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**THE H-4, H-5, AND H-6 IRRADIATION EXPERIMENTS:
IRRADIATION OF N-REACTOR GRAPHITE--
INTERIM REPORT NO. 1**

J. W. HELM

OCTOBER 1964

HANFORD LABORATORIES

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THE H-4, H-5, AND H-6 IRRADIATION EXPERIMENTS:
IRRADIATION OF N-REACTOR GRAPHITE--
INTERIM REPORT NO. 1

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HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

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THE H-4, H-5, AND H-6 IRRADIATION EXPERIMENTS:
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INTRODUCTION

An experimental program⁽¹⁾ started in November 1961 is being conducted to determine the long-term irradiation behavior of the graphite used as the moderator in N-Reactor.⁽²⁾ The primary objectives of the program are to provide data for predictions of (1) the distortion of the N-Reactor moderator and (2) the stress conditions which could arise from the difference in the rate and extent of contraction between the transverse and parallel orientations of the graphite bars. Secondary objectives are measurements of other properties (crystallite parameters, Young's modulus, and electrical resistivity) which will provide additional information of the effects of irradiation.

To meet these objectives a series of capsules, designated H-4, -5, -6, are being irradiated in the General Electric Test Reactor (GETR). Irradiations are scheduled so that two capsules are being irradiated and a third is being reassembled in the laboratory at any one time. Three sets of samples rotated into two reactor positions provide sample data on all the graphite types and orientations being tested at each irradiation temperature, and minimize the effect to the program of the possible failure of any individual capsule. They also allow return of a higher percentage of previously irradiated samples to successive capsules since duplicate samples are available.

Nine capsules, H-4-1 through H-6-3, containing three successive generations of samples, have been irradiated and results of these irradiations are presented in this report. Detailed interpretations and mechanisms of graphite damage will be discussed in future separate reports.

SUMMARY

Irradiations are being performed in the D7 and F7 positions of the GETR to determine the long-term irradiation behavior of N-Reactor moderator graphite, designated TSX. Results are now available for samples irradiated to a maximum neutron exposure of 4.8×10^{21} nvt, $E > 0.18$ MeV. Mean sample temperatures, which ranged from 425 to 825 C, agreed within ± 50 C from capsule to capsule and from one reactor cycle to the next.

The TSX graphite tested was obtained from three separate full-size unmachined blocks. The contraction of the graphite showed a dependence on the temperature of irradiation. The transverse samples showed a large spread in contraction for several samples irradiated at the same temperature to equivalent exposures, with no statistical differences among samples taken from several locations in the block. All TSX samples showed continued contraction upon increased neutron exposure and the parallel samples contracted more and at a faster rate than did the transverse. The TSX graphite showed nearly the same contraction behavior as the CSF graphite in both the transverse and parallel orientations. Data on radiation-induced changes of sample volume, crystallite parameters, Young's modulus, and electrical resistivity are also presented.

SAMPLE SELECTION AND MEASUREMENTS

Sample Selection and Preparation

The TSX graphite samples were obtained from three full-size N-Reactor moderator blocks. The CSF graphite samples, used for reference, were taken from two full-size blocks, and in a few capsule positions TSGBF graphite was used also as a reference material. The graphites being irradiated are described in Table I.

TABLE I
GRAPHITE DESCRIPTION

Hanford Designation	Hanford Block Numbers	Coke Source and Type	Block Size, in.	Remarks
TSX*	158, 160, 167	Continental-Lake Charles (needle type)	6 x 6 x 48	Reactor grade; graphitized at 3000 C; very anisotropic; density: 1.71 g/cm ³
CSF*	141, 142	Cleves (conventional type)	4 x 4 x 50	Reactor grade; F-purified at 2700 C; density: 1.66 g/cm ³
TSGBF*	125	Texas-Lockport (conventional type)	3 3/4 x 3 3/4 x 48	Reactor grade; graphitized and F-purified in one step at 2450 C; density: 1.65 g/cm ³

* Graphite supplied by National Carbon Co.

The sampling scheme for the TSX graphite is shown in Figure 1. Three locations E (edge), M (mid-point), and C (center), of transverse samples were used. The 4 in. transverse samples were cut from the center two-thirds of the block cross section. The sampling scheme for the CSF graphite is shown in Figure 2. The sampling scheme for the TSGBF graphite was the same as for CSF. Orientation and anisotropy are discussed in HW-71500 A. ⁽³⁾

After machining to a quarter-round shape, the individual samples were annealed at 1800 C for 1 hr at a pressure of 3×10^{-4} mm Hg to remove a small, thermally annealable strain present in fabricated samples. ⁽⁴⁾ Tests were made to determine the effect on mechanical moduli, crystallite parameters, and length changes caused by varying heating rates, dwell times, and cooling rates, and no effects were noted. Further studies ⁽⁵⁾ on samples subjected to these varying heating and cooling

rates and several annealing temperatures and then subsequently irradiated to identical neutron exposures indicate that no effects were introduced by the annealing procedure.

FIGURE 1
Sampling Scheme
TSX Graphite

FIGURE 2
Sampling Scheme
CSF Reference Graphite

Preirradiation Measurements

Several measurements were made on the samples prior to irradiation. Lengths were measured physically and optically on all samples. A Bausch and Lomb DR-25 Optical Gage (Type 33-14-23) was used for end-to-end length measurements, and a Bausch and Lomb Bench Comparator (Type 33-12-11) was used for the measurements of the distances between holes drilled in the samples. These length measurements have a standard deviation of 2×10^{-5} and 12×10^{-5} in., respectively.

Crystallite parameters were measured on the samples by X-ray diffraction. Electrical resistivity was determined by passing a current through the sample and measuring the voltage drop between two precisely spaced knife edges in contact with the sample surface. Young's modulus was measured by the resonance or sonic technique.⁽⁶⁾ Details on the capsule design and the experimental procedure are discussed in Appendix A.

Postirradiation Measurements

Lengths of the irradiated samples were measured both physically and optically. Crystallite parameters, Young's modulus, and electrical resistivity were measured on all samples.

EXPOSURE DETERMINATION

The neutron exposure to the samples irradiated in the H-4, -5, -6 series of experiments was determined experimentally. The exposure to high-energy neutrons was of primary interest and was measured by nickel, iron, and titanium flux monitor foils contained in the capsule cooling rings. The reactions occurring are: $\text{Ni}^{58}(\text{n}, \text{p})\text{Co}^{58}$, $\text{Fe}^{54}(\text{n}, \text{p})\text{Mn}^{54}$, and $\text{Ti}^{46}(\text{n}, \text{p})\text{Sc}^{46}$.

Burnout of the Co^{58} and $\text{Co}^{58\text{m}}$ by thermal neutrons presents problems in the use of the Ni^{58} reaction. The current values of the (n, γ) cross sections are 1650 barns for Co^{58} ($T_{1/2} = 71.3$ days) and 170,000 barns for $\text{Co}^{58\text{m}}$ ($T_{1/2} = 9.1$ hr).⁽⁷⁾

The activation cross section for Ni^{58} is known reasonably accurately as a function of neutron energy. The lethargy-dependent activation cross section used for the Ni^{58} reaction is shown in Figure 3.⁽⁸⁾ Lethargy (u) is defined as $u = \ln(10 \text{ MeV}/E)$. The estimated lethargy-dependent activation cross section used for the Fe^{54} reaction is shown in Figure 4.^(9, 10)

Nothing is known about the lethargy-dependent activation cross section for the Ti^{46} reaction, so an average cross section based on a ratio to the nickel and iron results was used. The relative values from the several flux monitor locations provide a check on the orientation of the capsule in-reactor and will be normalized to a measured value when it becomes available.

The neutron spectra in the graphite samples located in the D7 or F7 testing positions used for the irradiations are shown in Figure 5. These spectra were calculated by use of the 2DXY computer code.⁽¹¹⁾ This is a two-dimensional, multiregion, transport-theory code which is set up with 18 energy groups, 16 of which are greater than 0.183 MeV. A grid spacing of 1 by 1 in. was used and the results give the neutron flux as a function of space and energy.⁽¹²⁾ For the nickel and iron monitors, for which at least an approximate lethargy-dependent activation cross section, $\sigma(u)$ is known, the computer calculation gives an effective cross

FIGURE 3
Activation Cross Section
 $\text{Ni}^{58} (n, p) \text{Co}^{58}$

FIGURE 4

Activation Cross Section
 $\text{Fe}^{54} (n, p) \text{Mn}^{54}$

FIGURE 5
Neutron Spectra
Center of Graphite Sample

section, $\bar{\sigma}$ defined by:

$$\bar{\sigma} = \frac{\int_{\infty}^0 \phi(u) \sigma(u) du}{\int_{u_1}^0 \phi(u) du}$$

where $\phi(u)$ is the neutron flux distribution.

The effective cross section for each monitor foil position was used to determine the neutron exposure, and then the relative flux intensities calculated for the foil positions and the samples were used to determine the exposure to the samples. (See Appendix B of HW-71500 B⁽¹³⁾ for a detailed discussion of the methods and calculations used.) The exposure equivalence for N-Reactor as discussed in HW-79793⁽¹²⁾ is 1.88×10^{17} nvt, $E > 0.18$ MeV equals 1 MWd/AT_(N-Reactor).

IRRADIATION RESULTS

The irradiation results from the samples in the first nine H-4, -5, -6 capsules are presented in Tables II through X* by capsule number. Length changes are based on the end-to-end measurements with the exception of the four samples from H-4-2 Position 1 for which the hole-to-hole measurements were used (Appendix A; Disassembly). Sample weights did not vary more than 0.05% during each irradiation period with the exception of the seven samples from H-6-1 discussed under "Disassembly."

All the data tabulated are presented graphically in the several figures discussed in the following subsections. For the CSF graphite, all data presently available, including those obtained from the EGCR Graphite Irradiation Experiment,⁽¹³⁾ are presented. Consequently, CSF data are presented to much higher exposures than the TSX. Data obtained from more than one sample at any particular exposure are presented as a mean point, with a bar indicating the maximum and minimum values and not the standard deviation. The small number by the mean data point indicates the number of individual data points that were averaged.

* See pages 34 through 45.

Length Change

The length change data from Tables II through X are presented graphically as a function of exposure in Figures 6 through 10. Data for the samples taken transverse and parallel to the extrusion axis are shown on separate figures to reduce the number of curves per graph, but both orientations for one graphite type should be considered together. The isotherms show that for both orientations the samples irradiated at the higher temperatures contract less than those irradiated at lower temperatures.

The data for the CSF samples cut transverse to the extrusion axis are presented in Figure 6. The contraction of the sample irradiated at the maximum temperature, 775 to 800 C, has reached a maximum and the sample is expanding with increasing exposure.

The data for the CSF parallel samples are presented in Figure 7. The figure is to the same scale as Figure 6 so that the large differences between the transverse and parallel data are readily apparent. All isotherms indicate an increasing contraction with increasing exposure and for all data except the 425 to 475 C the contraction rate is increasing.

The data for the TSX samples cut transverse to the extrusion axis are presented in Figure 8. There is a large spread in individual data points as indicated by the length of the vertical bars; however, the mean data points form uniform curves. The 675 to 800 C isotherm indicates that, at least to present exposures, this graphite is not quite as temperature sensitive as the CSF. The contraction behavior is nearly the same as that of the CSF. Since the TSX samples were cut from the center two-thirds of the block cross section, a comparison of CTE* data for full 6 in. long and 4 in. long samples is being made to determine what effect the edges may have on these length comparisons with the CSF samples that were cut from edge to edge. All isotherms show an increasing contraction rate as well as increasing contraction with continued exposure. There were no statistical differences among the three types of transverse samples; E, M, and C, and consequently only one isotherm is plotted for all three types.

* Coefficient of thermal expansion

Figure 9 presents the data from the TSX parallel samples. There is an indication of slightly more temperature sensitivity than for the transverse samples, since the 700 to 725 C and 750 to 775 C isotherms are two separate curves. In all cases, the contraction is increasing with continued exposure although the contraction rate is nearly constant. The behavior is the same as that of the CSF parallel samples with the exception that the 750 to 775 C data are contracting slightly less than the highest temperature CSF samples.

The TSGBF transverse sample data are presented in Figure 10. The behavior is nearly the same as both the TSX and CSF at temperatures up to 600 C. However, at the higher temperatures the data show a much higher contraction rate and considerably more contraction. The 775 to 800 C data are apparently approaching the maximum contraction at an exposure which is only approximately two-thirds of that for the CSF data.

