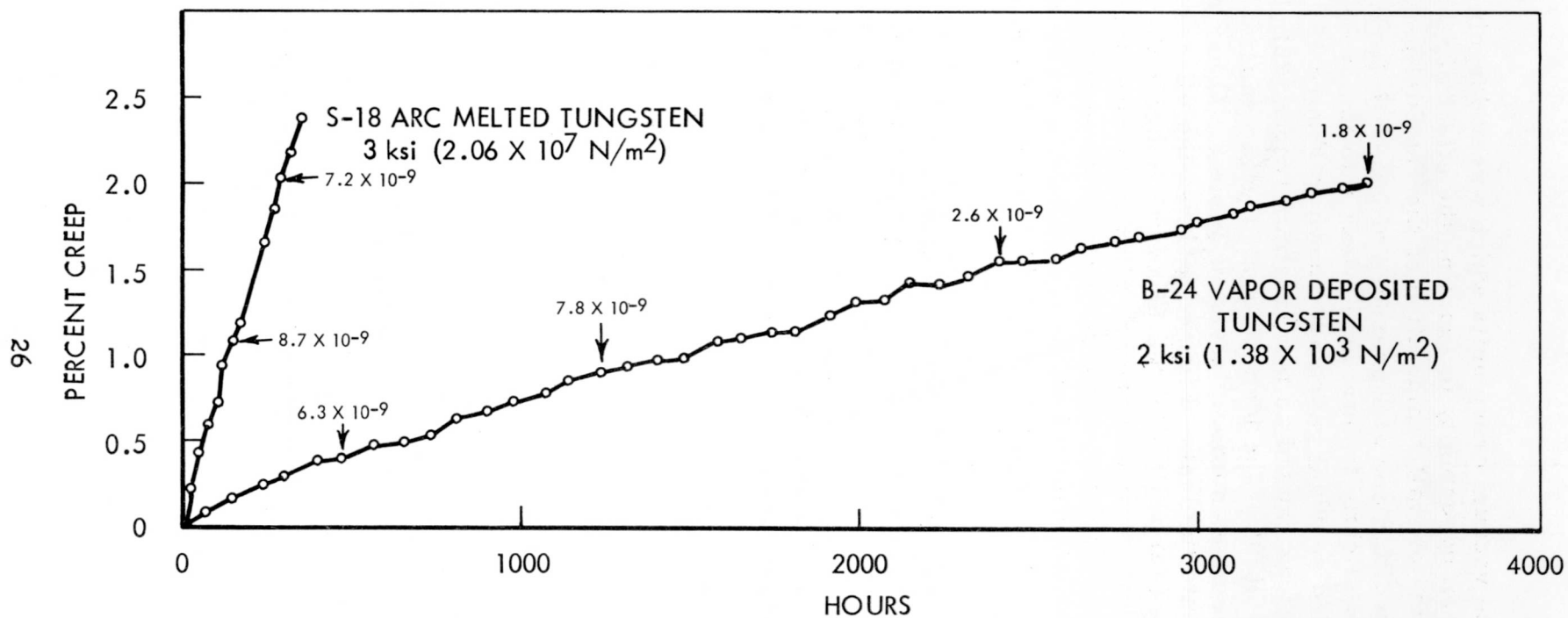


FIGURE 14: CREEP DATA FOR VAPOR-DEPOSITED AND ARC-MELTED TUNGSTEN ANNEALED 2800°F, 1 HOUR, AND TESTED AT 2800°F (1538°C) IN VACUUM ENVIRONMENT $< 1 \times 10^{-8}$ TORR.

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.

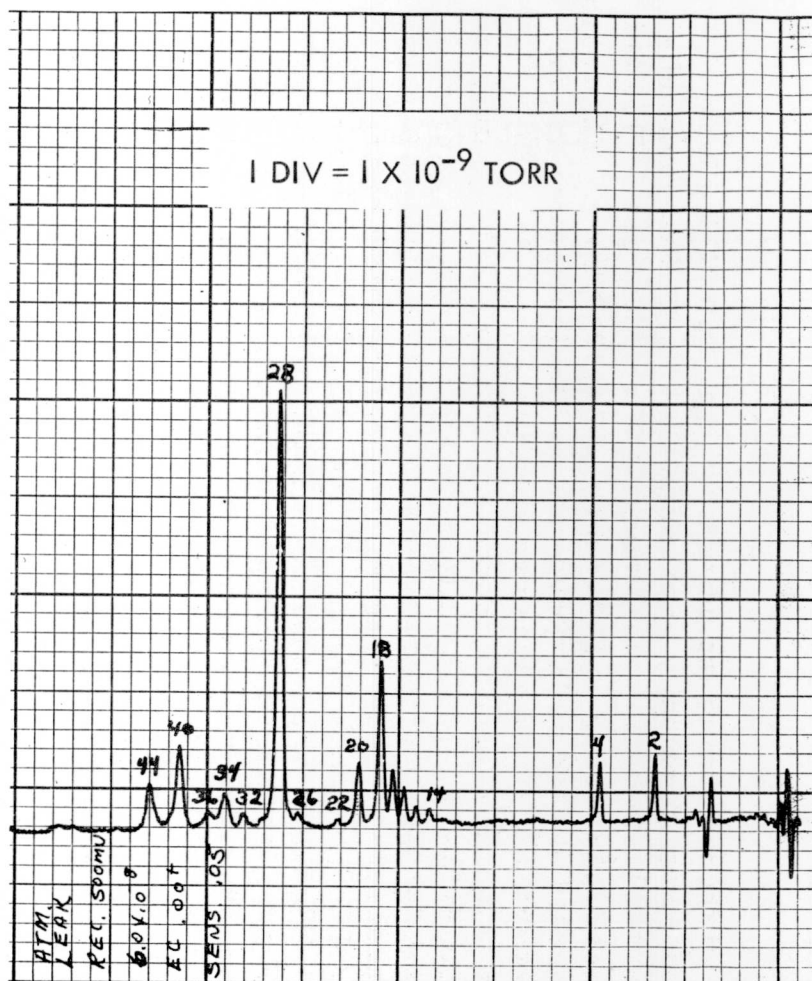
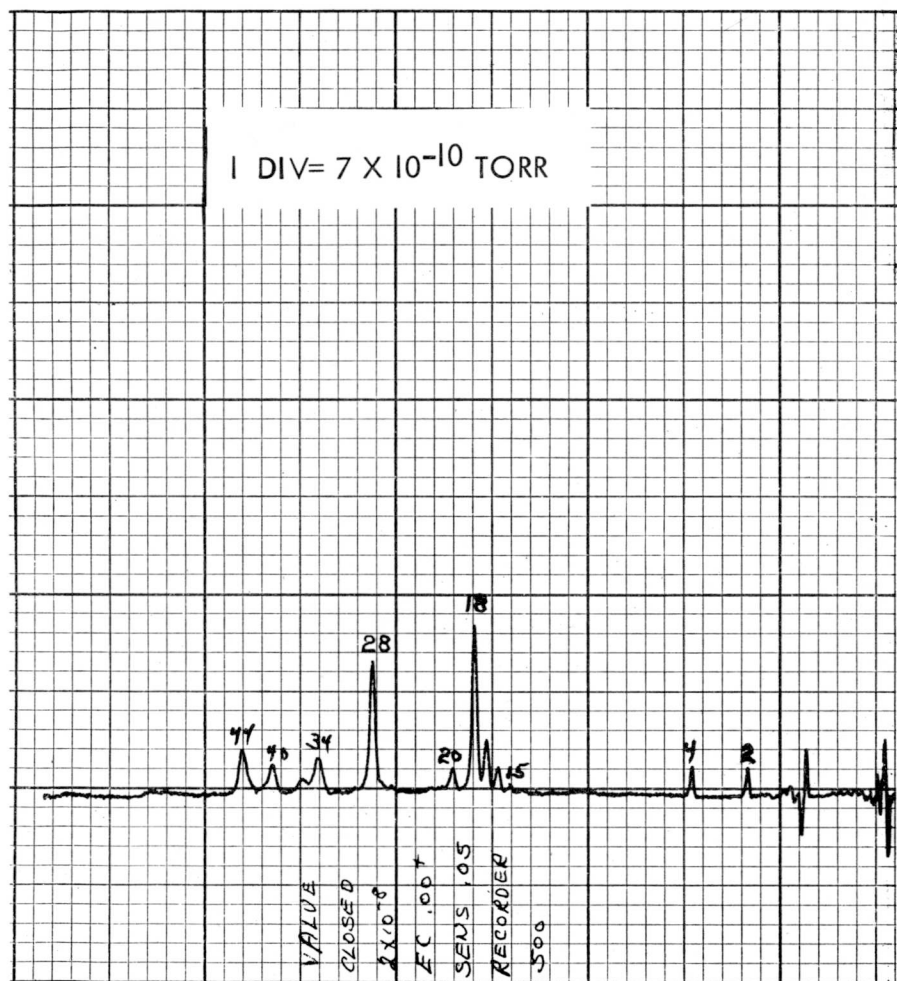


FIGURE 15 CHANGE IN COMPOSITION OF RESIDUAL GAS WHEN AN AIR LEAK IS MADE IN THE SYSTEM.

