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

SIXTEENTH QUARTERLY REPORT

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
UNDER CONTRACT NAS 3-9439

TRW EQUIPMENT LABORATORIES
CLEVELAND, OHIO

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For

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

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Prepared for:

National Aeronautics and Space Administration
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FOREWORD

The work described herein is being performed by TRW Inc. under the sponsorship of the National Aeronautics and Space Administration under Contract NAS 3-9439. 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, K. D. Sheffler is the Principal Investigator, and R. R. Ebert contributed to the program. The NASA technical director is Paul E. Moorhead.

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ABSTRACT

The molybdenum-base alloys TZC and TZM, and the tantalum-base alloys T-111, Ta-10W and ASTAR 811C are being creep tested at temperatures of 1600°F-2600°F (870 to 1427°C) in a vacuum environment of <1 x 10^{-8} torr. Test parameters are generally chosen to provide extensions of 0.5 to 1% in tests as long as 15,000 hours.

Test results from TZC and TZM show the effects of variations in composition and thermal mechanical processing history on 1/2% creep life. Analysis of these data using the Larson-Miller parameter indicate that at higher stress levels and lower temperatures a specially processed lot of TZM, having a somewhat higher than normal carbon content, is superior to TZC in the stress relieved condition. At lower stresses and higher temperatures, however, the behavior of the two materials is comparable.

Results of a sequential test on W-25% Re alloy show that this alloy does not creep in the 1600 to 1800°F (870 to 982°C) range at 10 Ksi (6.89 x 10^7 N/m^2). Preliminary results indicate that some creep may be occurring in this same temperature range at 15 Ksi (10.4 x 10^7 N/m^2).

Creep data for five different heats of tantalum-base T-111 alloy show good agreement between heats, and sufficient data are presented to provide a Larson-Miller design curve.

Progressive stress results indicate that T-111 creeps at essentially the same rates in this type of test as in static tests at equivalent stress levels. This result has permitted development of a strain rate integration technique for prediction of progressive stress creep lives which appears at least as good and possibly better than the Larson-Miller integration technique discussed in the Nine Month Summary Report.

Preliminary results from a Ta-10W sequential test indicate that the creep resistance of this alloy will lie near the upper edge of the T-111 scatter band on a Larson-Miller plot.

Results at a single creep test in progress on ASTAR-811C, a relatively new dispersion strengthened tantalum-base alloy developed by Westinghouse for NASA show excellent agreement with data published by the developer which indicate significantly better creep resistance than T-111.

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INTRODUCTION

Refractory metal alloys are currently specified or considered for a variety of applications in space electric power systems. Among these is the proposed use of the molybdenum base alloys TZC and TZM as turbine components, and the tantalum-base alloys T-111, Ta-10W, and ASTAR 811C for tubing or radioisotope capsule fabrication. Long time creep strength is a critical property in these applications because of the high service temperatures. Since the systems will operate either in the vacuum of outer space or in liquid metal environments where the partial pressure of reactive gases is extremely low, it is necessary to creep test candidate materials in a non-contaminating environment in order to generage representative design data because of the sensitivity of creep behavior to interstitial contaminants. The purpose of this program is to develop the required creep data for TZM, TZC, and the tantalum base alloys in an ultra-high vacuum of $<1 \times 10^{-8}$ torr at temperatures and stresses chosen to provide 1/2% to 1% creep in times up to 15,000 hours.

Consideration of T-111 for radiosotope capsule fabrication has created a need to study the creep behavior of this material under the influence of progressively increasing stresses. The isotopes involved generate helium gas as a decay product, so that the sealed capsule is subjected to continuously increasing pressure during operation, as well as a decreasing temperature because of decay. Two approaches are being taken to obtain the required data; first, analytical techniques are being developed to predict the progressive stress 1% creep life of T-111 from conventional constant load creep test data. Second, creep tests are being conducted on T-111 with progressively increasing loads in order to evaluate the analytical predictions. Methods for correlating the stress rate and temperature dependence of the experimental progressive stress creep lives are also being studied.

In addition to long-time creep testing, several auxiliary studies are being made under this program. A sequential creep test is being performed on Ta-10W alloy to aid in the selection of parameters for long time tests, while an annealing study is being made on ASTAR 811C in order to select the optimum heat treatment for this alloy prior to initiation of a long time test program. A sequential test is also in pregress on W-25% Re to evaluate the suitability of this alloy for stressed diaphram or high temperature spring applications.

EXPERIMENTAL DETAILS

Materials

Sources of the test materials and details of the available processing histories have been presented elsewhere (1). Chemical analyses of each of the heats tested are shown in Table 1.

TZM has been evaluated in three forms -- swaged bar (Heat 7463), a conventionally processed disc forged at 2200°F (1204°C) (Heat 7502), and a section of another disc which has a higher than normal carbon level and was fabricated with a sequence designed to produce improved creep resistance (2). TZM is being evaluated primarily in the stress relieved condition.

The tantalum-base alloys are being evaluated in the form of 0.030 inch sheet. T-111 and Ta-10W are recrystallized 1 hour at 3000°F (1649°C) prior to testing, while the specimen of ASTAR 811C currently being tested was annealed 1/2 hour at 3600°F (1982°C).

Test Procedures

The experimental program involves creep testing of sheet and bar specimens at temperatures ranging from 1600 to 2600°F (870 to 1427°C), and at stresses between 500 and 65,000 psi (0.34 to 44.8 x 10^7 N/m^2). A combination of parameters is generally selected which will provide 1/2 to 1% total creep in 5000 to 15,000 hours. Two inch gauge length button-head bar type specimens and double-shoulder pin loaded sheet-type specimens are used respectively for testing of plate and sheet-type materials. The orientation of the specimen with respect to the working direction is given below:

Material Form	Specimen Axis Parallel to
Disc Forging	Radius of disc
Plate	Extruding direction
Sheet	Rolling Direction (except where indicated)

Both the construction and operation of the test chambers and the service instruments in the laboratory have been described in detail in previous reports (Appendix I). The creep test procedure involves initial evacuation of the test chamber to a pressure of less than 5 x 10^{-10} torr at room temperature, followed by heating of the test specimen at such a rate that the pressure never rises above 1 x 10^{-6} torr. Pretest heat treatments are performed in situ, and complete thermal equilibrium of the specimen is insured by a two hour hold at the test temperature prior to load application.

TABLE 1

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

Material	W	Re	Mo	Ta	Hf	C	Ti	Zr	PPM			Finished Form
									N_2	O_2	H_2	
TZM (Heat 7463)			Bal.			.016	.48	.08	1	2	1 (2)	5/8" dia. bar
(Heat 7502)			Bal.			.010	.51	.091	100	20	7	Forged disc
(Heat KDTZM-1175)			Bal.			.035	.61	.120	43	34	9	Forged disc
TZC (Heat M-80)			Bal.			.127	1.02	.17	18	41	10	Rolled plate
(Heat M-91)			Bal.			.113	1.17	.270	34	37	10	Forged plate
(Heat 4345)			Bal.			.075	1.19	.16	9	19	2	Forged plate
T-111 (Heat 70616)	8.5			Bal.	2.30	.0044			20	55	6	Nominal
(Heat 65079)	8.7			Bal.	2.30	.003			50	130	4	0.030 in.
(Heat 65076)	8.6			Bal.	1.95	.004			20	100	3	Rolled
(Heat D-1102)	7.9			Bal.	2.28	.003			34	20	3	Sheet
(Heat D-1670)	7.9			Bal.	2.37	<.001			20	72	<5	"
(Heat D-1183)	8.7			Bal.	2.2	.0036			10	25	6	"
ASTAR 811C	8.0	1.0		Bal.	0.7	.0250			-	-	-	"
Commercially Pure Ta				Bal.		.0051			2.4	7	3	Extruded tubing
Ta-10W (Heat 630002)	9.9			Bal.		.0044			25	100	5	Nominal 0.030" Rolled sheet
W-25% Re (Heat 35-75002)	Bal.	24.88			.52	.0300			17	20	3	"

The pressure is always below 1×10^{-8} torr during the tests and generally falls into the 1×10^{-10} or 1×10^{-11} range as testing proceeds. Specimen extension is determined over a two inch gauge length with an optical extensometer which measures the distance between two scribed reference marks to an accuracy of $\pm$ 50 microinches.

Specimen temperature is established at the beginning of each test using a W-3% Re - W-25% Re thermocouple. Since thermocouples of all types are subject to a time dependent change in EMF output under isothermal conditions, the absolute temperature during test is maintained by an optical pyrometer. In practice the specimen is brought to the desired test temperature using the calibrated thermocouple attached to the specimen as a temperature standard. The use of this thermocouple is continued during the temperature stabilization period which lasts 50 to 100 hours. At this time a new reference is established using an optical pyrometer having the ability to detect a temperature difference of $\pm$ 1F°, and this reference is used subsequently as the primary temperature standard.

RESULTS AND DISCUSSION

A complete tabulation of all tests conducted on the creep program is presented in Appendix II, while creep curves for each test involved in the current reporting period are compiled in Appendix III.

The property generally used to characterize creep behavior is the time required to reach 1/2% or 1% creep, as measured from a loaded start. The Larson-Miller parameter is employed for correlation and presentation of the design data.

Molybdenum Base Alloys

The final test in the TZC program (B-37) has been completed, and the results are summarized together with all of the TZC data on a Larson-Miller plot in Figure 1. Significant variation of properties is observed between the various heats and heat treatments studied, but the data can be used to indicate the general capabilities of this material for comparison with other refractory alloys.

The extrapolated creep life of a single test still in progress on TZM Heat KDTZM-1175 (B-38) is shown on a Larson-Miller plot in Figure 2 together with the TZM data from Appendix II. This heat (KDTZM-1175) received a special processing involving a very high temperature side forging (3400°F) (1870°C) followed by pancake forging in the 2800-2100°F (1538 to 1147°C) range, and this special processing has provided improved creep resistance. Comparison of the TZM results with those in Figure 1 shows that at higher stress levels and lower temperatures this material is superior to TZC. However, at lower stress levels and higher temperatures the behavior of the two materials is comparable.

W-25% Re Alloy

Results of a sequential test series (S-55A-E) performed on W-25% Re stress relieved 1 hour at 2550°F (1400°C) have shown essentially no creep in the temperature range of 1600 to 1800°F (870 to 982°C) at 10 Ksi. A second test program (S-61) involving five successive 200 hour tests at 50F° intervals between 1600 and 1800°F (870 and 982°C) has therefore been initiated at 15 Ksi on the same sample. Results of the first two sequences again show little or no creep at 1600 and 1650°F (869 and 900°C), but it appears that a small amount of creep (approximately .008% in 200 hours) has occurred at 1700°F (927°C). Results of the completed test series will be analyzed in the next quarterly report.

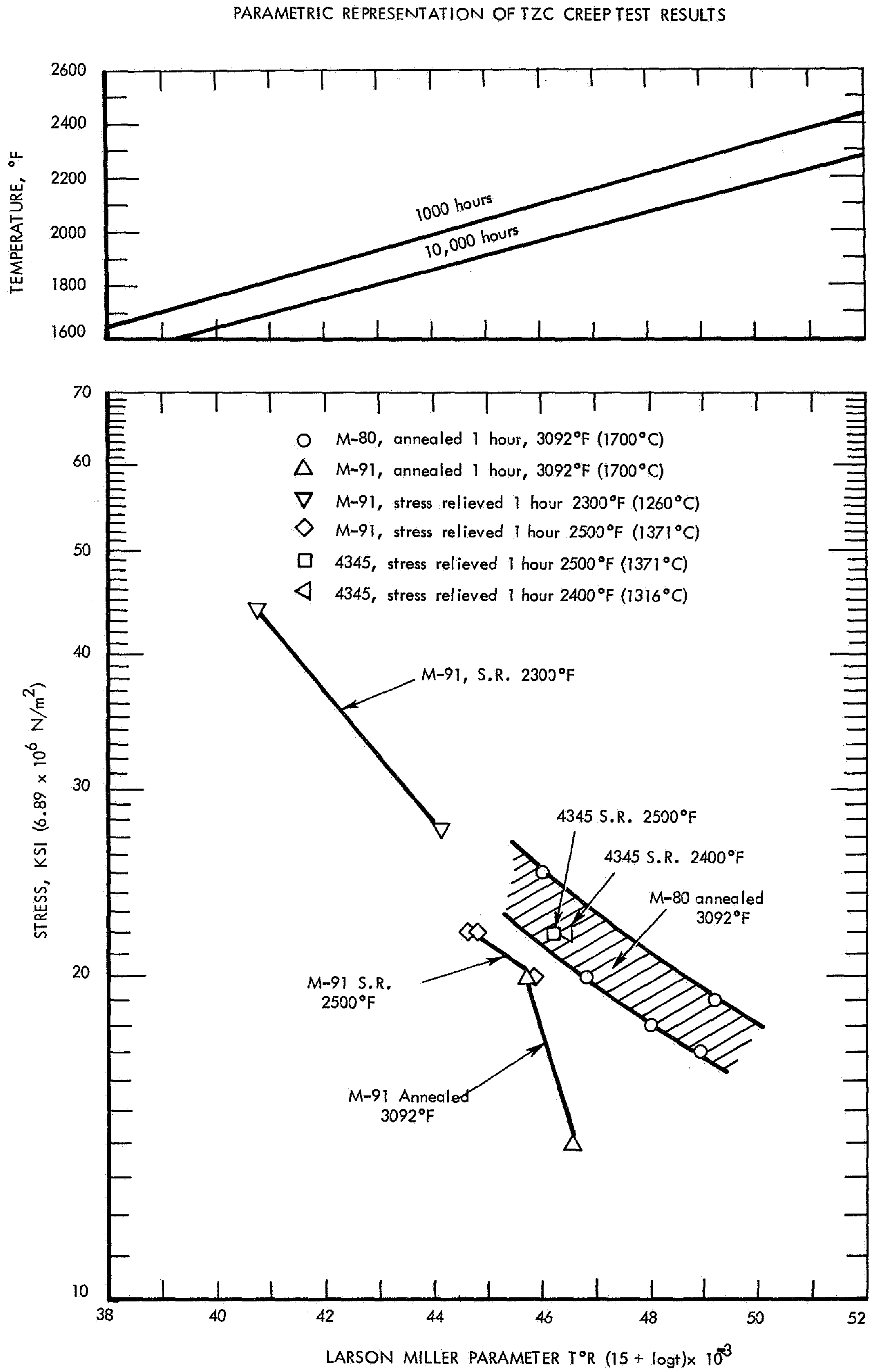

FIGURE 1. PARAMETRIC REPRESENTATION OF TZC 0.5% CREEP TEST RESULTS.

