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LMFBR SHIELDING DESIGN EXPERIMENTS AND METHODS EVALUATION

SECOND QUARTERLY PROGRESS REPORT
APRIL-JUNE 1972

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LMFBR SHIELDING DESIGN EXPERIMENTS AND METHODS EVALUATION

Second Quarterly Progress Report
April - June 1972

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Approved: *D. R. Wilkins*
D. R. Wilkins
Program Manager

Approved: *M. L. Weiss*

M. L. Weiss
Technical Project Engineer

U. S. Atomic Energy Commission
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SUNNYVALE, CALIFORNIA 94086

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ABSTRACT

This report is the second in a series of quarterly progress reports published under the LMFBR shielding development program (PA-62). Both experimental and analytical work on axial and radial shields is being conducted, with the experimental part being performed at the ORNL Tower Shielding Facility. Activities and technical progress for the period April through June 1972 are reported. The major topics include program definition and scheduling, test assembly design and fabrication, analytical studies, and quality assurance.

1. INTRODUCTION

The LMFBR shielding program is based on design requirements for reduced uncertainties in critical parameters of the plant shielding design. In the current P.A. 62 program, shielding experiments and their analyses are being conducted to reduce calculational uncertainties for the following neutron shields (Figure 1-1):

- Reactor closure lower neutron shield (This is the principal bulk shield for reducing the neutron flux level above the reactor closure head.)
- Radial neutron shield (This shield limits neutron fluences at the lateral core support and at the reactor vessel.)

An important calculational uncertainty for these two neutron shields arises from their actual heterogeneous form as opposed to their approximated homogeneous form in calculations. Configurations simulating the actual shields have been designed and fabricated for testing at the ORNL Tower Shielding Reactor to provide accurate data on neutron transmission through heterogeneous near-core neutron shields. These measurements will also provide neutron flux inputs to calculations and/or experiments for regions farther from the core.

Figure 1-1. Near-Core Upper Axial and Radial Neutron Shields

2. SUMMARY

Fabrication and assembly of all shielding configurations to be tested under this program were completed. All hardware was shipped to ORNL. Fabrication procedures were monitored by quality assurance personnel; accuracies and material compositions were verified. The pre-measurement analytical studies were completed. A final determination of neutron spectrum modifier/diffuser materials and thicknesses was made. The primary axial and radial shielding configurations were analyzed by 1-D diffusion theory to give a preliminary estimate of attenuation factors for the total neutron flux. Final implementation of the Monte Carlo code MORSE was achieved, including program checkout with a problem simulating a typical TSR-II collimated beam source/modifier/Bonner ball detector geometry.

The TSF experimental program for the P.A. 62 axial and radial shield tests was updated and finalized in consultation with personnel from ORNL's Neutron Physics Division.

3. TECHNICAL ACCOMPLISHMENTS

3.1 PROGRAM DEFINITION AND SCHEDULING

3.1.1 Objectives

The major objectives of the current P.A. 62 program are to reduce calculational uncertainties for (a) the reactor closure lower neutron shield and (b) the radial neutron shield (Figure 1-1). Important calculational uncertainties for these two shields arise from their actual heterogeneous form as compared with their assumed homogeneous form in calculations. The planned measurements will provide accurate data on neutron transmission through heterogeneous near-core neutron shields. Results of the measurements will be compared with the calculated results as a means of assessing accuracy of the calculational methods. These measurements also provide neutron flux inputs to calculations and/or experiments for regions farther from the core.

3.1.2 Experimental Hardware

The axial experiment, composed of solid Type-304 stainless steel rods immersed in sodium, simulates the reactor closure lower neutron shield. Neutron streaming through the sodium interstitial spaces requires measurement. Figure 3-1 illustrates the geometry of this experiment. The solid Type-304 stainless steel rods are 5-1/4 inches in diameter and 2 feet in length.

The radial experiment, consisting of rows of B_4C -filled tubes and their homogeneous slab equivalents, simulates the radial neutron shield surrounding the radial blanket. The heterogeneous streaming effect—which is the fraction of neutrons that leak, or stream, through minimum B_4C thicknesses in shields consisting of one or more rows of B_4C -filled tubes—requires measurement. Figures 3-2, 3-3, and 3-4 illustrate the geometries for this set of measurements. For the 1-inch and 2-inch tubes, the number of rows will be varied from one to four; for the 5-1/4-inch tubes, measurements will be made for a maximum of three rows. Additionally, neutron attenuation measurements through homogeneous slab equivalents of the 1-inch and 5-1/4-inch-diameter tube experiments will be made. The latter measurements provide a means of evaluating calculational errors due to methods, cross sections, geometric modeling, etc., as opposed to differences in measured-versus-calculated results due to the heterogeneous streaming effect.

3.1.3 Measurements

All measurements will be carried out using the Tower Shielding Reactor at ORNL as a neutron source. Since the last quarterly report, the proposed list of measurements¹ was reviewed with ORNL personnel and some modifications were made. These changes were made in order to accommodate experimental set-up procedures, background measurements, and available counting rates (TSR power), and also to give wider application to LMFBR Plant shield designs. Table 3-1 gives the revised list of measurements. It should be emphasized that this program plan is intended to detail the scope of the experimental measurements but that it does not necessarily indicate the exact order in which the experiments will be conducted. The order will be determined at ORNL during planning of detailed operation at the TSF. It is estimated that this program will require approximately 74 working days, with an additional 14 days allowed for set-up time, instrumentation breakdown, and repeats. Table 3-1A shows the estimated time for completing the measurements in each of the major categories listed in Table 3-1 and for the integral program.

3.1.4 Schedule

Table 3-2 illustrates the significant milestones of the P.A. 62 schedule. All hardware for the axial experiments was received at ORNL by April 15, 1972. Sodium filling of the axial shield rod array was completed at ORNL on June 2, 1972. Neutron measurements for the axial modifier began on June 21. The remainder of the experimental hardware for the current program was shipped to ORNL during June, 1972. Delivery to ORNL of all hardware was sufficiently timely to ensure full utilization of the Tower Shielding Facility (TSF).

Figure 3-1. Axial 5-1/4-inch-o.d. Solid Type-304 Stainless Steel Rods

**HOMOGENEOUS EQUIVALENT OF
5-1/4 in.-O.D. B₄C-FILLED TUBES**

Figure 3-2. Radial Shielding Experiment: 5-1/4-inch-o.d. B₄C-Filled Tubes and Slab Equivalents

Figure 3-3. Radial Shielding Experiment: 2-inch-o.d. B_4C -Filled Tubes

1-in.-O.D. B_4C -FILLED TUBES

**HOMOGENEOUS SLAB EQUIVALENTS OF
1 in.-O.D. B_4C -FILLED TUBES**

Figure 3-4. Radial Shielding Experiment: 1-inch-o.d. B_4C -Filled Tubes and Slab Equivalents

Table 3-1
EXPERIMENTAL PROGRAM FOR GENERAL ELECTRIC
AXIAL AND RADIAL SHIELD MEASUREMENTS AT TSF

Configuration Number And Description	Neutron Measurements ^(a)					
	NE-213	H ₂ Counter	Axial Traverse ^(b)		Radial Traverse ^(c)	
			All 9 Balls	3, 6, and 10 in.	All 9 Balls	3, 6, and 10 in.
I. Axial Shield						
A. Partial Modifier (18 in. SS only)	☑, Close ^(d)	☑, 12 in.	—	☑, 12 to 144 in.	—	—
B. Full Modifier (18 in. SS + 48 in. Na + 1/8 in. Boral)	☑, Close ^(d)	☑, 12 in.	☑, 12 to 144 in.	—	—	12 in.; 0 to 36 in. on each side of ☑. 144 in.; 0 to 144 in. on one side of ☑
C. Full Modifier + 24 in. Axial Shield (5-1/4 in. OD SS rods)	—	☑, 12 in.	—	☑, 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ☑. 144 in.; 0 to 144 in. on one side of ☑
D. Full Modifier + Axial Shield + 30 in. Na	—	—	—	☑, 12 to 144 in.	—	—
II. Radial Spectrum Modifier ^(f)						
A. Radial Modifier ^(e)	☑, Close ^(d) 45°, Close	☑, 12 in.	—	☑, 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ☑. 144 in.; 0 to 144 in. on one side of ☑
III. Axial Shield With Radial Spectrum Modifier						
A. Axial Shield with Radial Spectrum Modifier	☑, Close ^(d)	☑, 12 in.	—	☑, 12 in.	—	—

Table 3-1 Continued

Configuration Number And Description	Neutron Measurements ^(a)					
	NE-213	H ₂ Counter	Axial Traversa ^(b)		Radial Traversa ^(c)	
			All 9 Balls	3, 6, and 10 in.	All 9 Balls	3, 6, and 10 in.
IV. Radial Blanket Measurements for Westinghouse						
A. Radial Modifier + 5 in. Radial Blanket ^(e)	ϕ , Close ^(d) 45°, Close	ϕ , 12 in.	—	ϕ , 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ϕ . 144 in.; 0 to 144 in. on one side of ϕ
B. Radial Modifier + 10 in. Radial Blanket ^(e)	ϕ , Close ^(d) 45°, Close	ϕ , 12 in. 45°, 144 in.	—	ϕ , 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ϕ . 144 in.; 0 to 144 in. on one side of ϕ
C. Radial Modifier + 10 in. Radial Blanket + 5 in. Reflector ^(e)	ϕ , Close ^(d) 45°, Close	ϕ , 12 in.	—	ϕ , 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ϕ . 144 in.; 0 to 144 in. on one side of ϕ
V. Radial Shield—Stainless Steel versus B ₄ C Slabs						
A. IV.C. Modifier + 10 in. B ₄ C Slabs	ϕ , Close ^(d)	ϕ , 12 in.	—	ϕ , 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ϕ . 144 in.; 0 to 144 in. on one side of ϕ
B. IV.C. Modifier + 10 in. B ₄ C Slabs + Axial Shield	—	—	—	ϕ , 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ϕ . 144 in.; 0 to 60 in. on one side of ϕ
C. IV.C. Modifier + 10 in. SS + Axial Shield	—	—	—	ϕ , 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ϕ . 144 in.; 0 to 60 in. on one side of ϕ