FIGURE 6

Physical Distortion of CSF Graphite (Transverse) as a Function of Exposure

FIGURE 7

Physical Distortion of CSF Graphite (Parallel) as a Function of Exposure

FIGURE 8

Physical Distortion of TSX Graphite (Transverse) as a Function of Exposure

FIGURE 9

Physical Distortion of TSX Graphite (Parallel) as a Function of Exposure

FIGURE 10

Physical Distortion of TSGBF Graphite (Transverse) as a Function of Exposure

Volume Change

From the length-change data presented in Figures 6 through 9, an analysis of the resultant sample volume change was made. The model used was a sample of square cross section with both the width and thickness taken as transverse directions and the length as the parallel direction. The equation used is:

$$\frac{\Delta V}{V_o} = \left(1 + \frac{\Delta L}{L_{o\perp}}\right)^2 \left(1 + \frac{\Delta L}{L_{o\parallel}}\right) - 1$$

where V = volume

$L_{\perp}$ = length transverse to the extrusion axis

$L_{\parallel}$ = length parallel to the extrusion axis.

The calculated volume changes are shown on Figures 11 and 12 as a function of exposure. As would be expected from the length data, the volume changes are nearly identical for the TSX and CSF graphites. A nearly constant rate of change of volume with increasing exposure is evident except for the maximum temperature CSF data at the highest exposures.

FIGURE 11

Volume Distortion of CSF Graphite as a Function of Exposure

FIGURE 12
Volume Distortion of TSX Graphite as a Function of Exposure

Crystallite Parameters

The effects of continued neutron exposure on the crystallite parameters $\underline{c}$, the distance between alternate layer planes, and L_c , the apparent crystallite size in the $\underline{c}$ direction, are rather inconclusive, and there is a large scatter of results from individual samples. The $\underline{c}$ spacing data tend to fall in a general pattern of an increase in $\underline{c}$ followed by a decrease, while the L_c data show a general decrease. The effects of neutron exposure on $\underline{a}$, the unit cell dimension in the layer plane, and L_a , the apparent crystallite size in the $\underline{a}$ direction are even less conclusive with a general decrease being suggested. Results for each graphite are discussed in Appendix B.

Young's Modulus of Elasticity

Measurements of Young's modulus, E , are presented in Figures 13 through 17. The data indicate a rapid increase followed by a slower increase or in some cases a leveling off or even a decrease. The data for the CSF transverse samples are presented in Figure 13. The isotherms show an irregular behavior with the lowest temperatures causing the largest increase while the highest temperatures show an intermediate increase.

The CSF parallel data are presented in Figure 14. The isotherms indicate a more regular temperature behavior with the lowest temperature data showing the largest increase and the highest temperature data showing the least.

The data for the TSX transverse samples are presented in Figure 15. A much larger spread in individual data points is evident; however, the isotherms appear to follow a regular pattern with the largest increase at the lowest temperature and the least increase at the highest. The modulus has a higher unirradiated value than the CSF, undergoes a slightly larger increase with exposure, and, consequently, has a higher postirradiation value.

The TSX parallel data presented in Figure 16 show an extremely large spread in individual data points; however, the isotherms appear to follow the same regular pattern as the transverse data. At the intermediate temperatures, E appears to decrease significantly at the maximum exposures. All the moduli are considerably greater than the corresponding CSF parallel values.

The moduli data for the TSGBF transverse samples are presented in Figure 17. The isotherms tend to indicate two groupings of data with the lower temperatures showing a continued increase in moduli and the higher temperatures a constant value.

FIGURE 13

Young's Modulus of CSF Graphite (Transverse) as a Function of Exposure

FIGURE 14
Young's Modulus of CSF Graphite (Parallel) as a Function of Exposure

FIGURE 15
Young's Modulus of TSX Graphite (Transverse) as a Function of Exposure

FIGURE 16

Young's Modulus of TSX Graphite (Parallel) as a Function of Exposure

FIGURE 17

Young's Modulus of TSGBF Graphite (Transverse) as a Function of Exposure

Electrical Resistivity

Data on the effect of continued neutron exposures on electrical resistivity, ρ , are presented in Figures 18 through 22. The data show a rapid increase in ρ upon initial irradiation followed by a smaller rate of increase. The data for CSF transverse samples are presented in Figure 18. The isotherms indicate a regular behavior with the 425 to 475 C samples showing the largest increase and the 775 to 800 C data the least.

The data for the CSF parallel samples are presented in Figure 19. The lowest temperature samples show the largest initial increase in ρ while all the other data show a smaller initial increase followed by a constant value nearly the same as that for the 425 to 475 C data.

The TSX transverse sample data are presented in Figure 20. The same general trends are observed but the highest temperature data fall intermediate to the lowest and middle temperature data. The behavior is quite similar to that of the CSF transverse samples.

The data for the TSX parallel samples are presented in Figure 21. The data fall on two curves with the 425 to 475 C data showing a larger increase than the remaining data. The rate of increase of ρ with increasing exposure continues to be relatively large, but the changes are less than for the CSF parallel samples.

The TSGBF transverse sample data are presented in Figure 22. The 425 C isotherm shows a much larger initial increase than the remaining data, which are in a tight grouping. At the highest exposure the 700 to 725 C data increase rapidly while the 775 to 800 data decrease slightly.

FIGURE 18

Electrical Resistivity of CSF Graphite (Transverse) as a Function of Exposure

FIGURE 19
Electrical Resistivity of CSF Graphite (Parallel) as a Function of Exposure

FIGURE 20

Electrical Resistivity of TSX Graphite (Transverse) as a Function of Exposure

FIGURE 21
Electrical Resistivity of TSX Graphite (Parallel) as a Function of Exposure

FIGURE 22

Electrical Resistivity of TSGBF Graphite (Parallel) as a Function of Exposure

CONCLUSIONS

To the present exposures, irradiation effects in TSX graphite are nearly identical with those observed in CSF graphite for the following properties: length changes both transverse and parallel, volume change, crystallite parameters L_c and a , and electrical resistivity in the transverse direction. All other properties show the same trends but not the same values. Although the two graphites are considerably different materials both in raw materials and fabrication techniques, they apparently have basic similarities since the irradiation behavior is so nearly identical for so many properties. There is no indication as to whether the maximum contraction and subsequent expansion of the TSX graphite will be the same amount or occur at the same exposure as for the CSF graphite.

In applying the length-change data reported here to reactor conditions consideration should be given to the differences between small samples and large blocks. At present the largest block on which length data have been obtained was 4 by 4 by 24 in.⁽¹⁴⁾ For both the transverse and parallel orientations the large block showed contractions approximately twice the contraction of small, 0.43 in. dia. by 4 in. samples. Consequently, such a factor should be kept in mind when applying these data to changes expected in N-Reactor.

The possible effect of neutron flux intensity differences on the contraction and other properties is apparently of no significance at the temperatures studied. The neutron exposure at which the high-temperature contraction passes through a maximum, 6 to 8×10^{21} nvt, $E > 0.18$ MeV, appears to be a critical point for other parameters also. These items are discussed in more detail in HW-71500 B.⁽¹³⁾

The H-4, -5, -6 irradiation program is continuing and data for all the parameters discussed will continue to be measured on all samples so a more complete picture of the behavior of TSX graphite can be obtained. For the convenience of reactor designers and operators data are replotted in Appendix B as a function of temperature and exposure.

TABLE II
H-4-1 EXPERIMENTAL RESULTS

Capsule Position	Temperature, C	Exposure, nvt x 10 ⁻²¹ (E>0.18 Mev)	Sample Code	Sample Number	Capsules In	Length Change,		Crystallite Parameters, Å										Young's Modulus			Electrical Resistivity				
						Per Cent Δ L/L ₀	c		Per Cent Δ c/c ₀	L _c		Per Cent Δ L _c /L _{c0}	a		Per Cent Δ a/a ₀	r _a		Per Cent Δ r _a /r _{a0}	psi x 10 ⁻⁶		Per Cent Δ E/E ₀	ohm-cm x 10 ⁴		Per Cent Δ ρ/ρ ₀	
							Initial	Final		Initial	Final		Initial	Final		Initial	Final		Initial	Final		Initial	Final		Initial
1	450	0.51	CSF ⊥	142-28	4-1	-0.030	±0.001	6.730	6.771	+0.609	583	310	-46.8	2.462	2.4645	+0.101	480	440	- 8.3	0.79	1.30	+ 64.6	12.12	36.14	+198.2
			TSX ⊥(E)	158-E13	4-1	-0.032	±0.001	6.729	6.768	+0.579	581	305	-47.5	2.464	2.4651	+0.044	536	812	+51.5	0.88	1.35	+ 53.4	10.55	31.84	+201.8
			TSX ⊥(M)	158-M4	4-1	-0.025	±0.001	6.730	6.760	+0.445	593	325	-45.2	2.464	2.4653	+0.052	638	815	+27.7	0.89	1.38	+ 55.0	10.99	34.16	+210.8
			TSX ⊥(C)	158-C7	4-1	-0.027	±0.001	6.730	6.773	+0.638	590	325	-44.9	2.465	2.4646	-0.016	863	660	-23.5	0.92	1.38	+ 43.5	10.88	32.90	+202.4
2	550	0.71	CSF	142-218	4-1	-0.092	±0.001	6.724	6.769	+0.669	530	290	-45.3	2.466	2.4657	-0.012	745	493	-33.8	1.79	2.66	+ 48.6	6.81	21.17	+211.0
			TSX	158-210	4-1	-0.091	±0.001	6.725	6.773	+0.713	580	309	-46.7	2.464	2.4642	+0.008	410	740	+80.5	2.64	3.96	+ 50.0	5.20	17.30	+232.6
			TSX ⊥(E)	158-E12	4-1	-0.042	±0.001	6.729	6.766	+0.549	695	385	-44.6	2.464	2.4641	+0.004	620	467	+24.7	1.12	1.41	+ 25.9	11.43	31.37	+174.4
			TSGBF ⊥	125-4	4-1	-0.026	±0.001	6.760	6.787	+0.399	450	350	-22.2	2.464	2.4634	-0.024	420	435	+ 3.6	0.90	1.01	+12.2	20.88	35.96	+ 72.2
3	675	0.96	CSF ⊥	142-23	4-1	-0.035	±0.001	6.730	6.768	+0.564	550	330	-40.0	2.464	2.4650	+0.040	500	752	+50.4	0.89	1.21	+ 36.0	11.96	33.07	+176.5
			TSX ⊥(E)	158-E11	4-1	-0.031	±0.003	6.726	6.767	+0.609	650	332	-48.9	2.464	2.4653	+0.052	555	522	- 5.9	0.91	1.37	+ 50.5	11.25	30.65	+172.4
			TSX ⊥(M)	158-M2	4-1	-0.016	±0.001	6.734	6.756	+0.326	555	405	-27.0	2.464	2.4651	+0.044	505	737	+45.9	0.99	1.28	+ 29.3	10.74	30.98	+188.4
			TSX ⊥(C)	158-C6	4-1	-0.026	±0.001	6.725	6.757	+0.475	660	370	-43.9	2.465	2.4640	-0.040	508	780	+53.5	0.93	1.50	+61.3	10.70	30.46	+184.7
4	700	1.08	CSF	142-217	4-1	-0.066	±0.001	6.724	6.765	+0.609	515	340	-34.0	2.464	2.4650	+0.040	697	570	-18.2	1.52	2.30	+51.3	6.78	20.58	+203.4
			TSX	158-209	4-1	-0.081	±0.002	6.732	6.757	+0.371	480	325	-32.3	2.465	2.4662	+0.048	665	795	+19.5	2.19	2.85	+30.1	6.67	19.24	+188.5
			TSX ⊥(E)	158-F10	4-1	-0.020	±0.001	6.730	6.748	+0.267	505	245	-51.5	2.463	2.4650	+0.081	544	555	+ 2.0	0.92	1.34	+45.6	11.16	30.89	+176.8
			TSGBF ⊥	125-3	4-1	-0.018	±0.001	6.755	6.775	+0.296	410	248	-39.5	2.464	2.4637	-0.012	400	345	-13.8	0.93	1.31	+40.9	17.72	36.81	+107.7
5	675	0.99	CSF	142-213	4-1	-0.068	±0.001	6.735	6.762	+0.400	585	350	-40.2	2.463	2.4644	+0.056	885	787	-11.1	1.67	2.77	+65.9	7.41	21.02	+183.7
			TSX	158-201	4-1	-0.078	±0.001	6.728	6.771	+0.639	560	358	-36.1	2.464	2.4652	+0.048	890	620	-30.3	2.34	3.42	+46.2	5.69	17.87	+214.1
			TSX ⊥(E)	158-E4	4-1	-0.030	±0.001	6.735	6.760	+0.371	610	395	-35.2	2.464	2.4607	-0.133	480	282	-41.3	1.00	1.51	+51.0	11.08	29.85	+169.4
			TSGBF ⊥	125-1	4-1	-0.020	±0.002	6.752	6.793	+0.607	451	262	-41.9	2.462	2.4636	+0.064	350	278	-20.6	0.89	1.21	+36.0	18.83	37.56	+ 99.5
6	575	0.72	CSF ⊥	142-21	4-1	-0.048	±0.001	6.735	6.771	+0.534	510	385	-24.5	2.464	2.4646	+0.024	690	353	-48.8	0.73	1.15	+57.5	13.66	35.73	+161.6
			TSX ⊥(E)	158-E2	4-1	-0.048	±0.001	6.732	6.766	+0.505	610	415	-32.0	2.463	2.4648	+0.073	465	543	+16.8	1.06	1.44	+35.8	10.67	31.02	+190.7
			TSX ⊥(M)	158-M1	4-1	-0.050	±0.001	6.730	6.765	+0.520	600	375	-37.5	2.464	2.4647	+0.028	555	747	+34.6	0.88	1.35	+53.4	10.88	33.19	+205.1
			TSX ⊥(C)	158-C4	4-1	-0.043	±0.001	6.736	6.760	+0.356	483	310	-35.8	2.464	2.4647	+0.028	535	550	+ 2.8	1.15	1.45	+26.1	11.12	34.13	+206.9

