ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

POSTFABRICATION EVALUATION
OF INTEGRITY AND SERVICEABILITY OF
CANNED GRAPHITE FOR THE
EBR-II NEUTRON SHIELD

by

A. H. Heineman

Reactor Engineering Division

March 1968

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights, or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

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

DISCLAIMER

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

DISCLAIMER

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

TABLE OF CONTENTS

	<u>Page</u>
I. INTRODUCTION.	7
II. DESCRIPTION OF NEUTRON SHIELD	7
A. Basic Configuration	7
1. Top Shield	9
2. Inner Radial Shield	9
3. Outer Radial Shield	9
B. Can Components	15
1. Standard Cans	15
2. Special Cans	17
3. Sources of Graphite	17
C. Prefabrication Tests	18
1. Immersion of Uncanned and Canned Graphite in Sodium	18
a. Uncanned Graphite	18
b. Canned Graphite	19
2. Outgassing of Canned Graphite	21
3. Furnace Heating Test	22
4. Pressure Test	22
D. Specified Canning Procedures	23
1. Standard Cans	23
2. Special Cans	24
III. POSTFABRICATION TESTS	24
A. Objectives	24
B. Sources of Test Cans	24
1. Spare Standard Cans	24
2. Specific-purpose Cans	25
3. Others	26
C. Test Procedures and Results	26
1. Pressure-integrity Tests	26
2. Thermal-cycling Tests	29
a. Cycle A	29
b. Cycle B	29
c. Can Identification and Test Procedure	29
d. Results	31

TABLE OF CONTENTS

	<u>Page</u>
3. Sodium Immersion Tests	34
a. Objectives, Procedures, and Results	34
b. Supporting Calculations, Tests, and Analyses	35
IV. CONCLUSIONS.	39
ACKNOWLEDGMENTS	39

LIST OF FIGURES

<u>No.</u>	<u>Title</u>	<u>Page</u>
1.	Components of EBR-II Primary Tank	8
2.	Top: Plan View of Reactor Vessel Cover and Outer Radial Neutron Shield Installed in Primary Tank. Bottom: Arrangement of Boronated Graphite Shield Cans inside Vessel Cover. .	10
3.	Plan View of Reactor Vessel Showing Inner and Outer Radial Neutron Shields	11
4.	Elevation View of Reactor Vessel and Neutron Shield Assembly	12
5.	Top: Support Ring for Inner Radial Neutron Shield Being Lowered into Primary Tank. Bottom: Outer Row of Shield Cans Installed in Reactor Vessel	13
6.	Elevation View of Outer Radial Neutron Shield Assembly	14
7.	Sectional Views of Standard Full-can Assembly.	15
8.	Sectional Views of Standard Half-can Assembly.	16
9.	Closeup Views of Standard and Special Neutron-shield Cans Installed around Reactor Vessel, Instrument Thimble, and Sodium Outlet	17
10.	Sectional View of Piercing-adapter Components and Method of Effecting Temporary Attachment to Bottom of Standard Can. .	27
11.	Measured Pressures for Spare Standard and Specific-purpose Cans during Exposure in Cycle A Furnace	32
12.	Measured Pressures for Spare Standard and Specific-purpose Cans during Exposure in Cycle B Furnace	33
13.	Stress-strain-pressure Relationship for Exposed 40-mil-thick-walled Cans and a Theoretical 1-mil Can-wall Thickness for Plain and Boronated Graphites	36
14.	Calculated EHP and Sodium Uptake vs Lateral or Axial Growth of Graphites in Cylindrical Cans Exposed for 14,800 hr in Sodium at 800°F	36

LIST OF TABLES

<u>No.</u>	<u>Title</u>	<u>Page</u>
I.	Densities of Neutron-shield Graphites	18
II.	Summary of Sodium Immersion Tests of Uncanned Graphite Samples	19
III.	Standard Cans Selected for Postfabrication Tests	25
IV.	Measured Pressures in Spare Standard Cans Removed from Storage at EBR-II Site	28
V.	Summary of Sodium Immersion Tests with Cylindrical Cans . .	34
VI.	Summary of Ultimate Compressive Strength (UCS) Tests on Unexposed Plain and Boronated Graphites	38

POSTFABRICATION EVALUATION OF INTEGRITY AND SERVICEABILITY OF CANNED GRAPHITE FOR THE EBR-II NEUTRON SHIELD

by

A. H. Heineman

I. INTRODUCTION

The EBR-II neutron shield consists of a multiplicity of rectangular and irregular-shaped, Type 304 stainless steel cans of plain and/or boronated graphites. These cans are positioned inside and around the reactor vessel, and within the vessel cover. As shown in Fig. 1, the reactor vessel, the primary-sodium pumps and piping, the heat exchanger, and the fuel-handling system are submerged in the bulk sodium coolant within the primary tank. During reactor operation, the coolant is pumped into the reactor vessel, up through the reactor and the inner radial neutron shield. From the vessel, the coolant flows through the heat exchanger and discharges into the bulk sodium. Canned graphites around the vessel and within the vessel cover are cooled by the bulk sodium.

This submerged concept contributes significantly to the reliability and integrity of the primary coolant system. The arrangement is ideally suited to natural-convection cooling, providing extremely reliable shutdown cooling in the event of loss of forced convection. Essentially all of the radioactivity in the plant is confined to the primary tank.

Reliability and integrity of the neutron shield in the tank environs, exclusive of nuclear radiation, have been demonstrated by the series of tests described in this report. More specifically, they include: (1) pre-fabrication tests of prototype can assemblies and graphite to develop criteria for their commercial fabrication; (2) postfabrication tests of spare as-built cans to ensure vendor conformity with these specifications; and (3) similar tests with deliberately defected cans to assess the consequences of omissions or deviations from these specifications, or can failure, on reactor safety and operation.

II. DESCRIPTION OF NEUTRON SHIELD

A. Basic Configuration

As shown in Figs. 2 to 7, the neutron shield consists primarily of rectangular cans containing plain or boronated (nominally 3.0 w/o B₄C) graphite. These cans are stacked horizontally within the reactor vessel cover, and

111-6453G

Fig. 1. Components of EBR-II Primary Tank. After reactor shutdown, the reactor vessel cover is raised and fuel-handling mechanisms mounted on rotating plugs are indexed to exchange subassemblies between the reactor vessel and storage tank. All exchanges are made by remote control, with the subassemblies completely submerged in the bulk sodium coolant.

positioned vertically around the reactor outer-blanket subassemblies and the vessel periphery. The layers and rows are staggered to prevent neutron streaming and, as required, include specially shaped cans of corresponding graphite around guide tubes, pipes, and thimbles which penetrate the neutron shield. For purposes of description, the shield can be divided into three regions: top, inner radial, and outer radial.