Table 3-1 Continued

Configuration Number And Description		Neutron Measurements ^(a)					
		NE-213	H ₂ Counter	Bonner Balls			
				Axial Traverse ^(b)		Radial Traverse ^(c)	
				All 9 Balls	3, 6, and 10 in.	All 9 Balls	3, 6, and 10 in.
D. IV.C. Modifier + 10 in. SS		☒, Close ^(d)	☒, 12 in.	—	☒, 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ☒. 144 in.; 0 to 144 in. on one side of ☒
VI. Radial Shield Measurements for Westinghouse							
h {	A. IV.C. + 5 in. Inconel + 12 in. Na						
	B. VI.A. + 5 in. SS						
	C. Radial Modifier + 10 in. Radial Blanket + 2-1/2 in. Inconel						
	D. Radial Modifier + 10 in. Radial Blanket + 5 in. Inconel						
	E. IV.C. + 5 in. Inconel + 5 in. Stainless Steel						
VII. Radial Shield—B ₄ C Rods and Slabs							
A. Radial Modifier + 5-1/4 in. OD B ₄ C Rods							
a. 1 and 3 rows		☒, Close ^(d)	☒, 12 in.	—	☒, 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ☒. 144 in.; 0 to 144 in. on one side of ☒
b. 2 rows		—	—	—	☒, 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ☒. 144 in.; 0 to 144 in. on one side of ☒
B. Radial Modifier + 2 in. OD B ₄ C Rods							
a. 1 and 4 rows		☒, Close ^(d)	☒, 12 in.	—	☒, 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ☒. 144 in.; 0 to 144 in. on one side of ☒

Table 3-1 Continued

Configuration Number And Description	Neutron Measurements ^(a)					
			Axial Traverse ^(b)		Radial Traverse ^(c)	
	NE-213	H ₂ Counter	All 9 Balls	3, 6, and 10 in.	All 9 Balls	3, 6, and 10 in.
b. 2 and 3 rows	—	—	—	☐, 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ☐. 144 in.; 0 to 144 in. on one side of ☐.
C. Radial Modifier + 1 in. OD B ₄ C Rods						
a. 1 and 4 rows	—	—	—	☐, 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ☐. 144 in.; 0 to 144 in. on one side of ☐.
D. Radial Modifier + 0.6 in. and 3.8 in. B ₄ C Slabs						
a. 1 and 3 0.6 in. slabs; 1, 2, and 3 3.8 in. slabs	☐, Close ^(d)	☐, 12 in.	—	☐, 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ☐. 144 in.; 0 to 144 in. on one side of ☐.
E. Radial Modifier + 5-1/4 in. OD B ₄ C Rods (3 rows)						
a. 6 in. SS reflector ~4 in. behind B ₄ C	} Traverse with 3 in. Bonner ball adjacent to back of B ₄ C rods to locate peaks and valleys that may exist.					
b. Axial shield ~4 in. behind B ₄ C						

a. Measurements unless otherwise specified will be in the horizontal plane.

b. Axially out beam centerline from back of configuration.

c. Radially from beam centerline.

d. As close to the back of the sample as the upper limit of the gamma ray sensitivity of the scintillator will permit.

e. Gamma ray spectral measurements will be made (as part of the Westinghouse LMFBR shielding program) at one angle between 45° to 60° from centerline at a distance from the back of the slab to be determined by background considerations.

f. This radial spectrum modifier was specified by Westinghouse for use with their radial shield measurements of neutron and gamma fluxes. Its use is specified in the GE program (III V, and VII) since it also provides a satisfactory spectrum for the GE experiments and reduces overall TSF experimental time and costs.

g. IV is a part of the AEC-funded Westinghouse LMFBR shielding base program. A description of the measurements is included here since the radial modifier + 10 in. radial blanket + 5 in. SS reflector will be used as a spectrum modifier for Part V of the GE program.

h. VI is also a part of the AEC-funded Westinghouse LMFBR shielding base program. A description of the configurations to be measured is included for general information and schedule interaction.

Table 3-1A
ESTIMATED TIME FOR COMPLETING MEASUREMENTS IN
EACH OF THE MAJOR CATEGORIES LISTED IN TABLE 3-1

Measurement Category	Measurement Time	+	Contingency	+	Weekends/Holidays	=	Total Elapsed Time
I	19 days		4 days		9 days		32 days
II	8 days		2 days		4 days		14 days
III	5 days		1 day		3 days		9 days
IV	27 days		5 days		13 days		45 days
V	18 days		4 days		10 days		32 days
VI	35 days		7 days		18 days		60 days
VII	<u>32 days</u>		<u>5 days</u>		<u>14 days</u>		<u>51 days</u>
Total	144 days		28 days		71 days		243 days or 8 months

**Table 3-2
SIGNIFICANT MILESTONES**

FY-72					FY-73																
O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	
1	2		3			4			5					6	7			8	9	10	11

MILESTONES:

1. COMPLETE PRELIMINARY DESIGN AND COST ESTIMATE FOR SHIELDING CONFIGURATIONS TO BE TESTED. OBTAIN AGREEMENT WITH AEC-RDT AND ORNL ON DESIGN DETAILS, PROGRAM SCOPE AND SCHEDULE.
2. ORDER ALL LONG DELIVERY MATERIALS. INITIATE DETAILED ENGINEERING DESIGN AND PRE-MEASUREMENT ANALYTICAL PROGRAM.
3. INITIATE FABRICATION FOLLOWING RDT APPROVAL OF SYSTEM DESIGN DESCRIPTION.
4. ASSEMBLE HARDWARE FOR AXIAL EXPERIMENT AT ORNL (INCLUDES SODIUM FILLING).
5. INITIATE MEASUREMENTS (ORNL).
6. DELIVER ALL OTHER EXPERIMENTAL HARDWARE TO ORNL. COMPLETE PRE-MEASUREMENT ANALYSIS.
7. COMPLETE MEASUREMENTS (ORNL).
8. PROVIDE FINAL MEASURED DATA (ORNL).
9. COMPLETE POST-MEASUREMENT ANALYSIS.
10. COMPLETE DRAFT OF FINAL REPORT.
11. ISSUE FINAL REPORT.

3.2 TEST ASSEMBLY FABRICATION

The fabrication of all shielding configurations to be tested under this program was completed. Figures 3-5, 3-6, 3-7, and 3-8 are reduced-size drawings for the four major assemblies fabricated.

3.2.1 Fabrication Activities

The following fabrication activities were accomplished during the April-June 1972 quarter:

- a. Axial Shielding Test Assembly (Figure 3-5)

Sodium filling of this assembly was completed by ORNL personnel on May 23, 1972. The space between the sodium surface and the container top was filled with SS sheets. This change precludes the possibility of sodium "slumping" into this space during the period that the sample is in the vertical test orientation. Refer to photographs (Figures 3-9 and 3-10).

This assembly was ready for testing at ORNL on June 1, 1972.

- b. Radial Shielding Tubular Test Assemblies (Figure 3-6), Homogeneous Slab Test Assemblies (Figure 3-7), and Their Shipping Containers (Figure 3-8)

All assemblies fabricated. Shipment left San Jose on June 28, 1972, and arrived ORNL on June 30, 1972.

Refer to photographs (Figures 3-11, 3-12 and 3-13).

3.2.2 Compilation of Material Compositions and Densities

During the process of procuring materials, care was taken to accumulate accurate data on chemical compositions of shield assembly components and to supplement these data with additional chemical and/or spectrographic analysis where warranted. This information is, of course, essential input for the preparation of macroscopic cross sections for shielding calculations.

Table 3-3 summarizes the available data for stainless steel components, and Table 3-4 gives the data for aluminum components. It should be noted that blanks in the tables do not necessarily indicate the absence of a particular element in the material sample, but simply indicate that the best available information did not include the element in question. However, a study of the table reveals that these deficiencies are of minor significance, since the most important components have been chemically analyzed in detail.

Although the sodium used in filling the inter-rod spaces in the axial shield assembly has not been chemically analyzed to date, a sample has been retained for possible analysis at a later time. The filling process initially required 223 pounds of hot sodium plus another 29 pounds subsequently added to compensate for shrinkage during cooling, making a total of 252 pounds. The calculations reported in subsection 3.3.2 used a cold sodium density of 0.945 gm/cm^3 which is the value quoted by ORNL for the sodium used in the axial and radial spectrum modifier slabs.

Tables 3-5 to 3-8 summarize the results of chemical analysis done on samples of the three different mesh sizes of B_4C particles used to achieve a maximum density mixture by vibratory compaction. The mixture proportions used were 45, 35, and 20 weight percent respectively for 60/80, 14/20, and 200/finer mesh size particles. The theoretical or "solid" density of this mixture was calculated to be 2.463 gm/cm^3 . A chemical analysis was done at GE to verify the boron content of the B_4C . Table 3-9 shows the results of this verification.