TABLE III
H-5-1 EXPERIMENTAL RESULTS

Capsule Position	Temperature, C	Exposure, nvt x 10 ⁻²¹ (E>0.18 Mev)	Sample Code	Sample Number	Capsules In	Length Change,		Crystallite Parameters, Å										Young's Modulus,			Electrical Resistivity,			
						Per Cent ΔL/L ₀	g		Per Cent Δc/c ₀	L _c		Per Cent ΔL _c /L _{c0}	a		Per Cent Δa/a ₀	L _a		Per Cent ΔL _a /L _{a0}	psi x 10 ⁻⁶		Per Cent ΔE/E ₀	ohm-cm x 10 ⁴		Per Cent Δρ/ρ ₀
							Initial	Final		Initial	Final		Initial	Final		Initial	Final		Initial	Final		Initial	Final	
1	425	0.49	CSF II	142-214	5-1	-0.109 ± 0.001	6.734	6.774	+ 0.594	565	210	-62.8	2.465	2.4633	-0.068	525	294	-44.0	1.56	2.45	+ 57.0	7.74	24.96	+ 222.3
			TSX II	160-201	5-1	-0.144 ± 0.001	6.737	6.765	+ 0.415	485	220	-54.6	2.463	2.4633	+0.012	914	300	-67.2	2.04	3.12	+ 52.9	6.61	22.87	+ 246.0
			TSX ⊥(E)	160-E1	5-1	-0.047 ± 0.001	6.728	6.770	+ 0.624	635	260	-59.1	2.462	2.4635	+0.060	1010	355	-64.8	0.85	1.41	+ 65.9	11.82	34.92	+ 195.4
			TSGBF ⊥	125-5	5-1	-0.029 ± 0.001	6.755	6.801	+ 0.680	440	233	-47.0	2.463	2.4635	+0.020	325	267	-17.8	0.91	1.25	+ 37.4	18.50	40.49	+ 118.9
2	575	0.78	CSF ⊥	142-24	5-1	-0.066 ± 0.001	6.732	6.775	+ 0.638	600	245	-59.2	2.464	2.4651	+0.044	577	375	-35.0	0.87	1.33	+ 52.9	12.24	34.17	+ 179.2
			TSX ⊥(E)	160-E2	5-1	-0.059 ± 0.001	6.735	6.762	+ 0.400	680	313	-54.0	2.463	2.4653	+0.093	1250	362	-71.0	0.81	1.23	+ 51.8	11.34	33.49	+ 195.3
			TSX ⊥(M)	160-M1	5-1	-0.063 ± 0.001	6.730	6.760	+ 0.030	645	290	-55.0	2.463	2.4646	+0.064	930	570	-38.7	0.85	1.28	+ 50.6	11.42	32.53	+ 184.8
			TSX ⊥(C)	160-C1	5-1	-0.070 ± 0.001	6.730	6.767	+ 0.549	685	274	-60.0	2.462	2.4649	+0.117	998	290	-70.9	0.91	1.30	+ 42.8	10.89	32.58	+ 199.2
3	700	1.06	CSF ⊥	142-26	5-1	-0.026 ± 0.001	6.738	6.760	+ 0.326	471	296	-37.2	2.463	2.4654	+0.097	587	349	-40.5	0.84	1.26	+ 50.0	12.11	33.51	+ 176.7
			TSX ⊥(E)	160-E3	5-1	-0.033 ± 0.001	6.728	6.771	+ 0.639	760	280	-63.2	2.463	2.4656	+0.105	744	713	- 4.2	0.90	1.36	+ 51.1	10.92	32.84	+ 200.7
			TSX ⊥(M)	160-M2	5-1	-0.034 ± 0.001	6.730	6.762	+ 0.475	640	299	-53.3	2.465	2.4651	+0.004	572	370	-35.3	0.82	1.18	+ 43.9	11.49	33.21	+ 189.0
			TSX ⊥(C)	160-C2	5-1	-0.028 ± 0.001	6.722	6.761	+ 0.580	740	297	-59.9	2.464	2.4656	+0.064	1290	363	-71.9	0.81	1.24	+ 53.1	10.69	33.21	+ 210.7
4	750	1.24	CSF II	142-215	5-1	-0.129 ± 0.001	6.735	6.759	+ 0.356	600	251	-58.2	2.465	2.4651	+0.004	466	582	+24.9	1.61	2.48	+ 54.0	7.33	22.92	+ 212.8
			TSX II	160-202	5-1	-0.133 ± 0.001	6.734	6.762	+ 0.415	545	254	-53.4	2.463	2.4653	+0.093	1025	325	-68.3	2.04	3.05	+ 49.5	6.38	20.81	+ 226.1
			TSX ⊥(E)	160-E4	5-1	-0.056 ± 0.001	6.730	6.746	+ 0.237	740	254	-65.7	2.463	2.4640	+0.040	1150	400	-65.2	0.90	1.40	+ 55.6	11.43	33.34	+ 191.7
			TSGBF ⊥	125-6	5-1	-0.044 ± 0.001	6.756	6.795	+ 0.577	490	214	-56.3	2.463	2.4637	+0.028	360	280	-22.2	0.95	1.27	+ 33.7	17.68	37.63	+ 112.8
5	725	1.21	CSF ⊥	142-29	5-1	-0.058 ± 0.001	6.734	6.761	+ 0.400	554	283	-48.9	2.465	2.4649	-0.004	498	330	-33.7	0.80	1.26	+ 57.5	12.41	34.92	+ 181.4
			TSX ⊥(E)	160-E5	5-1	-0.074 ± 0.001	6.728	6.771	+ 0.639	803	298	-62.9	2.463	2.4648	+0.073	895	440	-50.8	1.00	1.49	+ 49.0	9.64	29.57	+ 206.7
			TSX ⊥(M)	160-M3	5-1	-0.048 ± 0.001	6.740	6.759	+ 0.281	599	370	-38.2	2.464	2.4656	+0.064	462	713	+54.3	0.82	1.28	+ 56.1	11.85	35.78	+ 201.9
			TSX ⊥(C)	160-C4	5-1	-0.051 ± 0.001	6.728	6.765	+ 0.549	625	293	-53.1	2.462	2.4637	+0.069	1010	585	-42.1	0.81	1.34	+ 65.4	11.42	34.11	+ 198.7
6	600	0.90	CSF II	142-216	5-1	-0.111 ± 0.001	6.726	6.767	+ 0.609	660	330	-50.0	2.465	2.4649	-0.004	475	265	-44.2	1.56	2.53	+ 62.2	10.22	23.64	+ 131.3
			TSX II	160-203	5-1	-0.114 ± 0.001	6.734	6.765	+ 0.460	740	410	-44.6	2.462	2.4646	+0.105	907	286	-86.1	2.02	3.19	+ 57.9	6.20	19.95	+ 221.9
			TSX ⊥(E)	160-E6	5-1	-0.075 ± 0.001	6.731	6.755	+ 0.356	645	340	-47.3	2.462	2.4651	+0.125	925	333	-64.0	0.94	1.58	+ 68.1	9.70	31.25	+ 222.1
			TSGBF ⊥	125-8	5-1	-0.050 ± 0.001	6.755	6.784	+ 0.429	490	310	-36.7	2.463	2.4633	+0.012	322	295	- 8.4	0.92	1.29	+ 40.2	18.47	39.54	+ 114.1

