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AN IRRADIATION EXPERIMENT TO STUDY THE COMPATIBILITY OF BEO WITH GRAPHITE AT 1500°C

PART II. OPERATION AND POSTIRRADIATION EVALUATION

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REACTOR DIVISION

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OCTOBER 1967

OAK RIDGE NATIONAL LABORATORY
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UNION CARBIDE CORPORATION
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*General Atomic Division of General Dynamics Corporation, San Diego, California

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ABSTRACT

An irradiation experiment was conducted at Oak Ridge National Laboratory as a part of a cooperative program with General Atomic to develop advanced gas cooled reactor technology. The lapped surfaces of BeO and graphite rings were maintained in intimate contact during 9 months exposure at 1280–1500°C to 1 x 10^{21} neutrons/cm^2, E > .18 Mev. Postirradiation examination of the contact surfaces indicated no chemical reaction had occurred.

These rings and other components of the irradiated assembly were examined for ^6Li. A massive BeO core (1-in. diam by 4.5-in. length) was found to have retained a major portion of the ^6Li generated within it during the irradiation.

No gross radiation induced physical damage was observed in either BeO or graphite components. The physical changes observed were in general agreement with previously reported results.

INTRODUCTION

An irradiation experiment to study the compatibility of BeO with graphite was conducted at the Oak Ridge National Laboratory as part of the advanced gas-cooled reactor technology research and development program being carried out cooperatively with General Atomic. The experiment was designed to study the effects of fast neutron radiation on the chemical compatibility of BeO in contact with graphite at 1500°C, the distribution of the ^6Li which is formed in the BeO, and the physical behavior of BeO and graphite.

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*General Atomic Division of General Dynamics Corporation, San Diego, California.

Information on these effects will be useful in the further evaluation of the BeO-graphite moderator system for high-temperature gas-cooled reactors.

The principal reaction between BeO and carbon is expected to be:

$$2\ BeO + 3C \rightleftarrows Be_2C + 2CO \quad .$$

Motzfeldt[1] has shown that in the absence of radiation very little, if any, reaction occurs at 1500° C. An objective of this experiment was to determine if the formation of Be_2C proceeds to a detectable extent in the presence of radiation. Formation of Be_2C would cause swelling of BeO components resulting in physical damage. In addition the existance of a high concentration of CO in the reactor coolant gas could cause a transfer of carbon from the core (by means of disproportionation of CO to carbon and CO_2).

BeO is of particular interest as a moderator material for advanced gas-cooled reactors because of its beneficial effect on the neutron economy resulting from the (n,2n) fast neutron reaction. However, another nuclear reaction, (n,α), results in the formation of the long-lived nuclear poison ^6Li (thermal cross section = 945b).

The net worth of beryllium moderation is strongly dependent upon the accumulation of ^6Li in the core.[2] Recently Stieglitz and Zumwalt[3] have studied the release of ^6Li at 1000 to 1600° C from BeO granules and pellets which had been irradiated to about 10^{21} neutrons/cm^2 (E > 1 Mev) at 380° C and 490° C, respectively. They estimate that nearly complete release (99%) of ^6Li can be expected for a reactor using BeO granules at a temperature of 1000° C. Their data from the pellets were inconclusive but strongly suggest much lower release rates.

The present irradiation experiment was carried out in the F-1 core position of the ORR in a perturbed fast flux of 5 x 10^{13} neutrons/cm^2·sec

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[1] Motzfeldt, K. Acta Uien. Scand. 18(2): 495, 1964.

[2] W. D. Manly, Some Physics Aspects for BeO Core Design, Proceedings of the First International Conference on Beryllium Oxide, Sidney, Australia, Oct. 21–25, 1963, published by North-Holland Publishing Company, Amsterdam, 1964.

[3] L. J. Stieglitz and L. R. Zumwalt, Release of ^6Li from Irradiated Beryllium-Oxide Moderator Material, Nuclear Applications, Vol. 2, p. 394, October 1966.

(E > 0.18 Mev). The irradiation began March 14, 1965 and was terminated December 13, 1965. During the last five months of the test, the temperature decreased gradually from 1500 to 1280°C. The test was terminated, even though the exposure achieved, 1×10^{21} neutrons/cm^2, was only approximately one-half the desired value, to avoid operation in a temperature range of <1200°C where the BeO might have swelled and cracked.[4]

The scope of the experiment included development of an irradiation facility, preirradiation characterization of materials, control and monitoring of irradiation conditions, and the postirradiation evaluation of results. The irradiation facility and preirradiation characterization have been described previously.[5] The irradiation conditions and postirradiation evaluation are described and discussed in this report.

MATERIALS

The BeO and graphite specimens were machined from stock sufficiently oversized to provide a number of control samples. The BeO, designated UOX,* had a density of 2.87 g/cm^3 and a purity of >99.5%. The graphite, designated 780S**, was obtained in the form of logs approximately 4-in. in diameter. The graphite was prepared with Texas petroleum coke bonded with coal-tar pitch and a single pitch impregnation was added to increase the strength and density. The material was estimated by the manufacturer to have been graphitized in the range 2700 to 2800°C. A more complete description of the graphite is given in reference 6. Fabrication procedures for the samples used in this experiment are detailed in reference 5.

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*Supplied by Brush Beryllium Company.

**Supplied by Speer Carbon Company.

[4]G. W. Keilholtz, J. E. Lee, Jr., R. E. Moore, Irradiation Damage to Sintered Beryllium Oxide as a Function of Fast Neutron Dose and Flux at 110°, 605° and 1100°C, Nucl. Sci. Eng. 36, pp. 329–338, 1966.

[5]C. A. Brandon, An Irradiation Experiment to Study the Compatibility of BeO with Graphite at 1500°C, USAEC Report ORNL TM-1255, Oak Ridge National Laboratory, November 1965.

[6]G. B. Engle, Dimensional and Property Changes of Impregnated and Isotopic Graphites Irradiated at 300°–1500°C, GA-7326, April 1967.

EXPERIMENTAL PROCEDURE

Facility Description

The irradiation facility is described in detail in reference 5 and only a brief summary will be given here. A diagrammatic section of the capsule assembly and a photograph of the major components are shown in Figs. 1 and 2, respectively. The assembly consisted of a graphite sleeve which was fitted over a BeO core. The reaction interface consisted of the lapped surfaces of a BeO ring and a graphite ring that were abutted. Notches were provided in the lapped surface of the graphite ring to allow an inert purge gas to penetrate close to the reaction surfaces and remove gases that might form. These rings were contained within the assembly by supporting the BeO ring on a shoulder midway along the length of the BeO core. The graphite ring was placed inside the larger internal diameter of the graphite sleeve and rested atop the BeO ring. Positive contact over the reaction interface was assured by alignment of the lapped surfaces of the specimen rings. The alignment was maintained by the mating of a spherical radius on the graphite ring and a conical shoulder in the graphite sleeve. Contact pressure was maintained by the weight of the graphite sleeve and the force from a molybdenum spring placed atop the assembly.

The design temperature was achieved with the gamma heating of the materials and by the thermal insulation of a series of molybdenum reflectors spaced to form gaps which were filled with static gas. Temperature control was maintained by varying the composition of the continuous helium-argon purge. The specimen temperatures were monitored by six tungsten-5% rhenium versus tungsten-26% rhenium thermocouples that were positioned within five molybdenum wells that penetrated to various depths within the BeO core and one well that penetrated to the mid-plane of the graphite sleeve.

Two stainless steel flux-monitor wires were positioned within the wall of the stainless steel primary container. A holder was attached to the outer surface of the secondary container for periodically replaceable flux monitors.

The continuous high-purity helium-argon purge was directed upward between the BeO core and the graphite sleeve, through the notches at the