3-12

Figure 3-6. Radial Shielding Tubular Test Assembly

Figure 3-8. Shipping Containers for Radial Tubular and Homogeneous Slab Test Assemblies

Figure 3-9. Assembly of Axial Shield Blocks and Preparation for Sodium Filling ORNL No. 79574

Figure 3-10. Sodium Filling of Axial Shield Block, ORNL No. 79659

Figure 3-11. Completed 1-inch Diameter B_4C Filled Tube and 1-inch Thick B_2C Filled Slab Radial Shield Assemblies, GE No. A72611

Figure 3-12. Completed 2-inch Diameter B_4C Filled Tube Radial Shield Assemblies, GE No. A 72612

Figure 3-13. Completed 5-1/4-inch Diameter B₄C Filled Tube and 5-1/4-inch Thick B₄C Filled Slab Radial Shield Assemblies, GE No. A 72610

Table 3-3
STAINLESS STEEL COMPOSITIONS (WEIGHT %)

Element	C	O	Al	Si	P	S	Ti	Va	Cr	Mn	Fe	Co	Ni	Cu	Nb	Mo	Ta	Determined by	Density
Atomic Weight	12.01115	15.9994	26.9815	28.086	30.9738	32.064	47.90	50.942	51.996	54.938	55.847	58.9332	58.71	63.546	92.906	95.94	180.948	by	(gm/cc)
Structural Component:																			
Axial Modifier 2-inch slabs Type-304 SS	0.024-0.085	0.013-0.021	---	0.33-0.65	---	---	---	---	18.72-19.10	1.04-1.65	Rem	---	9.60-9.85	---	---	---	---	(1)	7.88
Axial Modifier 1-inch slabs Type-304 SS	0.024-0.085	0.013-0.021	---	0.33-0.65	---	---	---	---	18.50	1.04-1.65	Rem	---	8.86	---	---	---	---	(1)	7.88
Axial Modifier 1-inch slabs Type-321 SS	0.024-0.085	0.013-0.021	---	0.33-0.65	---	---	0.4	---	18.50	1.04-1.65	Rem	---	8.86	---	---	---	---	(1)	7.88
Axial Rods Type-304 SS	0.054	---	---	0.720	0.032	0.025	---	---	18.62	0.65	72	0.075	8.56	0.27	<0.005	0.26	<0.002	(2)	---
	0.047	---	---	0.630	0.028	0.022	---	---	18.31	0.90	72	0.10	8.64	0.26	---	0.30	---	(3)	---
Axial Plates 1/16-inch thick Type-304 SS	0.017	---	<0.05	0.79-0.80	---	---	<0.01	0.02	18.0-18.2	1.57-1.59	Rem	---	9.16-9.25	0.20	<0.05	0.23	---	(1)	---
Axial Container Cover 0.5-inch thick Type-304 SS	0.07	---	---	0.83	0.026	0.011	---	---	18.14	1.60	Rem	---	8.83	---	---	---	---	(4)	---
Axial Container Cover 1.0-inch thick Type-304 SS	0.068	---	---	0.31	0.020	0.012	---	---	18.45	1.45	Rem	---	8.80	0.72	---	0.38	---	(5)	---
Radial Tube Assemblies:																			
Radial 1-inch end plug Type-304 SS	---	---	---	---	---	---	---	---	18.13	0.86	>72.1	---	8.14	---	---	0.17	---	(2)	---
Radial 2-inch end plug Type-304 SS	---	---	---	---	---	---	---	---	18.93	0.74	>70.5	---	8.78	---	---	0.23	---	(2)	---
Radial 1/16-inch half rounds Type-304 SS	---	---	---	0.48	---	---	---	---	18.80	0.69	Rem	---	8.56	---	---	0.006	---	(2)	---
Radial 3/32-inch half rounds Type-304 SS	---	---	---	0.52	---	---	---	---	19.13	0.68	Rem	---	8.75	---	---	0.19	---	(2)	---
Radial 1/8-inch half rounds Type-304 SS	---	---	---	0.55	---	---	---	---	18.86	0.67	Rem	---	8.89	---	---	0.09	---	(2)	---
Radial 1-inch Tubes Type-304 SS	0.06	---	---	0.70	0.024	0.011	---	---	18.32	0.81	Rem	---	8.89	---	---	---	---	(6)	---
	0.04	---	---	0.30	0.027	0.018	---	---	18.26	1.30	Rem	---	9.96	---	---	---	---	(6)	---
	0.05	---	---	0.55	0.022	0.018	---	---	18.95	0.79	Rem	---	9.51	---	---	---	---	(6)	---
	0.06	---	---	0.69	0.020	0.014	---	---	18.15	0.87	Rem	---	8.63	---	---	---	---	(6)	---
Radial 2-inch Tubes Type-304 SS	0.07	---	---	0.62	0.023	0.007	---	---	18.10	1.59	Rem	---	8.40	---	---	---	---	(7)	---
Radial 5-1/4-inch Tubes Type-304 SS	0.07	---	---	0.41	0.035	0.017	---	---	18.27	1.64	Rem	---	8.57	0.29	---	0.37	---	(8)	---
Radial Slab Assemblies:																			
0.109-inch Face Plate Type-304 SS	0.058	---	---	0.600	0.029	0.007	---	---	18.25	1.70	Rem	0.100	8.66	0.140	---	0.110	---	(4)	---
0.187-inch Face Plate 72 in. X 271 in. Type-304 SS	0.056	---	---	0.43	0.018	0.012	---	---	18.3	1.61	Rem	---	8.3	---	---	---	---	(4)	---
0.187-inch Face Plate 72 in. X 281 in. Type-304 SS	0.056	---	---	0.41	0.019	0.013	---	---	18.2	1.54	Rem	---	8.2	---	---	---	---	(4)	---

- 1. Oak Ridge National Laboratory
- 2. General Electric
- 3. ARMCO Steel Corp.
- 4. Reliance Steel & Aluminum Co.
- 5. Jessop Steel of California
- 6. Carpenter Technology Corp.
- 7. Union Steel Corp.
- 8. Western Pneumatic Tube Co.

Table 3-4
ALUMINUM COMPOSITIONS (WEIGHT %)

Element	Mg		Al		Si		Ti		Cr		Mn		Fe		Cu		Zn		Others		Others		Determined by
Atomic Weight	24.305		26.9815		28.086		47.90		51.996		54.938		55.847		63.546		65.37		Each	Total	Total		
Structural Component	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
Radial (Tube Assemblies)																							
Triflutes 6063-T5	0.45	0.90	Rem		0.20	0.60	0.10		0.10		0.10		0.35		0.10		0.10		0.05		0.15		(1)
Radial (Slab Assemblies)																							
0.05-in. Thick Sheet 6061-T6	0.8	1.2	Rem		0.40	0.80	0.15		0.15	0.35	0.15		0.7		0.15	0.40	0.25		0.05		0.15		(2)
0.08-in. Thick Sheet 6061-T6	0.8	1.2	Rem		0.40	0.80	0.15		0.15	0.35	0.15		0.7		0.15	0.40	0.25		0.05		0.15		(2)
0.375-in. Thick Sheet 6061-T6	0.8	1.2	Rem		0.40	0.80	0.15		0.15	0.35	0.15		0.7		0.15	0.40	0.25		0.05		0.15		(3)

(1) Royal Aluminum
(2) Olin Aluminum and Brass
(3) Kaiser Aluminum

Table 3-5
PROCESS DESCRIPTION AND CONTROL FOR BORON CARBIDE GRAIN

- 1) Boron carbide was produced in an arc furnace in ingot form. The crude ingot was crushed through primary crushers to a size approximately 3/8 inch and finer.
The crushed material was sampled at this point and analyzed for total boron, total carbon and B_2O_3 .
- 2) The analysis of the material was submitted to the quality control engineer. If the final expected analysis of the material met the specifications of the order the material was released for further processing.
- 3) The release material was crushed and screened to meet the size requirements of the G. E. specifications.
- 4) The material was acid and water washed to remove tramp iron picked up in crushing.
- 5) The material was screened on appropriate screens to meet the size requirement of the G. E. specifications.
- 6) The material was sampled and analyzed as per G. E. requirements.

Analysis performed on boron carbide samples.

Total Boron
 Total Carbon
 B_2O_3
 Iron
 Titanium
 Cobalt
 Copper
 Manganese
 Sodium
 Chlorine and Fluorine
 Loss on Drying
 Particle size distribution (2 samples per lot of powder)
 Isotopic Composition
 Particle Density

Table 3-6
ANALYTICAL DATA ^(a)
For 14/20 Mesh Size

Data in weight percent unless otherwise indicated.

	Sample Number			Average
	1	2	3	
Boron	76.20	76.19	76.39	76.26
Carbon	22.35	22.41	22.40	22.39
Boron Anhydride	0.01	0.01	0.03	0.02
Iron	0.34	0.35	0.36	0.35
Titanium	< 0.01	< 0.01	< 0.01	< 0.01
Chloride (ppm)	42	42	58	47
Fluoride (ppm)	Not detected			
Cobalt (ppm)	< 50	< 50	< 50	< 50
Copper (ppm)	< 100	< 100	< 100	< 100
Manganese (ppm)	< 100	< 100	< 100	< 100
Sodium (ppm)	< 100	< 100	< 100	< 100
Loss on drying ^(b) (ppm)	20	20	20	20
Density (gms/cc)	2.44	2.44	2.45	2.44

The isotopic composition is that which is normally found in boron—
18.3 ± 0.3 weight percent of B10.

U.S. Standard Sieve Series ^(c)

Mesh	%
+14	1.0
-14 + 20	54.5
-20 + 30	40.0
-30	4.5

^(a) Chemical analysis performed by: The Carborundum Company, Electro Minerals Division, Niagara Falls, New York.

^(b) Dried at 200°C for one hour.

^(c) Particles of mesh size 20 to 14 have diameters in the range 8.4×10^{-2} to 1.2×10^{-1} cm.

Table 3-7
ANALYTICAL DATA^(a)
For 60/80 Mesh Size

Data in weight percent unless otherwise indicated

	Sample Number			Average
	1	2	3	
Boron	77.20	77.23	77.38	77.27
Carbon	21.47	21.41	21.59	21.49
Boron Anhydride	0.02	0.05	0.04	0.04
Iron	0.32	0.34	0.36	0.34
Titanium	< 0.01	< 0.01	< 0.01	< 0.01
Chloride (ppm)	86	84	99	90
Fluoride (ppm)	Not detected			
Cobalt (ppm)	< 50	< 50	< 50	< 50
Copper (ppm)	< 100	< 100	< 100	< 100
Manganese (ppm)	< 100	< 100	< 100	< 100
Sodium (ppm)	< 100	< 100	< 100	< 100
Loss on drying ^(b) (ppm)	30	30	60	40
Density (gms/cc)	2.47	2.47	2.48	2.47

The isotopic composition is that which is normally found in boron— 18.3 ± 0.3 weight percent of B10.

U.S. Standard Sieve Series^(c)

Mesh	%
+60	6.0
-60 + 80	49.0
-80 + 100	31.0
-100	14.0

^(a) Chemical analysis performed by: The Carborundum Company, Electro Minerals Division, Niagara Falls, New York.

^(b) Dried at 200°C for one hour.

^(c) Particles of mesh size 80 to 60 have diameters in the range 1.75×10^{-2} to 2.50×10^{-2} cm.