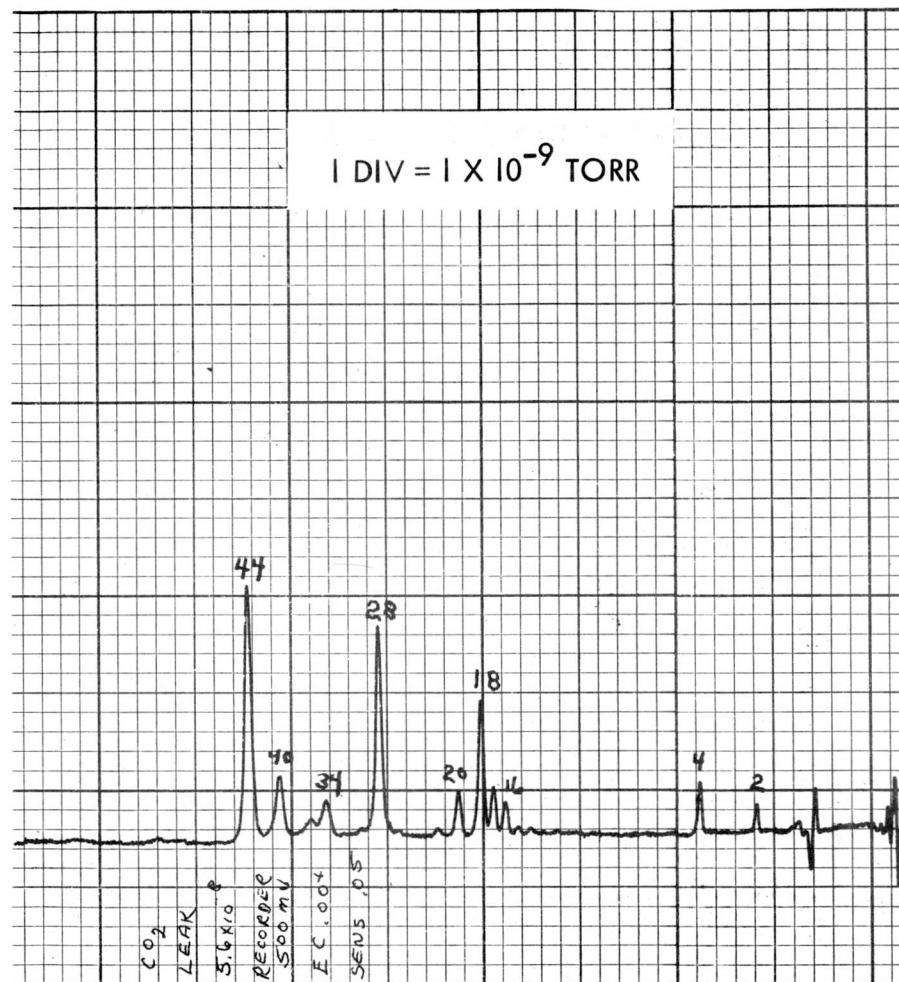
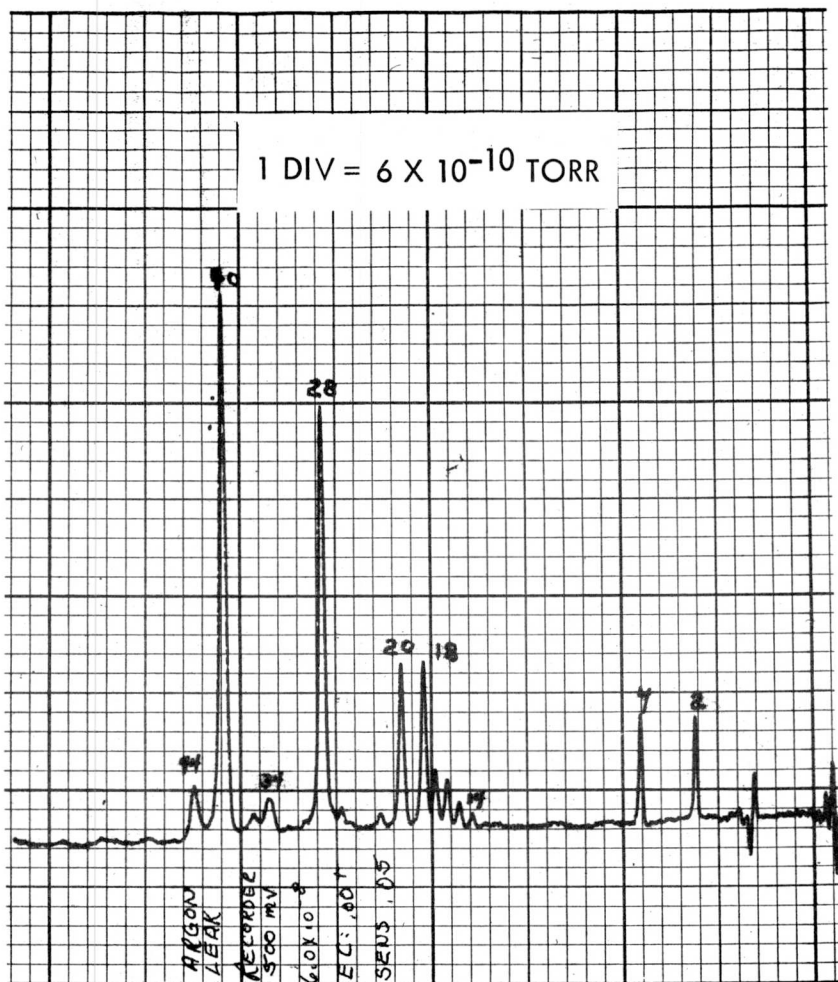


FIGURE 16 RESIDUAL GAS COMPOSITION WITH ARGON OR CO₂ INTRODUCED INTO LEAK.

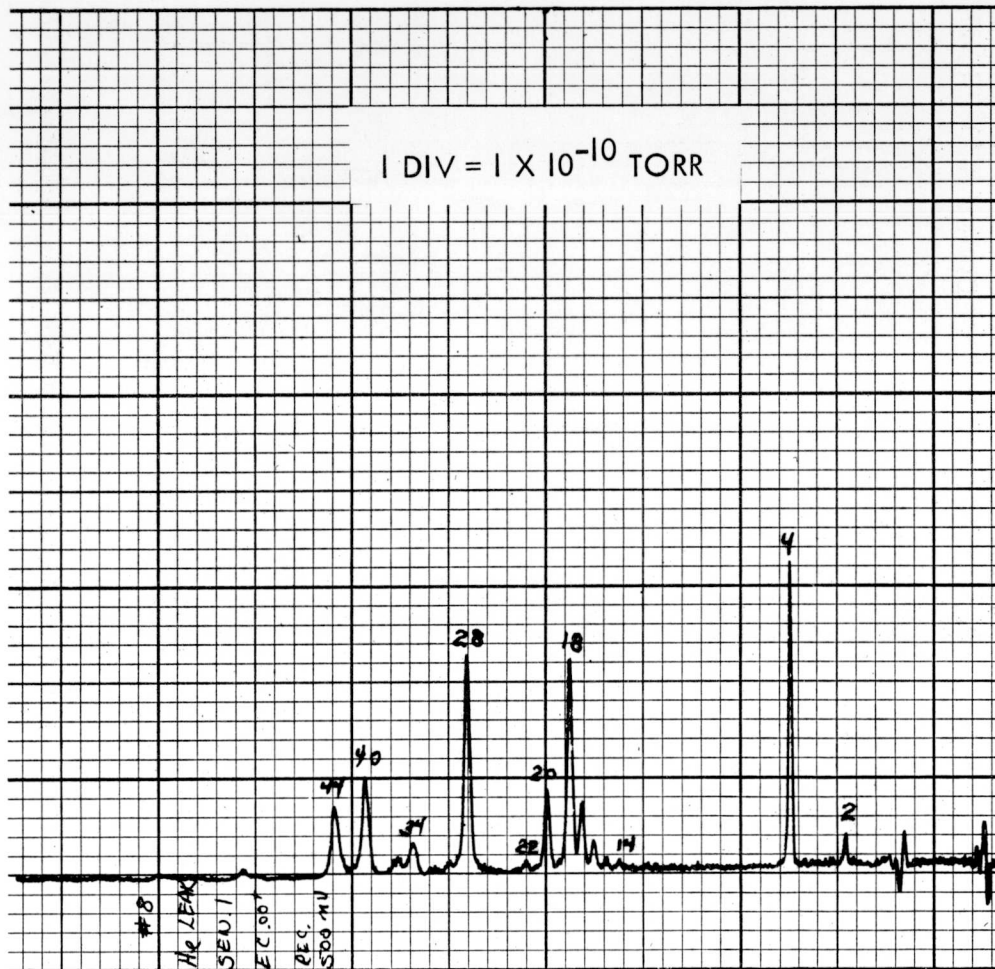


FIGURE 17 RESIDUAL GAS COMPOSITION WITH HELIUM INTRODUCED INTO THE LEAK.