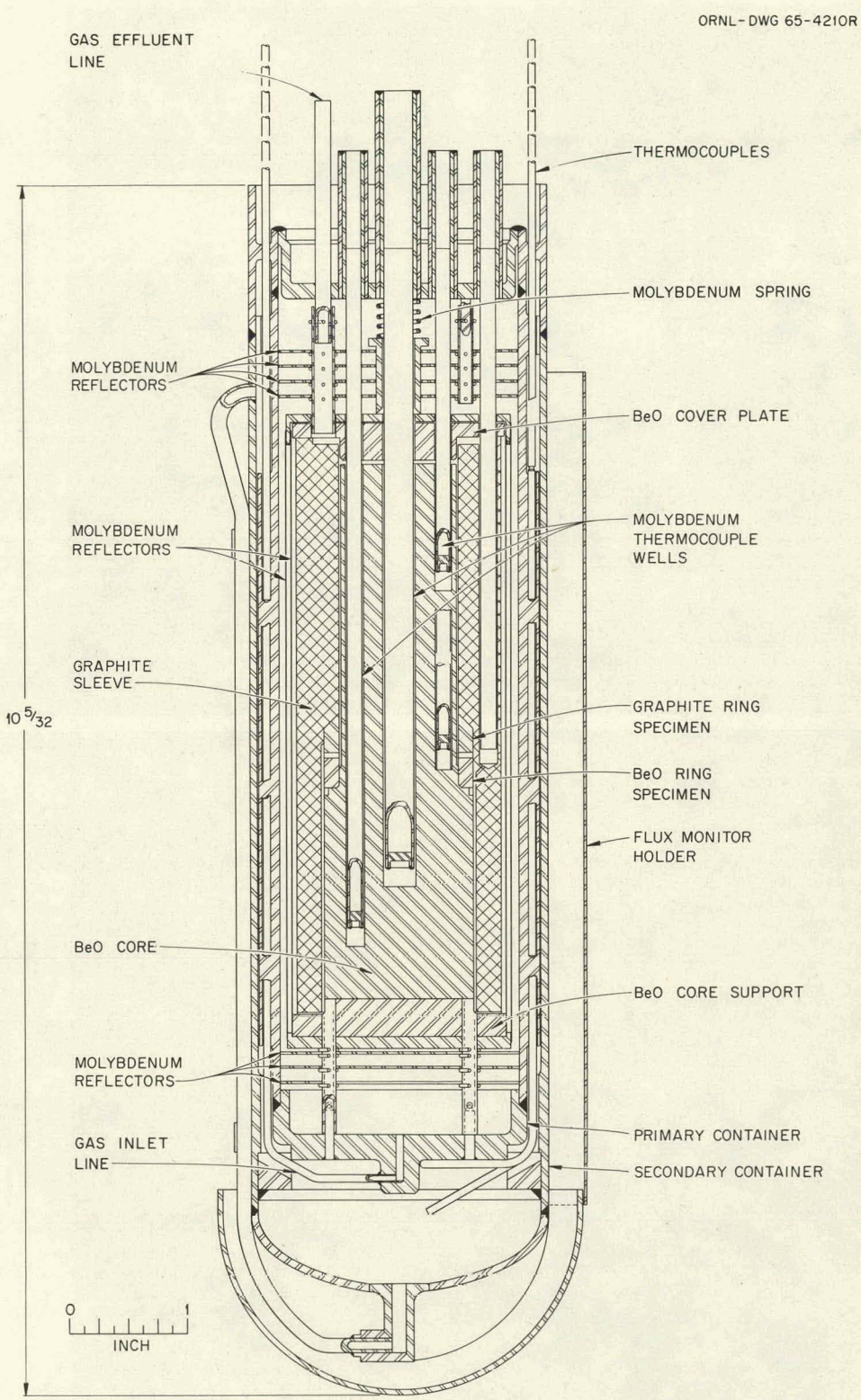


Fig. 1. BeO-Graphite Compatibility Irradiation Test Capsule Assembly Section.

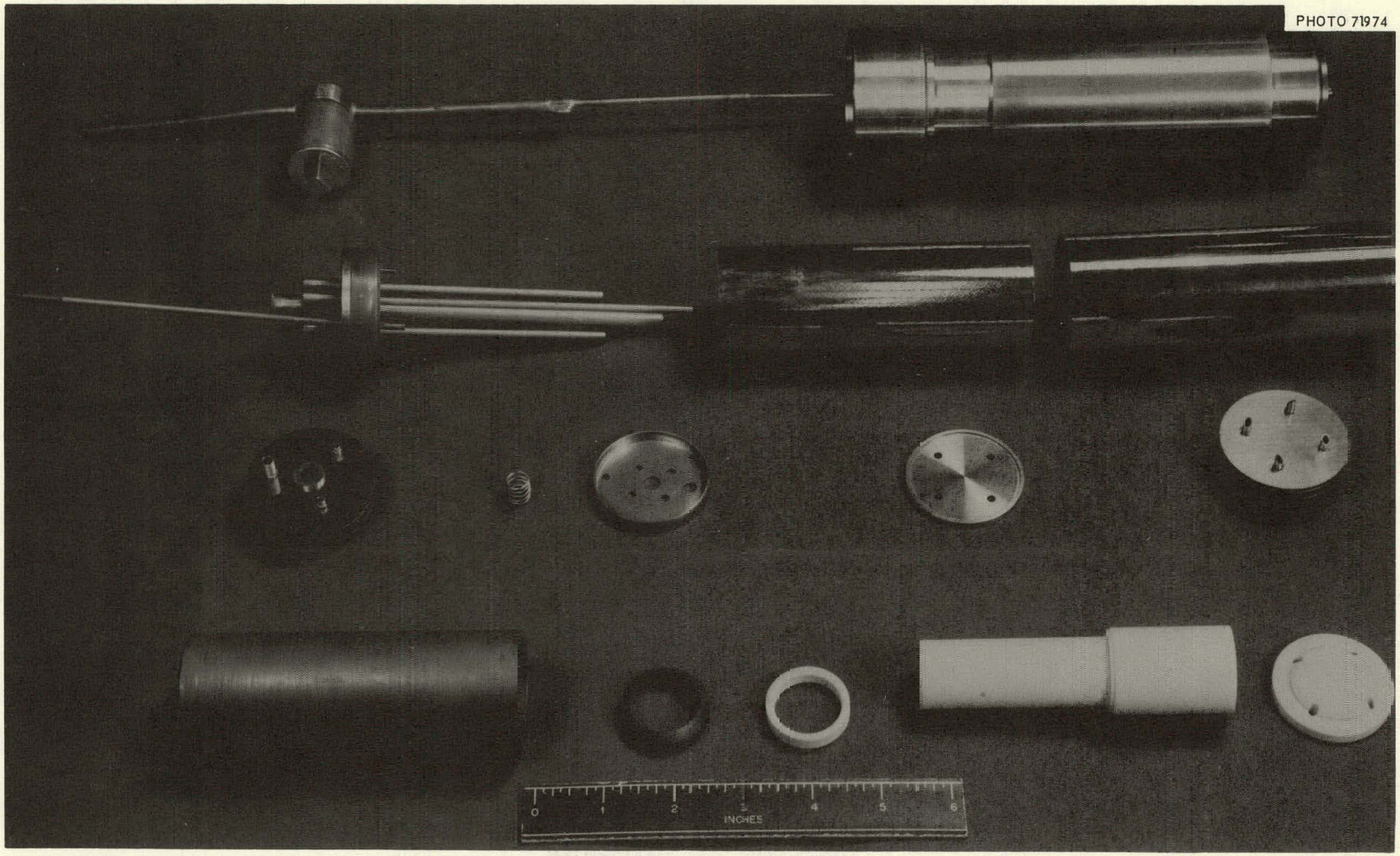


Fig. 2. Capsule Parts for BeO Graphite Compatibility Irradiation Test in Perspective Layout.

reaction interface, and exhausted at the top of the capsule. The helium and argon used in the purge were purified by passing through molecular-sieve drying towers and hot titanium sponge (at 1400°F). The gases were mixed just upstream of the titanium sponge and then passed through ~150 ft of ultrasonically cleaned tubing before entry into the capsule. A moisture monitor was positioned in the purge line at the closest position (~70 ft) ahead of the capsule. The periodically determined moisture content of the purge did not exceed 5 ppm.

Irradiation Conditions

The specimen temperatures and the fast neutron flux were the primary conditions which were controlled and/or monitored during the irradiation.

Specimen Temperature

During the initial reactor startup the purge gas consisted of 100% helium. Argon was gradually added over a period of a few hours until a maximum BeO temperature of 1600°C was achieved with 100% argon. The composition of the purge was then adjusted to obtain the desired temperature of 1500°C at the interface between the specimen rings. This temperature was not measured directly but was defined as the average of the thermocouples positioned in the BeO and graphite near the rings in the approximate plane of the interface. During the first four months, the interface temperature was maintained at ~1500°C by periodic adjustments of the purge gas.

During the last five months of the test the interface temperature decreased from 1500 to 1280°C even though a purge of pure argon was maintained continuously. This condition is believed to have resulted from the deterioration of the reflective thermal insulation. The longest exposure at a temperature below 1280°C occurred when the temperature was lowered to 930°C for two days while a leak between the two containments was investigated.

Neutron Exposure

Two types of neutron flux monitors were used during the irradiation test. Two stainless steel monitor wires which were sealed in the test

capsule were removed during the postirradiation hot cell examination. The results from these wires gave a value for the integrated exposure of the test materials. Each of a series of flux monitor canes were exposed for ~two weeks in a holder attached to the outside of the capsule. The results from these canes provided a periodic indication of the exposure during the course of the test.

Each flux monitor cane tubular assembly contained three sealed quartz ampules spaced 0.80-in. apart along the longitudinal axis of the capsule with the center ampule in the plane of the interface between the specimen rings. Each ampule contained a cobalt-aluminum alloy (0.0964 wt % cobalt) wire, a nickel wire, and an iron wire.

The thermal flux was determined from the $^{59}Co(n,\gamma)^{60}Co$ reaction and the fast flux (E > 0.18 Mev) from the $^{58}Ni(n,p)^{58}Co$ and $^{54}Fe(n,p)^{54}Mn$ reactions. The neutron dosimetry calculations are detailed in Appendix A. The fast neutron flux (E > 0.18 Mev) at the centerline of the specimens was ~5 x 10^{13} neutrons/cm^2·sec and the corresponding fast neutron exposure (E > 0.18 Mev) was ~1 x 10^{21} neutrons/cm^2. The neutron flux at the centerline was assumed to be the average over the volume of the BeO and graphite components.

EXPERIMENTAL RESULTS

Capsule Disassembly

Since the most probable reaction product for BeO and graphite, Be_2C, is reportedly hygroscopic, the disassembly of the capsule was performed in a dry box within a hot cell. Nitrogen sweep gas, with an effluent dew point below minus 46° C, was used in the dry box during the disassembly. The dry box was made of plexiglas to permit visual observation during the dismantling.