Table 3-8
ANALYTICAL DATA^(a)
For 200/Finer Mesh Size

Data in weight percent unless otherwise indicated

	Sample Number			Average
	1	2	3	
Boron	78.13	78.16	78.03	78.11
Carbon	20.39	20.39	20.35	20.38
Boron Anhydride	0.04	0.04	0.04	0.04
Iron	0.30	0.31	0.30	0.30
Titanium	< 0.01	< 0.01	< 0.01	< 0.01
Chloride (ppm)	< 100	< 100	< 100	< 100
Fluoride (ppm)	Not detected			
Cobalt (ppm)	< 50	< 50	< 50	< 50
Copper (ppm)	< 100	< 100	< 100	< 100
Manganese (ppm)	< 100	< 100	< 100	< 100
Sodium (ppm)	< 100	< 100	< 100	< 100
Loss on drying ^(b) (ppm)	< 100	< 100	< 100	< 100
Density (gms/cc)	2.473	2.483	2.464	2.473

The isotopic composition is that which is normally found in boron— 18.3 ± 0.3 weight percent of B10.

U.S. Standard Sieve Series^(c)

Mesh	%
+200	1.9
-200	98.1

(a) Chemical analysis performed by: The Carborundum Company, Electro Minerals Division, Niagara Falls, New York.

(b) Dried at 200°C for one hour.

(c) Particles of mesh size less than 200 have diameters in the range 0.0 to 7.4×10^{-3} cm.

Table 3-9
VERIFICATION OF ANALYTICAL DATA FOR B₄C^(a)
Particle Size Distribution and Composition

	14-20 Mesh		60-80 Mesh		200-Finer Mesh	
	Between U.S. Sieve Numbers	wt %	Between U.S. Sieve Numbers	wt %	Between U.S. Sieve Numbers	wt %
	10-18	42.5	45-60	2.2	140-200	0.6
	18-20	16.6	60-80	47.2	200-325	59.5
	20-25	19.0	80-140	50.5	< 325	39.9
	25-45	21.9	140-200	0.1		
Boron (wt %)	77.9		76.9		78.4	
Boron Anhydride (wt %)	0.04		0.03		0.01	
Chlorine (ppm)	< 3		< 3		< 3	
Fluorine (ppm)	1		2		4	
Weight loss (ppm)	121		142		126	

Contaminant Concentration (parts-per-million parts of B₄C)
 Mesh Size

	14-20	60-80	200 +
Fe	5000	4900	2700
Ti	300	350	290
Co	30	10	20
Cu	70	50	80
Mn	50	35	49
Na	80	40	70

^(a) Chemical and Spectrographic Analysis Performed By:
 General Electric Company
 Nuclear Energy Division
 175 Curtner Avenue
 San Jose, California

In order to determine real B₄C densities resulting from vibratory compaction, a careful weighing procedure was followed with frequent checks being made by quality assurance personnel. All tubes and slabs filled with B₄C were carefully weighed before and after filling. In order to accommodate the wide range of weights being measured, several different scales were used during the process. Table 3-10 lists the scales and associated accuracies that were used.

Table 3-10
DESCRIPTION OF BALANCES AND SCALES
USED IN B₄C BLENDING OPERATION

1. Accountability Balance A-30 (Toledo)

Readability	1 gm
Capacity	5000 gm
Accuracy	0.3 gm
Limit of Error	±0.52 gm

Application: Used for weighing individual charges of each of the three mesh sizes of B₄C particles to make up the 40 lb blending charge.

2. Verification Scale

Readability	10 gm
Capacity	20 Kg
Accuracy	±15 gm

Application: This balance was used for obtaining the tare weights of the 1-, 2-, and 5-1/4-inch diameter tubes, and also, the gross weights of the 1- and 2-inch diameter tubes after filling with B₄C.

3. Verification Scale (Toledo)

Readability	100 gm
Capacity	213 Kg
Limit of Error	±100 gm

Application: Used to weigh the loaded (gross) 1-inch thick slabs and the loaded 5-1/4-inch diameter tubes.

4. Accountability Balance A-26 (Toledo)

Readability	100 gm
Capacity	120 Kg
Limit of Error	±50 gm

Application: Used to obtain the tare weights of the 1- and 5-1/4-inch thick slabs.

5. Shipping Balance

Readability	1 lb
Limit of Error	±1 lb

Application: Used to obtain the gross weights of the 5-1/4-inch thick B₄C-filled slabs.

For the purpose of calculating densities, most slab and tube volumes were computed from drawing dimensions. However, a volumetric determination by liquid measurement was done for the 1-inch diameter tubes. Table 3-11 shows the results of measurements made on a sampling of ten 1-inch diameter tubes chosen at random from the original group of 200 tubes of this size. The average volume of this sample was in this way determined to be 462 cm³. A calculation of this value from drawing specifications yields a value of 450 cm³. In computing densities, allowance was made for a decrease in tube volume caused by a 1/4-inch insertion of the end plug and the presence of a steel wool plug (1/4-inch thick for 1- and 2-inch diameter tubes and 3/16-inch thick for 5-1/4-inch diameter tubes). Tables 3-12 to 3-14 summarize the results of the B₄C compacting operation for the three tube sizes, and Table 3-15 gives a density summary for all radial shield units.

Table 3-11
VOLUMETRIC CHECK FOR A RANDOM
SAMPLE OF TEN 1-INCH DIAMETER TUBES

Tube	Volume (cm ³)	o.d. (in.) ^(a)		i.d. (in.)
		0° Axis	90° Axis	
138 A	450	0.9975	0.9972	0.8574
141 B	475	1.0029	1.0036	0.8784
137 C	470	1.0054	1.0047	0.8778
135 D	470	1.0041	1.0030	0.8785
132 E	465	0.9943	0.9980	0.8704
134 F	445	0.9957	0.9968	0.8514
139 G	465	1.0065	1.0054	0.8741
140 H	470	1.0040	1.0043	0.8762
133 I	445	0.9964	0.9963	0.8545
136 J	465	1.0018	1.0019	0.8726
Average	462	1.0009	1.0011	0.8691

^(a) These outside diameter measurements were made along two orthogonal diameters, one of which was randomly chosen.

Table 3-12
1-in. B₄C ROD ASSEMBLY
VOLUME = 462 cm³/ROD
TD = 2.463 gm/cm³

Assembly G4-T1-1			Assembly G1-T1-2			Assembly G4-T1-3			Assembly G1-T1-4											
Rod	Net Wt kg	Percent of TD	Rod	Net Wt kg	Percent of TD	Rod	Net Wt kg	Percent of TD	Rod	Net Wt kg	Percent of TD	Rod	Net Wt kg	Percent of TD	Rod	Net Wt kg	Percent of TD	Rod	Net Wt kg	Percent of TD
Half Rod	(a)	(a)	178	0.835	73.50	158	0.795	69.85	67	0.825	72.69	Half Rod	(a)	(a)	131	0.810	71.06	156	0.800	70.25
50	0.790	69.44	136H	0.830	73.09	119	0.800	70.25	13	0.841	73.91	88	0.825	72.74	154	0.830	73.09	133	0.800	70.25
12	0.836	73.50	35	0.800	70.25	127	0.785	69.04	148	0.820	71.88	17	0.846	74.32	23	0.816	71.88	30	0.801	70.25
134F	0.810	71.06	48	0.740	69.44	100	0.825	72.74	24	0.836	73.50	4	0.831	73.09	90	0.810	76.34	60	0.815	71.47
59	0.795	69.84	33	0.801	70.25	62	0.845	74.32	117	0.820	71.88	15	0.826	72.69	138	0.800	70.25	112	0.795	69.85
159	0.815	71.47	171	0.785	69.04	25	0.831	73.09	84	0.830	73.09	165	0.825	72.74	166	0.845	74.32	22	0.816	71.88
142	0.840	73.91	45	0.826	72.69	89	0.810	71.06	70	0.825	72.69	145	0.830	73.09	129	0.820	71.88	5	0.842	73.91
54	0.795	69.84	179	0.840	73.91	98	0.835	73.50	93	0.860	75.53	162	0.835	73.50	166	0.830	73.09	140	0.835	73.50
141B	0.835	73.50	144	0.830	73.09	79	0.840	73.91	120	0.850	72.72	111	0.795	69.85	164	0.835	73.50	1	0.836	73.50
77	0.825	72.69	36	0.801	70.25	69	0.860	75.53	115	0.845	74.32	110	0.850	74.72	173	0.830	73.09	9	0.855	75.13
41	0.831	73.09	182	0.810	71.06	123	0.825	72.74	116	0.830	73.09	51	0.800	70.25	34	0.826	72.69	14	0.815	73.91
56	0.800	70.25	146	0.800	70.25	63	0.830	73.09	87	0.835	73.50	188	0.805	70.66	106	0.835	73.50	37	0.821	72.29
29	0.831	73.09	52	0.830	73.04	76	0.830	73.09	103	0.840	73.91	10	0.812	71.47	122	0.830	73.09	40	0.826	72.69
11	0.850	74.72	118	0.845	74.32	189	0.810	71.06	85	0.830	73.09	187	0.790	69.44	26	0.836	73.50	20	0.836	73.50
107	0.845	74.32	157	0.790	69.44	108	0.820	71.88	57	0.835	73.50	150	0.825	72.74	125	0.810	71.06	147	0.830	73.09
105	0.830	73.09	185	0.835	73.50	124	0.815	71.47	47	0.826	72.69	175	0.890	78.37	72	0.830	73.09	160	0.845	74.32
139G	0.830	73.09	46	0.800	70.25	99	0.860	75.53	113	0.840	73.91	44	0.831	73.09	74	0.840	73.91	38	0.831	73.09
114	0.790	69.44	186	0.815	71.47	75	0.825	72.69	96	0.840	73.91	78	0.800	70.25	109	0.840	73.91	176	0.825	72.74
64	0.810	71.06	168	0.805	70.66	126	0.830	73.09	53	0.810	71.06	3	0.846	74.32	16	0.826	72.69	19	0.831	73.09
86	0.825	72.69	55	0.815	71.47	130	0.820	71.88	170	0.805	70.66	177	0.835	73.50	58	0.825	72.69	132	0.835	73.50
2	0.826	72.69	167	0.840	73.91	91	0.840	73.91	137	0.840	73.91	94	0.820	71.88	163	0.835	73.50	181	0.835	73.50
68	0.840	73.91	Half Rod	(a)	(a)	71	0.855	75.13				6	0.851	74.72	Half Rod	(a)	(a)	169	0.840	73.91
184	0.835	73.50				92	0.840	73.91				128	0.820	71.88				32	0.816	71.88
42	0.800	70.25				97	0.835	73.50				65	0.825	72.69				191	0.840	73.91
151	0.805	70.66				121	0.815	71.47				82	0.840	73.91				104	0.825	72.74
81	0.800	70.25				95	0.840	73.91				21	0.826	72.69				135	0.835	73.50
61	0.810	71.06				66	0.825	72.69				190	0.845	74.32				143	0.825	72.74

Note: If rod assembly is positioned such that the ID number stamped on the frame, e.g., G4-T1-1, appears at the top left corner, then the rods will be in the sequence listed above, from left to right; i.e., half rod, 50, 12, 134F, ---, 167, half rod.