1389 B

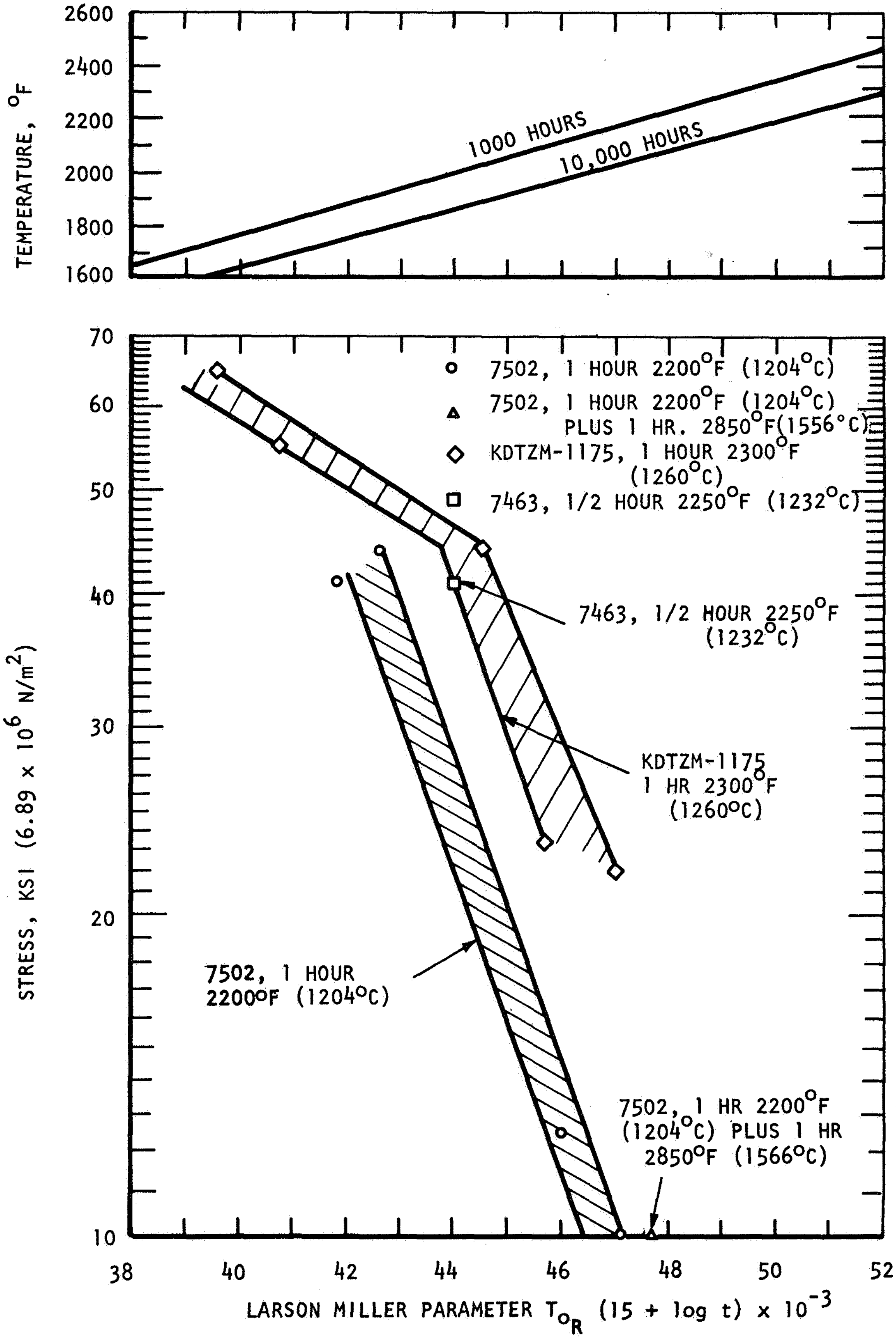

FIGURE 2. 1/2% CREEP TEST RESULTS FOR TZM TESTED IN A VACUUM ENVIRONMENT OF < 1 x 10^{-8} TORR.

2982 B

Tantalum Base Alloys

The test program on unalloyed tantalum was completed during this report period with the termination of test B-42B. The extrapolated 1% creep life of this test is essentially the same as that reported in the 15th quarterly.

One percent creep life results from the three tantalum base alloys T-111, Ta-10W, and ASTAR 811C are summarized on a Larson-Miller plot in Figure 3, together with data from the literature on ASTAR 811C (3). Excellent agreement is shown in this figure between the five heats of T-111 tested to date.

Ta-10W Alloy

The Ta-10W test results in Figure 3 indicate that the creep resistance of this alloy will lie at about the upper edge of the T-111 scatter band. Based on this observation a long time test at 2000°F (1093°C) and 16 Ksi (11.0×10^7 N/m^2) will be initiated during the coming report period.

ASTAR 811C

Results of a single test in progress on ASTAR 811C annealed 1/2 hour at 3600°F (1882°C) are plotted in Figure 3 together with a series of test results from the Westinghouse Astronuclear Laboratory, the developer of this alloy. While the creep resistance of ASTAR 811C is significantly better than T-111 in all conditions of heat treatment, the specimens annealed in the 3600°F (1982°C) range possess particularly good creep strength. However, some concern is felt over the grain growth which may have occurred at the high annealing temperature, and an annealing study has therefore been initiated on ASTAR 811C to develop a heat treatment which provides the optimum compromise between creep strength and grain size.

Data from Westinghouse indicate that the improved creep resistance is not produced by annealing as high as 3450°F (1900°C), thereby narrowing the range of evaluation necessary in this program. Results of the Westinghouse study on grain growth in ASTAR 811C (4) are shown on a Larson-Miller plot in Figure 4, where mean grain diameter (mm) is plotted against a Larson-Miller parameter calculated with a constant of 8, using the time and temperature of heat treatment as variables. Also shown on this plot are grain growth data generated at TRW on the same material. The two sets of results agree reasonably well, although the TRW results tend to be somewhat higher.

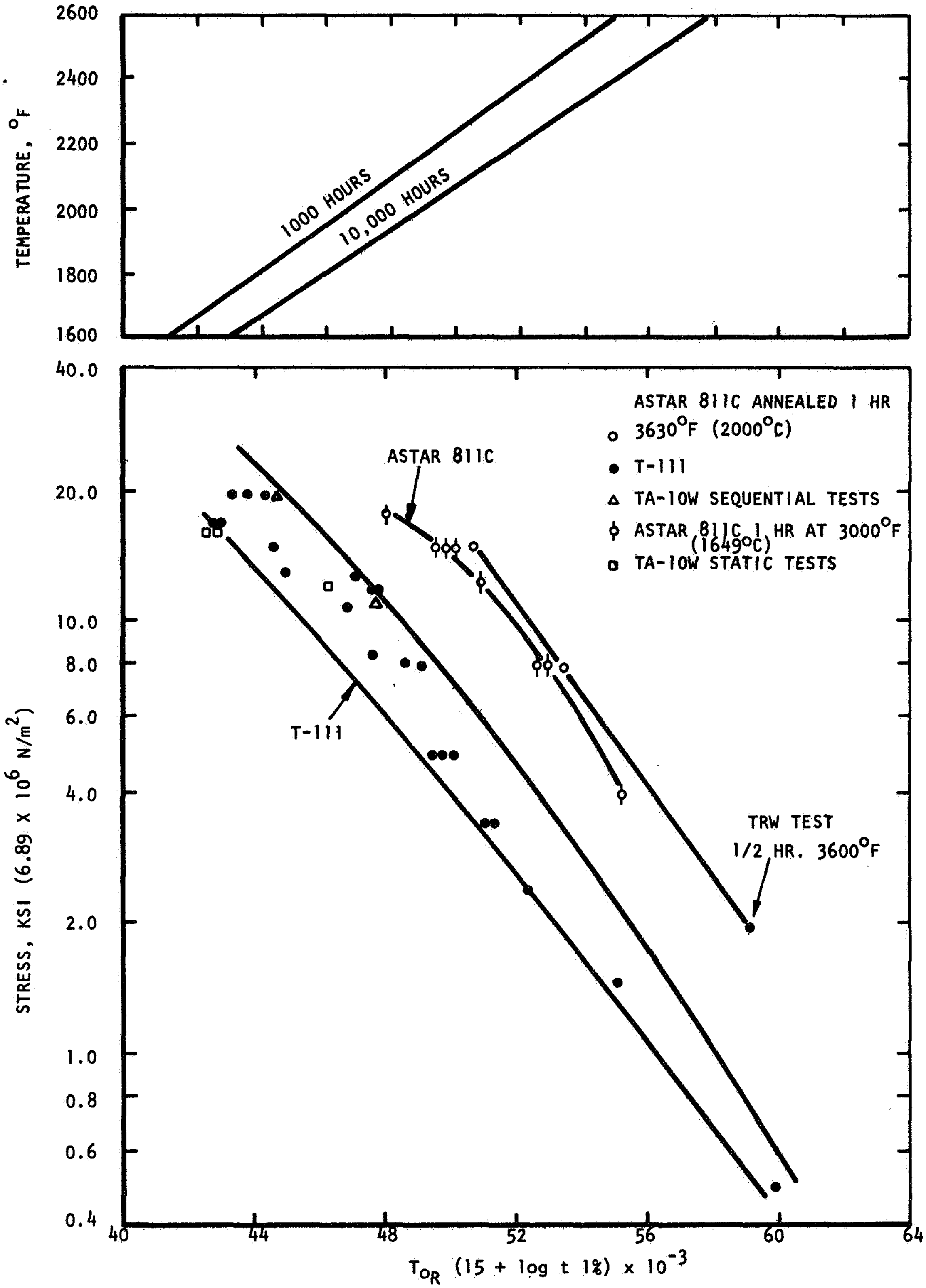

FIGURE 3. LARSON MILLER PLOT OF 1% CREEP LIFE DATA FOR TANTALUM BASE ALLOYS, ANNEALED 1 HOUR AT 3000°F (1640°C) EXCEPT WHERE NOTED OTHERWISE.

3895 B

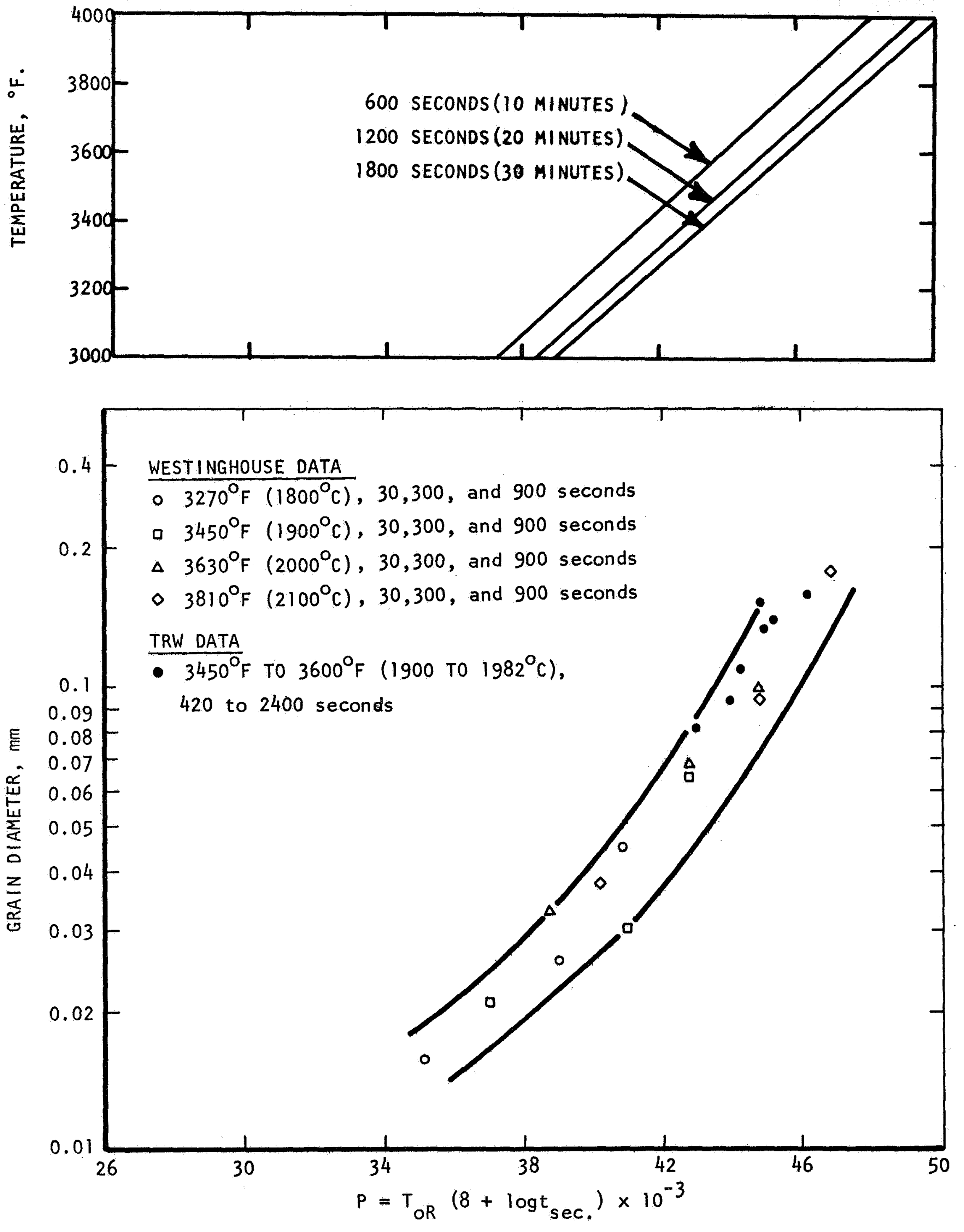

FIGURE 4. LARSON MILLER PLOT OF GRAIN GROWTH DATA FOR ASTAR 811C COLD ROLLED TO 85% R.A. (HEAT NASV-20-WS).

Arbitrarily selecting a mean diameter of 0.1 mm (0.004 in.) as the maximum acceptable grain size in a 0.035 in. sheet, a Larson-Miller parameter can be chosen from the upper edge of the scatter band and the various time-temperature combinations necessary to achieve this grain size can then be calculated. The required treatment times in the 3450 to 3600°F (1900 to 1982°C) range are shown in Figure 5. During the coming report period, experiments will be conducted to evaluate the potential creep resistance of samples heat treated in this range.

T-111 Progressive Stress Tests

Results of the progressive stress tests completed or in progress to date are summarized in Table 2. Several techniques are currently being evaluated for analysis of these results. The first involves plotting creep strain as a function of stress, which provides a classical stress-strain diagram on which progressive stress data can be compared to conventional tension test results (Figure 6). This form of analysis is particularly useful for visualizing the influence of stress rate and temperature on the relative shapes of the tension and creep test curves. At the higher test temperatures and lower stress rates, the curves show early "yield" followed by a gradually decreasing slope, while at the lower test temperatures and higher stress rates, a greater portion of the deformation is elastic, and the transition to plastic deformation is much sharper. The tendency for most of the deformation to be elastic at the lower temperatures and higher stress rates provides an excellent rationalization of the limiting stress rate concept proposed in the Nine Month Summary Report. Under these test conditions, very little plastic deformation occurs until the stress approaches a high percentage of the yield strength, at which point the curve breaks rather sharply and significant deformation is achieved in a relatively short time.