1. Top Shield

With reference to Fig. 2, the top shield comprises six layers of canned boronated graphite forming an assembly of ~7.7-ft OD and 2.5 ft thick within the reactor vessel cover. Successive layers are positioned at right angles to each other in polygonal array and staggered to minimize neutron streaming. The cans are cooled by radiation to the vessel cover walls. These walls, in turn, are cooled at the top center by sodium leakage between the control-rod drive shafts and guide bushings; on the underside by outlet plenum sodium; and around the top-plate periphery and side wall by natural convection of the bulk sodium.

2. Inner Radial Shield

This portion of the radial neutron shield (see Figs. 3-5) comprises two rows of rectangular cans, forming an annular ring (of ~7.3-ft OD, 9.25 in. thick, and 4.167 ft high) around the reactor liner within the vessel. The cans in each row are filled with plain graphite (cans in the vicinity of nuclear-instrument thimbles are filled with sodium and orificed for flow); they are staggered to minimize neutron streaming and spaced to provide channels for flow of primary-sodium coolant. Both rows are aligned vertically by retainer rings, and the entire assembly is supported at the periphery of the reactor upper grid plate.

3. Outer Radial Shield

This portion of the radial neutron shield consists of five rows of rectangular cans and special-shaped cans, which form an annular assembly (of ~11.8-ft OD, 1.75 ft thick, and 13.167 ft high) disposed in three tiers around the reactor vessel and cover. The two inner rows of cans in each tier are filled with plain graphite (Fig. 6). The outer rows are assembled of plain-graphite-filled cans interspersed with cans of boronated graphite at strategic locations. For example, the outer three rows in the middle tier are alternately boronated- and plain-graphite-filled cans. (Corresponding rows of graphite are installed in the large, special-shaped cans.) Boron is omitted from cans immediately adjacent to instrument thimbles to enhance instrument response.

Fig. 2. Top: Plan View of Reactor Vessel Cover and Outer Radial Neutron Shield Installed in Primary Tank Bottom: Arrangement of Boronated Graphite Shield Cans inside Vessel Cover.

Fig. 3. Plan View of Reactor Vessel Showing Inner and Outer Radial Neutron Shields

112-496A

Fig. 4. Elevation View of Reactor Vessel and Neutron Shield Assembly

Fig. 5 Top: Support Ring for Inner Radial Neutron Shield Being Lowered into Primary Tank. Bottom: Outer Row of Shield Cans Installed in Reactor Vessel. Workmen are positioning spacers for inner row.

Fig. 6. Elevation View of Outer Radial Neutron Shield Assembly

The rows of cans in each tier are staggered radially to minimize neutron streaming, aligned vertically by stainless steel bands, and enclosed in expanded wire screen. The triangular channels formed by the disposition of square cans in circular array accommodate natural-convection cooling by the bulk sodium. The entire outer radial shield is mounted on an extension of the base plate which supports the reactor vessel.

B. Can Components

In the following discussion and throughout the balance of this report, the rectangular cans and the special-shaped cans of graphite are referred to as "standard" and "special" cans, respectively.

1. Standard Cans

These cans contain most of the plain graphite and boronated graphite which comprise the EBR-II neutron shield. As shown in Figs. 7 and 8, each can has a nominal cross section of 4 in. square (full can) or

Fig. 7. Sectional Views of Standard Full-can Assembly

Fig. 8. Sectional Views of Standard Half-can Assembly

2 x 4 in. (half-can), and the majority measure 52½ in. overall length. Cans with shorter lengths are employed to fill in the layers in the vessel cover, and above and below the special cans, and in the inner radial shield.

Both cans are of all-welded, Type 304 stainless steel construction and are designed for an internal pressure of 50 psig. This rating was established by pressure tests on prototype cans. At 50 psig, the stresses were lower than the allowable stress (by strain-gauge measurements); at 300 psig, the cans bulged but did not burst. Accordingly, each can has side walls 0.109 in. thick (12 ga), and top and bottom plates 0.5 in. thick. Each top plate is equipped with a vent tube (of 0.188-in. OD and 0.0312-in. wall) to facilitate final outgassing and pressurizing of the loaded can.

Each can is loaded with previously outgassed plain or boronated graphite machined to a 4-in. square or 2 x 4-in. nominal cross section to permit a nominal clearance of 0.063 in. between the can and the graphite. The cans are pressurized with helium (nominal 175 mm Hg abs) to produce a low internal pressure at reactor operating temperature (700°F min) and

yet to transfer heat generated in the graphite to the can wall. At operating temperature, the helium generated by the (n,α) reaction with boron results in a pressure increase of ~ 19 psi during the reactor lifetime, assuming that all helium generated is released to the helium blanket.

2. Special Cans

With five exceptions, these cans are constructed and assembled similarly to the standard cans. First, they are larger and contoured or angulated to fit around penetrations in the neutron shield (see Figs. 6 and 9). Second, their side walls are 0.25 in. thick. Third, internal partitions (12 ga thick) are intermittent-welded to the walls to achieve a maximum unsupported span of ~ 9 in. and thus limit bending stresses to the allowable value. Fourth, certain cans contain part plain and part boronated graphite. Finally, because of their irregular geometry, the graphite is "tailored" precisely for each can and, hence, must be outgassed in the assembled can.

Fig. 9. Closeup Views of Standard and Special Neutron-shield Cans Installed around Reactor Vessel, Instrument Thimble, and Sodium Outlet

3. Sources of Graphite

The plain graphite consists of reactor-grade material (fully graphitized and of low impurity content). This material was selected, on the basis of similarity in chemistry and low boron content, from six types of graphite salvaged from the dismantled CP-2 reactor. These graphites were identified as No. 3, TO-7, TO-9, T-11, T-12, and T-16.

The boronated graphite was fabricated by the National Carbon Co. to ANL specifications. These specifications required that the basic coke flour used should conform with the vendor's standard for their AGSR-grade graphite (ash content = 0.30%). In addition, the finished product was to contain a minimum of 2.9 w/o B_4C .

To ensure this minimum boron content, 3.3 to 3.45 w/o B_4C powder was mixed with the coke flour prior to adding the pitch binder. Also, the final gas purge during graphitization at $2800^{\circ}C$ was not administered since the purge removes boron along with other impurities. As a consequence, the impurity content in the final product slightly exceeded that in AGSR-grade graphite.

Table I lists the measured densities of graphites comprising the EBR-II neutron shield.