(a) Data unavailable.

Table 3-13
TWO-INCH B₄C ROD ASSEMBLY
Volume = 1995 cm³/rod
Theoretical Density = 2.463 gm/cm³

Assembly Number G5-T2-1			Assembly Number G2-T2-2			Assembly Number G2-T2-3			Assembly Number G5-T2-4		
Rod Number	Net Weight (kg)	Percent of Theoretical Density	Rod Number	Net Weight (kg)	Percent of Theoretical Density	Rod Number	Net Weight (kg)	Percent of Theoretical Density	Rod Number	Net Weight (kg)	Percent of Theoretical Density
Half Rod	(a)	(a)	58	3.435	69.85	96	3.350	68.22	Half Rod	(a)	(a)
79	3.570	72.69	61	3.380	68.63	14	3.425	69.85	94	3.315	67.41
68	3.485	71.06	26	3.460	70.25	2	3.455	70.25	84	3.555	72.29
74	3.480	71.06	21	3.460	70.25	7	3.425	69.85	60	3.425	69.85
41	3.455	70.25	27	3.490	71.06	43	3.445	70.25	72	3.440	69.85
35	3.630	73.91	80	3.430	69.85	9	3.490	71.06	47	3.500	71.06
55	3.440	69.85	17	3.425	69.85	88	3.570	72.69	44	3.440	69.85
39	3.540	71.88	24	3.475	70.66	8	3.470	70.66	53	3.425	69.85
31	3.590	73.09	25	3.470	70.66	92	3.515	71.47	29	3.555	72.29
77	3.520	71.47	30	3.560	72.29	82	3.550	72.29	46	3.440	69.85
40	3.535	71.88	38	3.520	71.47	90	3.550	72.29	67	3.430	69.85
37	3.590	71.47	42	3.455	70.25	34	3.570	72.69	62	3.430	69.85
63	3.475	70.66	19	3.435	69.85	1	3.452	70.25	51	3.445	70.25
81	3.480	70.66	12	3.440	69.85	91	3.580	72.69	78	3.540	71.88
20	3.440	69.85	87	3.550	72.29	10	3.490	71.06	64	3.470	70.66
66	3.420	69.44	33	3.520	71.47	73	3.445	70.25	45	3.510	71.47
76	3.450	70.25	22	3.480	70.66	16	3.440	69.85	36	3.470	70.66
71	3.435	69.85	89	3.565	72.79	13	3.455	70.25	48	3.440	69.85
83	3.505	71.47	85	3.520	71.47	11	3.480	70.66	54	3.460	70.25
56	3.455	70.25	23	3.480	70.66	4	3.445	70.25	52	3.425	69.85
28	3.510	71.47	57	3.500	71.06	5	3.530	71.88	32	3.580	72.69
59	3.430	69.85	15	3.440	69.85	6	3.460	70.25	93	3.425	69.85
75	3.490	71.06	18	3.430	69.85	3	3.430	69.85	65	3.425	69.85
70	3.435	69.85	97	3.355	68.22	95	3.350	68.22	69	3.455	70.25
Half Rod	(a)	(a)							Half Rod	(a)	(a)

Note: If rod assembly is positioned such that the ID number stamped on the frame, e.g., G5-T2-1, appears at the top left corner, then the rods will be in the sequence listed above, from left to right; i.e., half rod, 79, 68, 74, ---, 70, half rod.

(a) Data unavailable.

Table 3-14
 5/8-INCH B₄C ROD ASSEMBLY
 Volume = 15,303 cm³/rod
 Theoretical Density = 2.463 gm/cm³

Assembly Number G3-T5-1			Assembly Number G3-T5-2			Assembly Number G3-T5-3		
Rod Number	Net Weight (kg)	Percent of Theoretical Density	Rod Number	Net Weight (kg)	Percent of Theoretical Density	Rod Number	Net Weight (kg)	Percent of Theoretical Density
11	25.25	57.01	Half Rod	Average Weight = 25.63	Average Percent = 68.02	8	25.17	67.01
21	26.06	69.04	10			16	26.43	70.25
7	24.55	65.38	15			1	25.63	68.22
22	25.67	68.22	26			19	25.89	68.63
9	25.26	67.01	14			2	25.63	68.22
13	24.21	64.16	3			18	25.47	67.81
24	25.77	68.22	5			4	26.16	69.44
6	26.20	69.44	17	23	25.61	67.81		
20	26.56	70.66	Half Rod			12	25.64	67.81

Note: If rod assembly is positioned such that the ID number stamped on the frame, e.g., G3-T5-1, appears at the top left corner, then the rods will be in the sequence listed above, from left to right; i.e., half rod, 11, 21, 7, ---, 6, 20.

Table 3-15
SUMMARY OF B₄C DENSITIES FOR RADIAL SHIELD UNITS^(a)

Identification Number One-Inch Slab Units	Percent of Theoretical Density ^(b)	B ₄ C Density		
G2-S1-1	66.97	1.649 gm/cc		
G2-S1-2	67.77	1.669 gm/cc		
G2-S1-3	73.91	1.820 gm/cc		
G2-S1-4	68.38	1.684 gm/cc		
5¼-Inch Slab Units				
G1-S5-1	75.81	1.867 gm/cc		
G1-S5-2	76.75	1.890 gm/cc		
G1-S5-3	73.91	1.820 gm/cc		
Percent of Theoretical Density ^(b)				
Identification Number	For Rod With Lowest Value	For Rod With Highest Value	Average	Average B ₄ C Density
One-Inch Rod Units				
G1-T1-2	69.04	75.53	72.95	1.797 gm/cc
G4-T1-1	69.04	74.72	71.86	1.770 gm/cc
G1-T1-4	69.85	75.13	72.88	1.795 gm/cc
G4-T1-3	69.44	78.37	72.87	1.795 gm/cc
Two-Inch Rod Units				
G2-T2-3	68.22	72.69	70.71	1.741 gm/cc
G5-T2-4	67.41	72.69	70.41	1.734 gm/cc
G5-T2-2	68.22	72.79	70.55	1.737 gm/cc
G5-T2-1	69.44	73.91	71.08	1.750 gm/cc
5¼-Inch Rod Units				
G3-T5-3	67.01	70.25	68.36	1.683 gm/cc
G3-T5-2	(c)	(c)	68.02	1.675 gm/cc
G3-T5-1	64.16	70.66	67.68	1.667 gm/cc

(a) Shield units in each group are listed according to position in experimental assembly, i.e., listed in sequence "down beam".

(b) Based on Theoretical Density of 2.463 gm/cm³ for B₄C.

(c) Data unavailable.

3.3 ANALYTICAL STUDIES

The following analytical activities were accomplished during the April-June 1972 quarter:

- a) Final determination of neutron spectrum modifier/diffuser materials and thicknesses.
- b) Axial and radial configuration one-dimensional diffusion calculations to determine approximate attenuation and spectra for all configurations and check out input data for ID-S_n calculations.
- c) Collapsing of Bonner ball response data for 3-inch and 6-inch Bonner balls from 100 or 104 groups to a 24-group structure for use with the BRD 24-group cross section library.
- d) A short (17 minutes on the IBM 370/165) Monte Carlo test case was run successfully using the MORSE code. This case used a source geometry and energy group structure which closely approximates the TSR II collimated neutron beam.

3.3.1 Final Determination of Neutron Spectrum Modifier/Diffuser Materials

3.3.1.1 Axial Spectrum Modifier Design

Several different thickness combinations of steel, sodium, and Boral (determined by existing slab materials at ORNL) were used for one-dimensional S₁₆ P₃ neutron transport calculations to establish the best possible combination of thicknesses and materials to simulate an LMFBR plant axial reference spectrum at the sodium crossflow/axial shield interface. In these calculations, the modifier configuration was in all cases backed with 1 ft of stainless steel simulating the actual reactor configuration (the axial shield has homogenized volume fractions of 0.8493 SS-304, 0.0931 sodium, and 0.0576 void). The results of these calculations showed that a close approximation to an LMFBR axial reference spectrum can be obtained with the TSR by using a modifier consisting of 18-inch SS-304 + 48-inch sodium + 1/8-inch Boral with the modifier backed by the GE axial shield mockup. ORNL currently has on hand 14 inches of SS-304 but has an additional 4 inches of SS-321 which would be an acceptable substitution for the remaining 4 inches of SS-304.

A comparison of calculated spectra (LMFBR reference vs TSR + modifier) is shown in Figure 3 14. The shape agreement is seen to be good. It will be noted that the TSR + modifier-produced spectrum is harder at high energies (above 1 MeV). This difference will tend to produce an overestimate of the neutron streaming through the sodium passages between the steel rods and hence tends toward a somewhat conservative shield design.

It should also be noted that the axial modifier needed for closely approximating an LMFBR axial reference spectrum (at the sodium crossflow/axial shield interface) is relatively thick, causing a total flux attenuation for the modifier + 2-ft thick axial shield of $\sim 10^6$. The assumption of zero buckling has the effect of underestimating the attenuation but probably by less than a factor of ten. Therefore, the real attenuation may be approximately $10^6 - 10^7$.

3.3.1.2 Radial Spectrum Modifier Option

A radial spectrum modifier option has been adopted which will facilitate scheduling of the GE experiments and reduce ORNL TSF time required for the spectrum modifier measurements. This option consists of using the Westinghouse ARD modifier (4-inch SS-304 + 6-inch sodium + 1-inch Boral) followed by the W blanket layers + reflector as the configuration modifying the spectrum for input to the GE radial B₄C shield rod or slab configurations. This procedure takes advantage of the fact that the GE and Westinghouse neutron spectra at the blanket-reflector interface are very similar.² The savings in TSF time for GE is the ~ 1 -month period required for measurements on the GE radial spectrum modifier.