TABLE IV

H-6-1 EXPERIMENTAL RESULTS

Capsule Position	Temperature, C	Exposure, nvt x 10 ⁻²¹ (E > 0.18 Mev)	Sample Code	Sample Number	Capsules In	Length Change,		Crystallite Parameters, Å										Young's Modulus,			Electrical Resistivity,				
						Per Cent		c		Per Cent	L _c		Per Cent	a		Per Cent	L _a		Per Cent	psi x 10 ⁻⁶		Per Cent	ohm-cm x 10 ⁴		Per Cent
						ΔL/L ₀		Initial	Final		Δc/c ₀	Initial		Final	ΔL _c /L _{c0}		Initial	Final		Δa/a ₀	Initial		Final	ΔL _a /L _{a0}	
1	425	0.52	CSF ⊥	142-27	6-1	-0.047	±0.001	6.733	6.769	+0.534	480	255	-46.9	2.465	2.4626	-0.097	622	426	-31.5	1.11	1.43	+ 28.8	12.83	37.60	+193.1
			TSX ⊥(E)	160-E7	6-1	-0.053	±0.001	6.735	6.770	+0.519	593	260	-56.2	2.465	2.4632	-0.073	645	345	-46.5	1.14	1.32	+ 15.8	10.25	33.05	+ 222.4
			TSX ⊥(M)	158-M6	6-1	-0.051	±0.001	6.733	6.766	+0.490	680	242	-64.4	2.463	2.4626	-0.016	1650	772	-53.2	1.08	1.50	+ 38.9	11.12	35.50	+ 219.2
			TSX ⊥(C)	160-C5	6-1	-0.047	±0.001	6.732	6.764	+0.475	684	280	-59.1	2.465	2.4635	-0.060	598	512	-14.4	1.05	1.45	+ 38.1	11.30	34.99	+ 209.6
2	575	0.83	CSF	142-223	6-1	-0.118	±0.002	6.734	6.761	+0.400	540	279	-48.3	2.465	2.4654	+0.016	503	472	- 6.2	1.56	2.40	+ 53.8	7.77	25.02	+ 222.1
			TSX	160-204	6-1	-0.119	±0.001	6.742	6.761	+0.281	527	310	-41.2	2.466	2.4630	-0.121	340	437	+28.5	2.31	3.40	+ 47.2	6.47	20.17	+ 211.8
			TSX ⊥(E)	160-E8	6-1	-0.077	±0.001	6.730	6.756	+0.386	629	280	-55.5	2.465	2.4632	-0.073	454	298	-34.4	1.02	1.53	+ 50.0	10.17	30.62	+ 201.1
			TSGBF ⊥	125-7	6-1	-0.024	±0.002	6.751	6.770	+0.281	360	244	-32.2	2.462	2.4671	+0.207	314	238	-24.2	0.98	1.37	+ 39.8	19.52	41.07	+ 110.4
3	700	1.14	CSF	142-224	6-1	-0.096	±0.002	6.733	6.761	+0.415	490	275	-43.9	2.464	2.4640	0	522	493	- 5.6	1.60	2.41	+ 50.6	7.44	22.78	+ 206.2
			TSX	160-205	6-1	-0.104	±0.001	6.725	6.759	+0.505	546	300	-45.1	2.465	2.4648	-0.008	413	523	+26.6	2.24	3.38	+ 50.9	6.34	19.76	+ 211.6
			TSX ⊥(E)	160-E9	6-1	Oxidized	6.733	6.759	+0.386	645	315	-51.2	2.466	2.4651	-0.037	423	412	- 2.6	1.13	1.27	+ 12.4	12.11	33.78	+ 178.9	
			TSGBF ⊥	125-9	6-1	-0.004	±0.001	6.757	6.773	+0.236	440	230	-47.7	2.463	2.4628	-0.008	328	321	- 2.1	0.92	1.19	+ 29.3	20.47	42.29	+ 106.6
4	775	1.31	CSF ⊥	142-30	6-1	Oxidized	6.734	6.736	+0.029	450	313	-30.4	2.464	2.4615	-0.142	477	563	+18.0	0.97	1.21	+ 24.7	12.56	36.92	+ 193.9	
			TSX ⊥(E)	160-E10	6-1	Oxidized	6.733	6.754	+0.311	607	325	-46.4	2.465	2.4616	-0.137	516	403	-21.9	--	1.22	--	12.22	35.89	+ 193.7	
			TSX ⊥(M)	158-M7	6-1	Oxidized	6.726	6.746	+0.297	630	266	-57.8	2.462	2.4647	+0.109	1350	270	-80.0	0.96	1.37	+ 42.7	10.99	35.96	+ 227.2	
			TSX ⊥(C)	160-C6	6-1	Oxidized	6.734	6.753	+0.282	590	310	-47.4	2.465	2.4613	-0.150	437	420	- 3.9	--	1.26	--	11.38	35.80	+ 214.6	
5	775	1.25	CSF	142-225	6-1	-0.070	±0.001	6.734	6.757	+0.341	470	272	-42.1	2.464	2.4644	+0.016	444	373	-16.0	1.06	2.10	+ 98.1	7.69	24.30	+ 216.1
			TSX	160-206	6-1	-0.087	±0.001	6.734	6.729	-0.074	635	241	-62.0	2.465	2.4644	-0.024	422	410	- 2.8	2.26	3.44	+ 52.2	6.26	19.63	+ 213.4
			TSX ⊥(E)	160-E11	6-1	Oxidized	6.741	6.729	-0.178	500	290	-42.0	2.465	2.4611	-0.158	373	428	+14.7	1.07	1.22	+ 14.0	12.10	35.21	+ 191.0	
			TSGBF ⊥	125-2	6-1	Oxidized	6.762	6.778	+0.236	380	211	-44.5	2.462	2.4632	+0.048	385	246	-36.1	0.94	1.25	+ 33.0	17.02	39.02	+ 129.2	
6	625	0.89	CSF ⊥	142-31	6-1	-0.047	±0.001	6.734	6.761	+0.400	500	295	-41.0	2.465	2.4650	0	550	367	-33.3	0.78	1.26	+ 61.5	12.55	35.48	+ 182.7
			TSX ⊥(E)	160-E12	6-1	-0.038	±0.001	6.719	6.765	+0.535	545	312	-42.8	2.465	2.4643	-0.028	399	437	+ 9.5	1.20	1.26	+ 5.0	12.06	32.26	+ 168.3
			TSX ⊥(M)	158-E14	6-1	-0.037	±0.001	6.738	6.756	+0.267	530	267	-49.6	2.463	2.4656	+0.105	937	292	-68.8	1.03	1.40	+ 35.9	11.79	32.50	+ 175.6
			TSX ⊥(C)	158-C16	6-1	-0.036	±0.001	6.733	6.750	+0.252	620	304	-51.0	2.462	2.4657	+0.150	950	405	-57.4	1.04	1.34	+ 28.8	11.62	32.15	+ 176.7

TABLE V
H-4-2 EXPERIMENTAL RESULTS

Capsule Position	Temperature, C	Exposure, nvt x 10 ⁻²¹ (E> 0.18 Mev)	Sample Code	Sample Number	Capsules In	Length Change, Per Cent Δ L/L ₀	Crystallite Parameters, Å										Young's Modulus,			Electrical Resistivity,				
							c		Per Cent Δ c/c ₀	L _c		Per Cent Δ L _c /L _{c0}	a		Per Cent Δ a/a ₀	L _a		Per Cent L _a /L _{a0}	psi x 10 ⁻⁶		Per Cent Δ E/E ₀	ohm-cm x 10 ⁴		Per Cent Δ ρ/ρ ₀
							Initial	Final		Initial	Final		Initial	Final		Initial	Final		Initial	Final		Initial	Final	
1	475	0.69	CSF II	142-232	4-2	-0.344* ±0.011	6.750	6.750	0.0	475	240	-49.5	2.4654	2.4611	-0.174	603	241	-60.0	1.58	1.97	+24.7	7.44	24.22	+225.5
	475	0.69	TSX ⊥ (E)	158-E22	4-2	-0.118* ±0.012	6.742	6.736	-0.088	640	278	-56.6	2.462	2.4612	-0.032	1125	237	-78.9	0.99	1.55	+56.6	12.01	34.93	+190.8
	450	1.20	TSX ⊥ (E)	158-E13	4-1,4-2	-0.188* ±0.017	6.729	6.733	+0.059	581	262	-54.9	2.464	2.4615	-0.101	536	212	-60.4	0.88	1.55	+76.1	10.55	33.20	+214.7
	450	1.20	TSX ⊥ (C)	158-C7	4-1,4-2	-0.156* ±0.010	6.730	6.742	+0.178	590	289	-51.0	2.465	2.4607	-0.174	863	252	-70.8	0.92	1.12	+21.7	10.88	34.42	+216.4
2	600	1.83	CSF II	142-218	4-1,4-2	-0.361 ±0.001	6.724	6.725	+0.014	530	240	-54.7	2.466	2.4611	-0.198	745	211	-71.7	1.79	2.75	+53.6	6.81	22.12	+224.8
	625	1.12	CSF II	142-240	4-2	-0.170 ±0.001	6.737	6.734	-0.044	445	287	-35.5	2.4650	2.4631	-0.077	569	268	-52.9	1.52	2.60	+71.0	7.19	21.12	+193.7
	625	1.12	TSX II	158-216	4-2	-0.188 ±0.001	6.733	6.728	-0.074	530	270	-49.1	2.462	2.4607	-0.052	1152	230	-80.0	2.58	3.89	+50.8	5.40	17.11	+216.8
	600	1.83	TSGBF ⊥	125-4	4-1,4-2	-0.222 ±0.001	6.760	6.759	-0.014	450	202	-55.1	2.464	2.4603	-0.150	420	224	-46.7	0.90	1.27	+41.1	20.88	36.30	+73.8
3	750	1.51	CSF ⊥	141-13	4-2	-0.080 ±0.001	6.754	6.723	-0.458	535	263	-50.8	2.4666	2.4623	-0.174	522	308	-41.0	0.86	1.35	+57.0	11.91	33.40	+180.4
	750	1.51	TSX ⊥ (E)	158-E24	4-2	-0.068 ±0.001	6.734	6.717	-0.252	610	278	-54.4	2.462	2.4613	-0.028	1150	298	-74.1	0.97	1.37	+41.2	12.14	32.68	+169.2
	725	2.47	TSX ⊥ (M)	158-M2	4-1,4-2	-0.174 ±0.002	6.734	6.722	-0.178	555	258	-53.5	2.464	2.4604	-0.146	505	303	-40.0	0.99	1.39	+40.4	10.74	34.33	+219.6
	725	2.47	TSX ⊥ (C)	158-C6	4-1,4-2	-0.183 ±0.001	6.725	6.711	-0.208	660	240	-63.6	2.465	2.4620	-0.121	508	320	-37.0	0.93	1.52	+63.4	10.70	33.84	+216.3
4	775	2.73	CSF II	142-217	4-1,4-2	-0.398 ±0.002	6.724	6.716	-0.118	515	238	-53.8	2.464	2.4607	-0.133	697	336	-51.8	1.52	2.47	+62.5	6.78	23.33	+244.1
	775	2.73	TSX II	158-209	4-1,4-2	-0.421 ±0.001	6.732	6.723	-0.133	480	248	-48.3	2.465	2.4573	-0.312	665	235	-64.7	2.19	3.18	+45.2	6.67	21.72	+225.6
	825	1.65	TSX ⊥ (M)	160-M4	4-2	-0.094 ±0.001	6.750	6.717	-0.488	570	270	-52.6	2.4667	2.4613	-0.218	605	305	-49.6	0.83	1.33	+60.2	11.97	35.18	+193.9
	825	1.65	TSGBF ⊥	125-10	4-2	-0.160 ±0.001	6.762	6.740	-0.325	405	198	-51.1	2.461	2.4605	-0.020	515	194	-62.3	0.92	1.22	+32.6	20.22	39.41	+94.9
5	750	2.58	TSX ⊥ (E)	158-E4	4-1,4-2	-0.192 ±0.001	6.735	6.717	-0.267	610	240	-60.7	2.464	2.4605	-0.142	480	291	-39.4	1.00	1.65	+65.0	11.08	32.67	+194.8
	800	1.59	TSX ⊥ (E)	160-E13	4-2	-0.113 ±0.001	6.748	6.722	-0.385	630	242	-61.6	2.4670	2.4614	-0.226	845	331	-60.8	0.81	1.31	+61.7	11.96	34.35	+187.2
	800	1.59	TSX II	160-208	4-2	-0.211 ±0.001	6.746	6.723	-0.340	650	273	-58.0	2.4677	2.4600	-0.312	577	293	-49.2	2.09	3.57	+70.8	6.16	19.09	+209.9
	750	2.58	TSGBF ⊥	125-1	4-1,4-2	-0.323 ±0.002	6.752	6.736	-0.236	451	179	-60.3	2.462	2.4599	-0.085	350	215	-38.6	0.89	1.22	+37.1	18.83	40.19	+113.4
6	625	1.90	CSF ⊥	142-21	4-1,4-2	-0.199 ±0.001	6.735	6.733	-0.029	510	230	-54.9	2.464	2.4609	-0.125	690	302	-56.2	0.73	1.23	+68.5	13.66	38.03	+178.4
	625	1.90	TSX ⊥ (E)	158-E2	4-1,4-2	-0.201 ±0.001	6.732	6.742	+0.148	610	273	-55.2	2.463	2.4604	-0.105	465	308	-33.8	1.06	1.54	+45.3	10.67	33.30	+212.1
	650	1.18	TSX ⊥ (E)	158-E19	4-2	-0.090 ±0.001	6.761	6.720	-0.606	532	290	-45.5	2.4648	2.4608	-0.162	773	278	-64.0	0.87	1.69	+94.2	9.82	28.71	+192.4
	625	1.90	TSX ⊥ (M)	158-M1	4-1,4-2	-0.194 ±0.001	6.730	6.724	-0.089	600	250	-58.3	2.464	2.4605	-0.142	555	285	-48.6	0.88	1.45	+64.8	10.88	35.42	+225.6