TABLE I. Densities of Neutron-shield Graphites

Sample size: 4 x 4 x 3 in.

Type Graphite	Sample No. 1	Sample No. 2	Average
No. 3--Plain	1.5428	1.5409	1.5419
TO-7--Plain	1.6097	1.6121	1.6109
TO-9--Plain	1.6282	1.6469	1.6376
T-11--Plain	1.6203	1.6163	1.6183
T-12--Plain	1.5783	1.6056	1.5920
T-16--Plain	1.6070	1.6333	1.6202
Random Specimen--Plain	1.5796	1.5905	1.5851
Boronated	1.5535	1.5666	1.5601

C. Prefabrication Tests

Four series of independent tests were made in conjunction with the selection of graphite material, development and evaluation of can-design criteria, and establishment of specifications and procedures for commercial outgassing and canning components of the neutron shield. The nature and specific objectives of these tests are summarized in the following subsections.

1. Immersion of Uncanned and Canned Graphite in Sodium

The specific objectives of tests which involved submersion in liquid sodium were threefold: (1) to evaluate coupled specimens of candidate graphites and Type 304 stainless steel in terms of graphite swelling, erosion, and deleterious effects on Type 304 as a function of sodium temperature and oxygen content; (2) to determine if a can with a sidewall wall thickness of 0.0625 in. could safely withstand the forces applied by graphite swelling incurred by sodium inleakage; and (3) to assess the consequent erosion and transport of particulate graphite.

a. Uncanned Graphite

These tests were made on duplicate couples of Type 304 stainless steel coupons strapped to: fully graphitized material salvaged

from the CP-2 reactor; semigraphite material (60% graphite and 40% carbon) of the type employed in the TREAT reactor; and semigraphite material containing 5 w/o B₄C. One of each pair of couples was immersed and sealed in an autoclave containing "clean" sodium (estimated oxygen content: ~15 ppm). The other was similarly immersed in "dirty" sodium (estimated oxygen content: ~115 ppm). Both autoclaves were then heated to and maintained at 800°F for about six months.

Upon removal from the autoclaves, the couples were disassembled and evaluated. Type 304 specimens were cleaned, and then subjected to hardness and bend tests and to metallographic examination. There was no indication of carburization, carbide precipitation, or other deleterious effects on the material properties.

The graphites were examined visually, then surveyed dimensionally, weighed, and the results compared with pretest values. As made evident by Table II, the two specimens of fully graphitized material experienced the least swelling in both "clean" and "dirty" sodium. Also, they appeared to be the least sensitive to sodium oxide content. However, the damage sustained by both specimens was considerably greater than that suffered by the semigraphites in "clean" sodium, whereas in "dirty" sodium, the semigraphites were approaching complete disintegration.

TABLE II. Summary of Sodium Immersion Tests of Uncanned Graphite Samples

Sample	O ₂ Content in Sodium, ppm	Growth, %			Weight Change, %	Appearance
		Axial	Horizontal	Vertical		
Plain graphite from CP-2	15	1.67	2.14	1.19	+9.06	Two corners spalled; large chip from one edge
	115	1.25	1.91	1.57	+14.10	One corner and edge spalled
Semigraphite (60% graphite and 40% C)	15	3.16	2.48	1.64	+8.97	Good; some surface cracks
	115	(a)	4.10	3.63	-	Badly cracked and spalled
Semigraphite with 5 w/o B ₄ C	15	2.83	3.55	3.40	+19.8	Fair; corners slightly spalled
	115	5.07	8.19	9.96	-	Badly cracked and spalled

(a) Unable to measure.

b. Canned Graphite

Two cylindrical cans (of 4-in. OD, 12 in. long, and of 0.0625-in. wall thickness) were fabricated with deliberate defects. These defects consisted of drilled holes plugged with soft solder that would melt at test temperature and permit sodium access to the contained graphite. The objectives here were to determine the consequences of such access in terms of graphite swelling, dimensional changes in the can, and degree of erosion and transport of particulate graphite.

Each can was loaded with plain graphite (CP-2) machined to provide an overall clearance of 0.010 in. Both cans were evacuated to a pressure of ≤ 1 mm Hg abs, and outgassed by heating and holding at 600°F for ~30 hr. At this point, the cans were backfilled with helium to atmospheric pressure, sealed, and immersed consecutively in a sodium bath maintained at 700°F.

The first can was removed after immersion for three months at test temperature and allowed to drain of excess sodium. Subsequently, one end of the can was cut off, whereupon the graphite slipped easily out of the can. A dimensional survey of the can and comparison with pretest values indicated no measurable permanent set in the can wall.

Visual inspection of the graphite revealed a few small surface cracks, but no evidence of disintegration. To determine the extent of sodium permeation, random samples were cut from the graphite bar, holes were drilled through the remains of the bar, and all exposed surfaces were visually inspected and checked for Na-H₂O reaction. These procedures indicated essentially complete sodium permeation of the graphite.

A sample of the sodium was ladled from the bottom and side of the bath, chemically reduced, and the residue examined visually for particles or chunks of graphite. Neither was found by this rough method.

The second can was removed after immersion for thirteen months in sodium at test temperature. This can also was allowed to drain of excess sodium, and one end was cut off to remove the graphite. In this case, however, the graphite was firmly lodged in the can; attempts to forcibly eject the graphite were unsuccessful.

Dimensional survey of the can and comparison with pretest values indicated strains well below those corresponding to allowable stresses. The can was then split and peeled away from the graphite.

Again, visual inspection of the graphite revealed only a few small surface cracks, and Na-H₂O reaction tests of randomly exposed surfaces indicated complete permeation of the graphite.

Sampling of the bath for graphite particulate was precluded by a sodium fire which occurred after removal of the test can.

Two theories are advanced to account for the similarity in appearance and sodium permeation, but difference in degree of swelling, evidenced by the graphite in both tests. First, while removing can No. 1 and inserting can No. 2, the sodium bath was exposed to air sufficiently to form a considerable quantity of oxide. Second, although sodium permeation was observed throughout the randomly exposed surfaces of both

graphite bars, it is conceivable that the longer exposure resulted in complete saturation of the less-accessible pores. It is well-known that either mechanism may enhance the swelling of graphitic materials.

In any event, it was concluded that: (1) cans of 4-in. OD with 0.0625-in.-thick side walls could withstand the forces generated by sodium-induced swelling of the graphite; and (2) there is no marked erosion and transport of graphite particulate from a leaky can.