Another approach to analysis of the progressive stress data involves comparison of static and progressive stress creep rates. It has been shown in a previous report that the static steady state creep rate of recrystallized T-111 can be described analytically as

$$\dot{\varepsilon} = Ae^{B\sigma}e^{-\Delta H/RT} \tag{1}$$

in the temperature and stress ranges of 1800 to 2400°F (982 to 1316°C) and 2400 to 20,000 psi (1.65 to 13.8 x 10^7 N/m^2). This expression is useful for comparison of static and progressive stress results since it allows all of the strain rates to be displayed on a single plot of stress versus $\dot{\varepsilon}e^{\Delta H/RT}$. The strain rate at various stresses in the progressive stress tests, which were obtained by simple numerical differentiation of the creep curves, are plotted according to this form in Figure 7 together with the static data. Although the scatter is somewhat greater, the strain rates achieved in the progressive stress tests are in the same range as the static test data.

TABLE 2

Summary of Progressive Stress Tests on T-111 Annealed 1 hour at 3000°F

Test No.	Heat No.	Temp.°F	Loading Rate psi/hr.	1% Creep Life Predicted(1)	1% Creep Life Observed	1% Creep Life Predicted(2)
S-36	65080	2200	16	485	600	-
S-38	65080	2200	1	4260	3830	-
S-46	65079	2200	16	880	1000*	895
S-49	65079	1800	20	1200/1700**	1660	1430
S-51	D-1183	2200	16	880	1080	895
S-52	65079	2000	13	2000	1600	1540
S-53	65079	2200	5	2200	2240	2260
S-54	65079	2000	5	4400	4000*	3500
S-56	65079	1800	5	8900	***	4990
S-57	65079	2200	1	7700	***	7340

* Extrapolated

** Based upon rate of approach to yield strength

*** Insufficient to extrapolate

(1) Predicted by the Larson-Miller integration technique.
(2) Predicted by integration of instantaneous static strain rates.

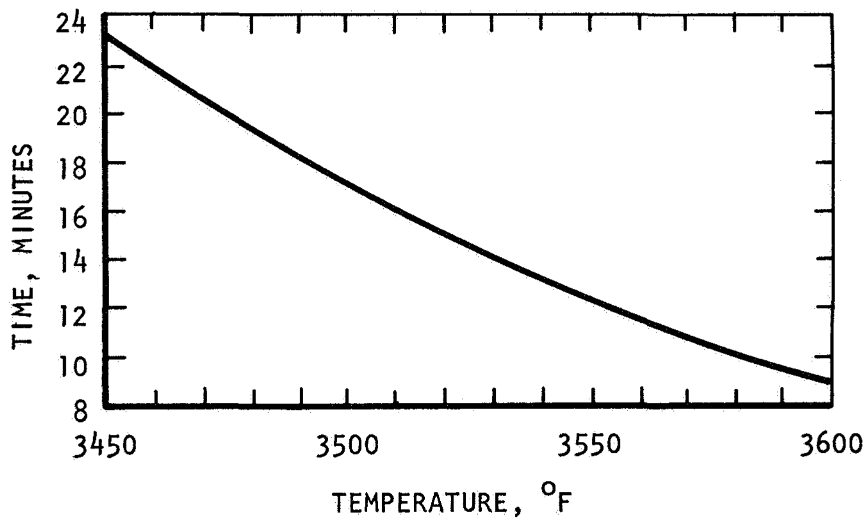

FIGURE 5. ANNEALING TIME REQUIRED FOR 0.1mm GRAIN DIAMETER IN ASTAR 811C COLD ROLLED TO 85% R.A. (HEAT NASV-20-WS).

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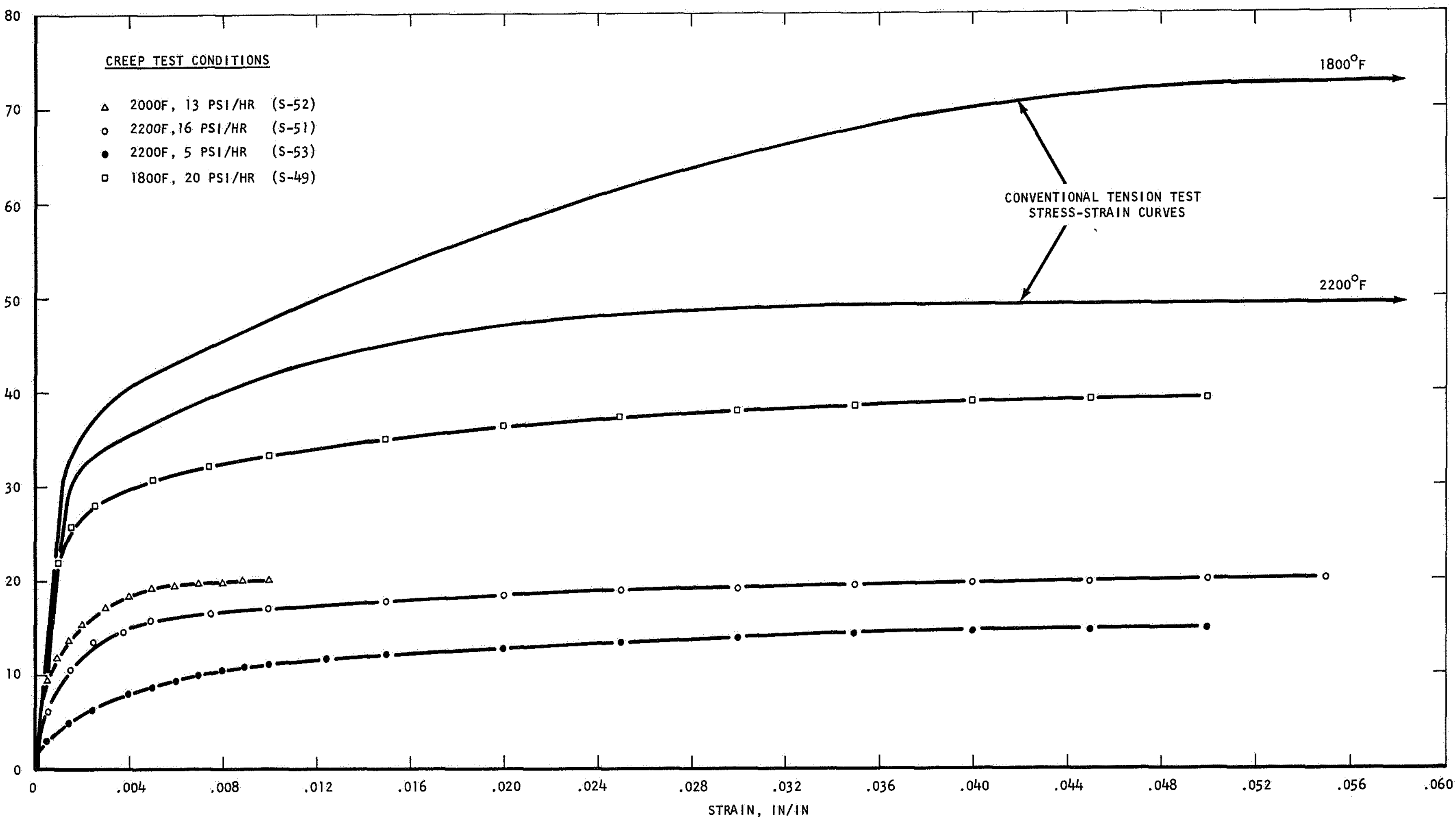

FIGURE 6. COMPARISON OF STRESS-STRAIN CURVES OBTAINED IN PROGRESSIVE STRESS CREEP TESTS WITH CONVENTIONAL TENSION TEST RESULTS FOR RECRYSTALLIZED T-111 ALLOY.

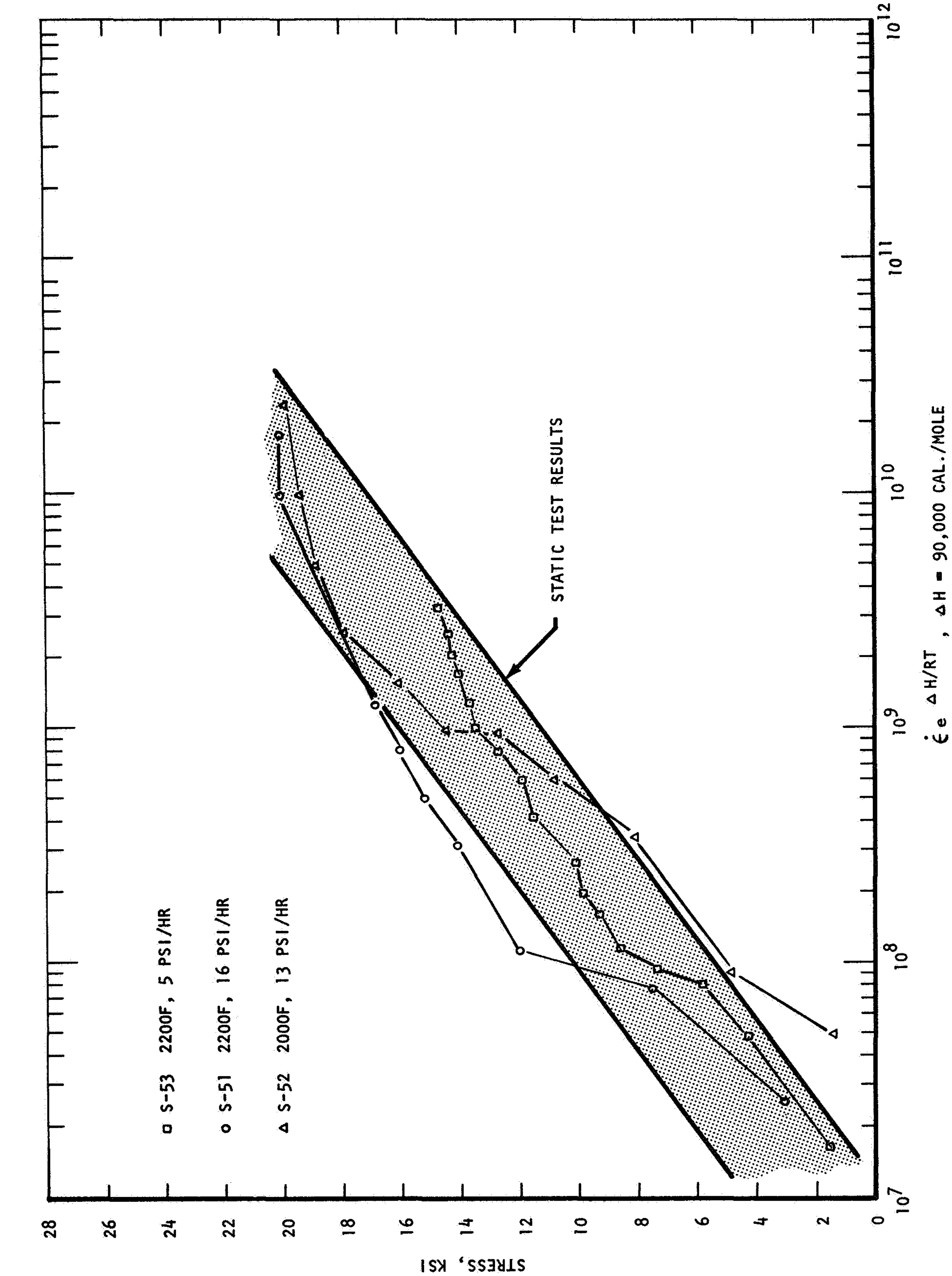

FIGURE 7. COMPARISON OF STATIC AND PROGRESSIVE STRESS CREEP RATES IN RECRYSTALLIZED T-111 ALLOY.

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The above result is significant because it means that integration of the static creep test steady state strain rates should predict the progressive stress creep lives. The strain at any point in a progressive stress test is simply the integral of the strain rate as a function of time:

$$\varepsilon = \int_0^t \dot{\varepsilon}(t)\, dt \qquad (2)$$

If the functional relationship of $\dot{\varepsilon}$ to stress and the time dependence of stress are known, this equation can be expressed in the form:

$$\varepsilon = \int_0^t \dot{\varepsilon}[\sigma(t)]\, dt \qquad (3)$$

We know the form of $\dot{\varepsilon}(\sigma)$ from Equation (1) and $\sigma(t)$ is simply

$$\sigma = \dot{\sigma}\, t \qquad (4)$$

for the linearly increasing stress test. Inserting these two expressions in (3) yields:

$$\varepsilon = \int_0^t Ae^{B\dot{\sigma}t} e^{-\Delta H/RT} dt \qquad (5)$$

which can be integrated analytically to evaluate the upper limit (which is creep life) for any desired strain. Choosing $\varepsilon = .01$ results in an expression for 1% creep life of the form:

$$0.01 = \frac{Ae^{-\Delta H/RT}}{B\dot{\sigma}} \left(e^{B\dot{\sigma}L} - 1\right) \qquad (6)$$

or, rearranging,

$$L = \frac{1}{B\dot{\sigma}} \ln\left\{ \frac{0.01B\dot{\sigma}}{Ae^{-\Delta H/RT}} + 1 \right\} \qquad (7)$$

Using appropriate values of A, B, and ΔH as listed in (5), the 1% creep life of each of the progressive stress tests has been calculated and listed in Table 2. Although sufficient data are not presently available for a critical evaluation of the predictions, it appears that they are at least as good and perhaps better than those made by the Larson-Miller integration technique described in the Nine Month Summary Report.

SUMMARY

1. Larson-Miller analysis of creep test results on molybdenum-base TZC and TZM alloys shows that at higher stress levels and lower temperatures a specially processed lot of TZM having a somewhat higher than normal carbon content is superior to TZC in the stress relieved condition, whereas at higher temperatures and lower stresses, the behavior of the two materials is comparable.

2. W-25% Re undergoes no detectable creep at 10 ksi (6.89 x 10^7 N/m^2) in the temperature range from 1600 to 1800°F (870 to 982°C).

3. Design data for T-111 in the temperature and stress range of 1800 to 2600°F (980 to 1427°C) and 0.5 to 20 ksi (.394 to 14.0 x 10^7 N/m^2) are presented in the form of a Larson-Miller plot for 1% creep life.

4. T-111 alloy creeps at essentially the same rate in progressive stress tests as in static tests at equivalent stress levels. A strain rate integration technique has been developed to predict the 1% creep life of a progressive stress test, and the results appear at least as good and possibly better than those from the Larson-Miller integration technique.

5. The creep resistance of Ta-10W appears to be slightly better than T-111.

6. Results of a single test on ASTAR 811C are in good agreement with data from Westinghouse, the developer of this alloy, which show it to have significantly better creep resistance than T-111.