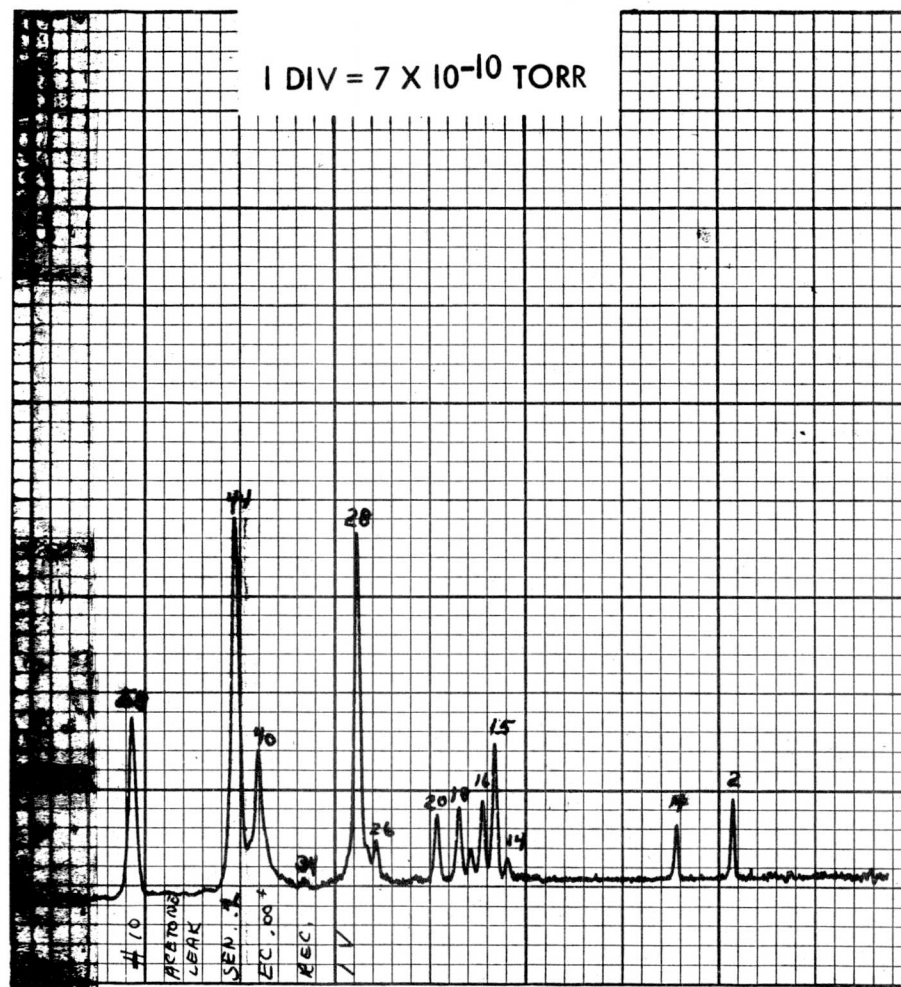
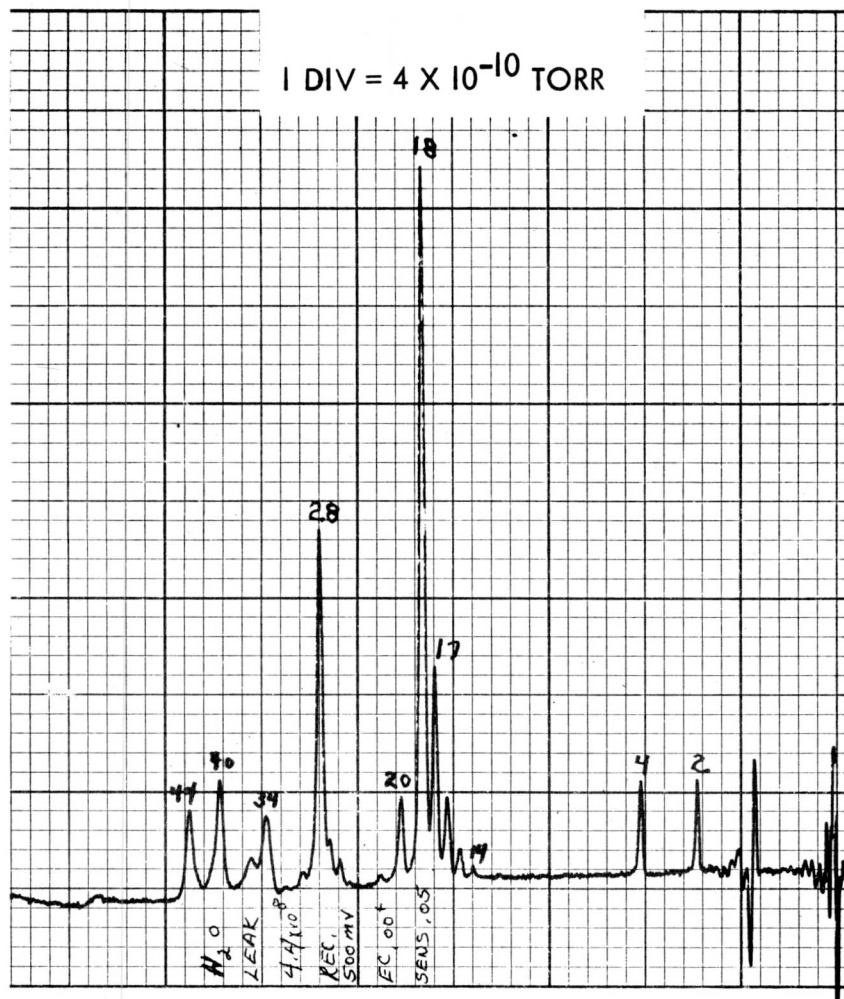


FIGURE 18 RESIDUAL GAS COMPOSITION WITH WATER OR ACETONE INTRODUCED INTO LEAK.

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 ($1.38 \times 10^8 \text{ N/m}^2$)

<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>
1 minutes	.00000	.000	1.2×10^{-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	2.6×10^{-9}
41.3	.00060	.030	2.2×10^{-9}
65.2	.00080	.040	2.2×10^{-9}
89.2	.00115	.058	2.0×10^{-9}
161.3	.00110	.055	1.3×10^{-9}
185.7	.00130	.065	1.7×10^{-9}
209.1	.00125	.068	1.7×10^{-9}
233.2	.00125	.062	1.4×10^{-9}
257.3	.00130	.065	1.3×10^{-9}
329.2	.00140	.070	2.0×10^{-9}
355.9	.00145	.072	3.2×10^{-9}
377.0	.00145	.072	3.4×10^{-9}
401.1	.00145	.072	2.4×10^{-9}
425.0	.00150	.075	1.5×10^{-9}
497.2	.00170	.085	1.9×10^{-9}
521.4	.00170	.085	3.1×10^{-9}
545.4	.00165	.082	4.8×10^{-9}
569.2	.00170	.085	4.5×10^{-9}
593.1	.00170	.085	4.6×10^{-9}
665.2	.00165	.082	5.0×10^{-9}
713.3	.00160	.080	4.6×10^{-9}
762.8	.00170	.085	--
833.4	.00175	.088	1.5×10^{-8}
881.4	.00185	.092	6.1×10^{-9}
905.2	.00175	.088	5.8×10^{-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>
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	7.8×10^{-9}
3689.9	.00500	.250	8.0×10^{-9}
3760.5	.00510	.255	8.0×10^{-9}
3856.2	.00515	.257	8.2×10^{-9}
3928.5	.00525	.262	8.2×10^{-9}
4024.1	.00575	.282	8.7×10^{-9}
4096.3	.00620	.310	8.2×10^{-9}
4192.3	.00640	.320	8.2×10^{-9}
4264.1	.00640	.320	8.2×10^{-9}
4384.3	.00640	.320	8.4×10^{-9}
4432.3	.00640	.320	9.0×10^{-9}
4528.3	.00630	.315	8.6×10^{-9}
4600.5	.00640	.320	9.4×10^{-9}
4696.7	.00625	.312	9.5×10^{-9}
4769.2	.00640	.320	8.5×10^{-9}
4866.4	.00635	.318	9.2×10^{-9}
4936.5	.00630	.315	9.2×10^{-9}
5032.5	.00635	.318	9.2×10^{-9}
5104.4	.00660	.330	8.4×10^{-9}
5200.9	.00660	.330	9.5×10^{-9}
5272.3	.00670	.335	8.8×10^{-9}
5368.8	.00675	.338	9.4×10^{-9}
5440.3	.00685	.342	9.4×10^{-9}
5536.2	.00700	.350	1.0×10^{-8}
5608.0	.00705	.352	3.4×10^{-9}
5705.8	.00715	.358	6.4×10^{-9}
5777.0	.00720	.360	4.9×10^{-9}
5873.3	.00730	.365	4.9×10^{-9}
5945.1	.00745	.372	3.4×10^{-9}
6041.2	.00750	.375	2.8×10^{-9}
6113.2	.00770	.385	3.4×10^{-9}
6209.9	.00770	.385	3.3×10^{-9}
6305.5	.00775	.388	3.5×10^{-9}
6377.5	.00780	.390	6.3×10^{-9}
6449.2	.00775	.388	7.0×10^{-9}
6545.7	.00770	.385	8.2×10^{-9}
6617.2	.00780	.390	7.4×10^{-9}
6713.2	.00780	.390	7.9×10^{-9}
6785.3	.00780	.390	7.8×10^{-9}
6881.6	.00810	.405	8.0×10^{-9}
6953.4	.00790	.395	8.3×10^{-9}
7052.7	.00805	.402	8.2×10^{-9}
7125.5	.00810	.405	8.1×10^{-9}