Visual observations made during disassembly of the capsule indicated that no gross irradiation induced physical damage had occurred to any of the BeO or graphite components. A segment was broken from the lower end of the graphite cylinder, Fig. 3, but this is believed to have resulted

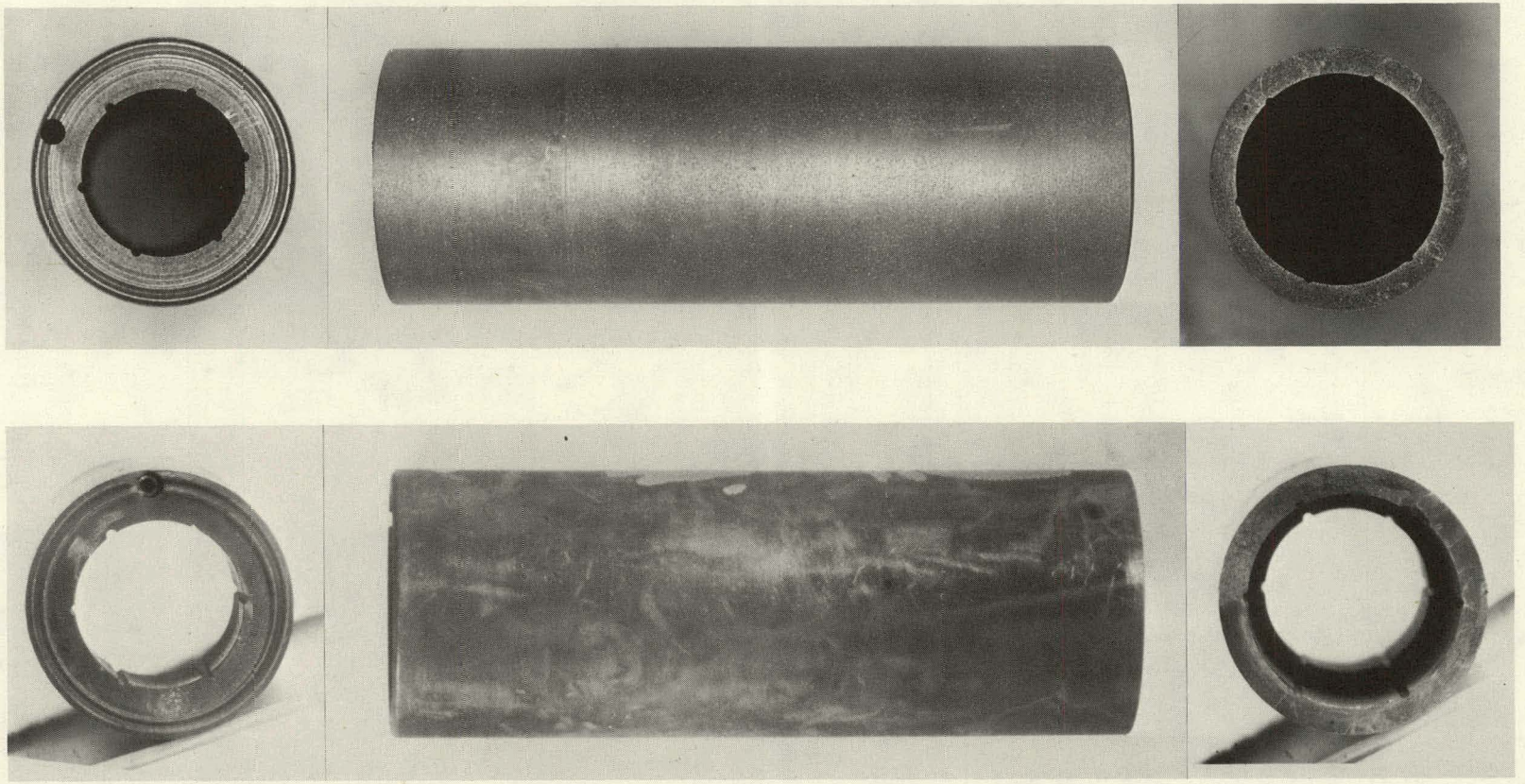


Fig. 3. BeO-Graphite Compatibility Irradiation Test, Graphite Cylinder, (a) preirradiation, (b) postirradiation.

from mechanical action during the removal of the graphite from the molybdenum heat shield that had deformed around it. The BeO cover plate was recovered in four pieces, Fig. 4, however, it had become tightly wedged in the molybdenum cover plate and was also probably broken during disassembly. No differences, other than marks, probably due to contact with graphite, are evident from comparison of the pre- and post-irradiation photographs of the BeO core and core support shown in Figs. 5 and 6 respectively.

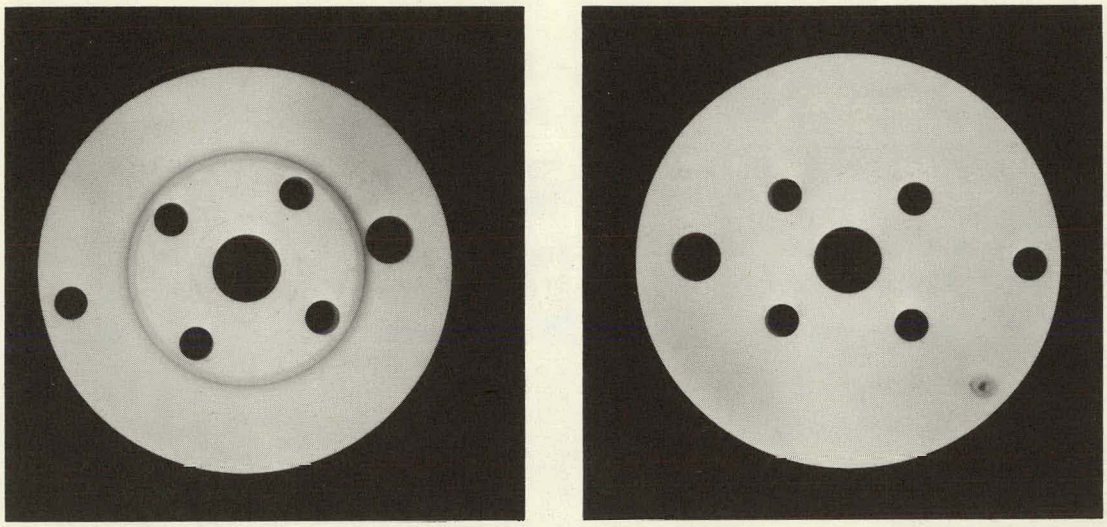
The inner molybdenum heat shield, shown in Fig. 7, had two large (~1/2-in. x ~3/4-in.) holes. Opposite these holes, on the surface of the graphite, there were deposits that appeared metallic. The deposits were determined by x-ray diffraction to be Mo_2C. The clearance between the graphite sleeve and the 0.003-in.-thick molybdenum heat shield was designed to be 0.034-in. Either the inner heat shield contacted the graphite or the Mo_2C was formed in the vapor phase and deposited on the graphite sleeve.

Most of the tungsten-5% rhenium versus tungsten-26% rhenium thermocouples and the molybdenum thermocouple wells were in good condition. One thermocouple, that had failed during the test, was found to have a broken lead wire immediately above a rather large junction bead. The thermocouple and well located in the graphite could not be removed intact. These are evident in the top view of the graphite cylinder, shown in Fig. 3.

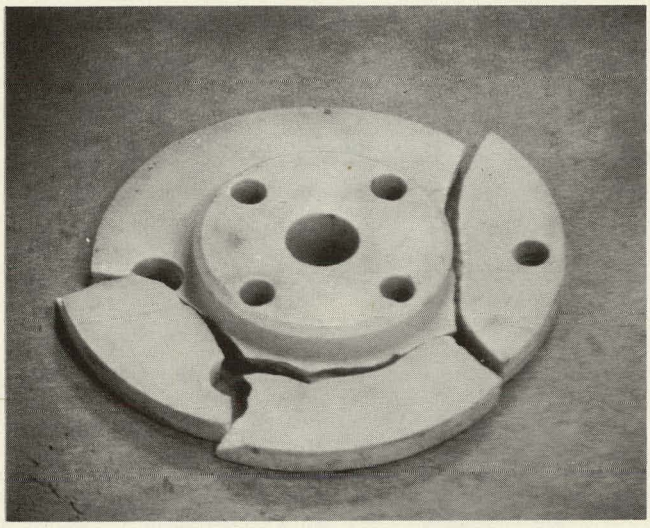
The interior of the primary container was coated with a black deposit as were the tubes and thermocouple extensions in the region immediately above the capsule. Some of the BeO insulation beads used with the high temperature thermocouples were also darkened. The beads near the thermocouple junction, the hottest region, were not discolored (see Fig. 8). The deposit was carbon apparently resulting from the disproportionation of CO and CO_2 and carbon.

Chemical Compatibility

The principle areas studied for evidence of a reaction between the BeO and graphite were the lapped surfaces of the BeO and graphite rings, which had been in intimate contact throughout the test. These surfaces are shown in Figs. 9 and 10. Visual examinations made during the capsule disassembly



(a)



(b)

Fig. 4. BeO-Graphite Compatibility Irradiation Test, BeO Cover Plate, (a) preirradiation, (b) postirradiation.

