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LMFBR SHIELDING DESIGN EXPERIMENTS AND METHODS EVALUATION

THIRD QUARTERLY PROGRESS REPORT

JULY-SEPTEMBER 1972

U.S. ATOMIC ENERGY COMMISSION
CONTRACT AT(04-3)-189 PROJECT AGREEMENT 62

Submitted

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ABSTRACT

This report is the third 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 Oak Ridge National Laboratory (ORNL) Tower Shielding Facility. Activities and technical progress for the period July through September 1972 are reported. The major topics include program definition and scheduling, experimental measurements, analytical studies, and comparisons between experimental and calculated data.

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 PA-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

A planning diagram was prepared which illustrates the schedule for completing the experiments, analyses, and documentation for this project during fiscal year 1973 (FY-73). Detailed priorities were established for the remaining experiments and analytical support from ORNL.

Preliminary experimental data were received from ORNL for parts of experiments I, II, and VII. Preliminary results from measurements on one row of large B,C-filled tubes indicate that the neutron attenuation through this highly heterogeneous configuration is almost the same as for a slab of equivalent mass and compositions. This somewhat surprising result is being carefully analyzed in order to understand its basis.

1D-S_n calculations were performed to compare the General Electric Breeder Reactor Department (GE-BRD) cross sections for sodium and stainless steel with cross section sets used by ORNL in benchmark calculations.

1D-S_n 24-group neutron transport calculations were performed for the partial axial modifier (18 inches of Type-304 stainless steel), complete axial modifier, and radial modifier test assemblies. Geometric transformation factors were calculated to convert the 1D-S_n results to a form directly comparable with experimental data.

Two MORSE calculations were performed for 18 inches of Type-304 stainless steel using GE-BRD 24- and ORNL 100-group P₃ scattering matrices. ORNL "point" total cross sections were used for collision site sampling and next flight estimation in Type-304 stainless steel.

Comparisons with experimental data were made of calculated 1D-S_n and MORSE values for Bonner ball response and neutron spectra.

3. TECHNICAL ACCOMPLISHMENTS

3.1 PROGRAM DEFINITION AND SCHEDULING

A planning diagram was prepared (Figure 3-1) which graphically illustrates the schedule for completing the experiments, analyses, and documentation for this project during FY-73. This diagram will be used to monitor progress in the program as well as to assure the timely completion of interfacing experimental and analytical data.

Table 3-1 is an updated version of the experimental program being conducted at ORNL. Compared to the same table presented in the second quarterly, two principal changes (both in Part VII) have been made:

1. The radial traverses at 144 inches from the back of the B₄C rods have been moved in to 72 inches. This change was made to reduce the ratio of background to total neutron signal at the point of measurement, which is excessive (about 50%) for these experiments at 144 inches.
2. The number of measurements was reduced. Principal reason for this reduction is the indication, from results for one row of large (5-1/4-inch o.d.) B₄C-filled tubes, that the neutron attenuation through this highly heterogeneous configuration is almost the same as for a slab of equivalent mass and compositions. This somewhat surprising result is being carefully analyzed in order to understand its basis. If the neutron attenuation through these heterogeneous arrays is essentially the same as for slab equivalents, then it is unnecessary to measure a large number of rows of tubes of varying sizes—especially where the tube outside diameters are less (1 and 2 inches) than the 5-1/4 inch o.d. tubes measured.

Figure 3-2 illustrates the schedule of ORNL measurements for the PA-62 program.

Table 3-2 illustrates the planned data disposition and analysis corresponding to specific experimental configurations to be tested. The GE-BRD analytical program will provide the minimum necessary for interpretation of the experimental results. Further, this analytical program will provide the good evaluation of the major shielding design methods applicable to LMFBR's. It has been recommended that ORNL also analyze a number of the measurements both to spot discrepancies in the measured data as well as to provide a means of evaluating analytical methods. Table 3-2 illustrates the priorities assigned by GE-BRD to this analytical work by ORNL. In some cases only programming assistance is required. The latter is considered necessary in order for GE-BRD to complete its analytical program satisfactorily and within FY-73. The schedule for completing the GE-BRD portion of the PA-62 analytical program is illustrated in Figure 3-3.