2. Outgassing of Canned Graphite

Early experience with tailoring and loading graphite into prototype special cans indicated that it would be more practical, economical, and, in some cases, necessary to outgas the graphite in the completely assembled can. Consequently, the specific objectives of a group of tests were: (1) to determine if the outgassing would have serious deleterious effects on the can material, and (2) to establish the minimum temperature and holding time required to outgas the graphite effectively and thus minimize further outgassing during exposure of the can to reactor operating temperatures.

An outgassing temperature of 1000°F, with a minimum holding time of 8 hr, was selected. This temperature is considerably above the normal reactor operating temperature (700-800°F) at the locations of the special cans, but is below the value at which carburization of the can might occur.

To test this mode of outgassing, a full-size can (4-in.-square cross section) was fabricated. A 1-in.-wide section was cut off one end and used to prepare test coupon standards. The balance of the can was loaded with plain graphite, welded closed, and helium leak tested. In addition, one coupon of the can material, with no special surface treatment, was screwed to a slab of graphite.

The can and the coupled specimens were then placed in a furnace equipped for continuous evacuation of the can and monitoring of the graphite temperature and the can pressure. The temperature was raised and held for ~20 hr at 1000°F. At no time during the heat-up or hold period did the can pressure exceed ~1 mm Hg abs.

At the conclusion of the outgassing, the coupled specimens were removed, cooled, and the coupon subjected to various mechanical tests and metallographic examination. Hardness tests revealed a "dead soft" condition on both sides (i.e., Rockwell B 60-65 or equivalent). A bend test indicated good ductility. Metallographic examination revealed no evidence of carburization and only slight sensitization with negligible carbide precipitation.

The can assembly was then subjected to a heat test for evidence of residual outgassing and/or metallurgical effects. Briefly, the evacuation system was isolated from the can after sealing off the connection, and the can was heated in the furnace at 800°F for 30 days. During this period, the can pressure increased (at a continuously decreasing rate) from a few microns to ~1 mm Hg abs.

Upon termination of this test, the can was removed from the furnace, cooled, and a 1-in.-wide band was cut from the central section. Similar mechanical tests and metallographic examination of samples from this section revealed no significant material-property changes from those observed in the outgassed test coupon.

On the basis of these test results, it was concluded that the special cans could be assembled, loaded with graphite, and then safely and effectively outgassed under the conditions prescribed earlier.

3. Furnace Heating Test

These tests were made on a standard can (4 in. square and 48 in. long) under adverse conditions to obtain data required to establish the design internal pressure and thickness of the side walls.

Briefly, the can was loaded with plain graphite as received from the CP-2 salvage inventory, i.e., exposed to the atmosphere for a long period; no preliminary outgassing was made. The assembly was welded closed, pressurized (via the vent tube) with helium to 5 psig, and leak tested. After leak integrity was established, the pressure was released to atmospheric.

Subsequently the can was placed in a furnace for three weeks. During this period, the furnace temperature was increased progressively to a maximum of 820°F, and the can pressure continuously monitored and recorded. The maximum value recorded was ~87 in. Hg (gauge) at 820°F.

Consideration of the results of this pessimistic test and a consensus of published information on radiation outgassing of graphite established 50 psig as the design internal pressure for both standard and special cans. Based on this criterion, stress calculations established corresponding side-wall thicknesses of 0.109 and 0.250 in. for the standard cans and special cans, respectively.

4. Pressure Test

As a further check of the structural design, a standard can (4 in. square, 48 in. long, and with 0.109-in.-thick side walls) was assembled

without graphite. Strain gauges were mounted on the side walls at the midpoint, and the can was pressurized increasingly with helium.

At the design pressure (50 psig), the strains at the midpoint indicated plastic behavior at the can corners, but corresponded to stresses of the order of one-half the yield strength (cold) of Type 304 stainless steel. At 295 psig, the can walls had bulged significantly, assumed a deep permanent set, but had not burst. Accordingly, it was concluded that the structural design of the standard can was adequate.

D. Specified Canning Procedures

On the basis of the foregoing test results, the following outgassing and canning procedures were specified for commercial fabrication of standard and special cans which comprise the EBR-II neutron shield.

1. Standard Cans

- (1) Outgas graphite in vacuum furnace at 1300°F and 400- μ pressure for 1 hr; cool to about 200°F in 4 hr (under vacuum).
- (2) Break furnace vacuum with argon.
- (3) Remove graphite and load directly into can (maximum exposure to air: 0.5 hr).
- (4) Close can and make final weld, leaving vent tube open; evacuate can to 400- μ pressure and hold for 1 hr.
- (5) Pressurize can with helium to 5 psig; make temporary seal weld at end of vent tube.
- (6) Helium leak test can.
- (7) Heat treat can assembly at 1000°F for 8 hr.
- (8) Helium leak test can (assuming helium pressure was not lost during Step (7)).
- (9) Cut off temporary vent tube seal, checking for outward flow of helium by sound and feel to ensure that helium pressure was not lost during Step (7).
- (10) Evacuate can to 150-200 mm Hg (helium).
- (11) Pinch vent tube and make first permanent seal weld; purge open end of tube with air; helium leak test seal weld; retest and reweld seal, if required.
- (12) Cut vent tube to final length; purge open end with helium, pinch tube, and make second permanent seal weld about 0.5 in. from open end; helium leak test seal weld; retest and reweld seal, if required; bend and tack-weld tube into slot in top plate of can. (See Fig. 7.)

2. Special Cans

(1) Load graphite into can; close can and make final weld, leaving vent tube open.

(2) Connect open vent tube to an external vacuum pump and outgas can in a furnace at 1000°F and 400- μ pressure for at least 8 hr (normally 16 hr overnight); cool to about 200°F.

(3) After cooling, remove can and complete the sequence of operations outlined in Steps (5) to (12) for standard cans.

III. POSTFABRICATION TESTS

A. Objectives

The following tests were made subsequent to installation of the EBR-II neutron shield and represent one phase of a continuing program of plant surveillance. Conducted in collaboration with Idaho Division personnel, the general objectives of this Program are to ensure plant safety and reliability, reduce operational complexities and cost, and enhance irradiation-test capability of the reactor.

The specific objectives of these tests were:

(1) to demonstrate the practicability of design criteria and specifications established for all-welded construction of light-weight stainless steel-canned components of the neutron shield;

(2) to demonstrate, under simulated conditions of reactor operation, the integrity of canned components fabricated in strict conformity with these specifications and procedures;

(3) to assess, under appropriate conditions, the consequences of inadvertent omissions or deviations from these specifications and procedures, and leaking cans.