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APPENDIX I

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APPENDIX II

SUMMARY OF ULTRA-HIGH VACUUM CREEP TEST RESULTS GENERATED ON THE REFRACTORY ALLOY CREEP PROGRAM

3679 B

TABLE II-I

Summary of Arc-Melted W Ultra-High Vacuum Creep Test Results

TEST NO.	HEAT NO.	HEAT TREATMENT			STRESS		TEST TEMPERATURE		1% CREEP LIFE	TERMINATION OF TEST		1% CREEP LARSON-MILLER PARAMETER
		TIME HOURS	TEMPERATURE °F	TEMPERATURE °C	KSI	N/M^2 $x10^{-7}$	°F	°C	HOURS	TIME, HOURS	PERCENT CREEP	$T_{°R}(15 + \log t)x10^{-3}$
S-5	KC-1357	24	3200	1760	3.0	2.07	3200	1760	6	32	5.38	57.8
S-7	KC-1357	2	3200	1760	0.4	0.28	3200	1760	***	714	118	***
S-9	KC-1357	2	3200	1760	1.0	0.69	3200	1760	675	3886	2.760	65.4
S-17	KC-1357	2	2800	1538	4.0	2.80	2800	1538	20	218	5.452	53.1
S-18	KC-1357	2	2800	1538	3.0	2.07	2800	1538	125	908	5.535	55.8

*** Insufficient creep to extrapolate

3680 B

TABLE II-2

Summary of Vapor-Deposited W Ultra-High Vacuum Creep Test Results

TEST NO.	HEAT NO.	HEAT TREATMENT TIME HOURS	HEAT TREATMENT TEMPERATURE °F	HEAT TREATMENT TEMPERATURE °C	STRESS KSI	STRESS N/M^2 $x10^{-7}$	TEST TEMPERATURE °F	TEST TEMPERATURE °C	1% CREEP LIFE HOURS	TERMINATION OF TEST TIME, HOURS	TERMINATION OF TEST PERCENT CREEP	1% CREEP LARSON-MILLER PARAMETER $T_{°R}(15 + \log t) \times 10^{-3}$
B-17	-	1	3200	1760	1.0	0.69	3200	1760	1140	2671	1.570	66.0
B-24	-	1	2800	1538	2.0	1.38	2800	1538	1500	6812	3.708	59.2

3884 B

TABLE II-3

Summary of W-25%Re Ultra-High Vacuum Creep Test Results

TEST NO.	HEAT NO.	HEAT TREATMENT TIME HOURS	HEAT TREATMENT TEMPERATURE °F	HEAT TREATMENT TEMPERATURE °C	STRESS KSI	STRESS N/M^2 $x10^{-7}$	TEST TEMPERATURE °F	TEST TEMPERATURE °C	1% CREEP LIFE HOURS	TERMINATION OF TEST TIME, HOURS	TERMINATION OF TEST PERCENT CREEP	1% CREEP LARSON-MILLER PARAMETER $T_{°R}(15 + \log t) x10^{-3}$
S-3	3.5-75002	48	3200	1760	5.0	3.44	3200	1760	12	45	6.03	58.9
S-4	3.5-75002	45	3200	1760	3.0	2.07	3200	1760	25	97	5.22	60.0
S-6	3.5-75002	1	3200	1760	0.5	0.34	3200	1760	***	253	0.090	***
S-8	3.5-75002	1	3200	1760	1.5	1.03	3200	1760	315	1306	5.113	64.0
S-55A	3.5-75002	1	2550	1400	10	6.89	1600	869	-	200	.005	-
S-55B	3.5-75002		- - -		10	6.89	1650	900	-	203	.005	-
S-55C	3.5-75002		- - -		10	6.89	1700	927	-	196	.008	-
S-55D	3.5-75002		- - -		10	6.89	1750	954	-	241	.018	-
S-55E	3.5-75002		- - -		10	6.89	1800	980	-	257	.035	-
S-61A	3.5-75002		- - -		15	10.4	1600	869	-	235	.008	-
S-61B	3.5-75002		- - -		15	10.4	1650	900	-	169	.022	-
S-61C	3.5-75002		- - -		15	10.4	1700	927	-	196	.038	-
S-61D	3.5-75002		- - -		15	10.4	1750	954	-	200	.058	-

** Test in Progress
*** Insufficient creep to extrapolate

3682 B

TABLE II-4

Summary of Sylvania A Ultra-High Vacuum Creep Test Results

TEST NO.	HEAT NO.	HEAT TREATMENT TIME HOURS	HEAT TREATMENT TEMPERATURE °F	HEAT TREATMENT TEMPERATURE °C	STRESS KSI	STRESS N/M^2 $x10^{-7}$	TEST TEMPERATURE °F	TEST TEMPERATURE °C	1% CREEP LIFE HOURS	TERMINATION OF TEST TIME, HOURS	TERMINATION OF TEST PERCENT CREEP	1% CREEP LARSON-MILLER PARAMETER $T_{°R}(15 + \log t)x10^{-3}$
S-12	-	2	3200	1760	5.0	3.44	3200	1760	35	170	5.25	60.6
S-15	-	2	3200	1760	3.0	2.07	3200	1760	250	907	5.862	63.7

3675 B

TABLE II-5

Summary of AS-30 Ultra-High Vacuum Creep Test Results

TEST NO.	HEAT NO.	HEAT TREATMENT TIME HOURS	HEAT TREATMENT TEMPERATURE °F	HEAT TREATMENT TEMPERATURE °C	STRESS KSI	STRESS N/M^2 $x10^{-7}$	TEST TEMPERATURE °F	TEST TEMPERATURE °C	1/2% CREEP LIFE HOURS	TERMINATION OF TEST TIME, HOURS	TERMINATION OF TEST PERCENT CREEP	1/2% CREEP LARSON-MILLER PARAMETER $T_{°R}(15 + \log t)x10^{-3}$
B-2	C5	As-Rolled			12.0	8.27	2000	1093	390	806	1.020%	43.3
B-6	C5	As-Rolled			11.0	7.58	2000	1093	450	1192	1.016%	43.5
B-7	C5	As-Rolled			8.0	5.51	2200	1204	115	230	1.025%	45.4

TABLE II-6

Summary of Cb-132M Ultra-High Vacuum Creep Test Results

TEST NO.	HEAT NO.	HEAT TREATMENT			STRESS		TEST TEMPERATURE		1/2% CREEP LIFE	TERMINATION OF TEST		1/2% CREEP LARSON-MILLER PARAMETER
		TIME HOURS	TEMPERATURE °F	TEMPERATURE °C	KSI	N/M^2 $\times 10^{-7}$	°F	°C	HOURS	TIME, HOURS	PERCENT CREEP	$T_{°R}(15 + \log t)\times 10^{-3}$
B-13	KC-1454	1	3092	1700	20.0	13.80	2056	1125	275	568	1.170	43.8
B-14	KC-1454	1	3092	1700	16.3	8.23	2056	1125	340	691	1.026	44.0
B-15	KC-1454	1	3092	1700	7.4	5.10	2256	1236	250	596	1.100	47.2

3677 B

3885 B

TABLE II-7

Summary of TZM Ultra-High Vacuum Creep Test Results

TEST NO.	HEAT NO.	HEAT TREATMENT TIME HOURS	HEAT TREATMENT TEMPERATURE °F	HEAT TREATMENT TEMPERATURE °C	STRESS KSI	STRESS $N/M^2 \times 10^{-7}$	TEST TEMPERATURE °F	TEST TEMPERATURE °C	1/2% CREEP LIFE HOURS	TERMINATION OF TEST TIME, HOURS	TERMINATION OF TEST PERCENT CREEP	1/2% CREEP LARSON-MILLER PARAMETER $T_{°R}(15 + \log t)\times 10^{-3}$
B-1	7502	1	2200	1204	12.6	8.65	2130	1165	605	646	1.105	46.1
B-3	7502	1	2200	1204	10.0	6.89	2000	1095	14,200*	10,048	0.375	47.1
B-29	7502	1	2200	1204	41.0	28.20	2000	1095	100	664	6.215	41.8
B-35	7502	1	2200	1204	44.0	30.30	1800	982	7000	7659	0.535	42.6
B-4	7502	1	2200	1204	10.0	6.89	2000	1095	25,000*	10,012	0.368	47.7
	Plus	1	2850	1566								
B-16	KDTZM-1175	1	2300	1260	23.4	16.10	1855	1013	62,500*	4376	0.035	45.8
B-18	KDTZM-1175	1	2300	1260	55.0	37.90	1600	871	60,000*	2159	0.018	40.7
B-21	KDTZM-1175	1	2300	1260	65.0	44.80	1600	871	15,000*	1630	0.085	39.5
B-25	KDTZM-1175	1	2300	1260	44.0	30.30	1800	982	50,000*	10,152	0.182	44.5
B-38	KDTZM-1175	1	2300	1260	22.0	15.10	2000	1093	12,000*	**	**	47.0
B-34	7463	1/2	2250	1232	41.0	28.20	2000	1093	790	1440	1.658	44.0

* Extrapolated data

** Test in progress

3676 B

TABLE II-8

Summary of Cb Modified TZM Ultra-High Vacuum Creep Test Results

TEST NO.	HEAT NO.	HEAT TREATMENT TIME HOURS	HEAT TREATMENT TEMPERATURE °F	HEAT TREATMENT TEMPERATURE °C	STRESS KSI	STRESS $N/M^2 \times 10^{-7}$	TEST TEMPERATURE °F	TEST TEMPERATURE °C	1/2% CREEP LIFE HOURS	TERMINATION OF TEST TIME, HOURS	TERMINATION OF TEST PERCENT CREEP	1/2% CREEP LARSON-MILLER PARAMETER $T_{°R}(15 + \log t) \times 10^{-3}$
B-23A	4305-4	1	2500	1371	20.0	13.80	2000	1093	20,000*	686	0.032	47.5
B-23B	4305-4	-	-	-	28.0	19.30	2000	1093	10,000*	307	0.028	46.7
B-23C	4305-4	-	-	-	40.0	27.60	2000	1093	630*	185	0.188	43.8
B-23D	4305-4	-	-	-	46.0	31.70	1800	982	4000*	403	0.078	42.0
B-23E	4305-4	-	-	-	34.0	23.40	2100	1149	1000*	329	0.170	46.1
B-27	4305-4	1	2500	1371	41.0	28.20	2000	1093	1090	1584	1.040	44.5

* Extrapolated

3886 B

TABLE II-9

Summary of TZC Ultra-High Vacuum Creep Test Results

TEST NO.	HEAT NO.	HEAT TREATMENT TIME HOURS	HEAT TREATMENT TEMPERATURE °F	HEAT TREATMENT TEMPERATURE °C	STRESS KSI	STRESS N/M^2 $x10^{-7}$	TEST TEMPERATURE °F	TEST TEMPERATURE °C	1/2% CREEP LIFE HOURS	TERMINATION OF TEST TIME, HOURS	TERMINATION OF TEST PERCENT CREEP	1/2% CREEP LARSON-MILLER PARAMETER $T_{°R}(15 + \log t)x10^{-3}$
B-8A	M-80	1	3092	1700	18.0	12.40	2200	1204	1100	2128	1.060	48.3
B-10	M-80	1	3092	1700	17.0	11.70	2200	1204	2500	2749	0.545	48.9
B-9	M-80	1	3092	1700	20.0	13.80	2000	1093	10,408	16,002	0.670	46.8
B-11	M-80	1	3092	1700	25.0	17.20	1856	1013	75,000*	14,406	0.182	46.0
B-12	M-80	1	3092	1700	19.0	13.10	2056	1125	75,000*	14,239	0.280	49.2
B-20	M-91	1	3092	1700	20.0	13.80	2000	1093	3650	12,795	1.008	45.7
B-31	M-91	1	3092	1700	14.0	9.65	2200	1204	329	912	1.092	46.6
B-19	M-91	1	2300	1260	44.0	30.30	1800	982	1075	4604	1.015	41.1
B-28	M-91	1	2300	1260	28.0	19.30	2000	1093	1100	4214	1.138	44.4
B-30	M-91	1	2500	1371	22.0	15.20	2200	1204	70	259	1.280	44.8
B-32	M-91	1	2500	1371	20.0	13.80	1935	1057	14,400	16,130	0.535	45.9
B-33	M-91	1	2500	1371	22.0	15.20	1900	1038	7720	9697	0.585	44.6
B-36	4345	1	2500	1371	22.0	15.20	2000	1093	5940	8563	0.640	46.2
B-37	4345	1	2400	1316	22.0	15.20	2000	1093	8853	9020	0.500	46.3

* Extrapolated

TABLE II-10

Summary of T-222 Ultra-High Vacuum Creep Test Results

TEST NO.	HEAT NO.	HEAT TREATMENT TIME HOURS	HEAT TREATMENT TEMPERATURE °F	HEAT TREATMENT TEMPERATURE °C	STRESS KSI	STRESS N/M^2 $x10^{-7}$	TEST TEMPERATURE °F	TEST TEMPERATURE °C	1% CREEP LIFE HOURS	TERMINATION OF TEST TIME, HOURS	TERMINATION OF TEST PERCENT CREEP	1% CREEP LARSON-MILLER PARAMETER $T_{°R}(15 + \log t)x10^{-3}$
S-13	AL-TA-43	1	3000	1649	12.0	8.27	2200	1204	560	1890	5.720	47.2
S-14	AL-TA-43	1	3000	1649	19.2	13.20	2056	1124	890	1314	1.685	45.1
S-20	AL-TA-43	1	2800	1538	12.0	18.27	2200	1204	405	1389	5.060	46.9

TABLE II-11

Summary of ASTAR 811C Ultra-High Vacuum Creep Test Results

TEST NO.	HEAT NO.	HEAT TREATMENT TIME HOURS	HEAT TREATMENT TEMPERATURE °F	HEAT TREATMENT TEMPERATURE °C	STRESS KSI	STRESS $N/M^2 \times 10^{-7}$	TEST TEMPERATURE °F	TEST TEMPERATURE °C	1% CREEP LIFE HOURS	TERMINATION OF TEST TIME, HOURS	TERMINATION OF TEST PERCENT CREEP	1% CREEP LARSON-MILLER PARAMETER $T_{°R}(15 + \log t) \times 10^{-3}$
S-29	NASV-20-WS	1/2	3600	1982	2.0	1.38	2600	1427	20,000*	**	**	59.3

* Extrapolated
** Test in progress

3887 B

3890 B

TABLE 11-12

Summary of T-111 Ultra-High Vacuum Creep Test Results

TEST NO.	HEAT NO.	HEAT TREATMENT TIME HOURS	HEAT TREATMENT TEMPERATURE °F	HEAT TREATMENT TEMPERATURE °C	STRESS KSI	STRESS N/M^2 $x10^{-7}$	TEST TEMPERATURE °F	TEST TEMPERATURE °C	1% CREEP LIFE HOURS	TERMINATION OF TEST TIME, HOURS	TERMINATION OF TEST PERCENT CREEP	1% CREEP LARSON-MILLER PARAMETER $T_{°R}(15 + \log t) x10^{-3}$
S-16	70616	1	2600	1427	8.0	5.51	2200	1204	725	1675	2.570	47.5
S-19	70616	1	3000	1649	8.0	5.51	2200	1204	2000	4870	3.368	48.7
S-21	70616	1	3000	1649	12.0	8.26	2200	1204	1140	3840	6.548	48.0
S-23	70616	1	3000	1649	12.0	8.26	2120	1160	3150	3698	1.225	47.7
S-22	70616	1	3000	1649	20.0	13.80	2000	1093	670	1099	2.010	43.8
S-24	70616	1	3000	1649	20.0	13.80	1860	1016	4730	4946	1.090	43.3
S-25	D-1670	1	3000	1649	15.0	10.30	2000	1093	1340	1584	1.210	44.6
S-26	D-1670	1	3000	1649	17.0	11.70	1800	982	9540	9624	1.030	42.9
S-25A	D-1670	1	3000	1649	1.5	1.03	2600	1427	1100*	482	0.632	55.2
S-28	D-1670	1	3000	1649	0.5	0.34	2600	1427	55,000*	**	**	60.0
S-27	D-1102	1	3000	1649	13.0	8.95	2000	1093	1880	3459	2.082	45.0
S-32	D-1102	1	3000	1649	5.0	3.44	2200	1204	4050	4322	1.042	49.5
S-40	D-1102	1	2000	1649	17.0	11.70	1800	982	8558	8717	1.028	42.8
S-33	65076	1	3000	1649	8.0	5.51	2200	1204	2850	2976	1.048	49.1
S-34	65076	1	3000	1649	11.0	7.58	2000	1093	10,800	10,875	1.010	46.9