TABLE I (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
7217.2 hours	.00810	.410	8.2×10^{-9}
7386.0	.00815	.408	7.9×10^{-9}
7457.2	.00825	.412	7.5×10^{-9}
7553.3	.00830	.415	7.6×10^{-9}
7625.7	.00835	.418	7.0×10^{-9}
7721.9	.00845	.422	7.0×10^{-9}
7793.6	.00845	.422	7.3×10^{-9}
7889.4	.00850	.425	6.5×10^{-9}
7961.2	.00855	.428	7.1×10^{-9}
8057.4	.00855	.428	7.4×10^{-9}
8129.4	.00860	.430	7.3×10^{-9}
8225.3	.00870	.435	5.2×10^{-9}
8297.5	.00875	.438	4.3×10^{-9}
8393.2	.00880	.440	1.6×10^{-9}
8465.6	.00885	.442	4.8×10^{-9}
8561.4	.00890	.445	4.8×10^{-9}
8633.1	.00895	.448	4.6×10^{-9}
8729.1	.00900	.450	5.3×10^{-9}
8801.3	.00905	.452	5.2×10^{-9}
8969.3	.00915	.458	6.0×10^{-9}
9065.3	.00920	.460	7.5×10^{-9}
9137.2	.00925	.462	9.6×10^{-9}
9233.1	.00930	.465	1.0×10^{-8}
9305.3	.00940	.470	1.0×10^{-8}
9401.9	.00965	.482	1.0×10^{-8}
9476.5	.00970	.485	1.6×10^{-8}
9569.4	.00965	.482	2.7×10^{-9}
9642.2	.00965	.482	5.4×10^{-9}
9737.6	.00960	.480	3.8×10^{-9}
9814.3	.00970	.485	5.0×10^{-9}
9904.3	.00980	.490	7.6×10^{-9}
9976.3	.00980	.490	4.6×10^{-10}
10,000.7	.00980	.490	5.2×10^{-10}
10,072.1	.00985	.492	8.5×10^{-10}
10,144.3	.00985	.492	1.0×10^{-9}
10,240.3	.00990	.495	1.5×10^{-9}
10,312.1	.00995	.498	1.9×10^{-9}
10,408.5	.01005	.502	2.2×10^{-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>
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</u> <u>ΔL (inch)</u> <u>(2" G. L.)</u>	<u>Creep</u> <u>%</u>	<u>Pressure</u> <u>(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 ΔL (inch) (2" G. L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
4564.6 hours	.00310	.155	2.0×10^{-9}
4661.2	.00315	.158	1.4×10^{-9}
4732.6	.00320	.160	2.0×10^{-9}
4828.5	.00305	.152	1.7×10^{-9}
4900.3	.00310	.155	1.7×10^{-9}
4998.1	.00305	.152	1.4×10^{-9}
5069.3	.00305	.152	2.4×10^{-9}
5165.5	.00305	.152	1.6×10^{-9}
5237.4	.00310	.155	1.2×10^{-9}
5333.5	.00310	.155	1.1×10^{-9}
5405.5	.00305	.152	1.6×10^{-9}
5502.2	.00305	.152	1.1×10^{-9}
5598.0	.00310	.155	1.4×10^{-9}
5669.8	.00310	.155	1.8×10^{-9}
5741.4	.00320	.160	1.6×10^{-9}
5838.0	.00315	.158	1.6×10^{-9}
5909.4	.00325	.162	1.5×10^{-9}
6005.6	.00315	.158	1.5×10^{-9}
6077.5	.00315	.158	1.6×10^{-9}
6173.9	.00315	.158	1.6×10^{-9}
6245.7	.00320	.160	1.6×10^{-9}
6345.0	.00325	.162	1.0×10^{-9}
6417.7	.00335	.168	1.3×10^{-9}
6509.4	.00335	.168	1.5×10^{-9}
6582.0	.00340	.170	1.0×10^{-9}
6678.2	.00335	.168	1.6×10^{-9}
6749.4	.00340	.170	1.5×10^{-9}
6845.6	.00345	.172	1.6×10^{-9}
6917.9	.00350	.175	2.2×10^{-9}
7014.1	.00355	.178	1.4×10^{-9}
7085.9	.00350	.175	2.1×10^{-9}
7181.9	.00345	.172	2.3×10^{-9}
7253.6	.00355	.178	3.0×10^{-9}
7350.0	.00345	.172	1.4×10^{-9}
7421.6	.00345	.172	1.4×10^{-9}
7517.6	.00345	.172	7.8×10^{-10}
7589.7	.00350	.175	1.8×10^{-9}
7685.4	.00345	.172	1.6×10^{-9}
7757.8	.00340	.170	2.2×10^{-9}
7853.8	.00345	.172	1.8×10^{-9}
7925.4	.00340	.170	1.6×10^{-9}
8021.3	.00340	.170	1.3×10^{-9}
8093.4	.00340	.170	1.6×10^{-9}
8189.3	.00345	.172	1.7×10^{-9}
8261.5	.00345	.172	1.9×10^{-9}
8357.5	.00335	.168	1.1×10^{-9}
8429.5	.00335	.168	1.6×10^{-9}

TABLE II (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
8525.3 hours	.00340	.170	1.7×10^{-9}
8597.7	.00350	.175	1.8×10^{-9}
8694.0	.00355	.178	1.6×10^{-9}
8769.8	.00350	.175	1.7×10^{-9}
8861.7	.00355	.178	1.7×10^{-9}
8934.4	.00355	.178	1.7×10^{-9}
9030.0	.00350	.175	1.7×10^{-9}
9106.9	.00350	.175	1.6×10^{-9}
9197.3	.00350	.175	2.2×10^{-9}
9268.5	.00350	.175	1.5×10^{-9}
9364.7	.00345	.172	1.6×10^{-9}
9436.8	.00335	.168	1.7×10^{-9}
9532.5	.00345	.172	1.7×10^{-9}
9604.3	.00345	.172	1.6×10^{-9}
9700.8	.00345	.172	1.6×10^{-9}
9774.3	.00335	.168	1.7×10^{-9}
9868.8	.00330	.165	1.6×10^{-9}
9940.4	.00340	.170	1.6×10^{-9}
10,060.9	.00345	.172	1.1×10^{-9}
10,108.5	.00340	.170	1.0×10^{-9}
10,207.3	.00335	.168	1.1×10^{-9}
10,276.3	.00335	.168	9.9×10^{-10}
10,300.4	.00340	.170	9.7×10^{-10}
10,372.4	.00340	.170	1.3×10^{-9}
10,444.8	.00335	.168	1.4×10^{-9}
10,540.5	.00345	.172	1.0×10^{-9}
10,612.5	.00340	.170	1.0×10^{-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 ($1.31 \times 10^8 \text{ N/m}^2$)

