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RADIATION-INDUCED DIMENSIONAL CHANGESIN LARGE GRAPHITE BARS*

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Evidence that the size of graphite samples may influence the magnitude of radiation-induced dimensional changes has recently been obtained. Although experiments designed to understand the phenomena are just getting started, the results available indicate that the contraction rate of large samples is appreciably higher than that of small samples. Moreover, in comparing these different contraction rates with reactor distortion measurements^{1,2} the best correlations (taking into account moderator temperatures and exposures) were obtained with large sample bars which are about the size of the bars used in the reactor construction.

Because of the significance of these results to investigators conducting irradiation studies on small graphite samples and to those using the data so obtained for reactor design or operations planning, a review of the results recently obtained on large samples is warranted even though the underlying causes for the effects are still speculative.

Three bars, 4 in. in cross section and 24 in. long, were measured after exposure in a Hanford reactor of 18,650 Mwd/At (equivalent to 1.8×10^{21} neutrons/cm² having energies above 0.18 Mev). Although the temperature in the test facility increased slowly during the irradiation period, most of the exposure was accumulated at 500 to 600° C, the average being 525° C. Each bar represented a different grade of nuclear graphite. However, the differences are in the type of purification used rather than in the raw materials or formulation.³

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The average values and standard deviations of sixteen measurements taken across the 4-in. dimension, transverse to the extrusion direction of each bar, are given in Table I. One measurement obtained from the 24-in. dimension of each bar parallel to the extrusion axis is also shown.

TABLE I. DIMENSIONAL CHANGE OF LARGE AND SMALL
GRAPHITE SAMPLES

Exposure: 18,650 Mwd/At $\approx 1.8 \times 10^{21}$ nvt, E > 0.18 Mev.

<u>Graphite Type³</u>	<u>Sample Size, in.</u>	<u>Length Change, %</u>	
		<u>Transverse</u>	<u>Parallel</u>
CSO - Graphitized at 2700° C	4 x 4 x 24	-0.45 $\pm$ 0.06	-0.69
CSF - Graphitized at 2700° C, then gas purified	4 x 4 x 24 0.43 dia. x 4	-0.53 $\pm$ 0.06 -0.29	-0.76 -0.37
CSGBF - Gas baked, then graphitized and purified at 2450° C	4 x 4 x 24 0.43 dia. x 4	-0.56 $\pm$ 0.06 -0.27	-0.79 -0.48

The data in Table I for small samples were obtained on 0.43-in. diameter cylinders of 4 in. length cut from bars which were originally the same cross section as the large samples. They were irradiated under conditions similar to those for the large bars to an exposure of 15,950 Mwd/At, and the measured contractions were extrapolated to the exposure of the large samples.

In each case the contraction of the large samples was approximately twice the contraction of comparable small samples. In addition samples 0.26-in. diameter by 1.75-in. long irradiated at 650° C were recently reported⁴ to have contracted at about one-half the rate of 0.43-in. diameter samples.

Possible explanations for the apparent relationship between sample size and contraction rates follow two lines of reasoning. The first considers

differences in neutron damage which could arise in samples of different size. Moderation of fast neutrons traversing large samples could produce a lower average fast flux in large samples than in small samples exposed to the same incident flux. This should reduce the contraction of large samples rather than contribute to the observed increase in large-sample contraction.

Recent calculations by Beeler⁵ predict that under certain conditions, a larger number of displaced atoms per unit volume can be produced in large samples. This is because at high neutron energies (> 0.1 Mev) the cross section for energy transfer generally decreases with decreasing neutron energy. Hence, the density of displaced carbon atoms produced by high-energy neutrons (which is the product of the energy-transfer cross section and the number of displacements ultimately produced by a knock-on atom of given energy) will first increase and then decrease as the neutron loses energy. This maximum in the probability for displacements occurs for carbon at a neutron energy of approximately 1 Mev.⁶ Therefore, the displacement density caused by neutrons with energies greater than 1 Mev would first increase and then decrease as a function of penetration into the sample. However, the displacement density caused by neutrons of lower energies would decrease continuously throughout the sample. When the actual neutron spectrum incident upon the large bars is considered, calculations show that the density of the displacements decreases continuously in transversing the sample. Hence, it is concluded that the size effect observed cannot be attributed to neutron-moderation effects.

Other explanations relating the behavior of graphite specimens of different size to structural features of the bars from which the specimens were obtained are presently considered more plausible. Internal stresses undoubtedly develop in the anisotropic graphite bars as they cool after graphitization. Relief of these stresses by the removal of small samples from large bars could result in a difference in radiation-induced contraction, since it has been postulated that this contraction

is, in part, a process of stress relief.^{7,8,9} Orientation, or more specifically the degree of alignment of the petroleum-coke particles comprising the filler material in nuclear graphite, is known to be more highly developed around the outside of a bar of graphite than in the center. Measurements of the coefficient of thermal expansion and electrical resistivity at intervals across a bar readily confirm this difference in structure which is developed by extrusion forming. In a large bar, circumferential contraction accelerated in the more highly oriented region would create a compressive stress, thereby increasing the contraction of the central portion of the bar. A small sample not subjected to these stresses should contract at a lower rate; however, the shape and location of samples, as well as size, could also determine how such stresses might influence contraction.

A clear understanding of the different contraction rates observed for large and small samples will require further data. Unfortunately, accelerated tests on large samples cannot be performed in the size-limited facilities usually found in high-flux test reactors. Tests in progress in the larger Hanford test facilities will, eventually, provide information on the influence of size, shape, and location of samples on contraction measurements. Until this information is available it would be premature to assign weighting factors to small-sample data in cases where their relationship with larger bars or reactor-distortion measurements are not known. It is not premature, however, to suggest that the methods of monitoring the distortion of graphite-moderated reactors be reviewed. If small samples alone are used, every effort should be made to obtain measurements on the stack itself. Where both methods of measurement are used, the correlation between them should be critically analyzed for information pertaining to the effects and possible explanations presented here.

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