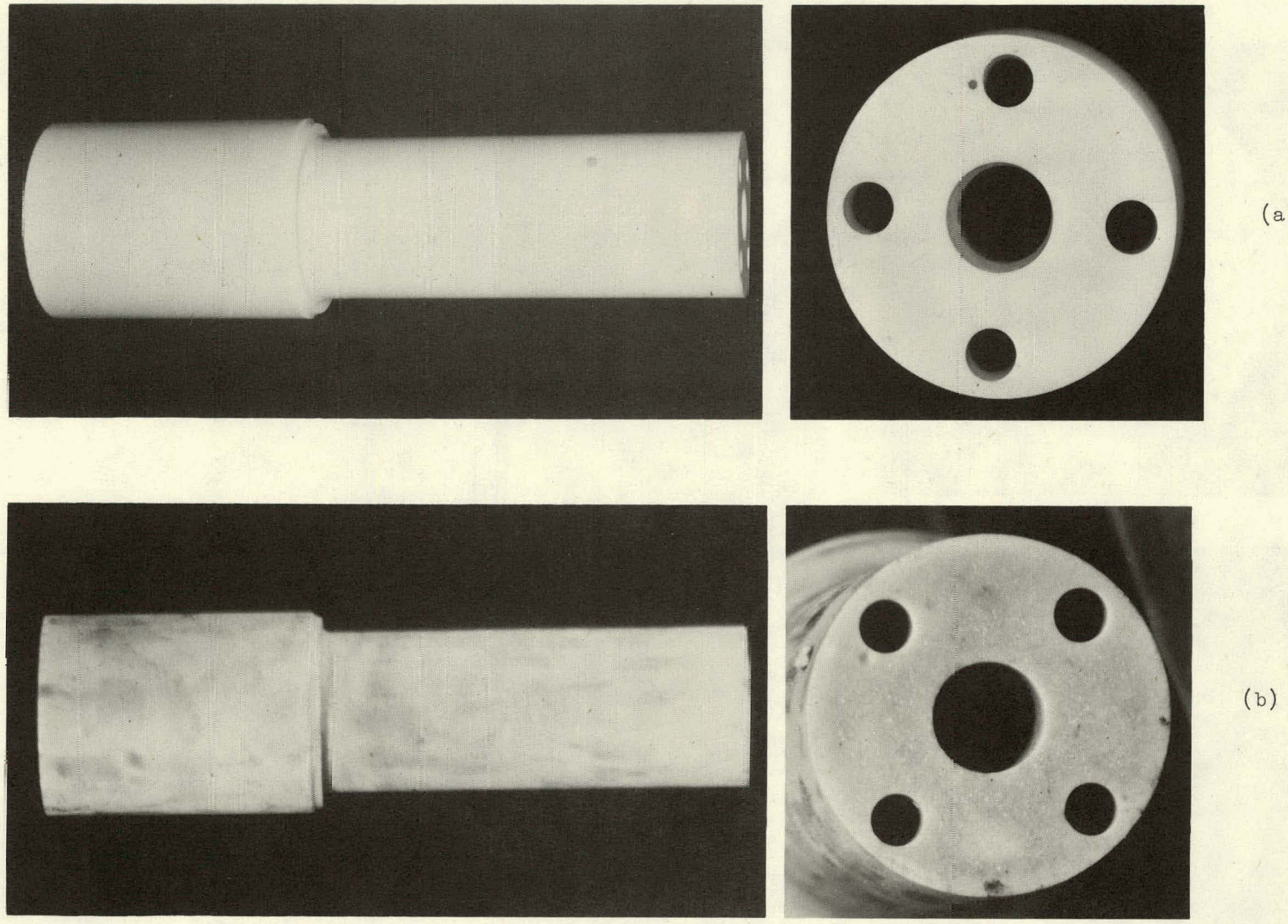
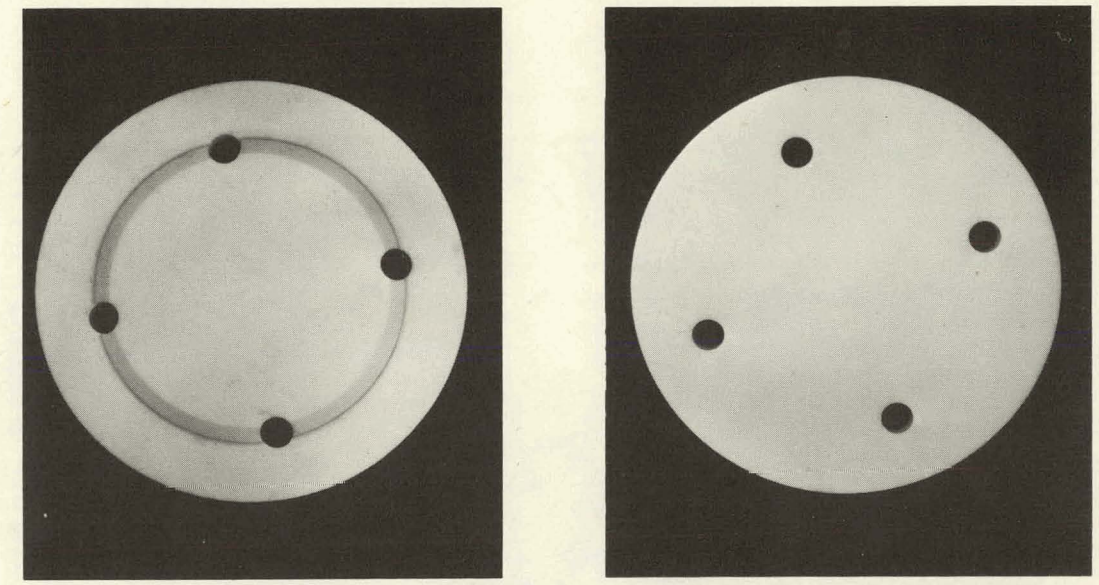
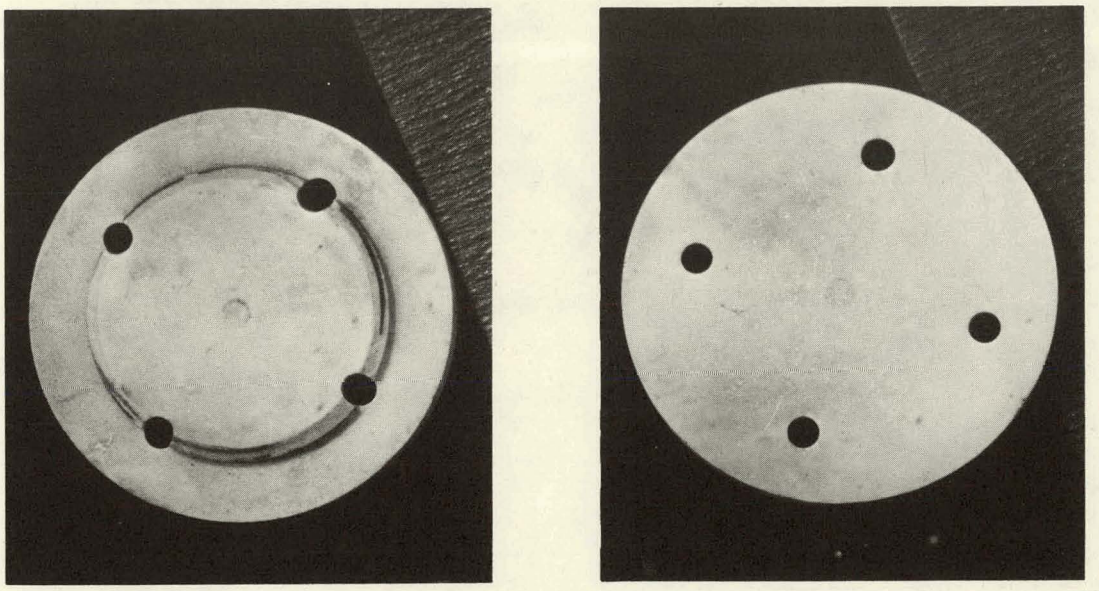


Fig. 5. BeO-Graphite Compatibility Irradiation Test, BeO Core, (a) preirradiation, (b) postirradiation.



(a)



(b)

Fig. 6. BeO-Graphite Compatibility Irradiation Test, BeO Core Support, (a) preirradiation, (b) postirradiation.