3.2 EXPERIMENTAL MEASUREMENTS

Preliminary experimental data were received during the quarter from ORNL. These data pertained primarily to the partial axial modifier (18 inches of Type-304 stainless steel), the radial modifier (4 inches of Type-304 stainless steel + 6 inches of Na + 1 inch of boral), and several of the B₄C rod and slab configurations. Tables 3-3 and 3-4 present the axial traverse Bonner ball response data as transmitted by ORNL for the partial axial modifier and radial modifier. Figures 3-4 and 3-5 are ORNL plots of neutron spectra for each of these two configurations as unfolded from hydrogen counter data. The spectra were measured on axis and at a point 1 foot behind the modifier in both cases. Table 3-5 gives a summary of Bonner ball radial shield (B₄C rod and slab) measurements performed during the quarter by ORNL for GE. The experimental data presented in these tables and graphs were used for comparisons with GE-BRD analytical results which are discussed in Subsection 3.3 of this report.

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	Bonner Balls		Radial Traverse ^(c)	
				Axial Traverse ^(b)		Radial Traverse ^(c)	
				All 9 Balls	3, 6, and 10 in.	All 9 Balls	3, 6, and 10 in.
IV.	Radial Blanket Measurements for Westinghouse						
g {	A. Radial Modifier + 5 in. Radial Blanket ^(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 ☒
	B. Radial Modifier + 10 in. Radial Blanket ^(e)	☒, Close ^(d) 45°, Close	☒, 12 in. 45°, 144 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. Radial Modifier + 10 in. Radial Blanket + 5 in. Reflector ^(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 ☒
V.	Radial Shield—Stainless Steel versus B ₄ C Slabs						
	A. IV.C. Modifier + 10 in. B ₄ C 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 ☒
	B. IV.C. Modifier + 10 in. B ₄ C Slabs + Axial Shield	—	—	—	☒, 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ☒. 144 in.; 0 to 60 in. on one side of ☒
	C. IV.C. Modifier + 10 in. SS + Axial Shield	—	—	—	☒, 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ☒. 144 in.; 0 to 60 in. on one side of ☒

Table 3-1 Continued

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.
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 ☉
h { VI. Radial Shield Measurements for Westinghouse						
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.; repeat 72 to 144 in. foreground; measure background at 72 and 144 in.	—	12 in.; 0 to 36 in. on each side of ☉. 72 in.; 0 to 172 in. on one side of ☉
b. 2 rows	—	—	—	☉, 12 to 144 in.; repeat 72 to 144 in. foreground; measure background at 72 and 144 in.	—	12 in.; 0 to 36 in. on each side of ☉. 72 in.; 0 to 72 in. on one side of ☉
B. Radial Modifier + 2 in. OD B ₄ C Rods						
a. 1 row	☉, Close ^(d)	☉, 12 in.	—	☉, 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ☉

Table 3-1 Continued

Configuration Number And Description	Neutron Measurements ^(a)					
	NE-213		Bonner Balls		Radial Traverse ^(c)	
			Axial Traverse ^(b)			
		H ₂ Counter	All 9 Balls	3, 6, and 10 in.	All 9 Balls	3, 6, and 10 in.
C. Radial Modifier + 1 in. OD B ₄ C Rods						
a. 4 rows	—	—	—	☒, 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ☒.
D. Radial Modifier + 0.6 in. and 3.8 in. B ₄ C Slabs						
a. 1, 2, 3, and 4 0.6 in. slabs			—	☒, 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ☒.
b. 1, 2, and 3 3.8 slabs	☒, Close ^(d)	☒, 12 in.	—	☒, 12 to 144 in.	—	12 in.; 0 to 36 in. on each side of ☒. 72 in.; 0 to 72 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 3-2
PA-62 EXPERIMENTAL AND ANALYTICAL PROGRAM