* Extrapolated
** Test in progress

3889 B

TABLE II-12 (Continued)

Summary of T-111 Ultra-High Vacuum Creep Test Results

TEST NO.	HEAT NO.	HEAT TREATMENT TIME HOURS	HEAT TREATMENT TEMPERATURE °F	HEAT TREATMENT TEMPERATURE °C	STRESS KSI	STRESS N/M^2 $x10^{-7}$	TEST TEMPERATURE °F	TEST TEMPERATURE °C	1% CREEP LIFE HOURS	TERMINATION OF TEST TIME, HOURS	TERMINATION OF TEST PERCENT CREEP	1% CREEP LARSON-MILLER PARAMETER $T_{°R}(15 + \log t) \times 10^{-3}$
S-37	65080	1	3000	1649	8.0	5.51	2200	1204	260	274	1.230	46.3
S-39	65080	1	3000	1649	13.0	8.95	1800	982	8202	8728	1.070	42.7
S-45	65080A	1	3000	1649	3.0	2.07	2200	1204	554	697	1.070	47.1
S-30	65079	1	3000	1649	3.5	2.41	2400	1316	860	2137	1.165	51.3
S-31	65079	1	3000	1649	5.0	3.44	2200	1204	6160	6594	2.372	50.0
S-35	65079	1	3000	1649	5.0	3.44	2200	1204	5400	5522	1.092	49.9
S-42	65079	1	3000	1649	3.5	2.41	2300	1263	3810	4247	1.048	51.3
S-47	65079	1	3000	1649	24.0	16.50	1750	954	38,000*	**	**	43.3
S-48	65079	1	3000	1649	2.4	1.65	2330	1275	6465*	**	**	52.3
S-50	65079	1	3000	1649	8.5	7.22	2000	1093	24,000*	**	**	47.7
S-43	65079	1/4	3000	1649	18.0	12.40	2000	1093	1500 *	361	0.108	44.7
S-44A	65079	1	3000	1649	9.5	6.55	2172	1189	3250*	467	0.152	48.7
S-44B	65079	1/4	3000	1649	3.3	2.27	2371	1299	2030*	335	0.168	51.9
S-44C	65079	1/4	3000	1649	18.0	12.40	2000	1093	1670*	1146	0.688	44.8
S-44D	65079	1/4	3000	1649	23.0	15.80	1800	982	14,650*	1391	0.112	43.3

* Extrapolated
** Test in progress

3888 9

TABLE II-12 (Continued)

Summary of T-111 Ultra-High Vacuum Creep Test Results

TEST NO.	HEAT NO.	HEAT TREATMENT TIME HOURS	HEAT TREATMENT TEMPERATURE °F	HEAT TREATMENT TEMPERATURE °C	STRESS KSI	STRESS N/M^2 $\times 10^{-7}$	TEST TEMPERATURE °F	TEST TEMPERATURE °C	1% CREEP LIFE HOURS	TERMINATION OF TEST TIME, HOURS	TERMINATION OF TEST PERCENT CREEP	1% CREEP LARSON-MILLER PARAMETER $T_{\circ R}(15 + \log t) \times 10^{-3}$
S-59	D-1183	1	3000	1649	13	8.95	2000	1093	***	**	**	***
S-60	D-1183	1	3000	1649	35	24.1	1600	870	***	**	**	***

** In progress
*** Insufficient to extrapolate

TABLE 11-13

Summary of T-111 Progressive Stress Ultra-High Vacuum Creep Test Results

TEST NO.	HEAT NO.	HEAT TREATMENT TIME HOURS	HEAT TREATMENT TEMPERATURE °F	HEAT TREATMENT TEMPERATURE °C	STRESS KSI	STRESS N/M^2 $x10^{-7}$	TEST TEMPERATURE °F	TEST TEMPERATURE °C	1% CREEP LIFE HOURS	TERMINATION OF TEST TIME, HOURS	TERMINATION OF TEST PERCENT CREEP
S-36	65080	1	3000	1649	16		2200	1204	600	624	1.120
S-38	65080	1	3000	1649	1		2200	1204	3830	4686	1.562
S-46	65079	1	3000	1649	16		2200	1204	1000*	761	0.225
S-49	65079	1	3000	1649	20		1800	982	1660	1964	5.125
S-51	D-1183	1	3000	1649	16		2200	1204	1080	1274	5.823
S-52	65079	1	3000	1649	13		2000	1093	1700*	1657	1.150
S-53	65079	1	3000	1649	5		2200	1204	2240	2970	5.292
S-54	65079	1	3000	1649	5		2200	1204	4000*	**	**
S-56	65079	1	3000	1649	5		1800	982	***	**	**
S-57	65079	1	3000	1649	1		2200	1204	***	**	**

* Extrapolated
** Test in progress

3891 B

3892 B

TABLE 11-14

Summary of Pure Ta Ultra-High Vacuum Creep Test Results

TEST NO.	HEAT NO.	HEAT TREATMENT TIME HOURS	HEAT TREATMENT TEMPERATURE °F	HEAT TREATMENT TEMPERATURE °C	STRESS KSI	STRESS N/M^2 $x10^{-7}$	TEST TEMPERATURE °F	TEST TEMPERATURE °C	1% CREEP LIFE HOURS	TERMINATION OF TEST TIME, HOURS	TERMINATION OF TEST PERCENT CREEP	1% CREEP LARSON-MILLER PARAMETER $T_{\circ R}(15 + \log t)\times 10^{-3}$
B-39A	-	1	1832	1000	13.6	9.37	1100	596	31	32	1.020	25.8
B-39B	-	1/4	1832	1000	11.6	7.99	1100	596	603*	264	0.542	27.8
B-39C	-	1/4	1832	1000	10.1	6.95	1183	639	463*	282	0.635	29.0
B-40A	-	1	1832	1000	7.0	4.83	1350	720	9	9	1.000	28.9
B-40B	-	1/4	1832	1000	4.9	3.38	1350	720	6600*	1386	0.300	34.0
B-41	-	1	1832	1000	11.1	7.65	1100	596	144	160	1.078	26.7
B-42A	-	1	1832	1000	4.0	2.75	1350	720	170	186	1.015	31.2
B-42B	-	1/4	1832	1000	4.0	2.75	1350	720	2070	1775	0.892	33.1

* Extrapolated
** Test in progress

3893 B

TABLE II-15

Summary of Ta-10W Ultra-High Vacuum Creep Test Results

TEST NO.	HEAT NO.	HEAT TREATMENT TIME HOURS	HEAT TREATMENT TEMPERATURE °F	HEAT TREATMENT TEMPERATURE °C	STRESS KSI	STRESS $N/M^2 \times 10^{-7}$	TEST TEMPERATURE °F	TEST TEMPERATURE °C	1% CREEP LIFE HOURS	TERMINATION OF TEST TIME, HOURS	TERMINATION OF TEST PERCENT CREEP	1% CREEP LARSON-MILLER PARAMETER $T_{°R}(15 + \log t) \times 10^{-3}$
S-58A	630002	1	3000	1649	20	3.8	2100	1148	285	308	1.125	44.7
S-58B	630002	1/4	3000	1649	11.5	7.93	2210	1209	770*	410	0.572	47.7
S-58C	630002	1/4	3000	1649	6.2	4.27	2320	1268	***	**	**	***

* Extrapolated
** Test in progress
***Insufficient to extrapolate

APPENDIX III

CREEP CURVES

2972 B

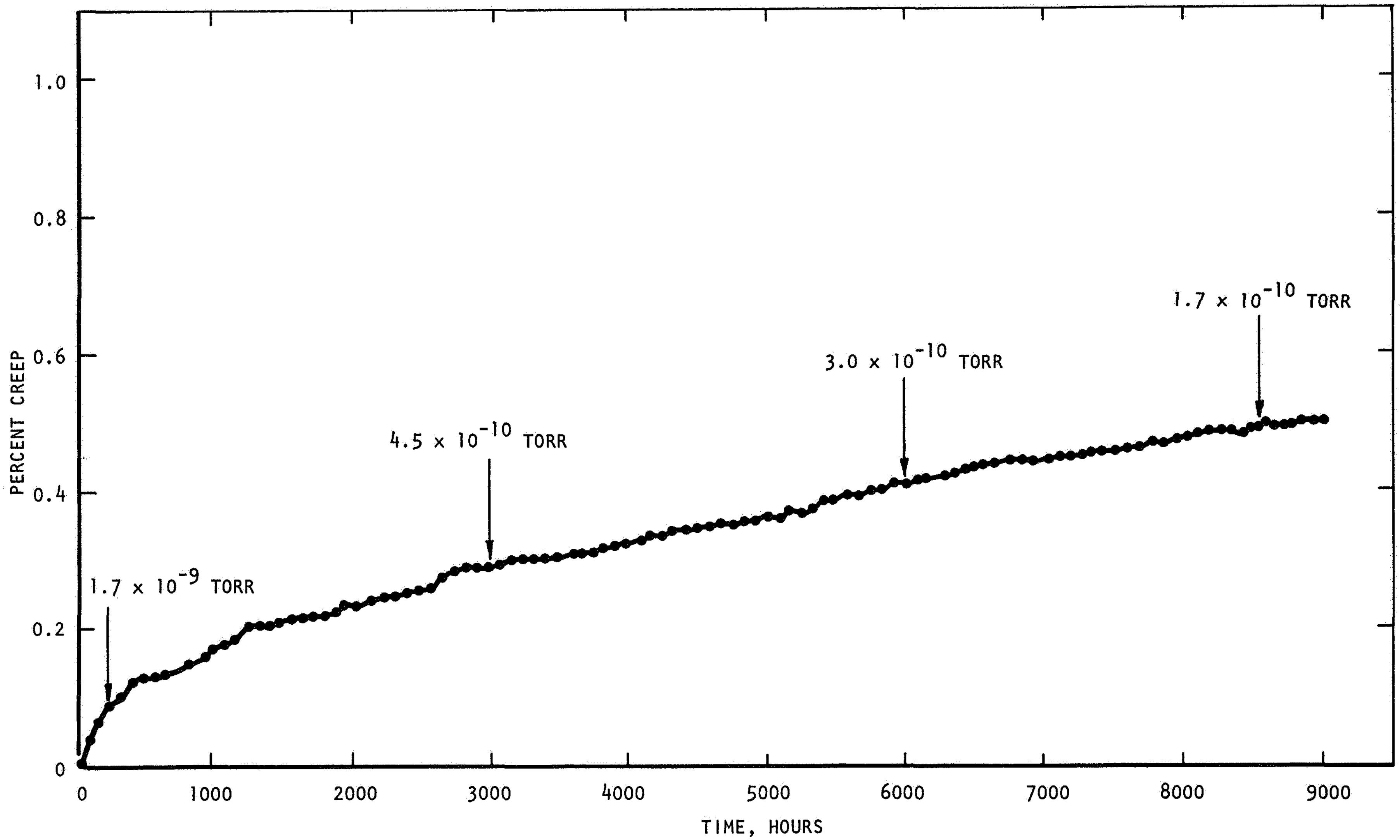

FIGURE III-1. CREEP TEST DATA, TZC HEAT NO. 4345 STRESS RELIEVED 1 HOUR AT 2400°F (1316°C), TESTED AT 2000°F (1093°C) AND 22 KSI (15.2 X 10^7 N/m^2), TEST NO. B-37, TESTED IN A VACUUM ENVIRONMENT OF $<1 \times 10^{-8}$ TORR. ARROWS ON THE CURVE INDICATE CHAMBER PRESSURE AT VARIOUS INTERVALS DURING THE TEST.

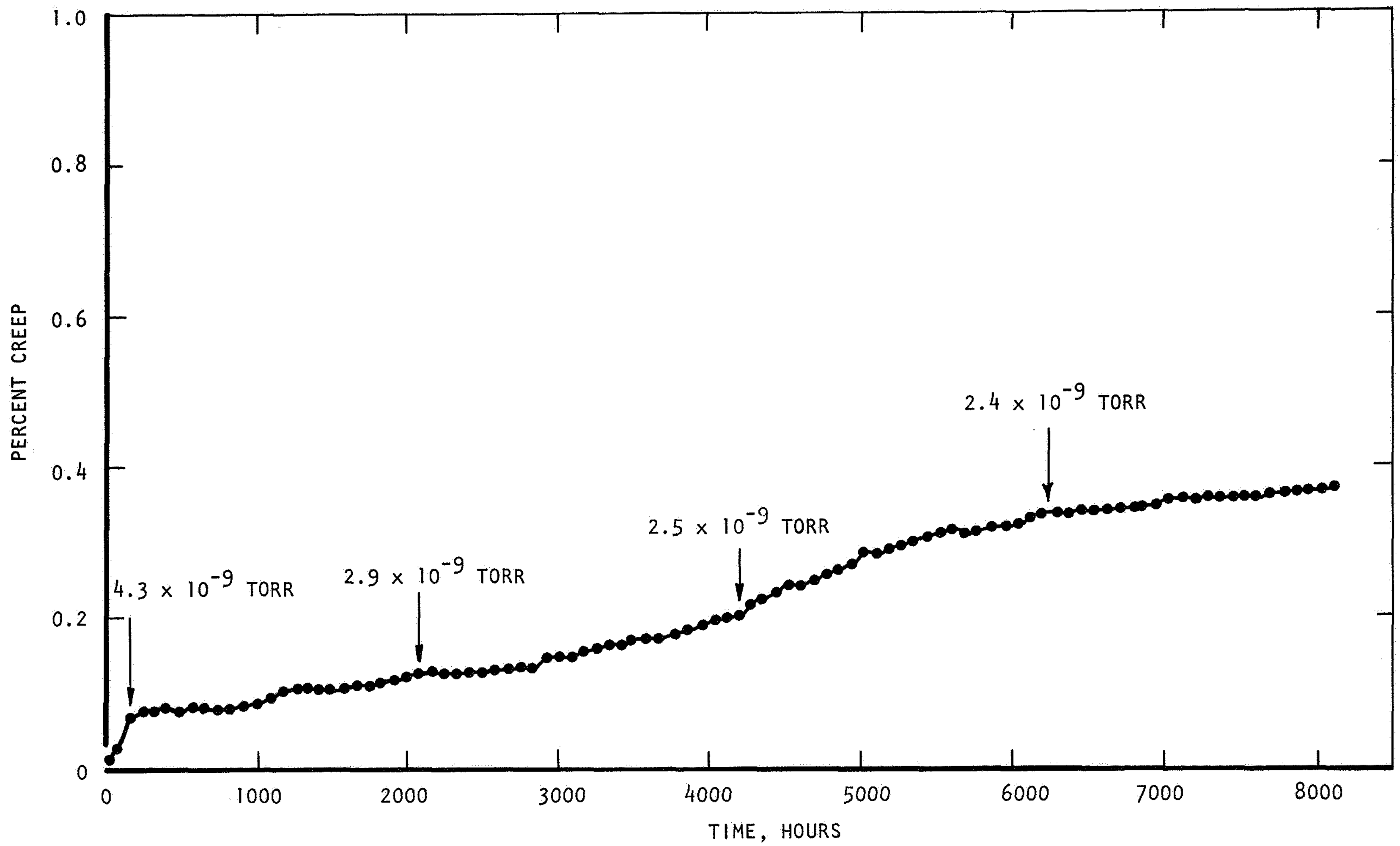

FIGURE III-2. CREEP TEST DATA, TZM HEAT NO. KDTZM-1175 STRESS RELIEVED 1 HOUR AT 2300°F (1260°C), TESTED AT 2000°F (1093°C) AND 22 KSI (15.1×10^7 N/m^2), TEST NO B-38, TESTED IN A VACUUM ENVIRONMENT OF $< 1 \times 10^{-8}$ TORR. ARROWS ON THE CURVE INDICATE CHAMBER PRESSURE AT VARIOUS INTERVALS DURING THE TEST.