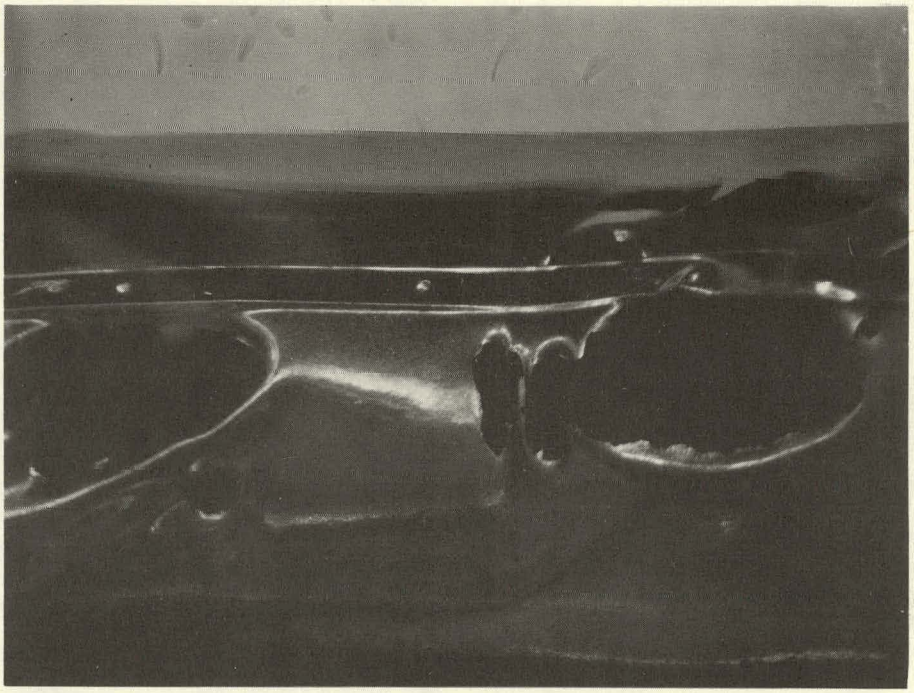


Fig. 7. Postirradiation View of BeO Graphite Compatibility Irradiation Test, Inner Heat Shield with 1/2" x 3/4" Holes.

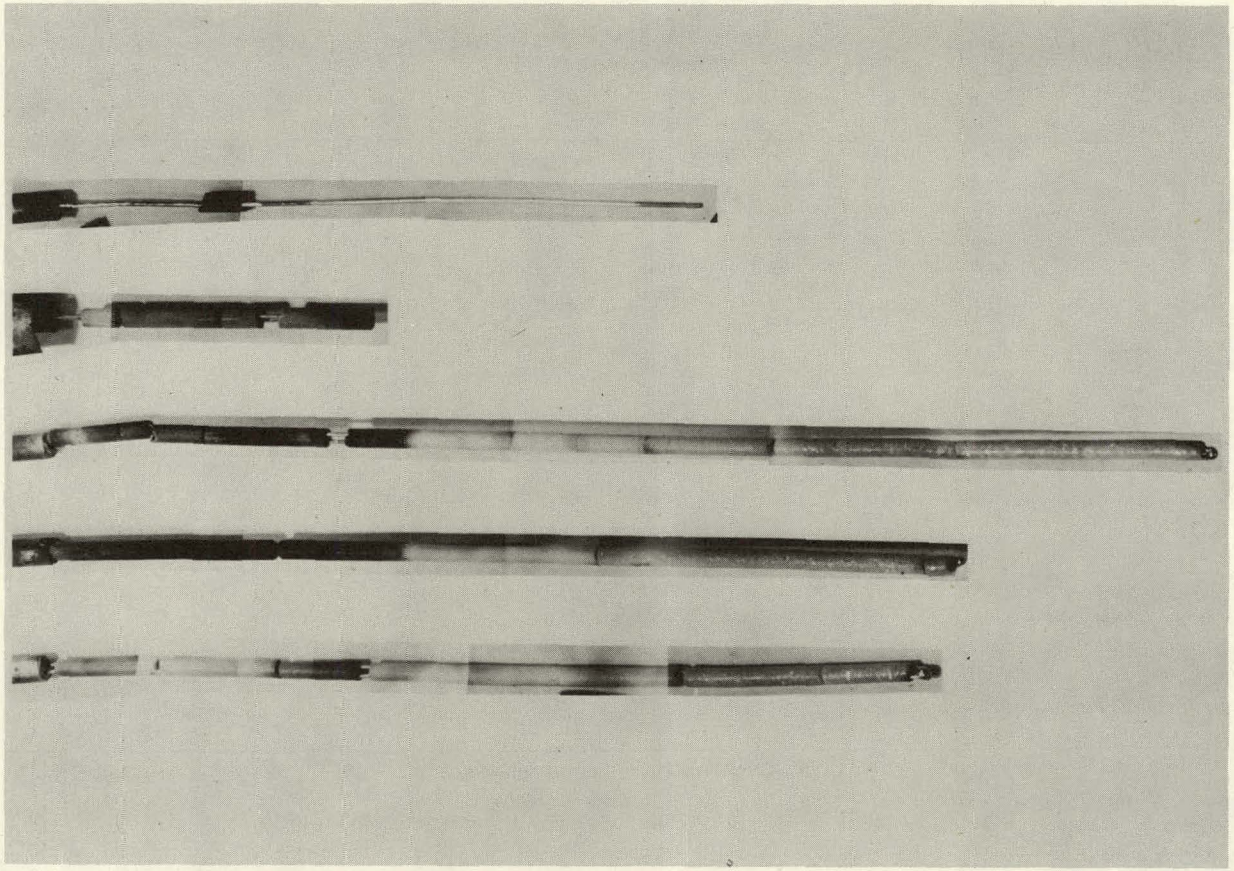
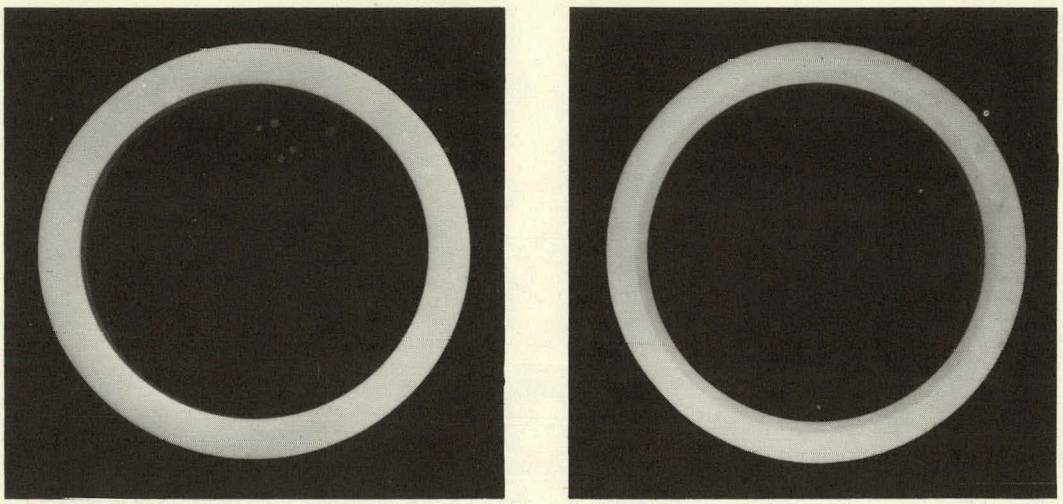
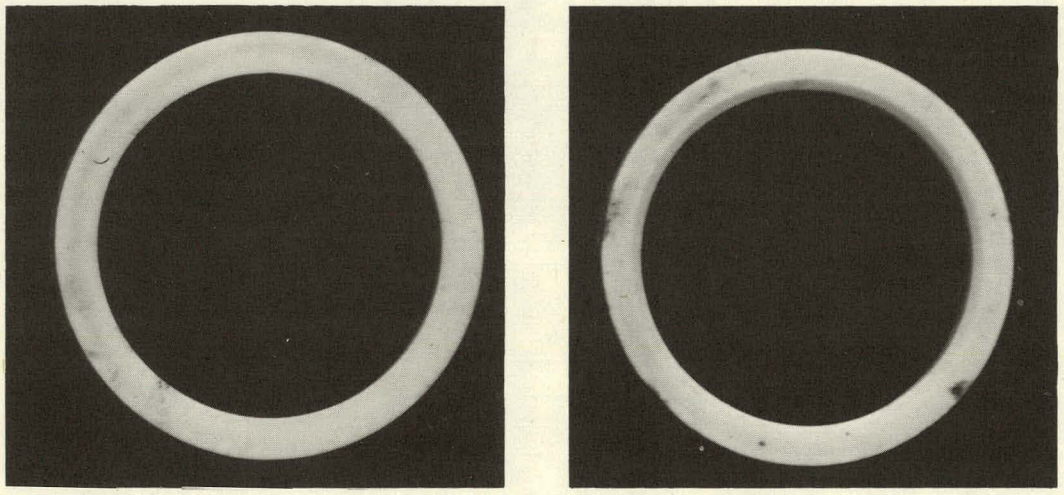


Fig. 8. Postirradiation View of BeO-Graphite Compatibility Irradiation Test Thermocouples Showing Black Deposits, (a) TE Nos. 4, and 5, (b) TE Nos. 1, 3, 9.