<u>Configuration No. and Description</u>	<u>Data Disposition and Analysis</u>	
	<u>GE-BRD</u>	<u>ORNL Program Priority</u>
I. Axial Shield		
A. Partial Modifier 18-in. SS	MORSE-100-gp MORSE-24-gp	MORSE - I (Done)
B. Full Modifier 18-in. SS + 48-in. Na + 1/8-in. Boral	1-D Trans/Diff	DOT III - I
C. Full Modifier + 24-in. Axial Shield (5-1/4-in. o.d. SS rods)	DOT/DOMINO/ MORSE	Programming Assistance - I
D. Full Modifier + Axial Shield + 30-in. Na	1-D Trans/Diff	DOT/DOMINO/MORSE + Programming Assist - II
II. Radial Spectrum Modifier (W)		
A. Radial Modifier 4-in. SS + 6-in. Na + 1-in. Boral	1-D Trans/Diff	MORSE - IV (Done)
III. Axial Shield with Radial Spectrum Modifier		
A. Radial Modifier + Axial Shield	Alternate for I-C; Omit Measurement if I-C is successful	Programming Assistance - I
IV. W Radial Blanket and SS Reflector		
D. Radial Modifier + 10-in. Blanket + 5-in. SS	No analysis	DOT III - I
V. Radial Shield — SS vs B₄C Slabs		
A. Radial Modifier + 10-in. Radial Blanket + 5-in. SS + 10-in. B ₄ C Slabs	A, D DOT III or DOT/DOMINO/ MORSE	Programming - I DOT or DOT/DOMINO/ MORSE - II
B. Same as + Axial Shield		

Table 3-2 (Continued)

Configuration No. and Description	Data Disposition and Analysis	
	GE-BRD	ORNL Program Priority
C. As above except 10-in. SS replaces 10-in. B ₄ C slabs	B, C 1-D Trans/Diff	No Analysis
D. As above except remove axial shield		
VII. Radial Shield - B ₄ C Rods and Slabs		
A. Radial Modifier + 5-1/4-in. o.d. B ₄ C Rods		
a. 1 and 3 rows	MORSE - 1 row only	MORSE - I
b. 2 rows	Omit	Omit
B. Radial Modifier + 2-in. o.d. B ₄ C Rods	1 MORSE calculation on B or C	Programming - I
a. 1 row		
C. Radial Modifier + 1-in. o.d. B ₄ C Rods		
a. 4 rows		
D. Radial Modifier + 0.6-in. and 3.8-in. B ₄ C Slabs	DOT III for 1 and 3 0.6-in. slabs; DOT III for 1 3.8-in. slab	DOT III for 3 3.8-in. slabs - I
a. 1, 2, 3, and 4 0.6-in. slabs		
b. 1, 2, and 3 3.8-in. slabs		
E. Radial Modifier + 5-1/4-in. o.d. B ₄ D Rods (3 rows)		
a. 6-in. SS reflector about 4 in. behind B ₄ C	Compare Experimental results to unreflected experimental results in VII A	DOT III and/or DOT/DOMINO/ MORSE - III
b. Axial shield about 4-in. behind B ₄ C		

Table 3-3
**BONNER BALL AXIAL TRAVERSE ALONG BEAM CENTERLINE
 BEHIND THE GE PARTIAL SPECTRUM MODIFIER, 18-INCH STAINLESS STEEL
 ITEM I A.3**

Position (inches measured from outside surface)	BONNER BALL RESPONSES (cpm/1 kW)					
	3-INCH BALL		6-INCH BALL		10-INCH BALL	
	Foreground	Background	Foreground	Background	Foreground	Background
12	432,556		2,515,786		1,011,724	
15			2,039,342			
24	214,150		1,238,920		476,446	
36			707,772			
48	81,860		452,924		173,915	
72	40,875	4,278	226,538	12,673		3,264
72			234,225			
96	25,422		139,313		87,078	
96	25,347					
120	17,263		94,245		34,692	
120			94,757			
144	13,107	3,437	70,342	10,517 424*	25,256	2,814

* H₂O plus 12-in. LiH — this shows that much of the apparent background originate in the sample and are scattered into the detector by the ground. The background at 144-in. is too low since some of the ground scattered contributions are shielded by the background shield.