Figure 3-14. Spectrum Comparison - TSR + Axial Modifier versus LMFBR Spectrum into Axial Shield

3.3.2 Total Flux Attenuation for Axial and Radial Configurations

One-dimensional, 24-group neutron diffusion calculations for five axial and seven radial configurations were performed. These calculations were done primarily for the purpose of partially checking out the input which will be used for more expensive 1D-S_n (S₁₆ P₃) transport calculations. The calculations were selected as being representative of the range of attenuations to be expected during the GE experiments and were useful for determining the order of magnitude of the total flux attenuation and spectrum variation to be expected from each configuration.

The TSR-II neutron source was represented by collapsing the 100-group ORNL data of reference 4 to 24 groups as discussed in reference 1. Table 3-16 shows the GE-BRD 24-group representation of this source. For purposes of these calculations, the buckling factors were purposely set equal to zero to allow later comparisons when bucklings have been determined from DOT III two-dimensional calculations. No attempt was made to guess these values at this stage of the analysis since it was felt that 2- and 3-dimensional calculations are needed to provide a valid basis for such approximations. It is reasonable to expect that the diffusion approximation overpredicts the attenuation of the total flux, whereas the assumption of "zero buckling" tends to underpredict the attenuation. The experimental measurements and DOT III and MORSE analyses of these configurations will yield important information on the magnitude of the error resulting from diffusion, transport, and buckling approximations.

Table 3-16
TSR-II 24-GROUP SOURCE SPECTRUM

Group Number	Energy Band	Lethargy Increment (ΔU)	Percent of Total Flux	Neutron Flux ^(a) (n/cm ² -min-W)
1	10.0-16.5 MeV	0.5	0.13	3.1800 (+2)
2	6.07-10.0	0.5	2.17	5.1480 (+3)
3	3.68-6.07	0.5	7.88	1.8730 (+4)
4	2.23-3.68	0.5	12.93	3.0740 (+4)
5	1.35-2.23	0.5	10.67	2.5135 (+4)
6	0.821-1.35	0.5	5.20	1.2355 (+4)
7	498-821 keV	0.5	4.11	9.7800 (+3)
8	302-498	0.5	2.45	5.8150 (+3)
9	183-302	0.5	1.91	4.5500 (+3)
10	111-183	0.5	1.71	4.0540 (+3)
11	67.4-111	0.5	1.64	3.6600 (+3)
12	40.9-67.4	0.5	1.42	3.3800 (+3)
13	24.8-40.9	0.5	1.31	3.1200 (+3)
14	15.0-24.8	0.5	1.23	2.9300 (+3)
15	9.12-15.0	0.5	1.14	2.7100 (+3)
16	5.53-9.12	0.5	1.08	2.5700 (+3)
17	3.35-5.53	0.5	1.02	2.4200 (+3)
18	2.03-3.35	0.5	0.98	2.3300 (+3)
19	1.01-2.03	0.7	1.29	3.0730 (+3)
20	0.249-1.01	1.4	2.33	5.5380 (+3)
21	55.6-249 eV	1.5	2.29	5.4450 (+3)
22	12.4-55.6	1.5	2.27	5.4040 (+3)
23	0.625-12.4	3.0	4.57	1.0855 (+4)
24	Thermal	0.0	28.47	6.7675 (+4)
			Total 100.00	Total 2.3774 (+5)

^(a) As collapsed from 100 group structure given in Reference 3, and normalized to a power level of 1 watt.

The densities and composition of materials used in these pre-experiment calculations were determined from vendors data, chemical and spectrographic analysis done at the General Electric Nuclear Energy Division, manufacturing procedures, and data provided by ORNL. Table 3-17 summarizes this information. It should be noted that the B_4C density of 2.463 gm/cm^3 is a theoretical (maximum) density based on mixing 3 different mesh sizes of B_4C particles as explained in subsection 3.2.2 of this report. For purposes of these calculations the actual density resulting from compacting of each separate homogeneous slab configuration was used. These values turned out to be approximately 70% of the theoretical density and are shown in subsection 3.2.3.

Figures 3-15 to 3-20 show the schematic diagrams depicting the major sublayers of 12 configurations and give the details of the multilayer configurations used. These one-dimensional configurations are equivalent to those being tested at ORNL except that in the axial configurations all steel was assumed to be SS-304. ORNL is using 4-inch SS-321 + 14-inch SS-304 to make up the 18-inch SS specified for the axial modifier. Also, the thin aluminum cladding comprising the front and back layers of the Boral sheet has been neglected (20 mil thick cladding in the case of the 1/8-inch thick sheet used in the axial modifier). These approximations are of minor significance to the calculational results and allow some simplification.

Table 3-17
DENSITIES AND COMPOSITIONS OF MATERIALS USED
IN PRE-EXPERIMENT 1-D DIFFUSION CALCULATIONS

Material	Density	Atom Density
Sodium	0.945 gm/cc	Na = $2.4766 (-2)$ atoms/barn-cm
Aluminum	2.702 gm/cc	Al = $6.0366 (-2)$ atoms/barn-cm
B_4C	2.463 gm/cc	B-10 = $2.0902 (-2)$ atoms/barn-cm C ⁽¹⁾ = $1.1318 (-1)$ atoms/barn-cm
Boral	2.3 gm/cc	B-10 = $7.3779 (-3)$ atoms/barn-cm C ⁽¹⁾ = $3.9947 (-2)$ atoms/barn-cm Al = $3.1951 (-2)$ atoms/barn-cm
Type-304 SS	7.88 gm/cc	C = $1.8578 (-4)$ atoms/barn-cm Si ⁽²⁾ = $1.1405 (-3)$ atoms/barn-cm Cr = $1.6717 (-2)$ atoms/barn-cm Mn = $7.7777 (-4)$ atoms/barn-cm Fe ⁽³⁾ = $6.0238 (-2)$ atoms/barn-cm Ni = $6.9869 (-3)$ atoms/barn-cm Cu = $1.9427 (-4)$ atoms/barn-cm Mo = $1.4846 (-4)$ atoms/barn-cm

(1) Boron-11 is included in this density.

(2) Sulphur and phosphorus are included in this density.

(3) Cobalt is included in this density.

REGION	WIDTH	COMPOSITION		
		MATERIAL	VOL FR	DENSITY
1	45.72 cm	304SS	1.0	7.88 gm/cc
2	0.63 cm	ALUMINUM	1.0	2.702 gm/cc
3	30.48 cm	SODIUM	1.0	0.945 gm/cc
4	1.27 cm	ALUMINUM	1.0	2.702 gm/cc
5	30.48 cm	SODIUM	1.0	0.945 gm/cc
6	1.27 cm	ALUMINUM	1.0	2.702 gm/cc
7	30.48 cm	SODIUM	1.0	0.945 gm/cc
8	1.27 cm	ALUMINUM	1.0	2.702 gm/cc
9	30.48 cm	SODIUM	1.0	0.945 gm/cc
10	0.63 cm	ALUMINUM	1.0	2.702 gm/cc
11	0.32 cm	BORAL	1.0	2.30 gm/cc

Figure 3-15. Schematic Diagram of Axial Modifier

REGION	WIDTH	COMPOSITION		
		MATERIAL	VOL FR	DENSITY
1	2.54 cm	304SS	1.0	7.88 gm/cc
2	0.63 cm	SODIUM	1.0	0.945 gm/cc
3	60.32 cm	SODIUM	0.0931	0.945 gm/cc
		304SS	0.9069	7.88 gm/cc
4	1.90 cm	SODIUM	1.0	0.945 gm/cc
5	0.63 cm	304SS	1.0	7.88 gm/cc
6	1.27 cm	304SS	1.0	7.88 gm/cc

Figure 3-16. Schematic Diagram of Axial Shield

COMPOSITION					
REGION	WIDTH	MATERIAL	VOL FR	DENSITY	
1	1.27 cm	ALUMINUM	1.0	2.702 gm/cc	
2	73.42 cm	SODIUM	1.0	0.945 gm/cc	
3	1.27 cm	ALUMINUM	1.0	2.702 gm/cc	

Figure 3-17. Schematic Diagram of 30-inch Sodium (tank)

COMPOSITION				
REGION	WIDTH	MATERIAL	VOL FR	DENSITY
1	10.16 cm	304SS	1.0	7.88 gm/cc
2	0.63 cm	ALUMINUM	1.0	2.702 gm/cc
3	15.24 cm	SODIUM	1.0	0.945 gm/cc
4	0.63 cm	ALUMINUM	1.0	2.702 gm/cc
5	2.54 cm	BORAL	1.0	2.30 gm/cc

Figure 3-18. Schematic Diagram of Radial Modifier

REGION	WIDTH	COMPOSITION			DENSITY
		MATERIAL	VOL. FR.		
1	0.127 cm	ALUMINUM	1.0		2.702 gm/cc
2	0.475 cm	304SS	1.0		7.88 gm/cc
3	9.525 cm	B ₄ C	1.0		a x 2.463 gm/cc
4	0.475 cm	304SS	1.0		7.88 gm/cc
5	0.952 cm	ALUMINUM	1.0		2.702 gm/cc

WHERE, $a = 0.7581$ FOR SLAB 1

$a = 0.7675$ FOR SLAB 2

$a = 0.7391$ FOR SLAB 3

Figure 3-19. Schematic Diagram of One 5-1/4-inch B₄C Homogeneous Slab Unit

REGION	WIDTH	COMPOSITION		
		MATERIAL	VOL FR	DENSITY
1	0.236 cm	304SS	1.0	7.88 gm/cc
2	1.524 cm	B ₄ C	1.0	a x 2.463 gm/cc
3	0.236 cm	304SS	1.0	7.88 gm/cc
4	0.203 cm	ALUMINUM	1.0	2.702 gm/cc

WHERE, a = 0.6697 FOR SLAB 1
a = 0.6777 FOR SLAB 2
a = 0.7391 FOR SLAB 3
a = 0.6836 FOR SLAB 4

Figure 3-20. Schematic Diagram for One 1-inch B₄C Homogeneous Slab Unit

Figures 3-21 to 3-32 display the attenuation curves of the total flux and attenuation curves of 4 energy groups, providing a 1-figure summary of a calculation actually done in 24 energy groups. The fluxes in all figures have been normalized to a TSR power of 1 watt.