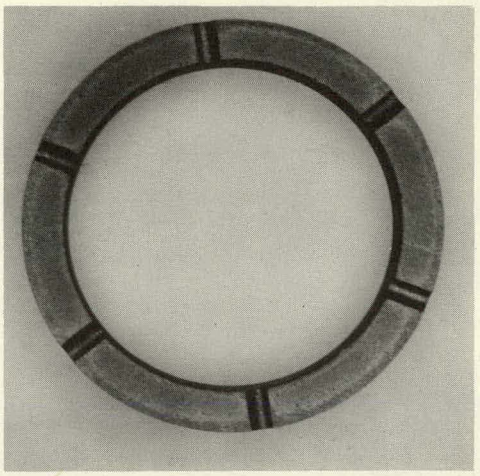
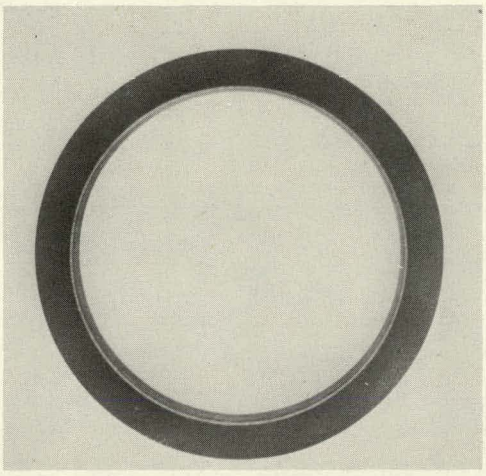


(a)

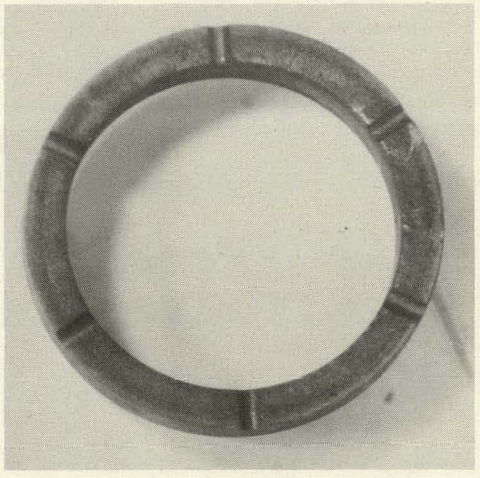
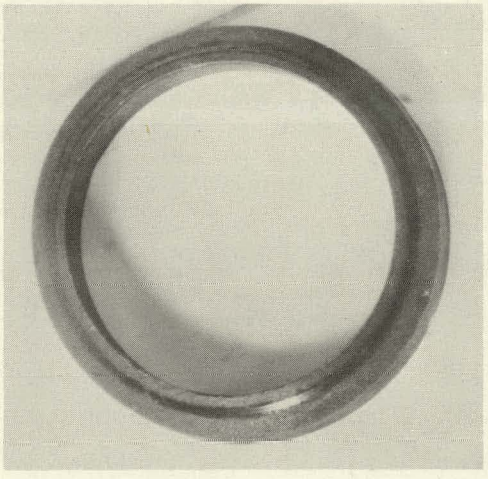


(b)

Fig. 9. BeO-Graphite Compatibility Irradiation Test, BeO Ring, (1a) lapped surface, preirradiation, (1b) back side, preirradiation, (2a) lapped surface, postirradiation, (2b) back side, postirradiation.

(a)

(b)

Fig. 10. BeO-Graphite Compatibility Irradiation Test, Graphite Ring (1a) lapped surface, preirradiation, (1b) back side, preirradiation, (2a) lapped surface, postirradiation, (2b) back side, postirradiation.

at a magnification of 10X showed no evidence of reaction products on the surfaces. X-ray diffraction results on the BeO ring surface revealed only BeO with no evidence of Be_2C. Metallographic examination of the surfaces at a magnification of 200X (see Fig. 11) also showed no reaction products.

Distribution of ^6Li

The (n,2n) reaction in beryllium offers a possible enhancement of the breeding ratio by about 0.08 in a large BeO reactor.[2] If a major portion of the BeO is not associated with fuel and consequently is not reprocessed with the fuel but remains permanently in the reactor, ^6Li poisoning from the (n,α) reaction, would saturate in a short time compared to reactor life and negate the benefits of the (n,2n) reaction. Therefore, it is important to determine under what conditions the ^6Li will diffuse out of the BeO where it is formed. Thus, the determination of the distribution of ^6Li was one of the major objectives of this experiment.

A procedure first suggested by Smales[7] and later modified by Stieglitz[3] uses the nuclear reactions $^6Li(n,t)^4He$ followed by $^{16}O(t,n)^{18}F$ to determine ^6Li in an oxygen-lithium mixture. This method was used to determine the concentrations of ^6Li in samples selected from various components of the irradiation capsule. The results are shown in Table 1.

No significant differences were found among the concentrations in six core-drilled samples from the BeO core. The samples were taken from three longitudinal locations and divided to yield averages for the inner and outer half radii. While the ^6Li concentrations are low, in the $\mu g/g$ range, they are at least an order of magnitude greater than concentrations found in unirradiated control BeO. Based on the average concentration, the irradiated core contained ~400 μg of ^6Li, which is a major portion of the calculated 725 μg of ^6Li produced.

The production of ^6Li was calculated on the basis of the neutron flux and irradiation time. The result of the calculation is subject to large uncertainties related to the flux spectrum in the facility and the variations in the (n,α) cross sections with neutron energy. The uncertainty

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[7] A. A. Smales, Ann. Reports Chem. Soc. 46, p. 290, 1949.

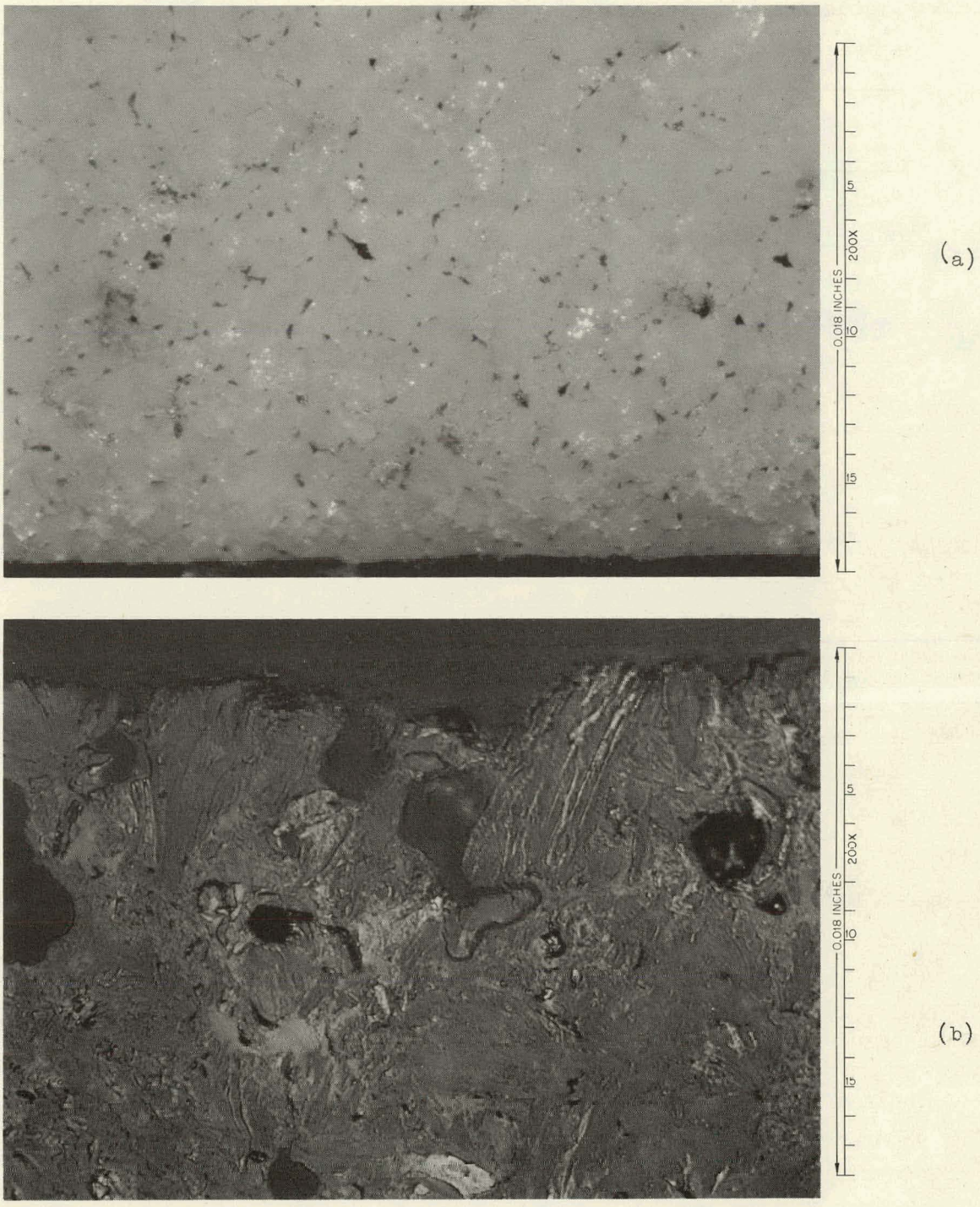


Fig. 11. BeO and Graphite Surfaces that were in Contact During Irradiation (a) BeO and (b) Graphite.

Table 1. ^{6}Li Concentrations in Capsule Components of BeO-C Compatibility Irradiation Test

Component Sampled	Concentration of ^{6}Li (μg/g of Component)
Portion of Mo effluent gas line	2.9
Graphite cylinder	0.12
Graphite ring	<0.02
BeO ring	0.2
BeO core drill near top	
Outer 1/2	3.0
Inner 1/2	2.4
BeO core drill near center	
Outer 1/2	1.1
Inner 1/2	2.0
BeO core drill near bottom	
Outer 1/2	2.3
Inner 1/2	1.7
Portion of primary stainless steel containment	0

in the calculated production and the scatter in the measured concentrations, make a quantitative determination of the released ^{6}Li questionable. Since a major portion of the calculated production was accounted for and no appreciable concentrations of ^{6}Li were found in other parts of the capsule, it was concluded that most of the ^{6}Li formed in the core remained in the core.