<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>
1 minutes	.00010	.005	7.0×10^{-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	6.9×10^{-8}
20	.00165	.082	
25	.00170	.085	
30	.00170	.085	6.9×10^{-8}
40	.00175	.088	
45	.00175	.088	
60	.00180	.090	6.8×10^{-8}
90	.00180	.090	6.7×10^{-8}
15.7 hours	.00180	.090	3.5×10^{-8}
87.1	.00180	.090	1.4×10^{-8}
111.2	.00100	.050	9.8×10^{-9}
133.4	.00140	.070	7.0×10^{-9}
159.0	.00135	.068	3.0×10^{-9}
181.6	.00130	.065	--
239.9	.00135	.068	4.2×10^{-9}
263.7	.00130	.065	5.1×10^{-9}
287.7	.00150	.075	4.5×10^{-9}
309.9	.00140	.070	3.8×10^{-9}
334.3	.00150	.075	3.2×10^{-9}
406.5	.00145	.072	3.5×10^{-9}
459.3	.00155	.078	--
503.2	.00150	.075	2.2×10^{-9}
573.9	.00175	.088	1.2×10^{-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	1.1×10^{-9}
669.9	.00180	.090	3.8×10^{-9}
742.3	.00185	.092	2.8×10^{-9}
790.2	.00190	.095	2.8×10^{-9}
838.3	.00185	.092	1.8×10^{-9}
909.9	.00195	.098	3.2×10^{-9}
964.8	.00205	.102	2.6×10^{-9}
1006.2	.00210	.105	2.6×10^{-9}
1055.3	.00215	.108	2.7×10^{-9}
1102.0	.00220	.110	2.9×10^{-9}
1126.8	.00220	.110	1.7×10^{-9}
1173.9	.00220	.110	1.0×10^{-9}
1245.9	.00215	.108	4.2×10^{-10}
1294.0	.00225	.112	2.1×10^{-9}
1342.0	.00235	.118	2.1×10^{-10}
1414.1	.00235	.118	1.4×10^{-9}
1466.7	.00235	.118	2.5×10^{-9}
1509.0	.00225	.112	2.0×10^{-9}
1581.8	.00245	.122	7.5×10^{-10}
1654.2	.00245	.122	1.2×10^{-9}
1750.2	.00240	.120	1.3×10^{-9}
1822.1	.00235	.118	7.0×10^{-10}
1942.2	.00235	.118	8.4×10^{-10}
1990.6	.00240	.120	7.4×10^{-10}
2086.2	.00250	.125	1.6×10^{-9}
2158.2	.00260	.130	1.4×10^{-9}
2254.4	.00265	.132	7.2×10^{-10}
2326.1	.00265	.132	2.0×10^{-9}
2424.7	.00280	.140	1.4×10^{-9}
2497.4	.00305	.152	1.2×10^{-9}
2600.1	.00310	.155	8.0×10^{-10}
2664.7	.00325	.162	2.4×10^{-9}
2759.8	.00345	.172	2.6×10^{-9}
2854.3	.00355	.178	1.5×10^{-9}
2926.3	.00355	.178	1.5×10^{-9}
2998.2	.00355	.178	2.1×10^{-9}
3094.0	.00365	.182	2.1×10^{-9}
3166.4	.00360	.180	2.2×10^{-9}
3262.2	.00355	.178	9.2×10^{-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>
3334.1 hours	.00360	.180	2.2×10^{-9}
3454.1	.00340	.170	1.6×10^{-9}
3502.1	.00365	.182	2.0×10^{-9}
3598.2	.00315	.158	1.1×10^{-9}
3670.3	.00315	.158	1.0×10^{-9}
3766.6	.00300	.150	9.0×10^{-10}
3839.0	.00305	.152	2.5×10^{-9}
3936.4	.00300	.150	9.1×10^{-10}
4006.3	.00295	.148	2.0×10^{-9}
4102.6	.00305	.152	2.1×10^{-9}
4174.3	.00310	.155	1.9×10^{-9}
4270.6	.00320	.160	1.0×10^{-9}
4342.2	.00330	.165	2.0×10^{-9}
4438.7	.00330	.165	2.5×10^{-9}
4510.1	.00355	.178	1.4×10^{-9}
4606.2	.00340	.170	2.0×10^{-9}
4677.8	.00345	.172	1.8×10^{-9}
4775.6	.00345	.172	1.8×10^{-9}
4846.8	.00335	.168	1.6×10^{-9}
4943.1	.00335	.168	1.6×10^{-9}
5015.0	.00355	.178	1.7×10^{-9}
5111.1	.00340	.170	1.6×10^{-9}
5183.2	.00345	.172	1.0×10^{-9}
5279.7	.00350	.175	1.6×10^{-9}
5375.6	.00355	.178	1.5×10^{-9}
5447.3	.00355	.178	2.5×10^{-9}
5518.9	.00355	.178	2.5×10^{-9}
5615.6	.00355	.178	1.0×10^{-9}
5687.0	.00360	.180	2.5×10^{-9}
5783.8	.00355	.178	2.4×10^{-9}
5855.1	.00365	.182	2.4×10^{-9}
5951.5	.00375	.188	2.4×10^{-9}
6023.3	.00380	.190	2.5×10^{-9}
6122.5	.00395	.198	9.0×10^{-10}
6195.3	.00390	.195	2.4×10^{-9}
6286.9	.00400	.200	2.5×10^{-9}

TABLE III (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
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	1.3×10^{-9}
10,077.9	.00500	.250	1.3×10^{-9}
10,150.1	.00500	.250	1.4×10^{-9}
10,222.5	.00505	.252	1.3×10^{-9}
10,318.1	.00510	.255	1.3×10^{-9}
10,390.8	.00510	.255	1.3×10^{-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 (8.28×10^7 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	3.0×10^{-9}
2	.00005	.002	3.0×10^{-9}
3	.00010	.005	3.0×10^{-9}
4	.00015	.008	3.0×10^{-9}
5	.00015	.008	3.0×10^{-9}
6	.00010	.005	3.0×10^{-9}
7	.00010	.005	3.0×10^{-9}
8	.00005	.002	3.0×10^{-9}
9	.00010	.005	3.0×10^{-9}
10	.00005	.002	3.0×10^{-9}
15	.00000	.000	3.0×10^{-9}
30	-.00005	-.002	3.0×10^{-9}
45	.00010	.005	3.0×10^{-9}
60	.00010	.005	3.0×10^{-9}
19.6 Hours	.00025	.012	3.1×10^{-9}
50.1	.00060	.030	2.4×10^{-9}
67.5	.00070	.035	2.3×10^{-9}
91.5	.00080	.040	2.4×10^{-9}
164.0	.00100	.050	2.1×10^{-9}
187.5	.00115	.058	2.1×10^{-9}
211.3	.00125	.062	2.2×10^{-9}
238.7	.00140	.070	2.2×10^{-9}
331.5	.00190	.095	1.7×10^{-9}
355.6	.00195	.098	1.8×10^{-9}
379.3	.00205	.102	2.3×10^{-9}
404.3	.00205	.102	2.3×10^{-9}
427.4	.00215	.108	1.9×10^{-9}
499.8	.00245	.122	2.2×10^{-9}
523.3	.00240	.120	2.2×10^{-9}
547.5	.00250	.125	2.2×10^{-9}
576.4	.00270	.135	2.2×10^{-9}
595.3	.00275	.138	2.4×10^{-9}
667.2	.00340	.170	2.5×10^{-9}
690.6	.00370	.185	2.4×10^{-9}

TABLE IV (Continued)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
714.4	.00380	.190	2.3×10^{-9}
738.5	.00385	.192	2.4×10^{-9}
762.9	.00385	.192	2.4×10^{-9}
834.3	.00440	.220	2.4×10^{-9}
858.4	.00445	.222	2.3×10^{-9}
882.5	.00455	.228	2.3×10^{-9}
906.7	.00480	.240	2.3×10^{-9}
930.3	.00515	.258	2.3×10^{-9}
1002.4	.00560	.280	2.2×10^{-9}
1026.2	.00575	.288	2.2×10^{-9}
1050.4	.00620	.310	2.2×10^{-9}
1074.2	.00630	.315	2.2×10^{-9}
1098.6	.00620	.310	2.2×10^{-9}
1170.7	.00640	.320	2.2×10^{-9}
1194.3	.00655	.328	2.2×10^{-9}
1218.3	.00665	.332	2.2×10^{-9}
1242.5	.00690	.345	2.2×10^{-9}
1266.3	.00715	.358	2.3×10^{-9}
1338.7	.00750	.375	2.3×10^{-9}
1362.5	.00760	.380	2.3×10^{-9}
1386.3	.00775	.388	2.2×10^{-9}
1410.4	.00785	.392	2.2×10^{-9}
1434.3	.00795	.398	2.2×10^{-9}
1530.8	.00850	.425	6.7×10^{-10}
1554.5	.00880	.440	6.8×10^{-10}
1578.4	.00890	.445	6.8×10^{-10}
1602.4	.00905	.452	2.2×10^{-9}
1677.5	.00955	.478	2.2×10^{-9}
1698.3	.00965	.482	6.7×10^{-9}
1722.3	.00980	.490	2.1×10^{-9}
1746.2	.00990	.495	6.6×10^{-10}
1770.2	.00995	.498	6.9×10^{-10}
1842.3	.01055	.528	2.0×10^{-9}
1866.3	.01070	.535	2.0×10^{-9}
1890.4	.01100	.550	6.3×10^{-10}
1914.6	.01095	.548	2.2×10^{-9}
1938.3	.01145	.572	6.4×10^{-10}
2010.4	.01190	.595	2.1×10^{-9}
2034.3	.01210	.605	6.3×10^{-10}
2058.4	.01220	.610	6.4×10^{-10}
2082.4	.01235	.618	6.3×10^{-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 ($1.38 \times 10^8 \text{ N/m}^2$)