Table 3-18 summarizes the results of the calculations by giving the attenuation factors for the total flux for each complete configuration (modifier + shield) and also for each major slab layer. It is seen that the largest attenuation is produced by the axial modifier + axial shield + 30-inch sodium configuration and that this value, 3×10^6 , is close to the allowable attenuation limit of $\lesssim 10^7$ which provides an adequate detector response. It should be noted that a transport calculation would give less attenuation than the diffusion calculation presented here but that inclusion of non-zero buckling will increase the attenuation. These uncertainties led to a decision to add part III to the experimental program (allowing the option of a smaller attenuation if it should prove necessary).

Table 3-18
CALCULATED NEUTRON FLUX ATTENUATION FACTOR
(Slab—24 gr Diffusion Without Buckling)

Experiment	Configuration	Attenuation Factor	
		System	Following Modifier
I A	18 inches of Steel	3.86 (+1)	---
I B	Axial Modifier	3.23 (+1)	---
I C	Axial Modifier Plus Axial Shield	9.85 (+5)	8.37 (+3)
I D	Axial Modifier Plus Axial Shield Plus 30-in. Sodium	3.00 (+6)	2.55 (+4)
III A	Radial Modifier ^(a) Plus Axial Shield	4.92 (+2)	1.50 (+2)
VII A-a1	Radial Modifier Plus One 5-1/4-in. B ₄ C Slab Unit	6.55 (+1)	1.19 (+1)
VII A-a2	Radial Modifier Plus Two 5-1/4-in. B ₄ C Slab Units	3.91 (+2)	7.18 (+1)
VII A-a3	Radial Modifier Plus Three 5-1/4-in. B ₄ C Slab Units	2.10 (+3)	3.86 (+2)
VII D-a1	Radial Modifier Plus One 1-in. B ₄ C Slab Unit	1.48 (+1)	1.95
VII D-a2	Radial Modifier Plus Two 1-in. B ₄ C Slab Units	1.95 (+1)	3.07
VII D-a3	Radial Modifier Plus Three 1-in. B ₄ C Slab Units	2.63 (+1)	4.55
VII D-a4	Radial Modifier Plus Four 1-in. B ₄ C Slab Units	3.52 (+1)	6.35

^(a) Radial Modifier = 4 inches Type-304 SS + 6 inches Na + 1 inch Boral.

Figure 3-21. Neutron Attenuation through 18 inches SS304

Figure 3-22. Neutron Attenuation through Axial Modifier
(18 inches SS304 + 48 inches Na + 0.125 inches Boral)

Figure 3-23. Neutron Attenuation through Axial Modifier + Axial Shield

Figure 3-24. Neutron Attenuation through Axial Modifier + Axial Shield + 30 inches Na

Figure 3-25. Neutron Attenuation through Radial Modifier + Axial Shield

Figure 3-26. Neutron Attenuation through Radial Modifier + One 5-1/4-inch B₄C Slab Unit

Figure 3-27. Neutron Attenuation through Radial Modifier + Two 5-1/4-inch B₄C Slab Units

Figure 3-28. Neutron Attenuation through Radial Modifier + Three 5-1/4-inch B₄C Slab Units

Figure 3-29. Neutron Attenuation through Radial Modifier + One 1-inch B_4C Slab Unit

Figure 3-30. Neutron Attenuation through Radial Modifier + Two 1-inch B₄C Slab Units

Figure 3-31. Neutron Attenuation through Radial Modifier + Three 1-inch B₄C Slab Units

Figure 3-32. Neutron Attenuation through Radial Modifier + Four 1-inch B₄C Slab Units

Figures 3-33 to 3-36 display the variation of transmitted + reflected neutron spectra through the thickest configurations of the four primary types treated (axial modifier + axial shield + 30-inch Na, radial modifier + axial shield, radial modifier + three 5-1/4-inch B₄C slab units, and radial modifier + four 1-inch B₄C slab units). It is noted that although the attenuation of the total flux for these four configurations lies in the range 3×10^1 to 3×10^6 , there is a much wider range of variation in attenuation factors for the group-wise fluxes. For example, depending on the shield assembly configuration, neutrons with energies of ~ 100 keV experience an attenuation in the range 10^1 to 10^7 . The lowest energy group (0.625 - 12.4 eV) is attenuated by a factor in the range 10^6 to 10^{10} , and the highest energy group (10.0 - 16.5 MeV) is attenuated by a factor in the range 10^2 to 10^{18} . Table 3-19 summarizes this information.

Table 3-19
APPROXIMATE NEUTRON ATTENUATION FACTORS FOR AXIAL
AND RADIAL SHIELD CONFIGURATIONS

Configuration	Attenuation Factor (Diffusion/No Buckling)		
	Group 1 10.0-16.5 MeV	Group 11 67.4-111 keV	Group 23 0.625-12.4 eV
1. Axial Modifier + Axial Shield + 30 Inches Na	1.56 (+ 18)	4.28 (+ 6)	8.36 (+ 5)
2. Radial Modifier + Axial Shield	3.03 (+ 16)	2.48 (+ 5)	8.90 (+ 5)
3. Radial Modifier + Four 1-Inch B ₄ C Slab Units	2.85 (+ 2)	1.01 (+ 1)	2.11 (+ 8)
4. Radial Modifier + Three 5-1/4-Inch B ₄ C Slab Units	1.40 (+ 4)	7.49 (+ 2)	5.40 (+ 9)

3.3.3 Bonner Ball Response Functions

In order to use the ORNL Bonner ball response functions^{4,5} in future 24-group transport or Monte Carlo calculations, it was necessary to collapse the data for 3-, 6-, and 9.86-inch diameter Bonner spheres from 100-, 104-, and 123-energy groups to the GE-BRD 24-group structure. The determination of values for the reduced number of groups was done using log-log interpolation and extrapolation.

For the 3-inch diameter sphere, ORNL 194-group data were used for neutron energies between 1.855 eV and 3.679 MeV. For energies below or above this range, extrapolations were made using a shape derived from the ORNL 100-group data. For the 6-inch diameter sphere, ORNL 123-group data were used for energies above 101.3 eV with an extrapolation below this energy made using the shape of the 100-group data. Collapsed values for the 9.86-inch diameter sphere used ORNL 100-group data exclusively. Table 3-20 shows the results of this collapsing procedure.

Figure 3-33. Spectrum Variation through Axial Modifier + Axial Shield + 30 inches Na

Figure 3-34. Spectrum Variation through Radial Modifier + Axial Shield

Figure 3-35. Spectrum Variation through Radial Modifier + Three 5-1/4-inch B₄C Slab Units

Figure 3-36. Spectrum Variation through Radial Modifier + Four 1-inch B₄C Slab Units

Table 3-20
**BONNER BALL NEUTRON RESPONSE FUNCTIONS
 FOR 3-INCH, 6-INCH, AND 9.86-INCH DIAMETER SPHERES**

Group	Energy Range		Bonner Ball Responses ^(a) (Counts/Incident Neutron-cm ⁻²)		
			3-In. Diameter	6-In. Diameter	9.86-In. Diameter
1	10.0	— 16.5 MeV	0.004	0.282	0.635
2	6.07	— 10.0	0.007	0.456	0.917
3	3.68	— 6.07	0.012	0.708	1.106
4	2.23	— 3.68	0.019	0.964	1.177
5	1.35	— 2.23	0.035	1.267	1.169
6	0.821	— 1.35	0.053	1.492	1.003
7	498	— 821 keV	0.077	1.570	0.782
8	302	— 498	0.116	1.573	0.596
9	183	— 302	0.142	1.496	0.462
10	111	— 183	0.188	1.502	0.371
11	67.4	— 111	0.238	1.318	0.314
12	40.8	— 67.4	0.259	1.340	0.276
13	24.8	— 40.8	0.294	1.295	0.252
14	15.0	— 24.8	0.333	1.219	0.234
15	9.12	— 15.0	0.367	1.195	0.220
16	5.53	— 9.12	0.414	1.225	0.209
17	3.35	— 5.53	0.501	1.139	0.192
18	2.03	— 3.35	0.445	1.270	0.200
19	1.01	— 2.03	0.538	1.221	0.183
20	0.249	— 1.01	0.670	1.138	0.167
21	55.6	— 249 eV	0.873	1.070	0.141
22	12.4	— 55.6	1.110	1.002	0.126
23	0.625	— 12.4	1.402	0.729	0.088
24	0.0	— 0.625	0.764	0.205	0.248

^(a) Values derived from ORNL 100, 104 and 123 Energy Group Data.

3.3.4 Implementation of the MORSE Monte Carlo Code

During the quarter, the MORSE Monte Carlo neutron shielding computer program was further adapted for local use on an IBM 370, model 165 computer. The program, including user routines, was compiled successfully and one of the sample test cases supplied with the program was run (a point fission source in infinite air).

The next step undertaken was to run a test case consisting of a much shortened version of one of ORNL's sodium benchmark calculations (for 2-1/2 feet of sodium). This procedure required the preparation and use of user routines and input data obtained from ORNL describing the geometry and energy spectrum of the TSR collimated neutron beam. Also, 100-group sodium cross sections, which will be used in the 3-dimensional calculations, were used. This test run was made for 5 batches of 1000 particles each, i.e., a run of 5000 histories.

Table 3-21 shows a comparison between the GE 5000-particle run and the ORNL 51,000-particle run for 3 detector points located near the rear face of the 2-1/2-ft thick sodium slab. The geometry of the configuration is shown in Figure 3-37.

It is interesting to note that the short 5000-history run provided fractional standard deviations of ~3%, as compared to ~0.7% for the 51,000-history run. Thus, as would be expected, the fractional standard deviations for the 5000-history run are larger than those of the 51,000-history run by approximately the square root of the ratio of the number of histories, i.e., by $(51000/5000)^{1/2} \cong 3.2$.