B. Sources of Test Cans

1. Spare Standard Cans

Eighteen standard cans containing plain or boronated graphites (see Table III) were selected at random from spares stored at the reactor site. These spares were procured with the original lot to replace lost or damaged cans, or to provide for any deficiencies during installation of the neutron shield. At the time of their selection for test purposes, the cans had been stored for two years: in the vendor's plant, at Argonne, and, finally, at the reactor site.

TABLE III. Standard Cans Selected for Postfabrication Tests

Can No.	Quantity	Nominal Cross Section, in.	Overall Length, in.	Type of Graphite
1	8	4 x 4 ^(a)	52 $\frac{1}{2}$	Plain
1B	4	4 x 4	52 $\frac{1}{2}$	Boronated
4	1	4 x 4	36 $\frac{23}{32}$	Plain
4B	1	4 x 4	36 $\frac{23}{32}$	Boronated
10	1	2 x 4 ^(b)	18	Plain
10B	1	2 x 4	18	Boronated
12B	2	2 x 4	52 $\frac{1}{2}$	Boronated

(a) Full can; see Fig. 7.

(b) Half-can; see Fig. 8.

As described below in Sect. III.C, all cans were subjected to pressure-integrity tests. In addition, eight cans were thermal-cycled to investigate outgassing and gas-generation characteristics of the contained graphite and serviceability.

2. Specific-purpose Cans

Eight cans containing plain, boronated, or part plain and part boronated graphite were fabricated at Argonne for specific tests. All cans were nominally 4 in. square in cross section, 26.25 in. long, and equipped for evacuation, pressurization, and monitoring of internal can pressure via a vent tube. Two cans were loaded with 50% plain and 50% boronated graphite, then outgassed, pressurized, and sealed as prescribed for the special cans installed in the neutron shield.

Six cans were fabricated to simulate omissions and deviations from the prescribed procedure. More specifically, two cans were loaded with plain graphite, two with boronated graphite, and two with 50% plain and 50% boronated graphite. No outgassing was performed. Each can was then pressurized with helium to 5 psig and checked for leaks. Subsequently, the pressure in three cans (one of each graphite loading) was reduced to 175 mm Hg; their counterparts were allowed to blow down to atmospheric.

All cans were then thermal-cycled as described in Sect. III.C.2 below.

3. Others

Two groups of six cans also were assembled at Argonne. Fabricated of Type 304 stainless steel to precise tolerances, the cans in each group measured (nominally) 1 in. in ID, 3 in. in length, with wall thicknesses (± 0.1 mil) of 5, 10, 15, 20, 30, and 40 mils.

To ensure uniformity of mechanical properties, surface finish, and dimensional accuracy, each can was machined from a length of comparatively heavy-walled, seamless pipe. First, the ID was machined to close tolerances. Then a tight-fitting arbor was inserted to minimize distortion while machining the OD.

Subsequently one group of cans was loaded with plain graphite tailored to a snug fit; the ends of the cans were left open. The other group was similarly loaded with boronated graphite.

Both groups of cans along with two spare standard cans (10 and 10B, of Table III) were subjected to sodium-immersion tests as described in Sect. III.C.3.

C. Test Procedures and Results

1. Pressure-integrity Tests

As an initial check on can integrity and canning procedure, the eighteen spare standard cans (see Table III) were pierced and their existing internal pressures measured for comparison with the design range (150-200 mm Hg abs).

To accomplish this objective, a pilot hole (of 0.625-in. diameter) was drilled in the bottom of each can, leaving a 0.0312-in.-thick diaphragm. In test, this diaphragm was penetrated by a leaktight, hydraulic-jack-actuated piercing adapter (see Fig. 10) mounted above the pilot hole. Ten of the cans were machined for temporary attachment of a bolted and O-ring-sealed-version of this adapter, which was transferred from can to can. A similar welded-type adapter was permanently attached to each of the eight cans selected for subsequent thermal-cycling tests. In all cases, the piercing adapter furnished a valved tubing connection for attachment to a manometer, or other external system, without significant loss of pressure or vacuum from the can. For the pressure-integrity tests, the external system consisted of a closed-end mercury manometer, a vacuum pump, a helium source, and an interconnecting-tubing manifold. The inherent volume of the adapter was held to a practicable minimum, and the tubing runs were made as short as possible to minimize the incremental volume increase in the system when the can was pierced.

Fig. 10. Sectional View of Piercing-adaptor Components and Method of Effecting Temporary Attachment to Bottom of Standard Can. O-ring groove and screw holes are omitted in welded-type adapter.

Each test was carried out in the following sequence:

- (1) Mount adapter on can and connect to external system.
- (2) Helium leak test interconnected external system.
- (3) Evacuate system to < 1 mm Hg abs and hold for ~ 5 min; isolate vacuum pump.
- (4) Pressurize system with helium to expected can pressure, i.e., mean of specified range: 175 mm Hg abs. This was done to reduce volumetric error to a negligible value.

(5) Isolate helium source, leaving only the manifold, manometer, and piercing adapter on line.

(6) Operate hydraulic jack, forcing plunger of piercing adapter to penetrate diaphragm of test can.

(7) Retract plunger, manually if necessary, to release pressure in can. Record pressure indicated on manometer.

(8) Close bellows seal valve on cans with welded-type piercing adapter; disconnect from external system; seal open end connection with pipe plug daubed with glyptol.

As shown in Table IV, all can pressures were higher than the "expected" value, but within or only slightly above the prescribed range. The latter values cannot be ascribed to can leaks and entry of atmospheric air, since such inleakage could not produce the consistently small pressure gains in all of the cans. If leaks did exist, certainly some would be larger than others, and cans with larger leaks would register significantly higher pressures. (Note: this observation is attested by the pressure data obtained from subsequent thermal-cycling tests on the eight cans equipped with welded-type piercing adapters.) A more plausible explanation of the consistently small pressure increases is that a small amount of residual outgassing occurred in all cans during storage.

TABLE IV. Measured Pressures in Spare Standard Cans
Removed from Storage at EBR-II Site

Initial external system
pressure for all cans: 175 mm Hg abs

Can No.	Pressure, mm Hg abs	Can No.	Pressure, mm Hg abs
1(a)	232	1B(a)	185
1(a)	223	1B	203
1(a)	182	1B	233
1(a)	230	4	208
1	208	4B	219
1	233	10	206
1	220	10B	204
1	200	12B(a)	202
1B(a)	203	12B(a)	230

(a) Cans with welded-type piercing adapters.

On the basis of the foregoing test results and the random manner in which the spare standard cans were selected for test purposes, it was concluded that: (1) the cans were sound; (2) they were fabricated in strict compliance with specified procedures; and (3) they are representative of all standard cans produced and installed in the neutron shield.