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

TABLE V (Continued)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
787.7 Hours	.00410	.205	7.4×10^{-10}
811.6	.00420	.210	7.1×10^{-10}
835.3	.00435	.218	7.2×10^{-10}
859.2	.00440	.220	7.0×10^{-10}
883.2	.00445	.222	7.0×10^{-10}
956.3	.00460	.230	6.6×10^{-10}
980.0	.00470	.235	6.4×10^{-10}
1003.4	.00455	.228	6.4×10^{-10}
1027.2	.00465	.232	6.2×10^{-10}
1123.7	.00485	.242	6.0×10^{-10}
1195.5	.00490	.245	5.7×10^{-10}
1294.7	.00515	.258	6.0×10^{-10}
1367.4	.00525	.262	5.8×10^{-10}
1459.1	.00560	.280	5.6×10^{-10}
1531.7	.00585	.292	5.4×10^{-10}
1627.9	.00600	.300	5.4×10^{-10}
1699.2	.00620	.310	5.4×10^{-10}
1795.3	.00640	.320	5.4×10^{-10}
1867.8	.00655	.328	5.1×10^{-10}
1963.9	.00665	.332	5.1×10^{-10}
2035.6	.00695	.348	4.7×10^{-10}
2131.6	.00720	.360	4.8×10^{-10}
2203.3	.00740	.370	4.9×10^{-10}
2299.8	.00745	.372	4.9×10^{-10}
2371.4	.00755	.378	4.8×10^{-10}
2467.3	.00760	.380	3.6×10^{-10}
2539.5	.00770	.385	2.6×10^{-10}
2635.2	.00800	.400	3.8×10^{-10}
2707.6	.00820	.410	3.4×10^{-10}
2803.4	.00880	.440	3.4×10^{-10}
2875.1	.00900	.450	3.4×10^{-10}
2971.0	.00910	.455	3.1×10^{-10}
3043.1	.00920	.460	3.6×10^{-10}
3139.0	.00935	.468	3.3×10^{-10}
3211.3	.00930	.465	3.4×10^{-10}
3307.3	.00960	.480	3.3×10^{-10}
3379.2	.00965	.482	3.2×10^{-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 ($1.38 \times 10^8 \text{ N/m}^2$)

Time	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1 Minute(s)	.00010	.005	3.2×10^{-9}
2	.00000	.000	3.2×10^{-9}
3	.00000	.000	3.2×10^{-9}
4	.00010	.005	3.2×10^{-9}
5	.00015	.008	3.2×10^{-9}
6	.00010	.005	3.2×10^{-9}
7	.00020	.010	3.2×10^{-9}
8	.00015	.008	3.2×10^{-9}
9	.00015	.008	3.2×10^{-9}
10	.00020	.010	3.2×10^{-9}
15	.00020	.010	3.2×10^{-9}
30	.00015	.008	3.2×10^{-9}
45	.00015	.008	3.2×10^{-9}
60	.00020	.010	3.2×10^{-9}
65.2 Hours	.00070	.035	2.6×10^{-9}
89.1	.00085	.042	2.2×10^{-9}
113.2	.00110	.055	2.1×10^{-9}
137.4	.00135	.068	1.9×10^{-9}
161.0	.00140	.070	2.0×10^{-9}
233.1	.00160	.080	1.8×10^{-9}
256.9	.00165	.082	1.8×10^{-9}
281.1	.00160	.080	1.8×10^{-9}
305.0	.00180	.090	1.8×10^{-9}
329.3	.00195	.098	1.7×10^{-9}
401.4	.00195	.098	1.8×10^{-9}
425.0	.00200	.100	1.6×10^{-9}
449.1	.00200	.100	1.6×10^{-9}
473.3	.00210	.105	1.7×10^{-9}
497.0	.00205	.102	1.9×10^{-9}
571.4	.00205	.102	1.7×10^{-9}
593.3	.00210	.105	1.7×10^{-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	1.7×10^{-9}
641.1	.00215	.108	1.7×10^{-9}
665.1	.00220	.110	1.5×10^{-9}
761.5	.00230	.115	1.5×10^{-9}
785.3	.00230	.115	1.6×10^{-9}
809.1	.00235	.118	1.6×10^{-9}
833.2	.00235	.118	1.6×10^{-9}
908.2	.00235	.118	1.7×10^{-9}
929.1	.00240	.120	1.6×10^{-9}
953.1	.00240	.120	1.6×10^{-9}
976.9	.00245	.122	1.5×10^{-9}
1001.0	.00240	.120	1.4×10^{-9}
1073.1	.00250	.125	1.6×10^{-9}
1097.0	.00250	.125	1.6×10^{-9}
1121.1	.00255	.128	1.5×10^{-9}
1145.4	.00265	.132	1.6×10^{-9}
1169.0	.00275	.138	1.5×10^{-9}
1241.2	.00280	.140	1.5×10^{-9}
1265.0	.00290	.145	1.5×10^{-9}
1289.1	.00300	.150	1.6×10^{-9}
1313.2	.00305	.152	1.7×10^{-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 (1.93×10^8 N/m²)

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

TABLE VII (Continued)

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

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
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 ($1.52 \times 10^8 \text{ N/m}^2$)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 Minute(s)	.00005	.002	3.1×10^{-8}
2	.00000	.000	3.1×10^{-8}
3	.00000	.000	3.1×10^{-8}
4	.00000	.000	3.1×10^{-8}
5	-.00005	-.002	3.1×10^{-8}
6	.00000	.000	3.1×10^{-8}
7	.00010	.005	3.1×10^{-8}
8	.00005	.002	3.1×10^{-8}
9	.00015	.008	3.1×10^{-8}
10	.00015	.008	3.1×10^{-8}
15	.00015	.008	3.1×10^{-8}
30	.00030	.015	3.1×10^{-8}
45	.00050	.025	3.1×10^{-8}
60	.00060	.030	3.1×10^{-8}
3.0 Hours	.00150	.075	4.5×10^{-8}
4.0	.00165	.082	4.5×10^{-8}
18.9	.00465	.232	1.2×10^{-8}
22.4	.00500	.250	1.2×10^{-8}
27.1	.00565	.282	1.2×10^{-8}
46.8	.00765	.382	-
72.0	.01025	.512	-
90.9	.01190	.595	5.4×10^{-9}
98.9	.01255	.628	5.0×10^{-9}
114.9	.01410	.705	4.9×10^{-9}
122.9	.01490	.745	4.8×10^{-9}
138.8	.01570	.785	4.2×10^{-9}
162.7	.01825	.912	3.9×10^{-9}
170.9	.01885	.942	3.7×10^{-9}
187.1	.01995	.998	3.2×10^{-9}
195.3	.02080	1.040	3.2×10^{-9}
238.7	.02465	1.232	3.4×10^{-9}
259.2	.02560	1.280	3.2×10^{-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
1144.9	.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
1655.2	.00185	.092	3.5 x 10 ⁻¹⁰
1716.9	.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 ($9.65 \times 10^7 \text{ N/m}^2$)

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

TABLE XI (Continued)

<u>Time</u>	Length Change ΔL (inch) <u>(2" G.L.)</u>	Creep (%)	Pressure (Torr)
592.9 Hours	.01510	.755	3.5×10^{-9}
616.8	.01570	.785	3.2×10^{-9}
640.7	.01630	.815	3.6×10^{-9}
664.7	.01685	.842	3.5×10^{-9}
736.8	.01825	.912	3.4×10^{-9}
760.7	.01885	.942	3.3×10^{-9}
784.9	.01930	.965	3.2×10^{-9}
809.2	.01980	.990	3.6×10^{-9}
832.8	.02040	1.020	3.3×10^{-9}
904.9	.02175	1.088	3.2×10^{-9}
912.0	.02185	1.092	3.2×10^{-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 (1.38×10^8 N/m²)

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

Test In Progress

Specimen B-32

TABLE XIII

CREEP TEST DATA, TZG PLATE, HEAT NO. M-91, ANNEALED AT 2500°F (1371°C) FOR 1 HOUR,
TESTED AT 1900°F (1038°C), 22,000 PSI (1.52×10^8 N/m²)