*Based on hole-to-hole measurements

TABLE VI
H-5-2 EXPERIMENTAL RESULTS

Capsule Position	Temperature, C	Exposure, nvt x 10 ⁻²¹ (E > 0.18 Mev)	Sample Code	Sample Number	Capsules In	Length Change,		Crystallite Parameters, Å												Young's Modulus,			Electrical Resistivity,		
						Per Cent		c		Per Cent	L _c		Per Cent	a		Per Cent	L _a		Per Cent	psi x 10 ⁻⁶		Per Cent	ohm-cm x 10 ⁴		Per Cent
						ΔL/L ₀	±	Initial	Final		ΔL/L ₀	ΔL/L ₀		Initial	Final		ΔL/L ₀	ΔL/L ₀		Initial	Final		Initial	Final	
1	450	1.25	CSF	142-214	5-1,5-2	-0.430	±0.001	6.734	6.745	+0.163	565	197	-65.1	2.465	2.4590	-0.243	525	295	-43.8	1.56	2.43	+ 55.8	7.74	26.54	+ 242.9
	475	0.76	TSX	158-208	5-2	-0.240	±0.001	6.753	6.732	-0.310	445	218	-51.0	2.4654	2.4604	-0.202	845	328	-61.2	2.69	4.12	+ 53.2	5.45	17.51	+ 221.3
	475	0.76	TSX ⊥ (E)	158-E18	5-2	-0.159	±0.001	6.751	6.735	-0.237	472	246	-47.9	2.4647	2.4601	-0.186	865	310	-64.2	1.08	1.73	+ 60.2	9.95	29.36	+ 195.1
	450	1.27	TSX ⊥ (M)	158-M4	4-1,5-2	-0.170	±0.001	6.730	6.733	+0.044	593	231	-61.0	2.464	2.4599	-0.166	638	340	-46.7	0.89	1.36	+ 52.8	10.99	36.57	+ 232.8
2	600	1.16	CSF ⊥	142-46	5-2	-0.149	±0.001	6.759	6.738	-0.310	470	242	-48.5	2.4661	2.4609	-0.210	1100	435	-60.4	0.80	1.25	+ 56.2	12.24	35.71	+ 191.7
	600	1.87	TSX ⊥ (E)	158-E12	4-1,5-2	-0.231	±0.001	6.729	6.727	-0.029	695	248	-64.3	2.464	2.4591	-0.198	620	388	-37.4	1.12	1.43	+ 27.7	11.43	34.12	+ 198.5
	600	1.16	TSX ⊥ (M)	158-M8	5-2	-0.155	±0.001	6.748	6.705	-0.637	457	212	-53.6	2.4647	2.4599	-0.194	946	535	-43.4	0.92	1.47	+ 59.8	11.35	32.59	+ 187.1
	600	1.94	TSX ⊥ (C)	160-C1	5-1,5-2	-0.312	±0.001	6.730	6.728	-0.029	685	210	-69.3	2.462	2.4604	-0.064	998	420	-57.9	0.91	1.39	+ 52.7	10.89	35.05	+ 221.9
3	725	2.57	CSF ⊥	142-26	5-1,5-2	-0.258	±0.001	6.738	6.719	-0.281	471	210	-55.4	2.463	2.4593	-0.150	587	322	-45.1	0.84	1.37	+ 63.1	12.11	37.57	+ 210.2
	725	2.57	TSX ⊥ (E)	160-E3	5-1,5-2	-0.294	±0.001	6.728	6.723	-0.074	760	218	-71.3	2.463	2.4601	-0.117	744	400	-46.2	0.90	1.49	+ 65.6	10.92	36.31	+ 232.5
	725	1.51	CSF	142-238	5-2	-0.248	±0.001	6.756	6.724	-0.473	458	238	-48.0	2.4660	2.4603	-0.231	694	470	-32.3	1.78	—	+ —	7.18	21.97	+ 206.0
	725	1.51	TSX	158-220	5-2	-0.259	±0.001	6.749	6.720	-0.429	565	231	-59.1	2.4770	2.4609	-0.649	990	785	-20.7	2.76	3.69	+ 33.7	5.84	19.25	+ 229.6
4	775	1.63	CSF ⊥	141-16	5-2	-0.128	±0.001	6.751	6.729	-0.325	585	240	-59.0	2.4692	2.4599	-0.376	833	360	-56.8	0.86	1.40	+ 62.8	11.80	34.33	+ 190.9
	750	2.71	TSX ⊥ (E)	158-E10	4-1,5-2	-0.204	±0.001	6.730	6.712	-0.267	505	228	-54.8	2.463	2.4599	-0.125	544	369	-32.2	0.92	1.47	+ 59.8	11.16	35.51	+ 218.2
	775	1.63	TSX ⊥ (C)	158-C2	5-2	-0.103	±0.001	6.753	6.716	-0.547	505	245	-51.5	2.4656	2.4596	-0.243	720	400	-44.4	0.53	1.38	+ 62.4	11.79	36.34	+ 208.2
	775	2.87	TSGBF ⊥	125-6	5-1,5-2	-0.448	±0.001	6.756	6.760	+0.059	490	148	-69.8	2.463	2.4576	-0.219	360	192	-46.7	0.95	1.27	+ 33.7	17.68	39.60	+ 124.0
5	750	1.53	CSF ⊥	141-14	5-2	-0.128	±0.001	6.757	6.731	-0.384	462	273	-40.9	2.4671	2.4601	-0.283	467	392	-16.1	0.79	1.32	+ 67.1	12.05	34.51	+ 186.4
	750	1.53	TSX ⊥ (M)	158-M13	5-2	-0.124	±0.001	6.759	6.699	-0.887	393	240	-38.9	2.4659	2.4595	-0.259	1275	432	-66.1	0.88	1.46	+ 65.9	11.65	35.76	+ 207.0
	750	2.74	TSX ⊥ (C)	160-C4	5-1,5-2	-0.320	±0.001	6.728	6.722	-0.089	625	252	-59.7	2.462	2.4584	+0.125	1010	445	-55.9	0.81	1.47	+ 81.5	11.42	36.56	+ 220.1
	725	2.52	TSX	158-201	4-1,5-2	-0.390	±0.001	6.728	6.733	+0.074	560	242	-56.8	2.464	2.4594	-0.186	890	410	-53.9	2.34	3.69	+ 57.7	5.69	20.33	+ 257.3
6	575	1.12	CSF	142-233	5-2	-0.201	±0.001	6.759	6.721	-0.562	470	270	-42.6	2.4656	2.4597	-0.239	777	323	-58.4	1.76	2.37	+ 34.6	7.13	22.24	+ 211.9
	600	2.02	TSX	160-203	5-1,5-2	-0.406	±0.001	6.734	6.734	+0.0	740	268	-63.8	2.462	2.4593	-0.109	907	372	-59.0	2.02	3.10	+ 53.5	6.20	22.37	+ 260.8
	600	2.02	TSX ⊥ (E)	160-E6	5-1,5-2	-0.289	±0.001	6.731	6.731	+0.0	645	270	-58.1	2.462	2.4592	-0.113	925	330	-64.3	0.94	1.70	+ 80.8	9.70	33.12	+ 241.4
	575	1.12	TSGBF ⊥	125-11	5-2	-0.114	±0.001	6.769	6.744	-0.369	411	285	-30.6	2.4640	2.4593	-0.190	668	288	-56.9	0.88	1.45	+ 64.8	15.24	35.68	+ 134.1

TABLE VII
H-6-2 EXPERIMENTAL RESULTS

Capsule Position	Temperature, C	Exposure, nvt x 10 ⁻²¹ (E>0.18 Mev)	Sample Code	Sample Number	Capsules In	Length Change,		Crystallite Parameters, Å												Young's Modulus,			Electrical Resistivity,								
						Per Cent		c		Per Cent		L _a		Per Cent		a		Per Cent		L _a		Per Cent		psi x 10 ⁻⁶		Per Cent		ohm-cm x 10 ⁴		Per Cent	
						Initial	Final	Δc/c ₀		Initial	Final	ΔL _a /L _{a0}		Initial	Final	Δa/a ₀		Initial	Final	ΔL _a /L _{a0}		Initial	Final	ΔE/E ₀		Initial	Final	Δρ/ρ ₀			
1	450	1.23	CSF ⊥	142-27	6-1,6-2	-0.236	±0.001	6.733	6.748	+0.222	480	200	-58.3	2.465	2.4563	-0.352	622	332	-46.6	1.11	1.40	+26.1	12.83	40.55	+216.1						
	450	1.20	TSX ⊥ (E)	160-E1	5-1,6-2	-0.246	±0.001	6.728	6.736	+0.118	635	195	-69.3	2.462	2.4577	-0.174	1010	271	-73.2	0.85	1.47	+72.9	11.82	37.90	+220.6						
	450	1.23	TSX ⊥ (M)	158-M6	6-1,6-2	-0.238	±0.001	6.733	6.739	+0.089	680	212	-68.8	2.463	2.4571	-0.239	1650	380	-77.0	1.08	1.50	+38.9	11.12	38.46	+245.9						
	450	1.23	TSX ⊥ (C)	160-C5	6-1,6-2	-0.224	±0.001	6.732	6.731	-0.014	684	210	-69.3	2.465	2.4577	-0.296	598	211	-64.7	1.05	1.39	+32.4	11.30	37.65	+233.2						
2	600	1.96	CSF	142-223	6-1,6-2	-0.471	±0.001	6.734	6.717	-0.252	540	188	-65.2	2.465	2.4577	-0.296	503	270	-46.3	1.56	2.15	+37.8	7.77	28.10	+261.6						
	600	1.84	TSX	158-210	4-1,6-2	-0.390	±0.001	6.725	6.723	-0.029	580	240	-58.6	2.464	2.4581	-0.239	410	356	-13.2	2.64	4.13	+56.4	5.20	20.30	+290.4						
	600	1.96	TSX ⊥ (E)	160-E8	6-1,6-2	-0.345	±0.001	6.730	6.732	+0.029	629	220	-65.0	2.465	2.4580	-0.283	454	296	-34.8	1.02	1.57	+53.9	10.17	33.11	+225.6						
	600	1.96	TSGBF ⊥	125-7	6-1,6-2	-0.273	±0.001	6.751	6.753	+0.029	360	198	-45.0	2.462	—	—	314	—	—	0.98	1.41	+43.9	19.52	41.87	+114.5						
3	725	2.67	CSF	142-224	6-1,6-2	-0.493	±0.002	6.733	6.728	-0.074	490	200	-59.2	2.464	2.4603	-0.150	522	505	- 3.3	1.60	2.54	+58.8	7.44	26.23	+252.6						
	725	2.67	TSX	160-205	6-1,6-2	-0.495	±0.001	6.725	6.723	-0.029	546	202	-63.0	2.465	2.4584	-0.267	413	414	+ 0.2	2.24	3.56	+58.9	6.34	23.12	+264.7						
	750	1.53	TSX ⊥ (E)	158-E21	6-2	-0.094	±0.001	6.747	6.716	-0.459	446	235	-47.3	2.4665	2.4591	-0.300	1250	375	-70.0	0.92	1.46	+58.7	11.96	35.73	+198.7						
	725	2.67	TSGBF ⊥	125-9	6-1,6-2	-0.390	±0.002	6.757	6.454	-0.044	440	160	-63.6	2.463	—	—	328	—	—	0.92	1.17	+27.2	20.47	43.47	+112.4						
4	800	1.74	CSF ⊥	142-34	6-2	-0.132	±0.001	6.753	6.723	-0.444	405	240	-40.7	2.4646	2.4581	-0.263	822	405	-50.7	0.81	1.34	+65.4	11.93	38.71	+224.5						
	775	2.98	TSX ⊥ (E)	160-E4	5-1,6-2	-0.347	±0.001	6.730	6.720	-0.148	740	200	-73.0	2.463	2.4585	-0.182	1150	307	-73.3	0.90	1.48	+64.4	11.43	40.22	+251.9						
	800	1.74	TSX ⊥ (C)	167-C21	6-2	-0.108	±0.002	6.754	6.713	-0.607	440	275	-37.5	2.4656	2.4587	-0.279	825	350	-57.6	0.78	1.42	+82.1	11.98	39.86	+232.7						
	775	2.98	CSF	142-215	5-1,6-2	-0.606	±0.001	6.735	6.720	-0.222	600	200	-66.7	2.465	2.4585	-0.263	466	323	-30.7	1.61	2.44	+51.6	7.33	27.49	+275.0						
5	725	2.64	CSF	142-213	4-1,6-2	-0.413	±0.001	6.735	6.726	-0.133	585	279	-52.3	2.463	2.4590	-0.162	885	430	-51.4	1.67	2.42	+44.9	7.41	26.94	+263.6						
	750	2.90	TSX	160-206	6-1,6-2	-0.560	±0.002	6.734	6.723	-0.163	635	230	-63.8	2.465	2.4588	-0.251	422	270	-36.0	2.26	3.54	+56.6	6.26	23.51	+275.6						
	750	2.86	TSX ⊥ (E)	160-E5	5-1,6-2	-0.390	±0.001	6.728	6.719	-0.133	803	230	-71.4	2.463	2.4584	-0.186	895	298	-66.7	1.00	1.65	+65.0	9.64	35.62	+269.5						
	750	1.65	TSGBF ⊥	125-17	6-2	-0.185	±0.001	6.771	6.734	-0.546	320	205	-35.9	2.4648	2.4579	-0.280	1110	1000	- 9.9	0.87	1.23	+41.4	15.74	40.26	+155.8						
6	625	2.09	CSF ⊥	142-31	6-1,6-2	-0.255	±0.001	6.734	6.723	-0.163	500	238	-52.4	2.465	2.4583	-0.271	550	380	-30.9	0.78	1.34	+71.8	12.55	42.00	+234.7						
	600	1.20	TSX ⊥ (E)	167-E26	6-2	-0.142	±0.001	6.730	6.707	-0.341	600	280	-53.3	2.4668	2.4597	-0.287	792	362	-54.3	0.86	1.50	+74.4	11.26	36.21	+221.6						
	600	1.92	TSX ⊥ (C)	158-C4	4-1,6-2	-0.217	±0.001	6.736	6.729	-0.103	483	259	-46.4	2.464	2.4588	-0.211	535	293	-45.2	1.15	1.39	+20.9	11.12	40.36	+262.9						
	600	1.20	TSX ⊥ (C)	167-C26	6-2	-0.120	±0.001	6.740	6.723	-0.252	682	323	-52.6	2.4655	2.4585	-0.283	870	323	-62.9	0.88	1.14	+29.5	12.80	38.38	+199.8						