2. Thermal-cycling Tests

These tests were made with the eight specific-purpose cans fabricated at Argonne and with eight spare standard cans that were previously subjected to pressure-integrity tests. The objectives here were to investigate their outgassing and gas-generation characteristics and serviceability under thermal-cyclic conditions anticipated in certain regions of the EBR-II neutron shield.

a. Cycle A

Four spare standard and five specific-purpose cans were thermally cycled in a furnace under conditions approximating those in the upper portion of the radial neutron shield and in the vessel cover.

One full cycle, designated Cycle A, consisted of a 30-day hold at 900°F, followed by ten cycles between 1,000 and 500°F. Heating and cooling of the furnace atmosphere was accomplished at rates of 100°F/hr or less. Nine full cycles were completed during the test period of 10,700 hr.

b. Cycle B

Four spare standard and three specific-purpose cans were thermally cycled in a separate furnace under conditions approximating those anticipated in the midsection of the neutron shield.

One full cycle, designated Cycle B, consisted of a 30-day hold at 800°F, followed by a 2-day hold at 900°F. Again, heating and cooling of the furnace atmosphere was effected at rates of 100°F/hr or less. Eleven full cycles were completed during the test period of ~9,600 hr.

c. Can Identification and Test Procedure

For ease of identification and comparison of results, the cans exposed to the respective thermal cycles are designated as follows:

<u>Cycle A</u>		<u>Cycle B</u>	
St-P-223	Sp-PBD-175	St-P-182	Sp-PB-175
St-B-185	Sp-BD-175	St-B-230	Sp-PD-ATM
St-P-230	Sp-PBD-ATM	St-P-1	Sp-PD-175
St-B-203	Sp-BD-ATM	St-B-1	
Sp-PB-175			

(1) Spare Standard Cans

These cans are denoted by the prefix St, followed by the letters P for plain or B for boronated graphite contained therein. With two exceptions, the numerals at the end of the symbol are the corresponding internal pressures measured earlier. The exceptions are cans St-P-1 and St-B-1; to facilitate greater accuracy in detecting incremental pressure changes, both cans were evacuated to <1 mm Hg abs and then sealed.

The test assembly and sequence for each of the standard cans, other than St-P-1 and St-B-1, was as follows:

- (1) Place can in appropriate furnace.
- (2) Connect bellows seal valve of piercing adapter to one leg of tee in manifold leading to an unbonded, strain-gauge-type, absolute pressure transducer of proper range, helium source, and closed-end manometer comprising the external system.
- (3) Open valve and unclamp rubber tube leading to helium source and manometer.
- (4) Pressurize and helium leak test external system.
- (5) Adjust system pressure to known internal pressure of test can.
- (6) Isolate helium source and manometer.
- (7) Open bellows seal valve on piercing adapter; proceed with thermal cycling; record pressures.

The test procedure for cans St-P-1 and St-B-1 was similar except that the internal pressures were monitored by Alphatron gauges and by closed-end manometers in the external system. Since the composition of the generated gases in the cans was unknown, it was not possible to apply the necessary correction factors to the Alphatron readings. However, periods of pressure peaks could be observed and were measured by means of the manometers.

The external systems for cans St-P-230 and St-B-203 were each provided with a sampling tap to accommodate standard gas-sampling flasks. Gas samples were taken from these cans at frequent intervals during the first six months of testing, and again at termination.* Therefore, these cans showed a relatively greater reduction in pressure as the tests proceeded.

*Spectrochemical analysis of these samples will be included in a separate report on compatibility of the can materials with the reactor environs.

(2) Specific-purpose Cans

These cans are denoted with the prefix Sp. The letters which follow, i.e., P, B, PB, identify the plain, boronated, or part plain-part boronated graphites contained in the cans, respectively. Where appearing, the additional letter D denotes a simulated defective can, i.e., the graphite was not outgassed as prescribed nor was the can partially evacuated in some cases (cans with suffix letters ATM). The other suffix numerals have the same connotation as those employed for the spare standard cans.

The test procedure also was essentially identical, except that the vent tubes were connected to the external system.

d. Results

Figures 11 and 12 show plots of internal pressures prevailing in cans exposed to Cycle A and Cycle B, respectively. These plots are based on "spot" pressure readings taken for each can: (1) at the time of initial peak pressure, which occurred within one week after start of each test; (2) at the end of each 30-day hold; and (3) at the highest point in each intervening thermal cycle. Listed on both graphs are the calculated perfect gas pressures (P_C) corresponding to the hold-period temperatures.

All pressures eventually subsided to, or remained at, a relatively low value as the tests proceeded. Significantly high initial peak pressures decrease at a rapid rate for several days, and then at a progressively decreasing rate until the end of the first 30-day hold period. As shown in Fig. 12, the second 2-day hold at 900°F was interrupted after $1\frac{1}{2}$ days by a furnace malfunction, which caused temporary loss of heating. As a consequence, the temperature decreased to about 300°F before heating was restored. At that time, the furnace temperature was increased to 800°F to initiate the third 30-day hold. This inadvertent thermal cycle caused a secondary peaking of pressure in most cans and, in some cases, higher subsequent pressures.

All transducers registered negative zero shifts at the end of both tests. This implies that all pressure readings, (except for cans St-P-1 and St-B-1) subsequent to the initial cycles were on the high side. Final room-temperature pressures corrected for zero shift are shown at the end of the plots.

Of the six "defective" specific-purpose cans, only one (Sp-PD-ATM) exceeded the design pressure for a relatively short period, and eventually decreased to ~15 psig. As shown in Fig. 12, the overpressure was ~16%, which all cans could sustain without damage. Moreover, this condition apparently could be incurred only by gross neglect of the specified canning procedure.

Fig. 11. Measured Pressures for Spare Standard and Specific-purpose Cans during Exposure in Cycle A Furnace

Fig 12. Measured Pressures for Spare Standard and Specific-purpose Cans during Exposure in Cycle B Furnace

3. Sodium Immersion Tests

a. Objectives, Procedures, and Results

These tests were made on the twelve cylindrical cans of graphite fabricated at Argonne, and on the two spare standard half-cans (Nos. 10 and 10B of Table III) selected from storage at the reactor site. As mentioned earlier, the wall thicknesses of six cylindrical cans were varied (5 to 40 mils $\pm$ 0.1 mil), they were loaded with plain graphite, and the ends were left open. The other six cans were similarly fabricated and loaded with boronated graphite. The bottom of each standard half-can was pierced with a small hole (from the pressure-integrity tests), which permitted access of sodium to the plain or boronated graphite contained therein.