2979 B

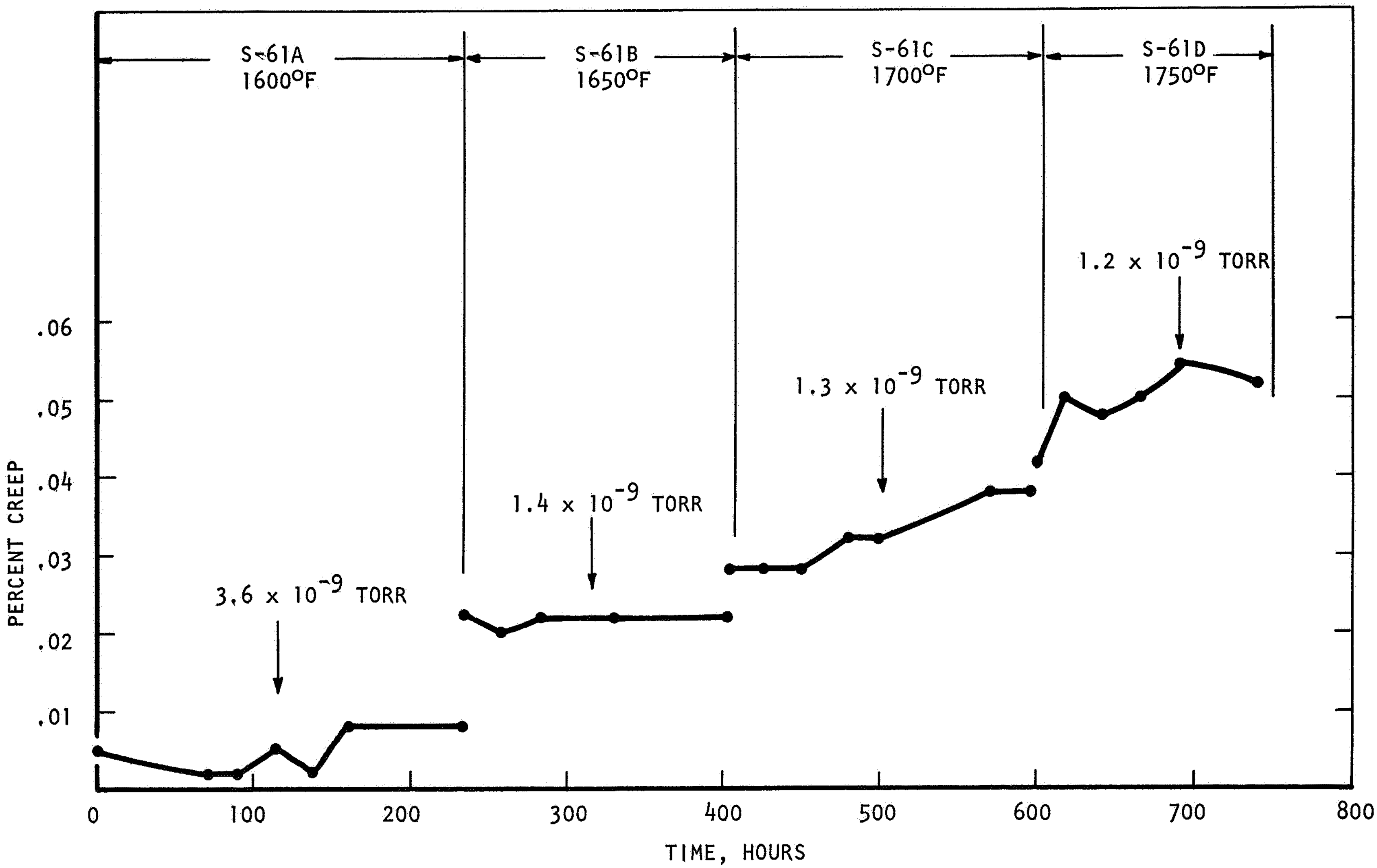

FIGURE III-3. CREEP TEST DATA, W-25% Re HEAT NO. 3.5-750002 STRESS RELIEVED 1 HOUR AT 2550°F (1400°C), TESTED AT VARIOUS TEMPERATURES AT 15 KSI (10.4×10^7 N/m^2), TEST NOS. S-61A,B,C, and D IN A SEQUENTIAL TEST PROGRAM, TESTED IN A VACUUM ENVIRONMENT OF $< 1 \times 10^{-8}$ TORR. ARROWS ON THE CURVES INDICATE CHAMBER PRESSURE AT VARIOUS INTERVALS DURING THE TEST.

2973 B

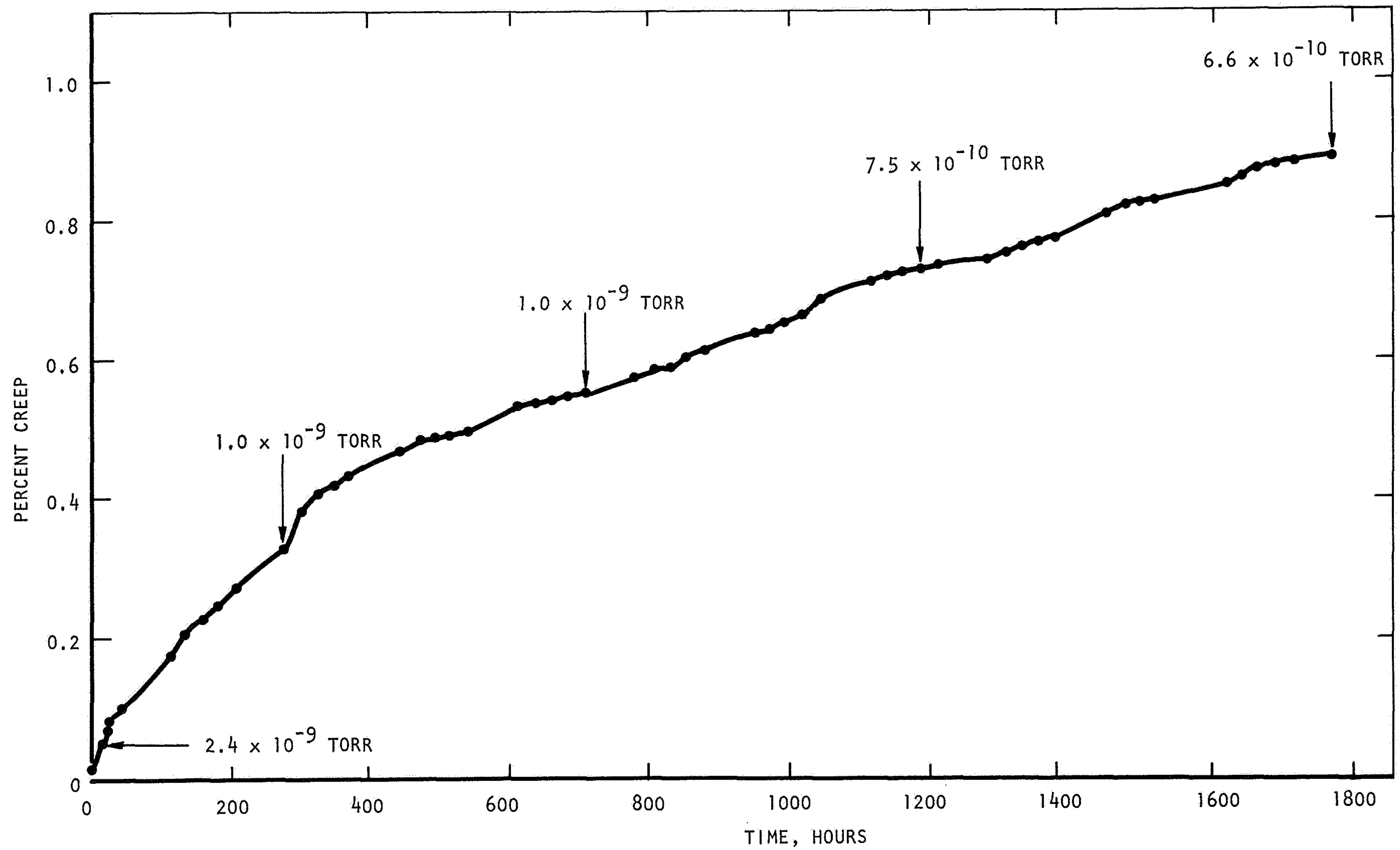

FIGURE III-4. CREEP TEST DATA, PURE Ta ANNEALED 1/4 HOUR AT 1832°F (1000°C), TESTED AT 1350°F (720°C) AND 4.0 KSI (2.75×10^7 N/m^2), TEST NO. B-42-B IN SEQUENTIAL TEST PROGRAM, TESTED IN A VACUUM ENVIRONMENT OF $<1 \times 10^{-8}$ TORR. ARROWS ON THE CURVE INDICATE CHAMBER PRESSURE AT VARIOUS INTERVALS DURING THE TEST.

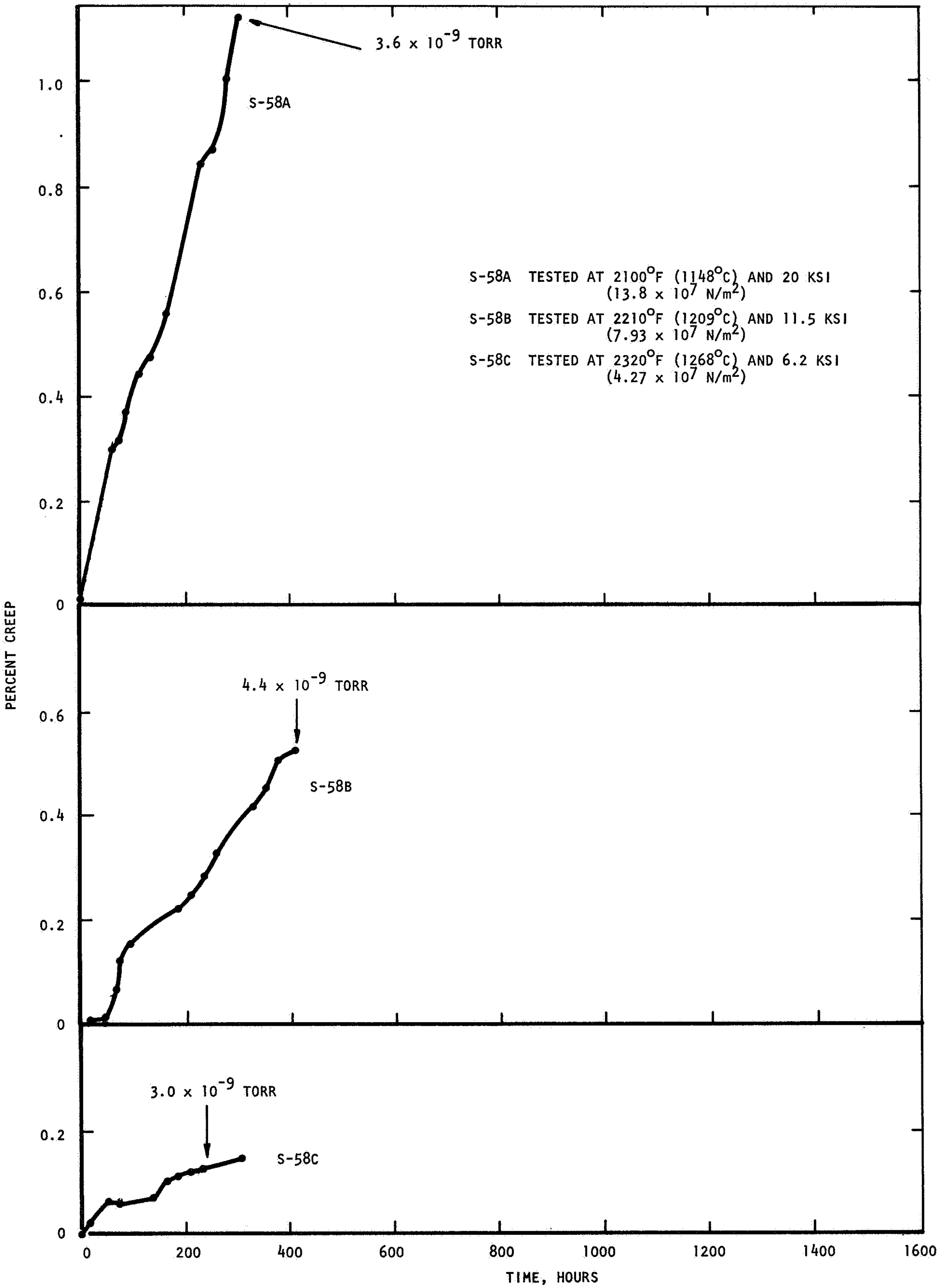

FIGURE III-5. CREEP TEST DATA, TA-10W HEAT NO. 630003 ANNEALED 1 HOUR AT 3000°F (1649°C) PRIOR TO TESTING AND 1/4 HOUR AT 3000°F (1649°C) BETWEEN EACH SEQUENCE. TEST NOS. S-58A, B, & C IN A SEQUENTIAL TEST PROGRAM, TESTED IN A VACUUM ENVIRONMENT OF <1 x 10^{-8} TORR. ARROWS ON THE CURVES INDICATE CHAMBER PRESSURE AT VARIOUS INTERVALS DURING THE TEST.