<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>
1 Minute(s)	-.00005	-.002	9.7×10^{-9}
2	-.00005	-.002	9.7×10^{-9}
3	-.00010	-.005	9.7×10^{-9}
4	.00005	.002	9.7×10^{-9}
5	.00005	.002	9.7×10^{-9}
6	.00005	.002	9.7×10^{-9}
7	.00005	.002	9.7×10^{-9}
8	.00010	.005	9.7×10^{-9}
9	.00010	.005	9.7×10^{-9}
10	.00010	.005	9.7×10^{-9}
15	.00015	.008	9.7×10^{-9}
30	.00020	.010	9.7×10^{-9}
45	.00020	.010	9.7×10^{-9}
60	.00030	.015	9.7×10^{-9}
17.2 Hours	.00065	.032	5.2×10^{-9}
41.3	.00115	.058	3.7×10^{-9}
44.2	.00120	.060	3.7×10^{-9}
70.1	.00180	.090	3.2×10^{-9}
98.5	.00195	.098	2.6×10^{-9}
116.1	.00200	.100	2.5×10^{-9}
137.2	.00200	.100	2.2×10^{-9}
161.1	.00205	.102	1.8×10^{-9}
184.9	.00210	.105	1.7×10^{-9}
209.0	.00205	.102	1.7×10^{-9}
281.1	.00240	.120	1.6×10^{-9}
305.0	.00245	.122	1.5×10^{-9}
329.2	.00250	.125	1.4×10^{-9}
353.4	.00270	.135	1.3×10^{-9}
377.0	.00275	.138	1.1×10^{-9}
449.1	.00285	.142	1.0×10^{-9}
473.0	.00295	.148	1.0×10^{-9}
497.1	.00300	.150	1.2×10^{-9}
521.9	.00310	.155	1.3×10^{-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 (2.82×10^{-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	2.4×10^{-8}
2	-.00010	-.005	2.4×10^{-8}
3	-.00015	-.008	2.4×10^{-8}
4	-.00010	-.005	2.4×10^{-8}
5	-.00010	-.005	2.4×10^{-8}
6	-.00010	-.005	2.4×10^{-8}
7	-.00010	-.005	2.4×10^{-8}
8	-.00015	-.008	2.4×10^{-8}
9	-.00015	-.008	2.4×10^{-8}
10	-.00010	-.005	2.4×10^{-8}
15	-.00015	-.008	2.4×10^{-8}
30	-.00005	-.002	2.4×10^{-8}
45	-.00005	-.002	2.4×10^{-8}
60	.00005	.002	2.4×10^{-8}
18.5 Hours	.00110	.055	2.7×10^{-9}
24.8	.00160	.080	3.0×10^{-9}
50.9	.00260	.130	1.4×10^{-9}
74.7	.00235	.118	9.7×10^{-10}
88.6	.00285	.142	1.0×10^{-9}
96.7	.00320	.160	1.0×10^{-9}
113.0	.00335	.168	9.4×10^{-10}
120.5	.00340	.170	9.5×10^{-10}
136.5	.00365	.182	8.8×10^{-10}
144.8	.00375	.188	8.0×10^{-10}
160.7	.00400	.200	6.4×10^{-10}
168.0	.00405	.202	6.3×10^{-10}
184.7	.00410	.205	8.0×10^{-10}
280.7	.00495	.248	5.5×10^{-10}
305.1	.00520	.260	5.5×10^{-10}
329.7	.00540	.270	5.4×10^{-10}
352.8	.00565	.282	5.4×10^{-10}
425.2	.00600	.300	5.9×10^{-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 (1.03×10^8 N/m²)

<u>Time</u>	<u>Length Change ΔL (inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 Minute(s)	.00010	.005	1.7×10^{-8}
2	.00020	.010	1.7×10^{-8}
3	.00030	.015	1.7×10^{-8}
4	.00035	.018	1.7×10^{-8}
5	.00040	.020	1.7×10^{-8}
6	.00035	.018	1.7×10^{-8}
7	.00040	.020	1.7×10^{-8}
8	.00035	.018	1.7×10^{-8}
9	.00035	.018	1.7×10^{-8}
10	.00030	.015	1.7×10^{-8}
15	.00040	.020	1.7×10^{-8}
30	.00030	.015	1.7×10^{-8}
45	.00035	.018	1.7×10^{-8}
60	.00035	.018	1.7×10^{-8}
26.2 Hours	.00055	.028	4.8×10^{-9}
49.7	.00065	.032	2.2×10^{-9}
63.4	.00095	.048	2.0×10^{-9}
87.3	.00110	.055	1.3×10^{-9}
111.4	.00130	.065	1.5×10^{-9}
135.4	.00155	.078	2.0×10^{-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 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	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</u> <u>ΔL (inch)</u> <u>(2"G.L.)</u>	<u>Creep</u> <u>(%)</u>	<u>Pressure</u> <u>(Torr)</u>
928.9 Hours	.00675	.338	9.7×10^{-10}
1001.3	.00845	.422	7.4×10^{-10}
1024.8	.00880	.440	7.9×10^{-10}
1049.0	.00930	.465	7.7×10^{-10}
1081.1	.01005	.502	7.2×10^{-10}
1097.0	.01015	.508	7.5×10^{-10}
1168.7	.01150	.575	1.0×10^{-9}
1192.1	.01190	.595	9.0×10^{-10}
1215.9	.01250	.625	7.5×10^{-10}
1240.0	.01290	.645	7.2×10^{-10}
1264.4	.01360	.680	7.1×10^{-10}
1336.0	.01490	.745	7.0×10^{-10}
1359.8	.01540	.770	6.6×10^{-10}
1384.0	.01580	.790	6.9×10^{-10}
1408.2	.01625	.812	7.9×10^{-10}
1431.8	.01670	.835	6.4×10^{-10}
1503.9	.01785	.892	6.4×10^{-10}
1527.9	.01915	.958	6.0×10^{-10}
1551.9	.02000	1.000	6.0×10^{-10}
1575.8	.02050	1.025	5.8×10^{-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 ($5.52 \times 10^7 \text{N/m}^2$)

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

TABLE XVII (Continued)

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

TABLE XVII (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>
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)

<u>Time</u>	<u>Length Change ΔL (Inch) (2" G.L.)</u>	<u>Creep (%)</u>	<u>Pressure (Torr)</u>
1 minute(s)	.00000	.000	2.9 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>	Length Change <u>ΔL (inch)</u> <u>(2" G.L.)</u>	Creep <u>(%)</u>	Pressure <u>(Torr)</u>
3184.0	.09755	4.878	1.6×10^{-9}
3208.1	.09910	4.955	1.6×10^{-9}
3232.1	.09995	4.998	1.6×10^{-9}
3304.5	.10360	5.180	1.7×10^{-9}
3328.3	.10455	5.228	6.5×10^{-10}
3352.1	.10570	5.285	6.8×10^{-10}
3376.2	.10725	5.362	6.3×10^{-10}
3400.1	.10810	5.405	5.5×10^{-10}
3496.8	.11265	5.632	8.0×10^{-10}
3520.2	.11380	5.690	8.4×10^{-10}
3544.1	.11535	5.768	7.0×10^{-10}
3568.1	.11640	5.820	6.8×10^{-10}
3644.9	.12035	6.018	8.2×10^{-10}
3664.1	.12125	6.062	8.0×10^{-10}
3688.1	.12265	6.132	1.2×10^{-9}
3712.0	.12395	6.198	1.2×10^{-9}
3736.0	.12610	6.305	6.9×10^{-9}
3808.1	.12945	6.472	8.3×10^{-10}
3832.0	.13040	6.520	8.0×10^{-10}
3840.1	.13095	6.548	1.0×10^{-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)

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

Test In Progress
Specimen B-24

EXTERNAL DISTRIBUTION

National Aeronautics and Space Administration
Washington, D. C. 20546
Attn: Walter C. Scott
Attn: James J. Lynch (RN)
Attn: George C. Deutsch (RR)

National Aeronautics and Space Administration
Scientific and Technical Information Facility
Box 5700
Bethesda, Maryland 21811

2 copies + 2 reproducible

National Aeronautics and Space Administration
Ames Research Center
Moffet Field, California 94035
Attn: Librarian

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771
Attn: Librarian

National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23365
Attn: Librarian

National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, Texas 77001
Attn: Librarian

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama 35812
Attn: Librarian

National Aeronautics and Space Administration
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91103
Attn: Librarian

Wah Chang Corporation
Albany, Oregon
Attn: Librarian
Attn: S. Worcester

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

Westinghouse Electric Corporation
Materials Manufacturing Division
RD No. 2 Box 25
Blairsville, Pennsylvania
Attn: Librarian
Attn: F. L. Orrell

Wolverine Tube Division
Calumet and Hecla, Inc.
17200 Southfield Road
Allen Park, Michigan
Attn: Mr. Eugene F. Hill

Wyman-Gordon Company
North Grafton, Massachusetts
Attn: Librarian

Westinghouse Electric
Aerospace Electrical Division
Lima, Ohio
Attn: Paul Kueser

Air Force Materials Laboratory
Research and Technology Division
Wright-Patterson Air Force Base, Ohio 45433
Attn: C. L. Harmsworth

Johns Hopkins University
Applied Physics Laboratory
8621 Sergia Avenue
Silver Spring, Maryland
Attn: Librarian

I. I. T. Research Institute
10 W. 35th Street
Chicago, Illinois 60616

Atomics International
8900 DeSoto Avenue
Canoga Park, California

AVCO
Research and Advanced Development Department
201 Lowell Street
Wilmington, Massachusetts
Attn: Librarian

Babcock and Wilcox Company
Research Center
Alliance, Ohio
Attn: Librarian

Battelle Memorial Institute
505 King Avenue
Columbus, Ohio
Attn: C. M. Allen
Attn: Librarian

The Bendix Corporation
Research Laboratories Division
Southfield, Detroit 1, Michigan
Attn: Librarian

The Boeing Company
Seattle, Washington
Attn: Librarian

Brush Beryllium Company
Cleveland, Ohio
Attn: Librarian

Carborundum Company
Niagara Falls, New York
Attn: Librarian

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

General Motors Corporation
Allison Division
Indianapolis 6, Indiana
Attn: Librarian

Hamilton Standard
Division of United Aircraft Corporation
Windsor Locks, Connecticut
Attn: Librarian

Hughes Aircraft Company
Engineering Division
Culver City, California
Attn: Librarian

Lockheed Missiles and Space Division
Lockheed Aircraft Corporation
Sunnyvale, California
Attn: Librarian

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

The Martin Company
Baltimore 3, Maryland
Attn: Librarian

The Martin Company
Nuclear Division
P. O. Box 5042
Baltimore 20, Maryland
Attn: Librarian