A single comparison of the concentrations in the BeO ring and in the BeO core indicates that the ^{6}Li retention may be a function of surface-to-volume ratio of the component. The surface-to-volume ratio of the ring was about 6 times that of the core whereas the ^{6}Li concentration in the ring is about one-tenth that of the core. Work by Stieglitz and Zumwalt[3] has shown that virtually all (99.6%) of ^{6}Li is removed from small (−20 to +40 mesh) granules of BeO which had been irradiated at 380–490° C and subsequently heated at 1400° C for 11.5 hours in a moving gas stream.

Physical Behavior of BeO and Graphite

Weight and dimensional changes for the BeO and graphite components of the experiment are summarized in Table 2. The shrinkage in the graphite was uniformly about 1%. These dimensional changes are in fair agreement with other work by Engle[6] on similar graphites. Dimensional changes are expected to become more anisotropic with increasing exposure.[6] The BeO core expanded both radially and longitudinally about 1/2%. The other BeO pieces showed expansions varying from 0.2% for the ID of the ring to 0.8% for the cover plate and 3% for the minor thickness of the core support. These large expansions are probably real. Work by Keilholtz and Moore[4] has shown that radiation-induced BeO expansion is more pronounced at lower temperatures and these components were in cooler portions of the assembly and in large temperature gradients. The weight changes are not large and the limited data indicate a surface-to-volume relationship for weight loss in the BeO.

Metallographic examination of a segment of the BeO ring showed marked changes from the unirradiated control. The grain size doubled and the grain boundaries are outlined by gas bubbles, Fig. 12. Similar examination of the graphite indicated no significant changes, Fig. 13.

CONCLUSIONS

The lapped surface of a ring of polycrystalline graphite was irradiated in contact with a lapped surface of a ring of high purity BeO at 1280 to 1500° C to a dose of ~1 x 10^{21} neutrons/cm^2 (E > .18 Mev). These abutted rings were 1 in. inside diameter by 1.25 in. outside diameter. Results of x-ray diffraction and metallographic examination indicated no evidence of the reaction product Be_2C.

There were no significant differences in ^6Li concentration among six samples taken from two radial and three axial positions in the irradiated BeO core (1-in. diam by 4.5-in. length). Based on the average concentration, a major portion of the calculated ^6Li production had remained within

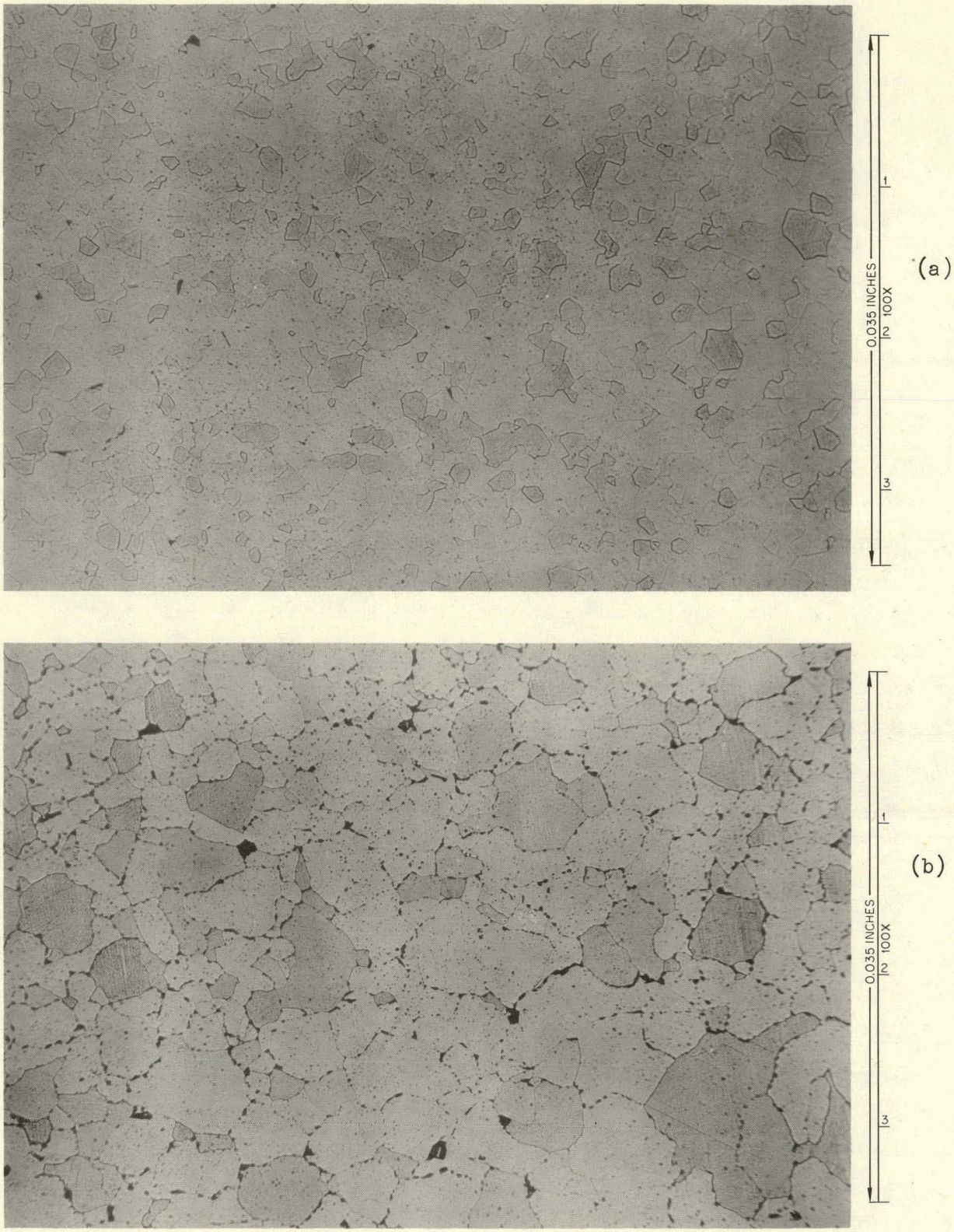
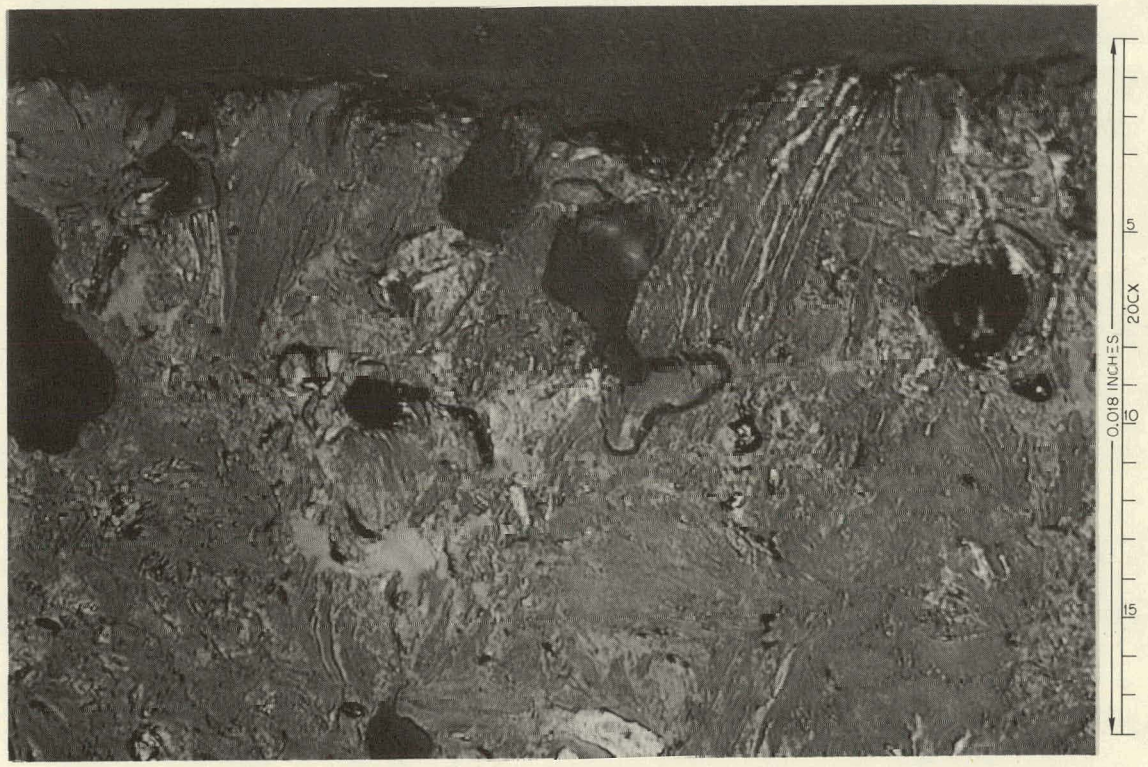


Fig. 12. Comparison of Irradiated BeO with Unirradiated Control for BeO Graphite Compatibility Irradiation Test. (a) Control (b) Irradiated.

a



b

Fig. 13. Comparison of Irradiated Graphite with Unirradiated Control for BeO Graphite Compatibility Irradiation Test (a) control (b) irradiated.