2981 B

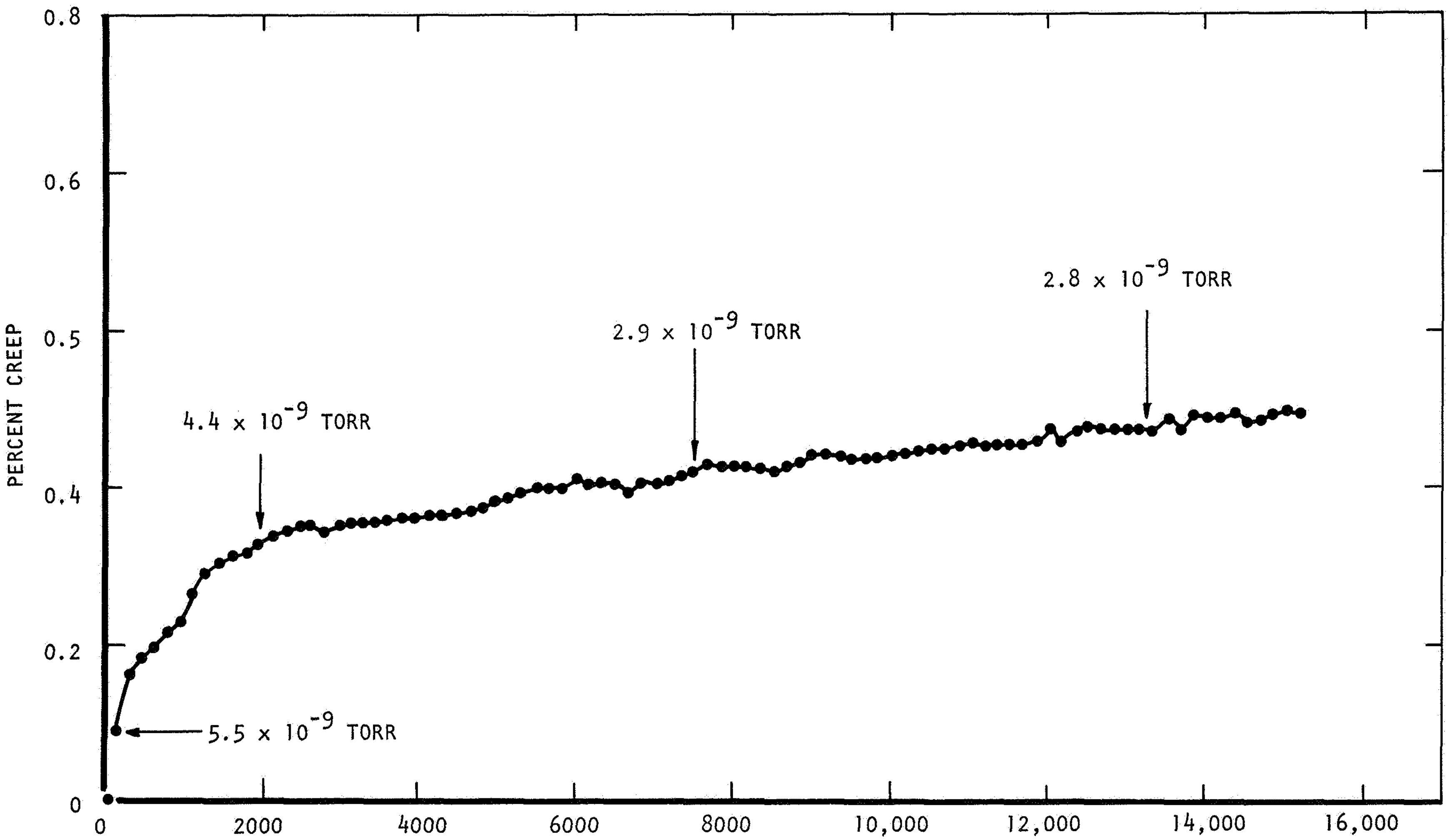

FIGURE III-6. CREEP TEST DATA, T-111 HEAT NO. D-1670 ANNEALED 1 HOUR AT 3000°F (1649°C), TESTED AT 2600°F (1427°C) AND 0.5 KSI (0.34×10^7 N/m^2). TEST NO. S-28 TESTED IN A VACUUM ENVIRONMENT OF $< 1 \times 10^{-8}$ TORR. ARROWS ON THE CURVES INDICATE CHAMBER PRESSURE AT VARIOUS INTERVALS DURING THE TEST.

2969 B

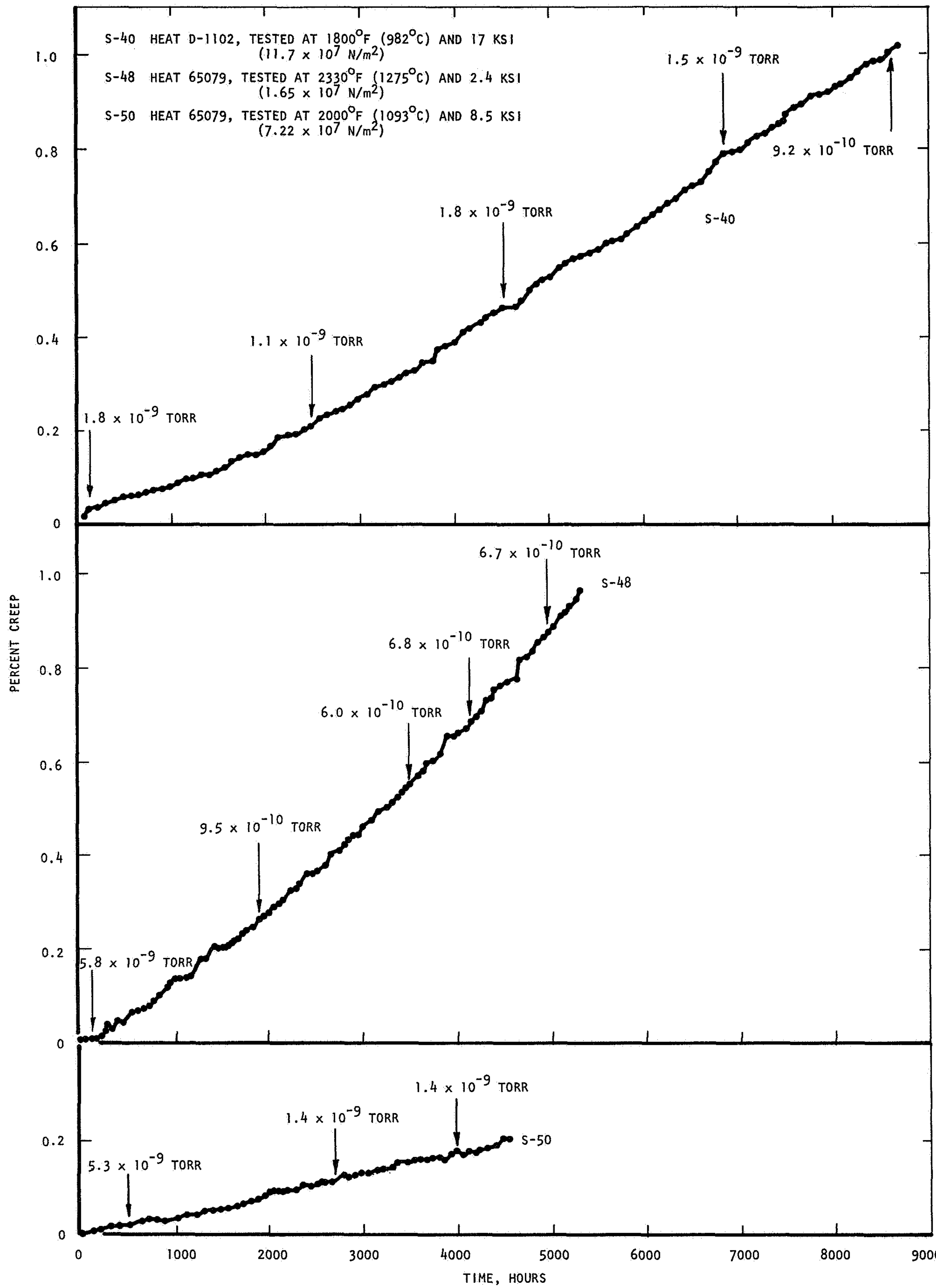

FIGURE III-7. CREEP TEST DATA, T-111 ANNEALED 1 HOUR AT 3000°F (1649°C). TEST NOS. S-40, S-48, AND S-50, TESTED IN A VACUUM ENVIRONMENT OF $< 1 \times 10^{-8}$ TORR. ARROWS ON THE CURVES INDICATE CHAMBER PRESSURE AT VARIOUS INTERVALS DURING THE TEST.

2983 B

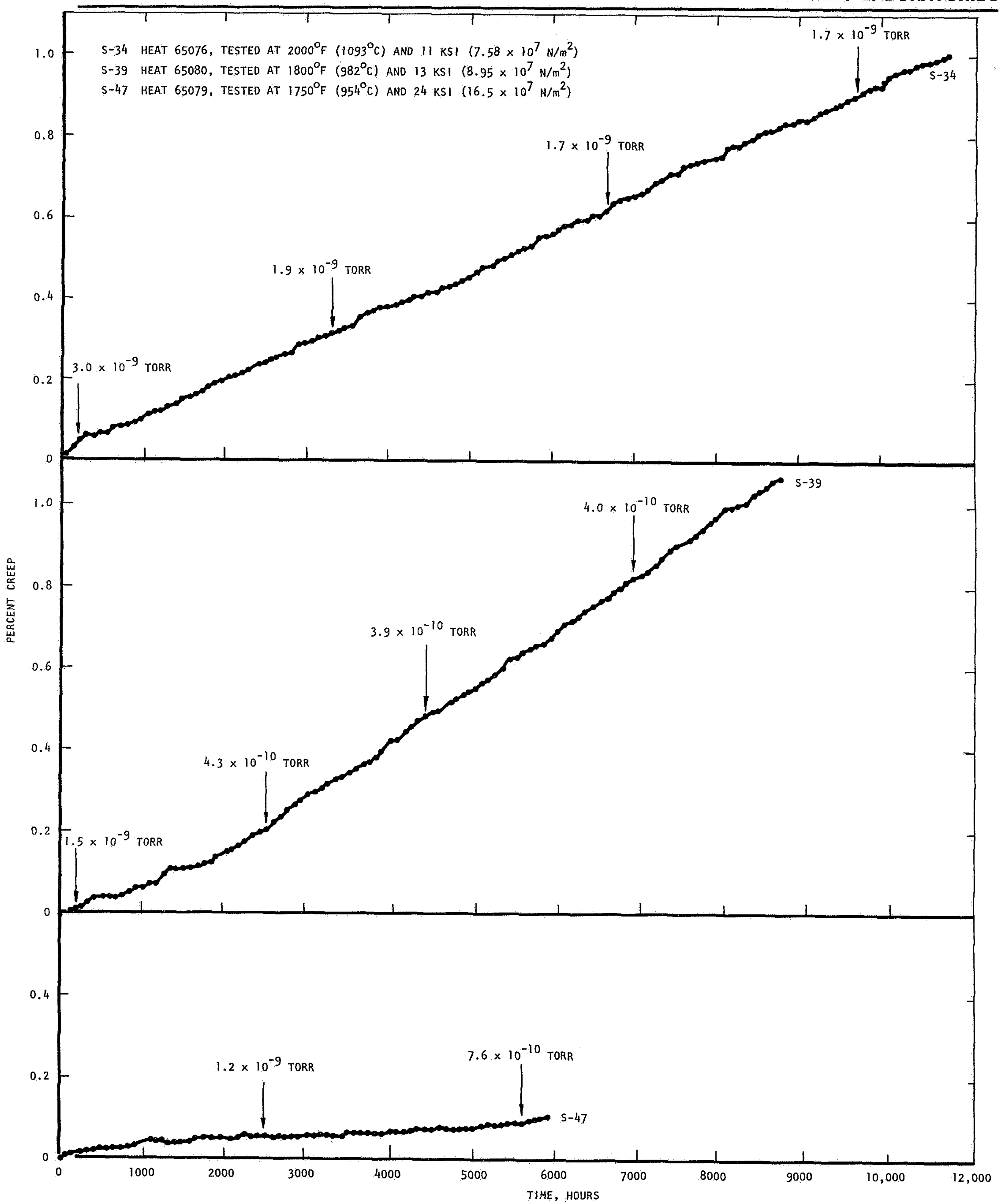

FIGURE III-8. CREEP TEST DATA, T-111 ANNEALED 1 HOUR AT 3000°F (1649°C). TEST NOS. S-34, S-39 AND S-47 TESTED IN A VACUUM ENVIRONMENT OF < 1 x 10^{-8} TORR. ARROWS ON THE CURVES INDICATE CHAMBER PRESSURE AT VARIOUS INTERVALS DURING THE TEST.

2978 B

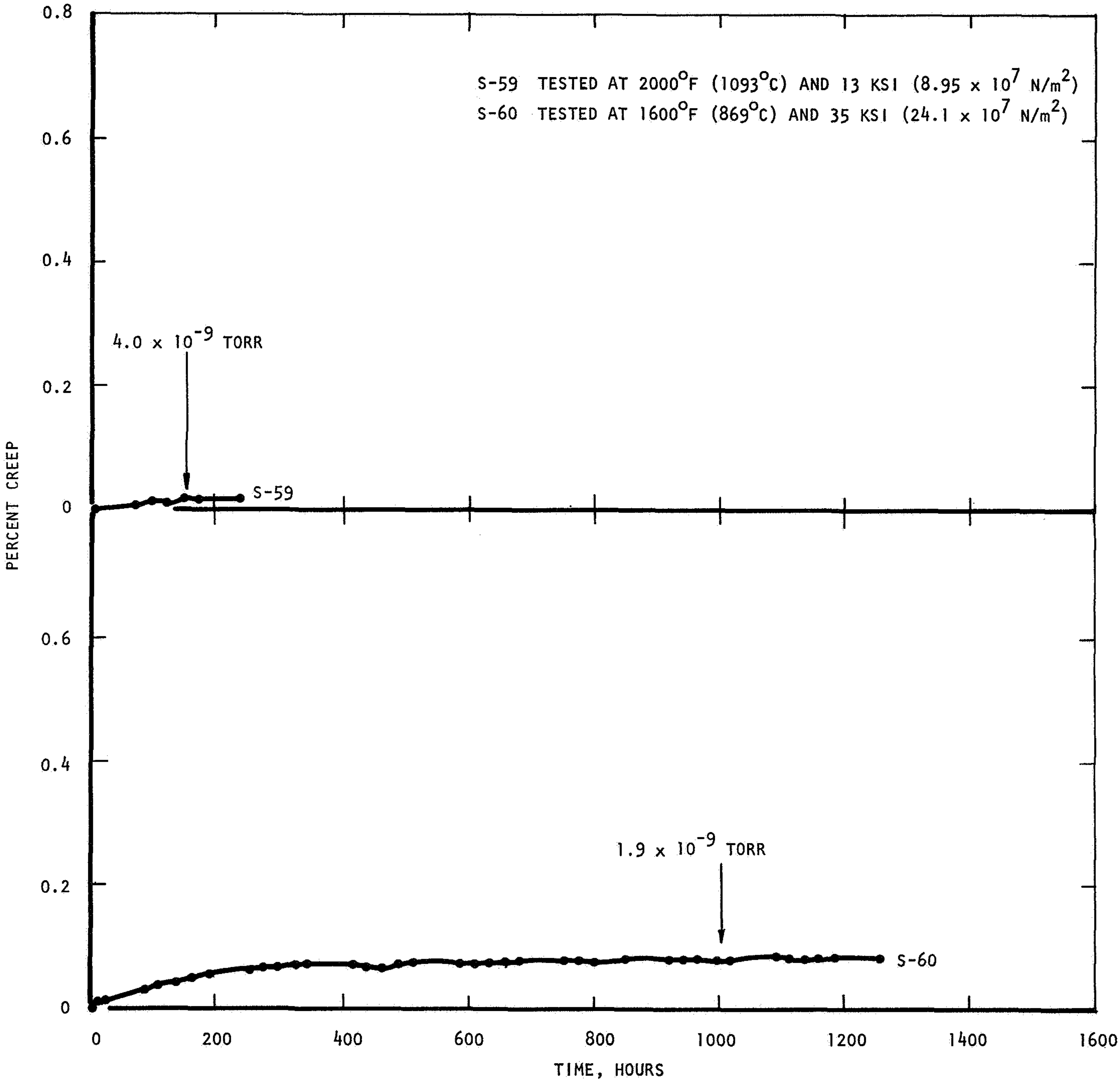

FIGURE III-9. CREEP TEST DATA, T-111 HEAT NO. D-1183 ANNEALED 1 HOUR AT 3000°F (1649°C). TEST NOS. S-59 AND S-60 TESTED IN A VACUUM ENVIRONMENT OF <1 x 10^{-8} TORR. ARROWS ON THE CURVES INDICATE CHAMBER PRESSURE AT VARIOUS INTERVALS DURING THE TEST.