Table 3-4
**BONNER BALL AXIAL TRAVERSE ALONG BEAM CENTERLINE
 BEHIND THE WESTINGHOUSE SPECTRUM MODIFIER
 4-INCH STAINLESS STEEL + 6-INCH Na + 1-INCH BORAL
 ITEM II A.4**

Position (inches measured from outside surface)	BONNER BALL RESPONSES (cpm/1 kW)					
	3-INCH BALL		6-INCH BALL		10-INCH BALL	
	Foreground	Background*	Foreground	Background	Foreground	Background
12	1,061,918		9,344,040		5,886,620	
18	707,851		6,307,080		4,075,620	
24	526,523		4,590,520		2,948,520	
30	410,970		3,475,210		2,271,790	
36	329,128		2,734,260		1,800,410	
48	215,901		1,841,860		1,230,500	
60	149,668		1,314,500		903,270	
72	113,185		984,762		690,220	
84	85,912		776,462		543,520	
96	68,927		639,468		454,830	
108	56,405		519,207		376,023	
120	48,726		441,388		321,723	
132	83,590		382,386		278,489	
144	72,673		334,967		242,150	

*For this configuration background measurements will be taken at some later date.

Table 3-5
**LISTING* OF BONNER BALL RADIAL SHIELD MEASUREMENTS
 PERFORMED BY ORNL FOR GE**

VII-A: 5-1/4 in. B₄C Rods

		0 Rows	1 Row	2 Rows	3 Rows	4 Rows	Repeat
a.1	Axial	—	8/ 1/72	—	8/15/72	—	8/21/72 (3 Rows)
2	12 in.	—	8/ 3/72	—	8/22/72	—	
3	144 in.	—	8/ 8/72	—	8/18/72	—	
6	72 in.	8/28/72	8/28/72	—	8/21/72	—	
b.1	Axial	—	—	8/11/72	—	—	8/29/72 (2 Rods)
2	12 in.	—	—	8/10/72	—	—	
3	144 in.	—	—	8/11/72	—	—	
4	72 in.	—	—	8/29/72	—	—	

VII-C: 1-in. B₄C Rods

a.1	Axial	—	7/19/72	—	—	7/19/72
2	12 in.	—	7/25/72	—	—	7/19/72
3	144 in.	—	7/21/72	—	—	7/20/72

VII-D: 1-in. Homogeneous Slabs

a.1	Axial	—	—	—	7/27/72	7/25/72
2	12 in.	—	—	—	7/28/72	—
3	144 in.	—	—	—	7/28/72	—
b.1	Axial	—	8/ 2/72	—	—	—

*Measurements not listed here have not been performed to date (9/16/72)

Figure 3-1. Fiscal Year '73 Planning Diagram for PA-62 LMFBR Shielding Experiments and Methods Evaluation

EXPERIMENTAL PROGRAM FOR 1972 AND 1973 (REVISED SEPTEMBER 30, 1972)

	1972							1973					
	J	J	A	S	O	N	D	J	F	M	A	M	J
I. GE AXIAL SHIELD MEASUREMENTS	■	■					■						
II. RADIAL SPECTRUM MODIFIER PLUS GAMMA MEASUREMENTS (W)		■	■										
III. GE AXIAL SHIELD WITH RADIAL SPECTRUM MODIFIER												■	
IV. W RADIAL BLANKET & STAINLESS STEEL REFLECTOR								■	■	■			
V. GE RADIAL SHIELD (B ₄ C SLABS vs STAINLESS STEEL									■	■			
VI. W RADIAL SHIELD										■	■	■	
VII. GE RADIAL SHIELD (B ₄ C-FILLED TUBES AND SLABS) WITH RADIAL SPECTRUM MODIFIER		■	■				■						
FFTF GAMMA-RAY EXPERIMENT				■	■	■	■						
SNAP PROGRAM												■	■