All cans were outgassed and then immersed for ~14,800 hr in an autoclave containing sodium maintained at 800°F. The objectives here were to determine: (1) the diametral changes (lateral growth) in the cans; (2) the axial growths of the contained graphites; (3) the sodium uptake by these graphites; and (4) the equivalent hydrostatic pressure developed by each graphite under varying degrees of restraint (can wall thickness).

Upon completion of the exposure, all cans were removed and cooled preparatory to examination. Dimensional surveys were made of the cylindrical cans and graphites. Diametral changes in the cans and axial growths of the graphites were obtained from comparisons between pre- and post-test dimensions. Sodium uptakes by the graphites were calculated on the basis of their respective weight gains. Equivalent hydrostatic pressures exerted by the graphites also were calculated, using stress-strain-pressure data from independent burst tests of the 40-mil-thick-walled cans. External dimensional surveys were made of the standard half-cans and sodium uptakes by the graphites were calculated from the weight gains. However, the latter values are suspect for reasons discussed later.

Accordingly, Table V summarizes the results of sodium immersion tests on the cylindrical cans. For ease of identification, the cans are

TABLE V Summary of Sodium Immersion Tests with Cylindrical Cans

Can No	Original Dimensions		Final Dimensions		Lateral Growth of Can		Axial Growth of Graphite		Sodium Uptake ^(a) %	EHP ^(b) psi
	Can OD in (avg)	G Length in	Can OD in (avg)	G Length in	in	$\Delta L/L$ %	in	$\Delta L/L$ %		
C40P	1 0783	2 940	1 0799	2 960	0 0016	0 148	0 020	0 680	33 3	2740
C40B	1 0778	2 938	1 0787	(c)	0 0009	0 084	(c)	(c)	29 7	1990
C30P	1 0586	2 930	1 0607	2 955	0 0021	0 198	0 025	0 853	34 4	2300
C30B	1 0584	2 938	1 0598	(c)	0 0014	0 132	(c)	(c)	30 9	2020
C20P	1 0379	2 939	1 0418	2 967	0 0039	0 375	0 028	0 953	35 6	1705
C20B	1 0384	2 938	1 0421	(c)	0 0037	0 356	(c)	(c)	31 0	1710
C15P	1 0283	2 941	1 0330	2 969	0 0047	0 457	0 028	0 952	33 4	1310
C15B	1 0282	2 938	1 0339	(c)	0 0057	0 555	(c)	(c)	30 3	1370
C10P	1 0167	2 937	1 0225	2 965	0 0058	0 570	0 028	0 954	38 6	910
C10B	1 0187	2 932	1 0271	(c)	0 0084	0 825	(c)	(c)	31 7	990
C5P	1 0056	2 939	1 0117	2 969	0 0061	0 606	0 030	1 021	38 3	460
C5B	1 0078	2 935	1 0186	(c)	0 0108	1 071	(c)	(c)	36 0	530

^(a) Percent of original graphite volume

^(b) Equivalent hydrostatic pressure exerted by graphite

^(c) Ends of graphite cracked and spalled unable to measure

denoted with the prefix C, followed by numerals indicating the wall thickness, and the suffix letters P for plain graphite or B for boronated graphite.

b. Supporting Calculations, Tests, and Analyses

(1) Sodium Uptake

Calculations for sodium uptake in the standard half-cans gave 21.4% of final graphite volume for can No. 10 (plain graphite) and 22.0% for can No. 10B (boronated graphite). However, the significance of these relatively small percentages is suspect, since it is theorized that, at some time during the exposure, swelling of the graphite partially blocked the pierced hole in each can, thereby limiting entry of the sodium. This theory is supported by subsequent radiographic examination which revealed the graphites had dilated sufficiently to effect such blockage. Neither can evidenced significant dimensional changes.

With respect to the cylindrical cans, Fig. 14 shows the calculated volume-percent sodium uptake as a function of lateral growth of both graphites and axial growth of the plain graphite. In general, the uptake increased with graphite dilation and decrease in restraint (wall thickness).

(2) Equivalent Hydrostatic Pressure (EHP)

In order to calculate the EHP of the graphites as a function of restraint by the cylindrical can walls during exposure, it was necessary to establish stress-strain-pressure relationships for the can material. It was postulated that final straining of the can wall occurred as the bath temperature approached the freezing point of sodium. Therefore, it was concluded that room-temperature properties established by burst tests on cans C40P and C40B (which had been exposed to sodium but not stressed beyond their elastic limit), would be adequate for calculating the EHP of graphites in all cylindrical cans. This conclusion gives results that are slightly conservative (208°F versus room temperature).

Accordingly, the graphites were removed from these cylindrical cans, and the cans subjected to internal pressures in a hydraulic burst-test apparatus developed for this purpose. Three sets of 3-mil gauges were mounted at 120° intervals around the axis of each can. Each set was mounted with the central gauge at the midplane, and the other two gauges 0.375 in. above and below the midplane. Subsequently the cans were pressurized, in increments, to well above the material yield strength, and the average strains measured at the various pressures. Corresponding stresses were calculated, based on ASME Code, Section VIII, and used to establish stress-strain-pressure relationships representative of the conditions at final straining during the sodium immersion test.

Figure 13 shows the stress-strain plots for the C40P and C40B cans, and the pressure-stress plot for a theoretical can with a 1-mil-thick wall containing plain or boronated graphite. These relationships were used to calculate the EHP as a function of lateral growth of the cans for both graphites, and axial growth of the plain graphite.

Fig. 13. Stress-strain-pressure Relationship for Exposed 40-mil-thick-walled Cans and a Theoretical 1-mil Can-wall Thickness for Plain and Boronated Graphites

Of the resultant plots (see Fig. 14) only Curves A and B have significant implications. In both curves, the greater portion of EHP data fall on a straight line, which represents an inverse function of strain. There is no deviation of data from Curve A, indicating that the limiting EHP was not attained in can C40P. On the other hand, the break in Curve B indicates the limit for can C40B was attained at ~ 2000 psi. A comparison of both curves leads to the conjecture that the limit of can C40P was being approached at ~ 2800 psi.

Fig. 14. Calculated EHP and Sodium Uptake vs Lateral or Axial Growth of Graphites in Cylindrical Cans Exposed for 14,800 hr in Sodium at 800°F

Extrapolation of both curves to zero EHP gives intercept values of 0.75% for the plain graphite and of 1.43% for the boronated graphite. These values would appear to represent the limits of lateral dilation for the respective graphites at which the EHP exerted by each is zero. The direction of dilation represented here is perpendicular to the direction of extrusion of both graphites. A standard EBR-II shield can (of 4-in.-square cross section) is assembled with a minimum total lateral clearance of $3/32$ in. between the graphite and the can. Therefore, the calculated data indicate that, should a leak develop, the can would accommodate maximum lateral dilation of either plain or boronated graphite contained therein.