Table 2. Weight and Dimensional Changes in Irradiated BeO and Graphite Parts of BeO Graphite Compatibility Irradiation Test Capsule

Part and Measurement	Dimensional Change at Orientation Indicated								Weight Change	
	0°		90°		180°		270°			
	Mils[a]	%	Mils[a]	%	Mils[a]	%	Mils[a]	%	Grams[b]	%
Graphite sleeve										
Outside diameter[c]										
1	(d)		-17.2	-1.0					(e)	
2	-16.3	-1.0	-17.1	-1.0						
3	-19.2	-1.1	-20.8	-1.2						
Inside diameter[c]										
1	-10.3	-1.0								
2	(d)									
Length			-49.2	-1.02	-48.3	-1.00	-49.5	-1.02		
Graphite ring										
Outside diameter	-11.5	-1.0	-11.4	-1.0					-0.0312	-0.7
Inside diameter	-10.0	-1.0	-9.4	-0.9						
Height	-3.9	-1.1	-4.3	-1.2	-4.9	-1.3	-4.9	-1.3		
BeO ring										
Outside diameter	+5.5	+0.4	+5.4	+0.4					-0.0355	-0.7
Inside diameter	+2.3	+0.2	+2.5	+0.2						
Length	+0.4	+0.2	+0.7	+0.3	+1.5	+0.6	+1.2	+0.5		
BeO central cylinder										
Outside diameter[c]										
1	+4.7	+0.5	+4.9	+0.5					-0.2697	-0.15
2	+4.7	+0.5	+4.7	+0.5						
3	+6.1	+0.6	+6.0	+0.6						
4	+5.3	+0.5	+4.7	+0.5						
5	+7.6	+0.6	+8.2	+0.7						
6	+8.5	+0.7	+8.6	+0.7						
Length	+26.9	+0.6	+27.1	+0.6	+26.7	+0.6	+27.1	+0.6		
BeO cover plant										
Major thickness	+2.5	+0.8	+2.6	+0.8	+2.9	+0.9	+2.2	+0.7	-0.0615	-0.33
Minor thickness	+1.0	+0.8	+1.0	+0.8	+0.9	+1.1	+1.1	+0.9		
Diameter[d]										
BeO core support										
Major thickness	+2.3	+0.7	+1.5	+0.5	+1.5	+0.5	+2.0	+0.6	-0.1059	-0.38
Minor thickness	+5.3	+2.8	+5.6	+3.0	+5.3	+2.8	+5.1	+2.7		
Diameter	+9.8	+0.6	+9.5	+0.5						

[a] Dimensions, while given to 0.1 mil, are generally believed good to ±0.5 mil.

[b] Weights are believed good to ±0.5 mg.

[c] Numbers refer to location of preirrad. measurements given in Ref. 5

[d] Part broken during disassembly.

[e] Thermocouple stuck in cylinder.

the BeO core. Relatively small amounts of ^{6}Li were found in the capsule components other than BeO. We conclude that most of the ^{6}Li generated in massive BeO components during irradiation in the temperature range 1280 to 1500°C will not diffuse out of the component.

No gross irradiation damage or pronounced physical changes occurred in either the BeO or graphite. Graphite shrinkage was uniformly ~1% in all directions whereas the BeO expanded ~0.6%. The BeO grain size doubled during irradiation whereas no changes were observed in the graphite microstructure. A small weight loss was observed for each BeO and graphite component.

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APPENDIX A

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Appendix A

DETERMINATION OF NEUTRON EXPOSURE FOR BEO-GRAPHITE COMPATIBILITY IRRADIATION TEST FROM FLUX MONITORS

Two types of neutron flux monitors were used during the irradiation test. Two stainless steel monitor wires were sealed in the test capsule to provide a measure of the integrated exposure. A series of flux monitor canes were exposed for about two weeks each to provide a periodic indication of the exposure rate during the course of the irradiation.

Each tubular cane assembly[1] contained three sealed quartz ampules spaced 0.80-in. apart along the longitudinal axis of the capsule with the center ampule in the plane of the interface between the BeO and graphite specimen rings. Each ampule contained a cobalt-aluminum alloy (0.0964 wt % cobalt) wire, a nickel wire, and an iron wire.

Neutron flux values calculated from activation analysis data of each monitor are listed in Table A-1. The thermal flux was determined from the $^{59}Co(n,\gamma)^{60}Co$ reaction and the fast flux ($E > .18$ Mev) from the $^{58}Ni(n,p)^{58}Co$, and $^{54}Fe(n,p)^{54}Mn$ reactions. The FOILS[2] program which was used to compute neutron flux, accounts for the thermal neutron burnup of ^{58m}Co when calculating the fast flux from ^{58}Ni activation, but does not include the effect of reactor down time during the irradiation period. The effect of reactor down time was neglected for the wires in the removable monitor canes. For the stainless steel monitor wires, the effect of reactor down time was approximated by averaging the resulting flux value from two cases: (1) using the actual foil decay time (from the end of irradiation to counting) and no reactor down time and (2) adding the total reactor down time during irradiation to the decay time at the end of the irradiation.

The average fast flux value at each of three positions in the plane through the BeO-graphite specimen interface were used to estimate the fast flux gradient through the capsule and the fast flux at the capsule

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[1] C. A. Brandon, J. A. Conlin, I. T. Dudley, W. R. Mixon, BeO-Graphite Compatibility, p. 210, GCRP Semiann. Progr. Rept. Sept. 30, 1965, ORNL-3885, Oak Ridge National Laboratory.

[2] W. C. Morgan, "FOILS: A Program for Computing Neutron Exposures from Foil Activation Data," HW-81367, 1964.

Table A-1. Flux Monitor Results from BeO-Graphite Compatibility Irradiation Test

Monitor Type	Monitor Irradiation Period		Equivalent Mwd	Monitor Location*	Thermal Neutron Flux ($n/cm^2 \cdot sec$) $^{59}Co(n,\gamma)^{60}Co$	Fast Neutron Flux ($E > .18$ Mev) ($n/cm^2 \cdot sec$)	
	From	To				$^{58}Ni(n,p)^{58}Co$	$^{54}Fe(n,p)^{54}Mn$
						x 10^{13}	x 10^{13}
Ampule	3-14-65	4-6-65	553.6	+1 1/4	10.80	8.18	10.10
	3-14-65	4-6-65	553.6	0	10.40	8.36	9.43
	3-14-65	4-6-65	553.6	-1 1/4	10.80	8.32	9.51
	4-6-65	5-2-65	726.5	+1 1/4	9.78	6.12	10.4
	4-6-65	5-2-65	726.5	0	9.94	6.65	6.25
	4-6-65	5-2-65	726.5	-1 1/4	10.10	7.33	9.01
	5-8-65	6-7-65	877.5	-1 1/4	10.20	7.69	9.16
	5-8-65	6-7-65	877.5	0	10.10	7.77	9.02
	5-8-65	6-7-65	877.5	-1 1/4	10.10	7.74	10.2
	7-9-65	7-27-65	411.1	+1 1/4	10.80	8.32	8.82
	7-9-65	7-27-65	411.1	0	10.60	8.23	8.74
	7-9-65	7-27-65	411.1	-1 1/4	11.10	8.48	9.62
	8-26-65	9-16-65	534.0	+1 1/4	10.50	8.27	9.33
	8-26-65	9-16-65	534.0	0	10.30	8.14	9.48
	8-26-65	9-16-65	534.0	-1 1/4	10.10	8.06	9.25
	10-19-65	11-5-65	424.8	+1 1/4	8.79	7.10	7.59
	10-19-65	11-5-65	424.8	0	9.21	7.21	7.47
	10-19-65	11-5-65	424.8	-1 1/4	9.21	7.39	7.77
SS Wire	3-14-65	12-12-65	7085.3	+2 27/32	6.58	5.61	4.18
	3-14-65	12-12-65	7085.3	+1 1/2	6.41	5.89	4.30
	3-14-65	12-12-65	7085.3	0	6.30	5.75	4.33
	3-14-65	12-12-65	7085.3	-1 1/2	6.17	5.40	4.13
	3-14-65	12-12-65	7085.3	-2 9/16	6.69	6.03	4.42
	3-14-65	12-12-65	7085.3	+2 27/32	4.73	4.50	3.44
	3-14-65	12-12-65	7085.3	+1 1/2	4.44	4.69	3.46
	3-14-65	12-12-65	7085.3	0	4.33	4.59	3.38
	3-14-65	12-12-65	7085.3	-1 1/2	4.52	4.70	3.54
	3-14-65	12-12-65	7085.3	-2 9/16	5.12	4.89	3.58

*Mean axial distance of monitor from specimen interface, inches. Positive values are above interface and negative values are below.

centerline. The neutron flux at this point was assumed to be the average value over the specimen rings. The resulting average fast neutron flux ($E > .18$ Mev) was 5×10^{13} and the average total fast neutron dose ($E > .18$ Mev) was 1×10^{21} nvt. Minimum and maximum fast neutron doses in the specimen rings were estimated to be 0.76×10^{21} nvt, respectively.

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