*THE SCHEDULE FOR THE WESTINGHOUSE ARD BASE PROGRAM EXPERIMENTS ARE SHOWN SINCE THEIR EXPERIMENTS ARE ALSO SCHEDULED FOR COMPLETION DURING FY-73 - HENCE, ARE INTERSPERSED WITH THE GE-BRD BASE PROGRAM EXPERIMENTS. FURTHER, PART V GE EXPERIMENTS USE THE PART IV-D ASSEMBLY AS A RADIAL SPECTRUM MODIFIER.

Figure 3-2. Schedule of ORNL Measurements for PA-62 LMFBR Shielding Experiments*

KEY

--- COMPARISON & EVALUATION
 — 1D CALCULATIONS
 == 2D CALCULATIONS
 === 3D CALCULATIONS
 ■ COUPLED 2D + 3D CALCULATIONS

	J	A	S	O	N	D	J	F	M	A	M	J
I. AXIAL SHIELD												
A. PARTIAL AXIAL MODIFIER = 18 in. STAINLESS STEEL												
B. AXIAL MODIFIER = 18 in. STAINLESS STEEL + 48 in. Na + 1/8 in. BORAL												
C. AXIAL MODIFIER + AXIAL SHIELD												
D. AXIAL MODIFIER + AXIAL SHIELD + 30 in. Na												
II. RADIAL MODIFIER												
A. 4 in. STAINLESS STEEL + 6 in. Na + 1 in. BORAL												
III. RADIAL MODIFIER + AXIAL SHIELD												
A. 4 in. STAINLESS STEEL + 6 in. Na + 1 in. BORAL + AXIAL SHIELD												
V. RADIAL SHIELD – STAINLESS STEEL vs B₄C SLABS												
A. W ASSEMBLY** + 10 in. B ₄ C SLAB												
B. AS ABOVE + AXIAL SHIELD												
C. AS ABOVE EXCEPT 10 in. STAINLESS STEEL REPLACES 10 in. B ₄ C SLAB												
D. W ASSEMBLY** + 10 in. STAINLESS STEEL SLAB												
VII. RADIAL MODIFIER + B₄C SLABS OR RODS												
A a. 1 ROW 5–1/4 in. RODS												
A a. 3 ROWS 5–1/4 in. RODS												
A b. 2 ROWS 5–1/4 in. RODS												
B a. 1 ROW 2 in. RODS												
C a. 4 ROWS 1 in. RODS												
D a. 1 ROW 0.6 in. SLABS												
D a. 2 ROWS 0.6 in. SLABS												
D a. 3 ROWS 0.6 in. SLABS												
D a. 4 ROWS OF 0.6 in. SLABS												
D b. 1 ROW 3.8 in. SLABS												
D b. 2 ROWS 3.8 in. SLABS												
D b. 3 ROWS 3.8 in. SLABS												
E a. 3 ROWS 5–1/4 in. RODS + 6 in. STAINLESS STEEL												
E b. 3 ROWS 5–1/4 in. RODS + AXIAL SHIELD												

*ORNL, WITHIN FY-73 FUNDING LIMITATIONS, PLANS TO ANALYZE A NUMBER OF THE CONFIGURATIONS TESTED.

**W ASSEMBLY = 4 in. STAINLESS STEEL + 6 in. Na + 1 in. BORAL + 10 in. BLANKET + 5 in. REFLECTOR.

Figure 3-3. Schedule for Completing the GE-BRD Portion* of the PA-62 Analytical Program

NOTE: Unfolded Hydrogen Counter Data from 1241A-SP27, 1241B-SP26, 124A-SP25.