Chance Vought Aircraft Inc.
P. O. Box 5907
Dallas 22, Texas
Attn: Librarian

Clevite Corporation
Mechanical Research Division
540 East 105th Street
Cleveland 8, Ohio
Attn: Mr. N. C. Beerli,
Project Administrator

Climax Molybdenum Company of Michigan
Detroit, Michigan
Attn: Librarian

Convair Astronautics
5001 Kerrny Villa Road
San Diego 11, California
Attn: Librarian

Curtiss-Wright Corporation
Research Division
Tuehanna, Pennsylvania
Attn: Librarian

E. I. dePont de Nemours and Company, Inc.
Wilmington 98, Delaware
Attn: W. E. Lusby, Jr.
Defense Contracts Supervisor

Electro-Optical Systems, Incorporated
Advanced Power Systems Division
Pasadena, California
Attn: Librarian

Fansteel Metallurgical Corporation
North Chicago, Illinois
Attn: Librarian
Attn: Henry L. Kohn

Ford Motor Company
Aeronutronics
Newport Beach, California
Attn: Librarian

General Atomic
John Jay Hopkins Laboratory
P. O. Box 608
San Diego 12, California
Attn: Librarian

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

General Electric Company
Missile and Space Vehicle Dept.
3198 Chestnut Street
Philadelphia 4, Pennsylvania

General Electric Company
Vallecitos Atomic Laboratory
Pleasanton, California
Attn: Librarian

General Electric Company
Evendale, Ohio 45215
FPD Technical Information Center
Bldg. 100, Mail Drop F-22

General Electric Company
Reentry Systems Dept.
Cincinnati, Ohio 45215
Attn: Dr. J. W. Semmel
E. E. Hoffman

2 copies

Mr. R. M. Hanschka
Materials Engineering
Hamilton Standard
Windsor Locks, Connecticut

Bureau of Ships
Department of the Navy
Washington 25, D. C.
Attn: Librarian

Bureau of Weapons
Research and Engineering
Material Division
Washington 25, D. C.
Attn: Librarian

U. S. Naval Research Laboratory
Washington 25, D. C.
Attn: Librarian

Advanced Technology Laboratories
Division of American Standard
369 Whisman Road
Mountain View, California
Attn: Librarian

Aerojet General Nucleonics
P. O. Box 77
San Ramon, California
Attn: Librarian

AiResearch Manufacturing Company
Sky Harbor Airport
402 South 36th Street
Pheonix, Arizona
Attn: Librarian
E. A. Kovacevich

AiResearch Manufacturing Company
9851-9951 Sepulveda Boulevard
Los Angeles 45, California
Attn: Librarian

Martin Marietta Corporation
Metals Technology Laboratory
Wheeling, Illinois

Massachusetts Institute of Technology
Cambridge 39, Massachusetts
Attn: Librarian

Materials Research and Development
Manlabs, Inc.
21 Erie Street
Cambridge 39, Massachusetts

Materials Research Corporation
Orangeburg, New York
Attn: Librarian

McDonnell Aircraft
St. Louis, Missouri
Attn: Librarian

MSA Research Corporation
Callery, Pennsylvania
Attn: Librarian

National Research Corporation
70 Memorial Drive
Cambridge 42, Massachusetts
Attn: Librarian

North American Aviation
Los Angeles Division
Los Angeles 9, California
Attn: Librarian

Norton Company
Worcester, Massachusetts
Attn: Librarian

Pratt & Whitney Aircraft
400 Main Street
East Hartford 8, Connecticut
Attn: Librarian

Pratt & Whitney Aircraft
Materials Development Laboratory
P.O. Box 611
Middletown, Connecticut
Attn: Librarian

RCA
Defense Electronics Products
Astro-Electronics Division
Princeton, New Jersey
Attn: S. H. Winkler

Lawrence Radiation Lab
Technical Information Division
Livermore, California 94550
Attn: W. Blake Myers

General Electric Company
Nuclear Materials & Propulsion Operation
P. O. Box 132
Cincinnati, Ohio 45215
Attn: J. W. Stephenson (2 copies)

Dr. James Hadley
Head, Reactor Division
Lawrence Radiation Laboratory
P.O. Box 808
Livermore, California

H. F. Conrad
Process and Materials Division
Chemistry Department
Lawrence Radiation Laboratory
P.O. Box 808
Livermore, California

Matthew King
TRW SYSTEMS INC.
1 Space Park
Redondo Beach, California

ATTN: Nuclear Technology Dept.

Republic Aviation Corporation
Farmingdale, Long Island, New York
Attn: Librarian

Solar
2200 Pacific Highway
San Diego 12, California
Attn: Frank Hill
Manager
Aerospace Sales

Southwest Research Institute
8500 Culebra Road
San Antonio 6, Texas
Attn: Librarian

Rocketdyne
Canoga Park, California
Attn: Librarian

Attn: N. Hoffman

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

Sylvania Electric Products, Inc.
Chemical and Metallurgical
Towanda, Pennsylvania
Attn: Librarian

Temescal Metallurgical
Berkeley, California
Attn: Librarian

Union Carbide Corporation
Parma Research Center
Technical Information Service
P. O. Box 6116
Cleveland, Ohio 44101

Ultek Corporation
Kingston Building, Rm. 211
1373 Grandview Avenue
Columbus, Ohio
Attn: Bruce Weber

General Electric Company
Materials Applied Research
Materials Development Laboratory
Mail Zone M78
Evendale, Ohio
Attn: W. H. Chang

R. C. A.
Astron-Electronics Division
Post Office Box 500
Princeton, New Jersey
Attn: Librarian, Mr. Fred Meigs

Dr. Alan Lawley
Franklin Institute
Philadelphia 3, Pennsylvania

L. J. Goetz
General Electric Co.
Refractory Metals Plant
21801 Tungsten Road
Cleveland, Ohio 44117

Union Carbide Metals
Niagara Falls, New York
Attn: Librarian

Union Carbide Stellite Corporation
Kokomo, Indiana
Attn: Librarian

Union Carbide Nuclear Company
P. O. Box X
Oak Ridge, Tennessee
Attn: X-10 Laboratory Records Department 2 copies

United Nuclear Corporation
5 New Street
White Plains, New York
Attn: Librarian
Attn: Mr. Albert Weinstein,
Sr. Engineer

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

University of Michigan
Department of Chemical and Metallurgical Eng.
Ann Arbor, Michigan
Attn: Librarian

U. S. Atomic Energy Commission
Technical Reports Library
Washington 25, D. C.
Attn: J. M. O'Leary

University of California
Lawrence Radiation Laboratory
Technical Information Division
P. O. Box 808
Livermore, California 94551

U. S. Atomic Energy Commission
Germantown, Maryland
Attn: Col. E. L. Douthett
SNAP 50/SPUR Project Office
Attn: H. Rothen
SNAP 50/SPUR Project Office
Attn: Socrates Christofer
Attn: Major Gordon Dicker
SNAP 50/SPUR Project Office

U. S. Atomic Energy Commission
Technical Information Service Extension
P. O. Box 62
Oak Ridge, Tennessee

3 copies

U. S. Atomic Energy Commission
Washington 25, D. C.
Attn: M. J. Whitman

Argonne National Laboratory
9700 South Cross Avenue
Argonne, Illinois
Attn: Librarian

Brookhaven National Laboratory
Upton Long Island, New York
Attn: Librarian

Oak Ridge National Laboratory
Oak Ridge, Tennessee
Attn: Dr. W. O. Harms
Attn: Dr. A. J. Miller
Attn: Librarian

Office of Naval Research
Power Division
Washington 25, D. C.
Attn: Librarian

Vought Astronautics
P. O. Box 5907
Dallas 22, Texas
Attn: Librarian

National Aeronautics and Space Administration
21000 Brookpark Road
Cleveland, Ohio 44135

Attn: Librarian

Dr. Bernard Lubarsky (SPSD) MS 86-1

Roger Mather (NPTB)

G. M. Ault MS 105-1

Joe Joyce (NPTB) MS 86-5

Paul Moorhead (NPTB)

10 copies

John Creagh MS 86-5

John E. Dilley (SPSPS) MS 85-1

Norman T. Musial MS 77-1

Thomas Strom MS 5-8

T. A. Moss (NPTB) MS 86-5

Dr. Louis Rosenblum (MSD) (106-1)

R. Titran MS 105-1

R. Hall MS 105-1

George Tulisiak MS 14-1

National Aeronautics and Space Administration
Western Operations Office
150 Pico Boulevard
Santa Monica, California 90406
Attn: Mr. John Keeler

National Bureau of Standards
Washington 25, D. C.
Attn: Librarian

Aeronautical Systems Division
Wright-Patterson Air Force Base, Ohio
Attn: Charles Armbruster (ASRPP-10)
T. Cooper
Librarian
John L. Morris
H. J. Middendorp ASNRG 33143

Army Ordnance Frankford Arsenal
Bridesburg Station
Philadelphia 37, Pennsylvania
Attn: Librarian