TABLE VIII
H-4-3 EXPERIMENTAL RESULTS

Capsule Position	Temperature, C	Exposure, nvt x 10 ⁻²¹ (E > 0.18 Mev)	Sample Code	Sample Number	Capsules In	Length Change, Per Cent $\Delta L/L_0$	Crystallite Parameters, Å												Young's Modulus			Electrical Resistivity,		
							c		Per Cent $\Delta c/c_0$	L _c		Per Cent $\Delta L_c/L_{c0}$	a		Per Cent $\Delta a/a_0$	L _a		Per Cent $\Delta L_a/L_{a0}$	psi x 10 ⁻⁶		Per Cent $\Delta E/E_0$	ohm-cm x 10 ⁴		Per Cent $\Delta \rho/\rho_0$
							Initial	Final		Initial	Final		Initial	Final		Initial	Final		Initial	Final		Initial	Final	
1	425	1.12	CSF $\perp$	142-28	4-1,4-3	-0.137 $\pm$ 0.001	6.730	6.734	+0.059	583	238	-59.2	2.462	2.4600	-0.081	480	330	-31.2	0.79	1.41	+78.5	12.12	41.15	+239.5
	425	1.13	TSX $\perp$ (E)	160-E7	6-1,4-3	-0.211 $\pm$ 0.001	6.735	6.742	+0.104	593	206	-65.3	2.465	2.4580	-0.284	645	280	-56.6	1.14	1.73	+51.8	10.25	35.76	+248.9
	425	1.10	TSX $\parallel$	160-201	5-1,4-3	-0.398 $\pm$ 0.001	6.737	6.744	+0.104	485	195	-59.8	2.463	2.4551	-0.321	914	328	-64.1	2.04	3.42	+67.6	6.61	25.55	+286.5
	425	1.10	TSGBF $\perp$	125-5	5-1,4-3	-0.155 $\pm$ 0.001	6.755	6.754	-0.015	440	195	-55.7	2.463	2.4562	-0.032	325	289	-11.1	0.91	1.32	+45.0	18.50	36.84	+99.1
2	600	2.15	CSF $\parallel$	142-240	4-2,4-3	-0.480 $\pm$ 0.001	6.737	6.729	-0.119	445	245	-44.9	2.4650	2.4584	-0.268	569	342	-39.9	1.52	2.84	+86.8	7.19	25.12	+249.4
	600	2.15	TSX $\parallel$	158-216	4-2,4-3	-0.537 $\pm$ 0.001	6.733	6.734	+0.015	530	198	-62.6	2.462	2.4573	-0.191	1152	440	-61.8	2.58	4.26	+65.1	5.40	21.44	+297.0
	525	1.81	TSX $\perp$ (E)	160-E2	5-1,4-3	-0.292 $\pm$ 0.001	6.735	6.730	-0.074	680	248	-63.5	2.463	2.4579	-0.207	1250	365	-70.8	0.81	1.46	+80.2	11.34	39.08	+244.6
	600	2.86	TSGBF $\perp$	125-4	4-1,4-2,4-3	-0.492 $\pm$ 0.001	6.760	6.762	+0.030	450	185	-58.9	2.464	2.4567	-0.296	420	342	-18.6	0.90	1.44	+60.0	20.88	40.71	+94.9
3	700	2.39	CSF $\perp$	142-23	4-1,4-3	-0.234 $\pm$ 0.001	6.730	6.723	-0.104	550	230	-58.2	2.464	2.4588	-0.211	500	645	+29.0	0.89	1.30	+46.1	11.96	39.72	+232.1
	750	2.94	TSX $\perp$ (E)	158-E24	4-2,4-3	-0.306 $\pm$ 0.001	6.734	6.705	-0.431	610	200	-67.2	2.462	2.4588	-0.130	1150	420	-63.5	0.97	1.54	+58.8	12.14	38.35	+215.9
	725	3.90	TSX $\perp$ (M)	158-M2	4-1,4-2,4-3	-0.409 $\pm$ 0.001	6.734	6.730	-0.059	555	275	-50.4	2.464	2.4580	-0.244	505	520	+3.0	0.99	1.43	+44.4	10.74	39.23	+265.3
	750	2.49	TSX $\perp$ (C)	160-C2	5-1,4-3	-0.284 $\pm$ 0.001	6.722	6.717	-0.074	740	205	-72.3	2.464	2.4587	-0.215	1290	372	-71.2	0.81	1.32	+63.0	10.69	40.59	+279.7
4	775	4.37	CSF $\parallel$	142-217	4-1,4-2,4-3	-1.028 $\pm$ 0.001	6.724	6.728	+0.059	515	200	-61.2	2.464	2.4585	-0.223	697	388	-44.3	1.52	2.46	+61.8	6.78	26.27	+228.5
	775	4.37	TSX $\parallel$	158-209	4-1,4-2,4-3	-1.023 $\pm$ 0.002	6.732	6.705	-0.401	480	185	-61.4	2.465	2.4587	-0.256	665	850	+27.8	2.19	3.16	+44.3	6.67	24.76	+271.2
	775	4.22	TSX $\perp$ (E)	158-E4	(4-1,4-2),*4-3	-0.433 $\pm$ 0.001	6.735	6.721	-0.208	610	240	-60.6	2.464	2.4584	-0.227	480	385	-19.8	1.00	1.69	+69.0	11.08	36.84	+232.5
	825	3.29	TSX $\perp$ (M)	160-M4	4-2,4-3	-0.367 $\pm$ 0.001	6.750	6.719	-0.459	570	202	-64.6	2.4667	2.4587	-0.324	605	700	+15.7	0.83	1.38	+66.3	11.97	40.79	+240.8
5	725	1.53	CSF $\perp$	142-53	4-3	-0.089 $\pm$ 0.001	6.727	6.717	-0.149	621	280	-54.9	2.4624	2.4588	-0.146	787	490	-37.7	0.77	1.19	+54.5	13.22	39.17	+196.3
	725	1.53	TSX $\perp$ (E)	167-E31	4-3	-0.101 $\pm$ 0.001	6.725	6.717	-0.118	475	240	-49.5	2.4619	2.4592	-0.110	1135	538	-52.6	0.90	1.28	+42.2	14.27	37.46	+162.5
	725	1.53	TSX $\parallel$	167-228	4-3	-0.222 $\pm$ 0.001	6.728	6.717	-0.163	453	240	-47.0	2.4627	2.4590	-0.150	1160	615	-47.0	2.70	3.77	+39.6	5.36	19.20	+258.2
	725	1.53	TSGBF $\perp$	125-18	4-3	-0.145 $\pm$ 0.001	---	6.740	---	---	198	---	---	2.4599	---	---	450	---	0.88	1.26	+43.2	15.74	39.82	+152.9
6	600	1.95	CSF $\parallel$	142-216	5-1,4-3	-0.392 $\pm$ 0.001	6.726	6.725	-0.015	660	247	-62.6	2.465	2.4586	-0.260	475	362	-23.8	1.56	2.50	+60.2	10.22	26.86	+162.8
	625	2.23	TSX $\perp$ (E)	158-E19	4-2,4-3	-0.314 $\pm$ 0.001	6.761	6.733	-0.414	532	308	-42.1	2.4648	2.4587	-0.247	773	1105	+42.9	0.87	1.75	+101.1	9.82	32.41	+230.0
	600	2.95	TSX $\perp$ (M)	158-M1	4-1,4-2,4-3	-0.460 $\pm$ 0.001	6.730	6.734	+0.059	600	210	-65.0	2.464	2.4587	-0.215	555	330	-40.5	0.88	1.48	+68.2	10.88	38.70	+255.7
	600	1.95	TSGBF $\perp$	125-8	5-1,4-3	-0.296 $\pm$ 0.001	6.755	6.757	+0.030	490	310	-36.7	2.463	2.4563	-0.272	322	350	+8.7	0.92	1.28	+39.1	18.47	43.28	+134.3

*Position 5

TABLE IX
H-5-3 EXPERIMENTAL RESULTS

Capsule Position	Temperature, C	Exposure, nvt x 10 ⁻²¹ (E>0.18 Mev)	Sample Code	Sample Number	Capsules In	Length Change, Per Cent ΔL/L ₀	Crystallite Parameters, Å										Young's Modulus,			Electrical Resistivity,				
							a		Per Cent Δ a/a ₀	L _c		Per Cent Δ L _c /L _{c0}	a		Per Cent Δ a/a ₀	L _a		Per Cent Δ L _a /L _{a0}	psi x 10 ⁻⁶		Per Cent Δ E/E ₀	ohm-cm x 10 ⁴		Per Cent Δ ρ/ρ ₀
							Initial	Final		Initial	Final		Initial	Final		Initial	Final		Initial	Final		Initial	Final	
1	450	1.99	CSF	142-214	5-1,5-2,5-3	-0.677 ± 0.001	6.734	6.751	+0.252	565	167	-70.4	2.465	2.4553	-0.393	525	220	-58.1	1.56	2.62	+67.9	7.74	27.52	+255.6
	450	1.50	TSX	158-208	5-2,5-3	-0.476 ± 0.001	6.753	6.741	-0.177	445	210	-52.8	2.4654	2.4560	-0.381	845	310	-63.3	2.69	4.43	+64.7	5.45	19.47	+257.2
	450	1.50	TSX ⊥ (E)	158-E18	5-2,5-3	-0.304 ± 0.001	6.751	6.738	-0.192	472	205	-56.6	2.4647	2.4576	-0.288	865	300	-65.3	1.08	1.89	+75.0	9.95	30.77	+209.2
	450	2.01	TSX ⊥ (M)	158-M4	4-1,5-2,5-3	-0.291 ± 0.001	6.730	6.742	+0.178	593	215	-63.7	2.464	2.4576	-0.259	638	318	-50.2	0.89	1.48	+66.3	10.99	37.35	+239.8
2	575	3.05	CSF	142-218	4-1,4-2,5-3	-0.744 ± 0.001	6.724	6.738	+0.208	530	205	-61.3	2.466	2.4580	-0.324	745	525	-29.5	1.79	2.88	+60.9	6.81	24.15	+254.6
	575	2.05	TSX	160-204	6-1,5-3	-0.459 ± 0.001	6.742	6.723	-0.281	527	238	-54.8	2.466	2.4604	-0.227	340	475	+39.7	2.31	3.39	+46.8	6.47	21.96	+239.4
	625	3.09	TSX ⊥ (E)	158-E12	4-1,5-2,5-3	-0.475 ± 0.001	6.729	6.720	-0.133	695	221	-68.2	2.464	2.4584	-0.227	620	560	-9.7	1.12	1.57	+40.2	11.43	36.00	+215.0
	575	3.16	TSX ⊥ (C)	160-C1	5-1,5-2,5-3	-0.611 ± 0.001	6.730	6.732	+0.029	685	198	-71.1	2.462	2.4579	-0.166	998	345	-65.4	0.91	1.50	+64.8	10.89	36.17	+232.1
3	725	3.23	CSF ⊥	141-13	4-2,5-3	-0.324 ± 0.001	6.754	6.719	-0.518	535	210	-60.7	2.4666	2.4588	-0.316	522	385	-26.2	0.86	1.42	+65.1	11.91	37.79	+217.3
	725	2.78	TSX ⊥ (M)	160-M2	5-1,5-3	-0.274 ± 0.001	6.730	6.723	-0.104	640	220	-65.6	2.465	2.4592	-0.235	572	910	+59.1	0.82	1.41	+72.0	11.49	36.80	+220.3
	725	4.19	TSX ⊥ (C)	158-C6	4-1,4-2,5-3	-0.387 ± 0.001	6.725	6.722	-0.044	660	240	-63.6	2.465	2.4610	-0.162	508	600	+18.1	0.93	1.51	+62.4	10.70	36.14	+237.8
	725	3.23	TSX	158-220	5-2,5-3	-0.766 ± 0.002	6.749	6.726	-0.340	565	200	-64.6	2.4770	2.4591	-0.722	990	905	-8.6	2.76	3.79	+37.3	5.84	20.60	+252.7
4	800	3.72	CSF ⊥	141-16	5-2,5-3	-0.432 ± 0.001	6.751	6.729	-0.325	585	200	-65.8	2.4692	2.4588	-0.421	833	460	-44.8	0.86	1.45	+68.6	11.80	36.81	+211.9
	775	4.80	TSX ⊥ (E)	158-E10	4-1,5-2,5-3	-0.452 ± 0.001	6.730	6.719	-0.163	505	219	-56.6	2.463	2.4578	-0.211	544	328	-39.7	0.92	1.49	+62.0	11.16	37.53	+236.3
	775	3.33	TSX	160-202	5-1,5-3	-0.644 ± 0.001	6.734	6.723	-0.163	545	195	-64.2	2.463	2.4596	-0.138	1025	470	-54.1	2.04	3.05	+49.5	6.38	23.79	+272.9
	775	4.96	TSGBF ⊥	125-6	5-1,5-2,5-3	-0.651 ± 0.001	6.756	6.771	+0.222	490	150	-69.4	2.463	2.4579	-0.207	360	500	+38.9	0.95	1.30	+36.8	17.68	40.18	+127.3
5	725	3.15	CSF ⊥	142-46	(5-2) ⁽¹⁾ 5-3	-0.446 ± 0.001	6.759	6.731	-0.414	470	200	-57.4	2.4661	2.4584	-0.312	1100	485	-55.9	0.80	1.46	+82.5	12.24	38.83	+236.6
	750	3.20	TSX ⊥ (M)	160-M3	5-1,5-3	-0.338 ± 0.001	6.740	6.725	-0.222	599	240	-59.9	2.464	2.4582	-0.235	462	810	+75.3	0.82	1.36	+65.8	11.85	38.85	+227.8
	775	3.58	TSX	160-208	4-2,5-3	-0.770 ± 0.001	6.746	6.723	-0.340	650	229	-64.8	2.4677	2.4573	-0.421	577	635	+10.0	2.09	3.68	+76.1	6.16	21.38	+247.1
	750	3.07	TSGBF ⊥	125-3	(4-1) ⁽²⁾ 5-3	-0.419 ± 0.001	6.755	6.754	-0.014	410	195	-52.4	2.464	2.4559	-0.328	400	465	+16.2	0.93	1.27	+36.6	17.72	40.15	+126.6
6	625	3.24	CSF ⊥	142-21	4-1,4-2,5-3	-0.461 ± 0.001	6.735	6.755	+0.296	510	229	-55.1	2.464	2.4598	-0.170	690	995	+44.2	0.73	1.32	+80.8	13.66	40.00	+192.8
	600	3.36	TSX ⊥ (E)	160-E6	5-1,5-2,5-3	-0.580 ± 0.001	6.731	6.740	+0.133	645	242	-62.5	2.462	2.4583	-0.150	925	762	-17.6	0.94	1.74	+85.1	9.70	33.80	+248.4
	600	3.36	TSX	160-203	5-1,5-2,5-3	-0.808 ± 0.001	6.734	6.733	-0.014	740	240	-67.6	2.462	2.4586	-0.138	907	250	-72.4	2.02	3.07	+52.0	6.20	23.48	+278.7
	600	2.50	TSGBF ⊥	125-11	5-2,5-3	-0.368 ± 0.001	6.769	6.740	-0.428	411	212	-48.4	2.4640	2.4564	-0.308	668	550	-17.7	0.88	1.47	+67.0	15.24	36.82	+141.6