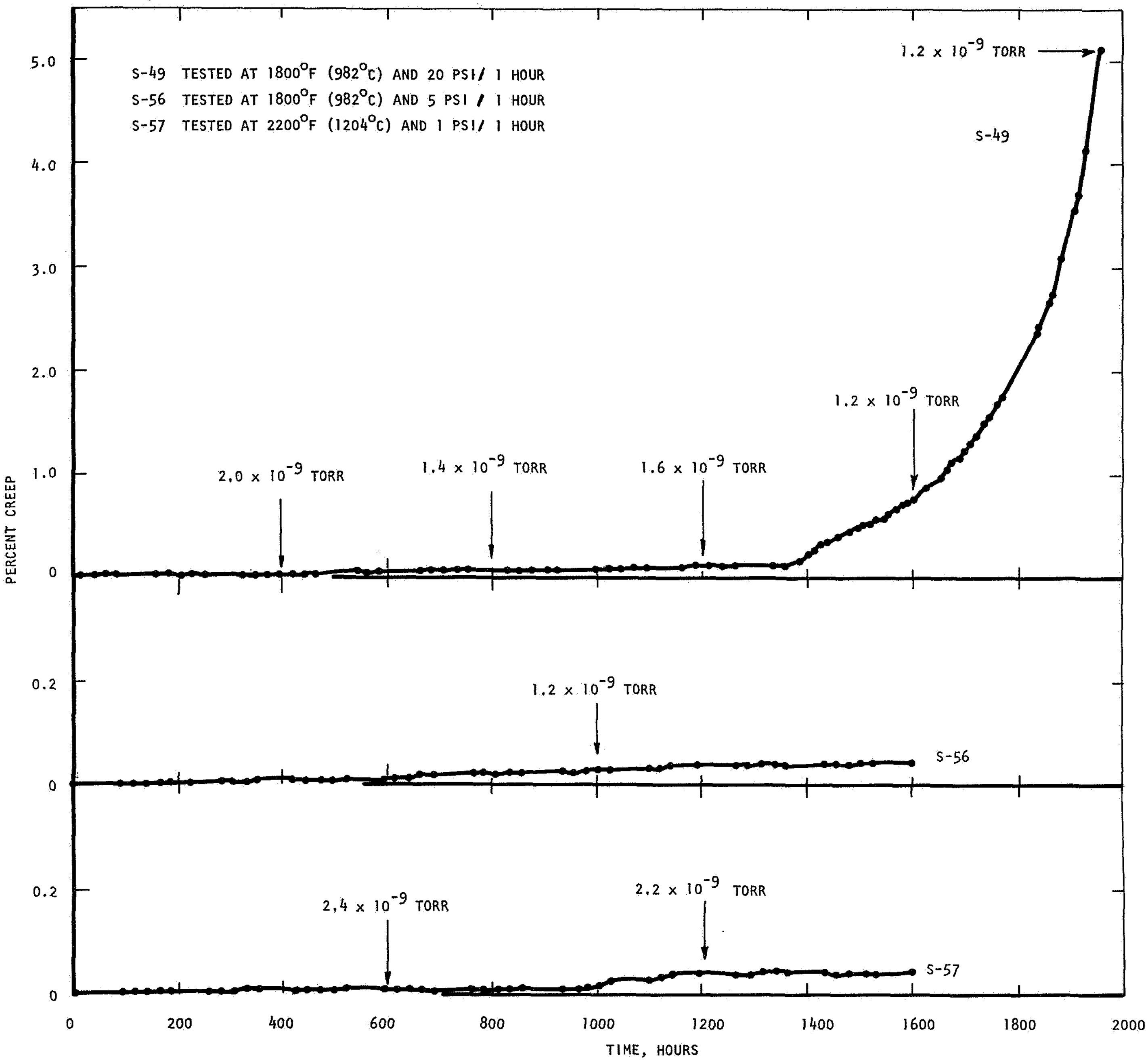

FIGURE III-10. CREEP TEST DATA, T-111 HEAT NO. 65079 ANNEALED 1 HOUR AT 3000°F (1649°C). TEST NOS. S-49, S-56, AND S-57 IN THE PROGRESSIVE STRESS PROGRAM, TESTED IN A VACUUM ENVIRONMENT OF <1 x 10^{-8} TORR. ARROWS ON THE CURVES INDICATE CHAMBER PRESSURE AT VARIOUS INTERVALS DURING THE TEST.

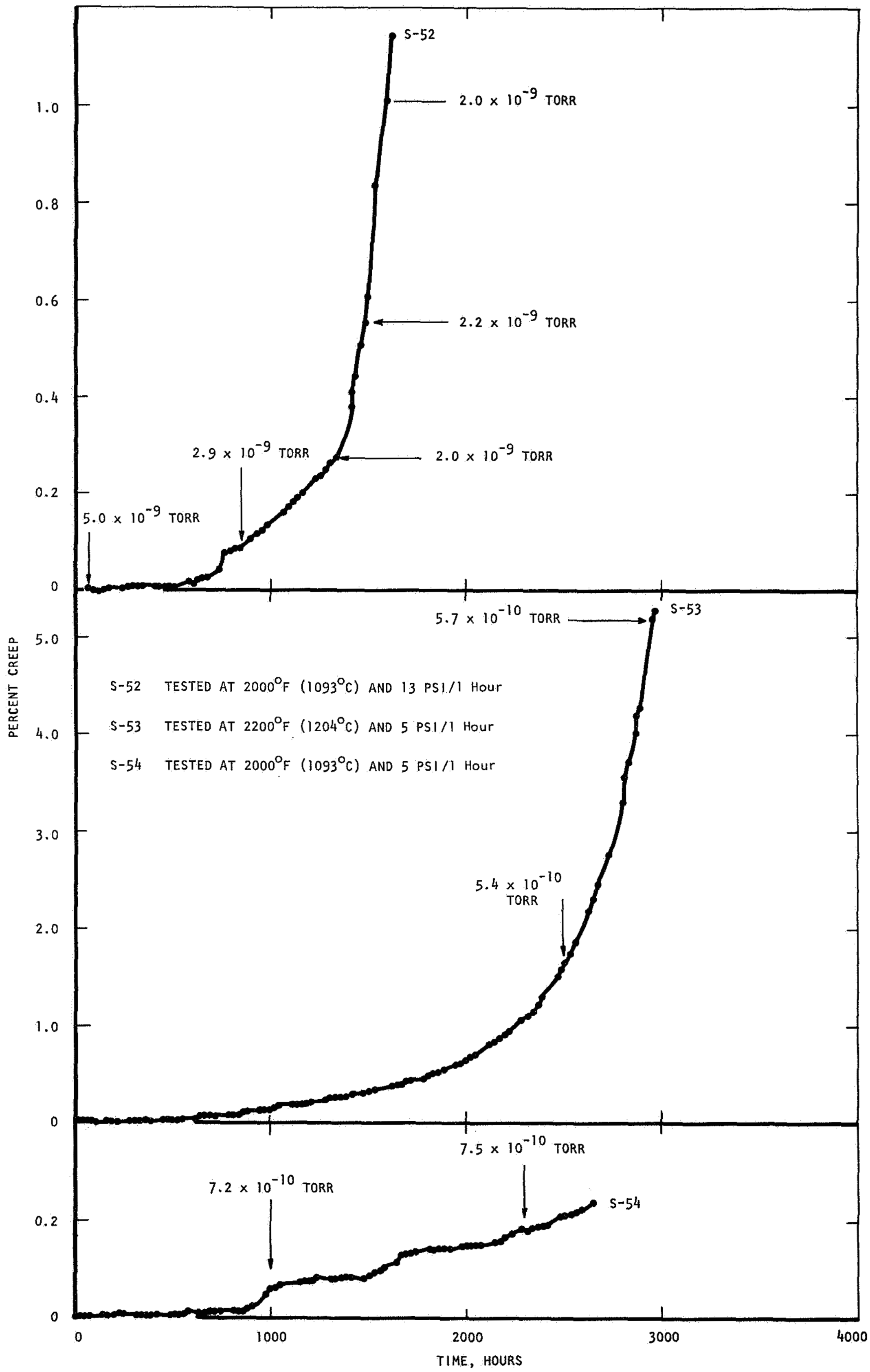

Figure III-11 CREEP TEST DATA, T-111 HEAT NO. 65079 ANNEALED 1 HOUR AT 3000°F (1649°C). TEST NOS. S-52, S-53, AND S-54 IN THE PROGRESSIVE STRESS PROGRAM, TESTED IN A VACUUM ENVIRONMENT OF $<1 \times 10^{-8}$ TORR. ARROWS ON THE CURVES INDICATE CHAMBER PRESSURE AT VARIOUS INTERVALS DURING THE TEST.

2980 a

2975 B

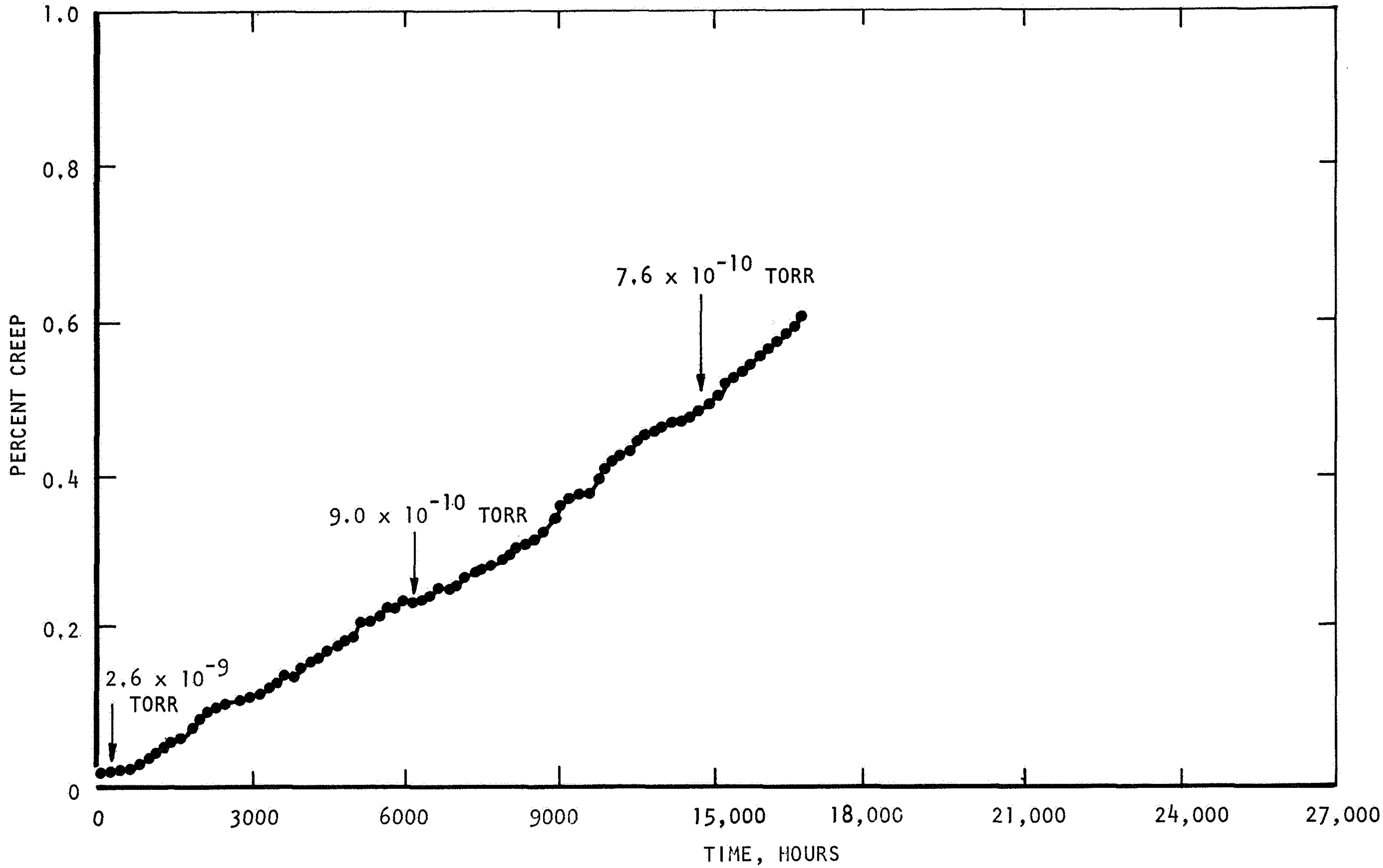

FIGURE III-12. CREEP TEST DATA, ASTAR-811C HEAT NO. NASV-20-WS ANNEALED ONE-HALF HOUR AT 3600°F (1983°C), TESTED AT 2600°F (1427°C) AND 2 KSI (1.38×10^7 N/m^2), TEST NO. S-29 TESTED IN A VACUUM ENVIRONMENT OF $< 1 \times 10^{-8}$ TORR. ARROWS ON THE CURVE INDICATE CHAMBER PRESSURE AT VARIOUS INTERVALS DURING THE TEST.

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