Table 3-21
COMPARISON BETWEEN TWO MONTE CARLO CALCULATIONS OF NEUTRON FLUX
TRANSMITTED THROUGH TWO AND ONE-HALF FEET OF SODIUM

Collided Neutron Flux ($n/cm^2 \cdot min \cdot W$)						
Detector Number 1		Detector Number 2		Detector Number 3		
X = 0.0 cm Y = 0.0 Z = 520.60		X = 0.0 cm Y = 0.0 Z = 159.92		X = 0.0 cm Y = 60.96 Z = 159.92		
Computer Run	ϕ	FSD ^(a)	ϕ	FSD ^(a)	ϕ	FSD ^(a)
51,000 histories (ORNL)	9.5000(+1)	0.00622	1.8011(+3)	0.00700	1.1850(+3)	0.00783
5,000 histories (GE-BRD)	9.7023(+1)	0.02094	1.8538(+3)	0.02772	1.2138(+3)	0.02777

^(a) Fractional Standard Deviation

Figure 3-37. Geometry for Monte Carlo Calculation of Neutron Flux Transmitted through 2-1/2 feet of Sodium

3.4 QUALITY ASSURANCE

3.4.1 Summary

The following quantities of P.A. 62 hardware were final inspected and released for shipment to ORNL on June 19, 1972.

Radial Shield Tube Assembly (with full-tube sides), 1-inch Tube — 2 ea.

Radial Shield Tube Assembly (with half-tube sides), 1-inch Tube — 2 ea.

Radial Shield Tube Assembly (with full-tube sides), 2-inch Tube — 2 ea.

Radial Shield Tube Assembly (with half-tube sides), 2-inch Tube — 2 ea.

Radial Shield Tube Assembly (with full-tube sides), 5-1/4-inch Tube — 2 ea.

Radial Shield Tube Assembly (with half-tube sides), 5-1/4-inch Tube — 1 ea.

Radial Shield Homogeneous Slab, 1-inch — 4 ea.

Radial Shield Homogeneous Slab, 5-1/4-inch — 3 ea.

Shipping Container Assembly — 3 ea.

The above items were packaged per shipping instructions. The shipping containers were identified by number (box 1, 2, 3) so that the contents could be determined by matching the shipper form.

All items identified as "open" were completed satisfactorily prior to BRD QA release for shipment.

Quality assurance historical document records are available which confirm that all source inspections at the vendor were completed per BRD QCI instructions. Receiving inspection reports are also available which provide evidence of inspection and acceptance for all parts and materials used in the fabrication of the P.A. 62 hardware. Material certifications are on file to certify all chemical and physical compositions as required by the base design requirements and/or drawings and specifications.

Quality assurance participation in the sodium filling of the axial shield container by ORNL personnel is documented. The container was satisfactorily filled with reactor grade sodium in accordance with procedures previously reviewed and approved by BRD design and Q.A. representatives. Details of the sodium filling operations are provided in 3.4.2.

3.4.2 Sodium Filling of the Axial Shield Container by ORNL Personnel

3.4.2.1 Scope

The quality assurance surveillance of liquid sodium filling of the P.A. 62 shielding experimental container was initiated through a mutual interest by both quality assurance and project engineering management. The objective of the visit to Oak Ridge National Laboratories was to provide quality assurance surveillance of sodium filling operations in accordance with the previously reviewed and approved procedure.

3.4.2.2 Area of Operations

All cleaning and sodium filling operations were conducted in the ORNL Reactor Division Building 9201-3, Area Y-12.

3.4.2.3 Procedure

- a. Precleaning with ethyl alcohol was accomplished just prior to installing the temporary fill cover to the axial container, GE Dwg. No. 816E289, Rev. 0. Certifications of the accomplishment of the cleaning are included in the Records Documentation Package.
- b. The temporary fill container was fabricated and installed per ORNL Sketch No. SK-WRH-3-71.
- c. Actual thermocouple and calrod heater installation used during the sodium filling operation is shown on the attached sketch (Figure 3-38).
- d. In addition to the configuration shown on various photographs (Figures 3-9 and 3-10) taken during the preparation for filling, the sodium drum, transfer tube, and the entire periphery of the axial container were heavily covered with asbestos matting (Figure 3-39) to retain heat as effectively as possible. The thickness attained was up to 6 inches. The air space beneath the container was also filled with the asbestos matting.
- e. A thin asbestos gasket was used between the sealing surface of the axial container and the temporary fill cover. Slight leakage was present at the early stages of sodium filling but sealed completely after approximately 2 hours had passed. This was attributed to a sealing action as the sodium vapors gradually coated the internal surfaces of the container.

3.4.2.4 Sequence of Events During Observation

- a. At 10:15 a.m. on Monday, May 22, 1972, the initial attempt to transfer the liquid sodium from the drum to the axial container was begun. The argon purge on the drum was maintained at 3.2 psig while the axial container outlet valve was relieved. The ΔP of 3.2 was judged to be adequate to initiate flow.
- b. Visual observation through the pyrex portholes revealed that no sodium flow occurred. An "oxide plug" was suspected and analyzed to be located at the 10 micron filter. The lowest line temperature (transfer tube apparatus) was 353°F. The line temperature just below the filter was monitored to be 682°F.
- c. The filter was removed from the line and visually examined for evidence of sodium flow. Sodium entered but did not pass through the filter.
- d. The filter was purged with ethyl alcohol and air pressure to relieve the blockage. Flow tests verified that both water and ethyl alcohol would freely pass through the filter following completion of the cleaning with no additional pressure required.
- e. After reinstallation of the filter a second attempt was started at 4:06 p.m. Flow through the transfer tube was instant verifying free flow through the filter with no problems with "oxide plugging." The transfer rate was approximately 1.6 pounds per minute. The sodium drum weighed 622-1/2 pounds at the start of transfer.
- f. The temperatures were monitored at each of the 20 thermocouple locations during the transfer.
- g. Visual observation of the sodium filling through the 4 portholes revealed a splash of sodium at the top faces of the 5-1/4-inch bars. The alkali cleaning action on each splash drop showed a light oxide film as the surfaces of the SST bars were cleaned.
- h. "Wetting" action was observed during the filling process. The action of the wetting actually appeared to be a vibratory action on the surface of the liquid sodium.

VARIAC NO.	NO. OF HEATERS	LOCATION	WIRING ARRANGEMENT	240V HEATER RATING	LOAD kW
1	1 EACH	LINE, NEAR DRUM	----	AS NEEDED	----
2	2 EACH	LINE (EXTRA TURN ON VALVE)	SERIES	EQUAL SIZE	----
3	1 EACH	FILTER (2 TURNS AROUND)	----	AS NEEDED	----
4	4 EACH	SIDE OF BOX COVER	SERIES - PAR	2000 W	2
5	14 EACH	BOTTOM OF BOX	SERIES - PAR	2000 W	7
6	4 EACH	SIDE OF BOX, MIDDLE	SERIES - PAR	2000 W	2
7	4 EACH	SIDE OF BOX, UPPER	SERIES - PAR	2000 W	2
8	4 EACH	TEMP COVER, LOWER	SERIES - PAR	2000 W	2
9	4 EACH	TEMP COVER, UPPER	SERIES - PAR	2000 W	2
10	6 EACH	DRUM	SERIES - PAR	2000 W	4.5

Figure 3-38. Schematic Diagram of Thermocouple and Calrod Heater Installation Used during the Sodium Filling Operation

Figure 3-39. Asbestos Covered Axial Container

- i. Overflow of sodium on the top of the SST bars occurred at 6:19 p.m.
- j. At this time a slight pressure buildup was experienced within the axial container. The sodium oxide vapors had apparently sealed the slight leaks in the temporary cover gasket.
- k. At 6:30 p.m. the axial container pressure reached 3 psig and manual venting was necessary.
- l. Complete filling to the desired level was observed at 6:30 p.m. and the transfer of sodium was stopped.
- m. Total sodium required was 223 pounds. (Back filling to compensate for shrinkage will increase this figure.)
- n. At this point the asbestos matting under the axial container was removed and the cooldown process begun.
- o. A portable electric fan was installed with temporary ducting to force the air flow through the air space beneath the axial container. The fan started at 6:55 p.m.
- p. Sodium oxide vapors gradually coated the pyrex portholes, and approximately four hours from the actual transfer (start time 4:06 p.m.) the glass became very cloudy.
- q. After 5 hours exposure (9:00 p.m.) visibility was lost.
- r. The cooling process was continued through the night shift, and a technician was assigned to monitor the argon purge pressures and cooldown temperatures.
- s. Tuesday morning, May 23, 1972, at 8:00 a.m. arrangements were made to assemble a "glove box" over each porthole to allow removal and cleaning of the pyrex view glasses so that the sodium level could be observed during the backfilling.
- t. An oxide crust was apparent on the surface of the molten sodium at this time (Figure 3-40). Previously conducted sampling by ORNL had determined that all oxides would rise to the surface and attain a depth of only about 1/64 inch.
- u. Backfilling of sodium was performed to retain the desired depth during the cooling cycle. An additional 29 pounds of sodium was added, making the total 252 pounds.

Figure 3-40. Molten Sodium with Oxide Crust

4. ADMINISTRATIVE

4.1 TRIPS

B. A. Hutchins, GE-BRD, to AEC-RDT, WARD, and ORNL to study and evaluate (as a member of a 4-man task force) an indicated serious shielding problem in the FTR due to streaming through the reactor cavity and vessel support structure. April 30 through May 5, 1972.

R. C. Copeman, GE-BRD, to ORNL to provide quality assurance surveillance of liquid sodium filling of the axial shield experimental assembly. May 21-23, 1972.

4.2 VISITS

C. E. Clifford and F. R. Mynatt, both from ORNL, visited GE-BRD for the purpose of reviewing both the proposed ORNL-LMFBR shielding program and the P.A. 62 experimental measurements program and schedule, May 17, 1972.

4.3 LIST OF CONTRIBUTORS

J. C. Amos
M. A. Bell
W. E. Butler
J. Castellanos
R. C. Copeman
P. Delvalle
R. P. Gomez
B. Gray
P. Greebler

W. H. Harless, Jr.
J. J. Hayashi
P. J. Hendriksz
B. A. Hutchins
D. T. Ikeuye
C. R. McMillan
G. W. Morris
R. Protsik
F. C. Rally

G. A. Robinson
R. Smith
A. H. Soper
P. Steck
H. J. Stock
T. F. Thompson
N. W. Wallace
M. L. Weiss
D. R. Wilkins

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