(1)Position 2 (2)Position 4

TABLE X
H-6-3 EXPERIMENTAL RESULTS

Capsule Position	Temperature, C	Exposure, nvt x 10 ⁻²¹ (E>0.18 Mev)	Sample Code	Sample Number	Capsules In	Length Change,		Crystallite Parameters, Å										Young's Modulus			Electrical Resistivity,			
						Per Cent ΔL/L ₀	c		Per Cent Δc/c ₀	L _c		Per Cent ΔL _c /L _{c0}	a		Per Cent Δa/a ₀	L _a		Per Cent ΔL _a /L _{a0}	psi x 10 ⁻⁶		Per Cent ΔE/E ₀	ohm-cm x 10 ⁴		Per Cent Δρ/ρ ₀
							Initial	Final		Initial	Final		Initial	Final		Initial	Final		Initial	Final		Initial	Final	
1	450	1.84	CSF ⊥	142-27	6-1,6-2,6-3	-0.377 ±0.001	6.733	6.748	+0.222	480	195	-59.4	2.465	2.4566	-0.340	622	370	-40.5	1.11	1.54	+38.7	12.83	40.43	+215.1
	450	1.81	TSX ⊥ (E)	160-E1	5-1,6-2,6-3	-0.408 ±0.001	6.728	6.745	+0.252	635	190	-70.1	2.462	2.4556	-0.259	1010	180	-82.2	0.85	1.66	+95.3	11.82	39.48	+234.0
	450	1.84	TSX ⊥ (M)	158-M6	6-1,6-2,6-3	-0.377 ±0.001	6.733	6.752	+0.282	680	195	-71.3	2.463	2.4561	-0.320	1650	382	-76.8	1.08	1.66	+53.7	11.12	38.45	+245.8
	450	1.84	TSX ⊥ (C)	160-C5	6-1,6-2,6-3	-0.378 ±0.001	6.732	6.746	+0.207	684	200	-70.8	2.465	2.4564	-0.348	598	280	-53.2	1.05	1.55	+47.6	11.30	38.21	+238.1
2	575	3.02	CSF	142-223	6-1,6-2,6-3	-0.905 ±0.001	6.734	6.740	+0.089	540	230	-57.4	2.465	2.4593	-0.231	503	295	-41.4	1.56	2.33	+49.4	7.77	14.56	+87.4
	575	2.90	TSX	158-210	4-1,6-2,6-3	-0.811 ±0.001	6.725	6.732	+0.104	580	210	-63.8	2.464	2.4581	-0.239	410	420	+2.4	2.64	3.75	+42.0	5.20	21.40	+311.5
	575	3.02	TSX ⊥ (E)	160-E8	6-1,6-2,6-3	-0.661 ±0.001	6.730	6.762	+0.475	629	205	-67.4	2.465	2.4560	-0.365	454	465	+2.4	1.02	1.72	+68.6	10.17	34.76	+241.8
	575	3.02	TSGBF ⊥	125-7	6-1,6-2,6-3	-0.573 ±0.001	6.751	6.746	-0.074	360	205	-43.1	2.462	2.4565	-0.223	314	362	+15.3	0.98	1.46	+49.0	19.52	40.58	+107.9
3	725	4.20	CSF	142-224	6-1,6-2,6-3	-1.077 ±0.002	6.733	6.732	-0.014	490	200	-59.2	2.464	2.4570	-0.284	522	410	-21.5	1.60	2.62	+63.8	7.44	26.71	+259.0
	725	4.20	TSX	160-205	6-1,6-2,6-3	-1.124 ±0.002	6.725	6.725	0.0	546	200	-63.4	2.465	2.4588	-0.251	413	585	+41.6	2.24	3.34	+49.1	6.34	24.53	+286.9
	725	4.10	TSX ⊥ (E)	160-E3	5-1,5-2,6-3	-0.606 ±0.001	6.728	6.717	-0.163	760	218	-71.3	2.463	2.4592	-0.154	744	960	+29.0	0.90	1.54	+71.1	10.92	39.84	+264.8
	725	4.20	TSGBF ⊥	125-9	6-1,6-2,6-3	-0.792 ±0.001	6.757	6.760	+0.044	440	149	-66.1	2.463	2.4563	-0.272	328	328	0.0	0.92	1.19	+29.3	20.47	46.97	+129.4
4	800	4.91	CSF	142-215	5-1,6-2,6-3	-1.471 ±0.001	6.735	6.731	-0.059	600	163	-72.8	2.465	2.4587	-0.255	466	400	-14.2	1.61	2.38	+47.8	7.33	27.97	+281.6
	800	4.91	TSX ⊥ (E)	160-E4	5-1,6-2,6-3	-0.646 ±0.001	6.730	6.728	-0.029	740	185	-75.0	2.463	2.4587	-0.174	1150	382	-66.8	0.90	1.54	+71.1	11.43	41.64	+264.3
	800	3.56	TSX ⊥ (C)	158-C2	5-2,6-3	-0.315 ±0.001	6.753	6.727	-0.385	505	222	-56.0	2.4656	2.4590	-0.267	720	615	-14.6	0.85	1.50	+76.5	11.79	41.45	+251.6
	800	3.58	TSGBF ⊥	125-10	4-2,6-3	-0.535 ±0.001	6.762	6.764	+0.029	405	150	-63.0	2.461	2.4587	-0.093	515	560	+8.7	0.92	1.22	+32.6	20.22	44.65	+120.8
5	750	4.53	CSF	142-213	4-1,6-2,6-3	-1.077 ±0.001	6.735	6.726	-0.133	585	215	-63.2	2.463	2.4592	-0.154	885	355	-59.9	1.67	2.38	+42.5	7.41	27.92	+276.8
	750	4.41	TSX	158-201	4-1,6-2,6-3	-0.985 ±0.001	6.728	6.716	-0.178	560	225	-59.8	2.464	2.4607	-0.133	890	325	-63.5	2.34	3.56	+52.1	5.69	16.33	+187.0
	775	4.75	TSX ⊥ (E)	160-E5	5-1,6-2,6-3	-0.707 ±0.001	6.728	6.731	+0.044	803	205	-74.5	2.463	2.4589	-0.166	895	620	-30.7	1.00	1.70	+70.0	9.64	36.49	+278.5
	750	4.63	TSX ⊥ (C)	160-C4	5-1,5-2,6-3	-0.568 ±0.001	6.728	6.709	-0.282	625	218	-65.1	2.462	2.4587	-0.134	1010	395	-60.9	0.81	1.42	+75.3	11.42	39.42	+245.2
6	625	3.43	CSF ⊥	142-31	6-1,6-2,6-3	-0.547 ±0.001	6.734	6.731	-0.044	500	212	-57.6	2.465	2.4570	-0.324	550	630	+14.5	0.78	1.24	+59.0	12.55	42.03	+234.9
	625	3.24	TSX ⊥ (E)	158-E2	4-1,4-2,6-3	-0.466 ±0.001	6.732	6.736	+0.059	610	240	-60.6	2.463	2.4579	-0.207	465	430	-7.5	1.06	1.58	+49.0	10.67	36.51	+242.2
	625	2.54	TSX ⊥ (C)	167-C26	6-2,6-3	-0.370 ±0.001	6.740	6.732	-0.118	682	275	-59.7	2.4655	2.4606	-0.198	870	630	-27.6	0.88	1.17	+33.0	12.80	42.46	+231.7
	600	2.46	CSF	142-233	5-2,6-3	-0.562 ±0.002	6.759	6.734	-0.369	470	245	-47.9	2.4656	2.4592	-0.259	777	488	-37.2	1.76	2.86	+62.5	7.13	24.39	+242.1

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APPENDIX A

EXPERIMENTAL PROCEDURE

APPENDIX A

EXPERIMENTAL PROCEDURE

CAPSULE DESIGN

Nine capsules, H-4-1 through H-6-3, have been constructed and irradiated. They were basically of similar design, and except as noted hereafter, can be considered identical. Substantial design features from the H-1 experiment,⁽¹⁵⁾ as modified in the H-3 experiment^(3, 13) were used in the design of the H-4, -5, -6 capsule series. The original heat-transfer calculations for the early capsules were made in the same manner as those presented in Appendix A of HW-71500 A.⁽³⁾ However, these have since been modified by use of an IBM 7090 computer program.⁽¹⁶⁾ The temperatures of all capsule parts are now determined in considerable detail with these calculations. A detailed discussion of the methods and calculations used is presented in Appendix A of HW-71500 B.⁽¹³⁾ All capsules in the H-4, -5, -6 series are of the "ungrounded" type with no center thermal-ground.

The basic H-4, -5, -6 design is shown in Figure A1. Cooling rings located at the sample ends and mid-span contain a total of 65 flux monitors. The second-generation capsules, H-4-2, -5-2, -6-2, contained 50 to 75%, and the third-generation 80 to 100% of radioactive samples (up to 2 rem/hr at 4 in.) from previous capsules. The basic design principles and the assembly technique are presented in HW-71500 A⁽³⁾ in some detail. In capsule H-4-2 and all subsequent capsules, the 2.00 in. OD by 0.065 in. wall shell was replaced by one 2.030 in. OD by 0.090 in. wall to provide a stronger capsule body and allow heavier end-plug welds. Several minor modifications were made at various times to improve capsule reliability and integrity in-reactor. Complete as-built drawings for the capsules are listed in Table AI.