(3) Compressive Strength Tests

Table VI lists the ultimate dry compressive strengths of cylindrical specimens of plain and boronated graphites used in the EBR-II neutron shield. All specimens were machined perpendicular to the direction of graphite extrusion to give values comparable to the radial EHP exerted by corresponding graphites in the cylindrical cans immersed in sodium at 800°F. Wherever possible, two specimens each were machined crosswise (NS) and at right angles (EW) from each graphite bar. One set of four specimens was taken from each lot of plain graphite as identified in Table I. A similar set of four specimens was machined from an unidentified bar of plain graphite. This set is designated Lot No. RT in Table VI. Two sets of four specimens were machined from randomly selected bars of boronated graphite. Finally, two specimens (BT-1EW and BT-2EW) were machined from a remnant of boronated graphite which had been used to prepare sodium-immersion test samples. All specimens were evaluated in an Instron Universal Tensile Test Machine adapted for compression tests.

A comparison of values in Tables V and VI shows that the highest calculated (and probably close to the highest attainable) EHP for the sodium-immersed plain graphites (C40P) is 76% of the minimum, 48% of the maximum, and 57% of the average ultimate compressive strength (UCS) of the unexposed graphites.

For the boronated graphites, the highest calculated (and apparently the highest attainable) EHP for the exposed samples (C30B) is 59% of the minimum, 51% of the maximum, and 53% of the average UCS of random samples of unexposed graphites. Finally, this EHP is 63% of the minimum, and 55% of the maximum UCS of unexposed boronated graphite from which the immersion samples were cut.

TABLE VI. Summary of Ultimate Compressive Strength (UCS) Tests
on Unexposed Plain and Boronated Graphites

Lot No.	Specimen No.	Diameter, in.	Area, in. ²	Max Load, lb	UCS, psi	
					At Failure	Avg/Group
Plain Graphite						
RT	1EW	0.627	0.3088	1,520	4,922	4,790
RT	2EW	0.627	0.3088	1,460	4,728	
RT	1NS	0.625	0.3068	1,360	4,433	
RT	2NS	0.626	0.3078	1,455	4,727	
T16A	1EW	0.627	0.3088	1,400	4,534	
T16B	2EW	0.627	0.3088	1,720	5,570	
T16A	1NS	0.627	0.3088	1,320	4,275	
T16B	2NS	0.626	0.3078	1,775	5,767(a)	
T12	1EW	0.627	0.3088	1,650	5,343	
T12A	2EW	0.625	0.3068	1,570	5,117	
T12	1NS	0.625	0.3068	1,350	4,400	
T12A	2NS	0.627	0.3088	1,500	4,858	
T11	1EW	0.627	0.3088	1,680	5,400	
T11A	2EW	0.625	0.3068	1,500	4,889	
T11	1NS	0.626	0.3078	1,560	5,068	
T11A	2NS	0.627	0.3088	1,490	4,825	
T09	1EW	0.619	0.3009	1,490	4,952	
T09	1EW	0.627	0.3088	1,585	5,133	
T09	2EW	0.627	0.3088	1,640	5,310	
T09	2NS	0.627	0.3088	1,400	4,534	
T07	1EW	0.627	0.3088	1,525	4,938	
T07A	2EW	0.627	0.3088	1,590	5,149	
T07	1NS	0.627	0.3088	1,300	4,210	
T07A	2NS	0.627	0.3088	1,585	5,133	
3	1EW	0.626	0.3078	1,115	3,622(b)	3,799
3	2EW	0.626	0.3078	1,190	3,866	
3	1NS	0.626	0.3078	1,230	3,996	
3	2NS	0.626	0.3078	1,345	4,370	
Boronated Graphite						
BRA	1EW	0.627	0.3088	1,060	3,433(c)	3,799
BRA	2EW	0.627	0.3088	1,125	3,643	
BRA	1NS	0.627	0.3088	1,215	3,935	
BRA	2NS	0.627	0.3088	1,180	3,821	
BRI	1EW	0.626	0.3078	1,230	3,996(d)	
BRI	2EW	0.627	0.3088	1,170	3,789	
BRI	1NS	0.627	0.3088	1,190	3,854	
BRI	2NS	0.627	0.3088	1,210	3,918	
BT	1EW	0.627	0.3088	1,140	3,692(e)	3,446
BT	2EW	0.626	0.3078	985	3,200(f)	

(a)Maximum and (b)minimum ultimate strength for plain graphite.

(c)Minimum and (d)maximum ultimate strength for random samples of boronated graphite.

(e)Maximum and (f)minimum ultimate strength for boronated graphite from which immersion test samples were cut.

IV. CONCLUSIONS

The pre- and post-fabrication tests have satisfactorily demonstrated:

- (1) integrity and ability of EBR-II neutron shield cans and graphite to withstand the operating conditions for which they were designed;
- (2) statistically good adherence by the vendor to prescribed out-gassing and canning procedures;
- (3) that cans fabricated with inadvertent omissions or deviations from these procedures, or cans which may have or develop leaks in service, will not fail with consequent jeopardy to reactor safety or deleterious effects on reactor operation.

Effects of nuclear radiation on can performance have not been included in these tests. However, the EBR-II neutron shield is in a region of relatively low neutron flux; therefore it is theorized that radiation effects, especially at the elevated operating temperatures, would be small. Whether this theory holds is subject to the results of an on-going surveillance program involving exposure of sample cans in special EBR-II irradiation test subassemblies.

ACKNOWLEDGMENTS

The author gratefully acknowledges Dr. H. O. Monson for his consultation and guidance in establishing test criteria, and the technical support rendered by many members of Reactor Engineering Division throughout the test program: in particular, D. L. Vetter, for supervision and installation of equipment, instrumentation and specimen systems, calibrations, etc., M. R. Gilbert, for supervision of autoclave design and sodium-immersion tests; W. F. Clemmons and R. A. Esposito, for operation of the respective autoclaves during these tests; E. F. Groh, for contributing to the design of the piercing adapter; J. S. Harmon for general assistance and performance of can-piercing procedures; N. B. Smith, for observations and recording of data during the pressure-integrity and thermal-cycling tests; D. Raridon, Jr., for installation, adjustment, and operation of the burst-test apparatus, and conducting the density tests; and H. J. Haupt, for conducting the compression tests.