Neg 0621362-1

FIGURE A1
Preassembly View
H-4, -5, -6 Capsules

TABLE AI
CAPSULE DRAWINGS

<u>Capsule</u>	<u>Drawing Number</u>
H-4-1	H-3-20574
H-5-1	H-3-20575 Rev. 1
H-6-1	H-3-20580
H-4-2	H-3-20577
H-5-2	H-3-20684
H-6-2	H-3-20581
H-4-3	H-3-20850
H-5-3	H-3-20585
H-6-3	H-3-20584

INSTALLATION

The capsules were installed in either the D7 or F7 positions of the GETR⁽¹⁷⁾ on the dates given in Table AII.

TABLE AII
CAPSULE HISTORY

<u>Capsule</u>	<u>GETR Position</u>	<u>Installation Date</u>	<u>Effective Days*</u>	<u>Removal Date</u>	<u>Thermocouple Failures</u>	
					<u>Thermocouple Number</u>	<u>Hours of Operation</u>
H-4-1	D7	November, 1961	72.0	March, 1962	4	722
H-5-1	F7	January, 1962	90.4	May, 1962	No failures	
H-6-1	D7	March, 1962	86.6	August, 1962	9	1870
H-4-2	F7	May, 1962	103.9	January, 1963	No failures	
H-5-2	D7	September, 1962	111.7	April, 1963	No failures	
H-6-2	F7	January, 1963	114.0	July, 1963	5	173
H-4-3	D7	April, 1963	108.0	September, 1963	No failures	
H-5-3	F7	July, 1963	115.2	January, 1964	No failures	
H-6-3	D7	September, 1963	115.8	March, 1964	No failures	

* GETR operation at 30.0 MW

Capsule H-4-1 was installed in a 2 in. diameter, schedule 40 aluminum-pipe guide-tube which had square aluminum sections welded to the ends for additional strength. The square section of the lower end was machined to the dimensions of an in-core filler piece, and the upper end was attached to the GETR flow deflector. The external Geminol N-Geminol P thermocouples were exited through a flexible stainless steel hose.

Capsule H-5-1 and all subsequent capsules were constructed with an integral 1.5 in. OD by 0.188 in. wall support-tube to provide additional protection for the thermocouple leadout tube and to fit in the bracketing system. This support-tube was held in place at the top of the reactor by a support-bracket attached to the flow deflector. The capsule body was centered in a special beryllium filler-piece having wear surfaces at both the top and bottom. A diagram of the experimental installation is given in Figure A2.

FIGURE A2
Diagram of Experimental Installation

IRRADIATION

Initially all nine thermocouples were operable in each of the nine capsules. Nearly all the thermocouples functioned properly for the entire capsule irradiation. After completion of the irradiation each capsule was transported to a radioactive materials laboratory for disassembly. A summary of thermocouple operation and capsule history is given in Table AII.

DISASSEMBLY

The disassembly procedure consisted of opening the ends of the outer shell with a tubing cutter and then slitting the shell longitudinally with a high-speed air-driven abrasive wheel at two places 180° apart. The appearances of the interior of the capsules immediately after opening are shown in Figures A3 through A5. The apparent capsule curvature is due to refraction through the lead-glass viewing window. The interior surfaces of the shell were relatively clean except for some carbon deposits mainly at the lower end. However, the H-6-1 capsule, Figure A3, showed a considerable amount of carbon deposit and some of the samples exhibited pitting on the outer surfaces (Figure A6). The oxidation seemed to be catalyzed in certain areas. Seven samples in the capsule had weight losses varying from 0.30 to 1.49%, while the others changed less than 0.05%. The oxidation was apparently caused by a slight leak of contaminated helium into the capsule from the external thermocouple leadout system during irradiation. However, the catalytic agent may have resulted from the helium density measurements made on six of the samples prior to irradiation.

The twist on the thermocouple in Figure A3 and the displaced cooling ring and warped spacer rod shown in Figure A4 occurred during insertion of the sample subassemblies into the shells. The other six capsules showed no unusual effects of the irradiation with the exception that the H-5-2 stainless steel protection tube over the capsule seal-off tube was lost into the reactor vessel during operation. From all available evidence it became unscrewed because of vibration. The 0.040 in. wall seal-off tube remained intact for the remainder of the irradiation.

All 24 samples from each of the nine capsules were recovered. However, the four samples from Position 1 in capsule H-4-2 had the ends inadvertently broken off during the disassembly. All 65 flux monitors were recovered from each of the nine capsules with the exception of one missing iron wire from H-5-3. There was no visible indication of the cause of the failure of H-4-1 thermocouple 4; however, H-6-1 thermocouple 9 and H-6-2 thermocouple 5 both failed at the right angle bend into the sample.

HAPO H4-1

HAPO H5-1

HAPO H6-1

FIGURE A3
Postirradiation Views
First Generation Capsules

FIGURE A4
Postirradiation Views
Second Generation Capsules

FIGURE A5

Postirradiation Views of Third Generation Capsules

FIGURE A6

Oxidized Sample of H-6-1 Capsule

THERMOCOUPLE CALIBRATION

Several thermocouples from each capsule were calibrated after irradiation. A new Geminol N-P thermocouple was used as a reference at several temperatures. The results of the calibration are shown in Table AIII.

TABLE AIII
CALIBRATION OF IRRADIATED GEMINOL N-P THERMOCOUPLES

Capsule	Thermocouple	Exposure* nvt $\times 10^{-21}$ (E > 0.18 MeV)	Irradiation* Temperature, C	Calibration Temperature, C		
H-4-1	Reference	0.0	---	400		
	3	0.71	565	389		
	6	1.10	705	381		
	9	0.70	560	384		
H-5-1	Reference	0.0	---	420		
	3	0.78	595	---		
	6	1.24	755	398		
	7	1.21	735	396		
H-6-1	Reference	0.0	---	320	709	911
	1	0.52	435	305	---	---
	6	1.31	770	297	667	867
	8	0.89	630	---	---	---
H-4-2	Reference	0.0	---	299	663	882
	7	1.55	805	282	621	---
	8	1.39	625	265	---	---
	9	1.14	650	275	---	833
H-6-2	Reference	0.0	---	211	530	676
	2	0.71	475	---	506	---
	7	1.65	755	198	492	646
	8	1.20	590	198	---	649
H-4-3	Reference	0.0	---	301	678	
	4	1.43	735	282	---	
	5	1.64	810	279	650	
	8	1.00	560	281	642	
H-5-3	Reference	0.0	---	224	597	903
	3	1.22	600	212	578	---
	4	1.72	740	201	564	859
	6	1.99	775	201	564	---
H-6-3	Reference	0.0	---	200	499	
	6	1.93	825	184	458	
	8	1.89	790	---	---	
	9	1.34	620	184	458	

* At the thermocouple junction

A graph of the true temperature as a function of the indicated temperature is given in Figure A7. The small numbers indicate the number of calibrations made. The figure includes all Geminol N-P thermocouple calibration data to date including those from the EGCR Irradiation Experiment.⁽¹³⁾

FIGURE A7

Calibration of Irradiated Geminol N-P Thermocouples

The above temperature difference is taken into account when sample mean irradiation temperatures are determined. (See Appendix A of HW-71500 B⁽¹³⁾ for a detailed discussion of the determination.)

APPENDIX B

SUPPLEMENTARY IRRADIATION RESULTS

APPENDIX BSUPPLEMENTARY IRRADIATION RESULTSCRYSTALLITE PARAMETERS

The effects of continued neutron exposure on $\underline{c}$ and L_c for each graphite type are presented in Figures B1 through B6, and on $\underline{a}$ and L_a in Figures B7 and B12. With the large spread in data from individual samples the only conclusive results are those for L_c which show a decrease to a relatively constant value. The data for both L_c and $\underline{a}$ fall on two distinct curves with the 425 to 475 C data lying below the 575 to 800 C data. The L_c and $\underline{a}$ data for TSX and CSF are nearly identical.

FIGURE B1

Crystallite Layer Spacing (c) of CSF Graphite as a Function of Exposure

FIGURE B2

Crystallite Layer Spacing (c) of TSX Graphite as a Function of Exposure

FIGURE B3

Crystallite Layer Spacing (c) of TSGBF Graphite as a Function of Exposure

FIGURE B4

Apparent Crystallite Size (L_c) of CSF Graphite as a Function of Exposure

FIGURE B5

Apparent Crystallite Size (L_c) of TSX Graphite as a Function of Exposure

FIGURE B6

Apparent Crystallite Size (L_c) of TSGBF Graphite as a Function of Exposure

FIGURE B7

Crystallite Layer Spacing (a) of CSF Graphite as a Function of Exposure

FIGURE B8

Crystallite Layer Spacing (a) of TSX Graphite as a Function of Exposure

FIGURE B9

Crystallite Layer Spacing (a) of TSGBF Graphite as a Function of Exposure

FIGURE B10

Apparent Crystallite Size (L_a) of CSF Graphite as a Function of Exposure

FIGURE B11

Apparent Crystallite Size (L_a) of TSX Graphite as a Function of Exposure

FIGURE B12

Apparent Crystallite Size (L_a) of TSGBF Graphite as a Function of Exposure

TEMPERATURE-EXPOSURE GRAPHS

For the direct convenience of reactor designers or others using the data presented in the body of the report, the data have been replotted as a function of irradiation temperature and exposure in the following figures:

<u>Figure</u>	<u>Parameter</u>
B13	Length change - CSF $\perp$
B14	Length change - CSF $\parallel$
B15	Length change - TSX $\perp$
B16	Length change - TSX $\parallel$
B17	Length change - TSGBF $\perp$
B18	Volume change - CSF
B19	Volume change - TSX
B20	Young's modulus - CSF $\perp$
B21	Young's modulus - CSF $\parallel$
B22	Young's modulus - TSX $\perp$
B23	Young's modulus - TSX $\parallel$
B24	Young's modulus - TSGBF $\perp$
B25	Electrical resistivity - CSF $\perp$
B26	Electrical resistivity - CSF $\parallel$
B27	Electrical resistivity - TSX $\perp$
B28	Electrical resistivity - TSX $\parallel$
B29	Electrical resistivity - TSGBF $\perp$

Comparison of Figures B13 and B15 and of B14 and B16 indicate that TSX graphite has a somewhat different irradiation-temperature behavior than CSF although the length changes are similar. The same trend appears to be true for both Young's modulus and electrical resistivity.

FIGURE B13

Physical Distortion of CSF Graphite (Transverse) as a Function of Temperature and Exposure

FIGURE B14

Physical Distortion of CSF Graphite (Parallel) as a Function of Temperature and Exposure

FIGURE B15

Physical Distortion of TSX Graphite (Transverse) as a Function of Temperature and Exposure

FIGURE B16

Physical Distortion of TSX Graphite (Parallel) as a Function of Temperature and Exposure

FIGURE B17

Physical Distortion of TSGBF Graphite (Transverse) as a Function of Temperature and Exposure

FIGURE B18

Volume Distortion of CSF Graphite as a Function of Temperature and Exposure

FIGURE B19

Volume Distortion of TSX Graphite as a Function of Temperature and Exposure

FIGURE B20

Young's Modulus of CSF Graphite (Transverse) as a Function of Temperature and Exposure

FIGURE B21

Young's Modulus of CSF Graphite (Parallel) as a Function of Temperature and Exposure

FIGURE B22

Young's Modulus of TSX Graphite (Transverse) as a Function of Temperature and Exposure

FIGURE B23

Young's Modulus of TSX Graphite (Parallel) as a Function of Temperature and Exposure

FIGURE B24

Young's Modulus of TSGBF Graphite (Transverse) as a Function of Temperature and Exposure

FIGURE B25

Electrical Resistivity of CSF Graphite (Transverse) as a Function of Temperature and Exposure

FIGURE B26

Electrical Resistivity of CSF Graphite (Parallel) as a Function of Temperature and Exposure

FIGURE B27

Electrical Resistivity of TSX Graphite (Transverse) as a Function of Temperature and Exposure

FIGURE B28

Electrical Resistivity of TSX Graphite (Parallel) as a Function of Temperature and Exposure

FIGURE B29

Electrical Resistivity of TSGBF Graphite (Transverse) as a Function of Temperature and Exposure

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