Figure 3-4. Measured Neutron Spectrum on Beam Axis 12 inches Behind 18 inches of Type-304 Stainless Steel

NOTE: Unfolded Hydrogen Counter Data from 1240A, 1240B, and 1239A.

Figure 3-5. Measured Neutron Spectrum on Beam Axis 12 inches Behind 4 inches of Stainless Steel + 6 inches Sodium + 1 inch Boral

3.3 ANALYTICAL STUDIES

The following analytical activities were accomplished during the July-September 1972 quarter:

- 1D- S_n diffusion calculation comparison of GE-BRD and ORNL neutron cross sections for sodium
- 1D- S_n diffusion and transport calculation comparisons of GE-BRD and ORNL neutron cross sections for Type-304 stainless steel
- 1D- S_n transport calculations for the partial axial modifier, full axial modifier, and radial modifier
- MORSE Monte Carlo calculations for the partial axial modifier (18 inches of Type-304 stainless steel)

3.3.1 1D- S_n Diffusion Calculation Comparison of GE-BRD and ORNL Neutron Cross Sections for Sodium

Since both the axial and radial modifiers contain sodium slabs, it was deemed advisable to test the adequacy of the GE-BRD 24-group P_1 scattering matrix before performing extensive analyses of the experiments. This was possible because ORNL has done sodium benchmark calculations at the tower shielding facility (TSF) (References 1 to 9) and provided GE with 100-group P_3 sodium cross sections (MOD O ENDF/B-III) which have been used in these calculations and accurately predict neutron transport through sodium slabs with thicknesses as large as 15 feet.

In order to make a relatively inexpensive comparison test, the 100-group ORNL P_0 through P_3 cross section set was converted from ANISN format to the format required by the GE-BRD version of ANISN via the computer programs SNOAN and SNLIB. Both the ORNL 100-group set and the GE-BRD 24-group set were then used to predict the neutron transport through 30 inches of sodium by running the GE version of ANISN in the diffusion mode (thereby using P_0 and P_1 cross sections). Figures 3-6 and 3-7 show the results of these calculations. Neutron flux attenuation curves are shown for the total flux and four energy groups which summarize the results of the 24- or 100-group calculations. The total flux values from the two diffusion calculations agree quite closely, with the values at the 30-inch thickness differing by only ~6% and the higher result being given by the 24-group calculation. This difference in calculated total flux is due not only to the number of groups used in the calculations but also due to the fact that the GE-BRD 24- and ORNL 100-group sodium cross section libraries come from different data sets. Also, the ORNL 100-group sodium cross section set includes the effects of impurities in the sodium (400-ppm calcium, 200-ppm oxygen, 150-ppm potassium, and 60-ppm hydrogen) whereas the GE-BRD 24-group set represents pure sodium. The 1D- S_n transport calculation has not yet been done for the 100-group library but will be done later if time and budget allow.

3.3.2 1D- S_n Diffusion and Transport Calculation Comparisons of GE-BRD and ORNL Neutron Cross Sections for Type-304 Stainless Steel

For reasons analogous to those given for performing comparison calculations on the GE-BRD sodium cross sections, 1D calculations were performed using the GE version of ANISN in both the diffusion and transport modes to compare GE and ORNL cross sections for Type-304 stainless steel. For purposes of this comparison the 18-inches of Type-304 stainless steel configuration provided a convenient test problem. ORNL provided an improved, benchmark-tested 100-group P_3 Type-304 stainless steel cross section set which was developed during the recent iron and stainless steel benchmark experiments.^{10, 11, 12, 13} Figures 3-8 to 3-11 display the results of these calculations. As in the case of the sodium calculations, the 24-group and 100-group calculations are seen to agree fairly closely. There is only ~2% difference in the total flux predicted by the two cross section sets at the exit face of the 18-inch thick slab for the diffusion calculation. The difference in the total flux values at the exit face for the transport calculations was ~11%. In both diffusion and transport calculations the GE-BRD 24-group library gave the highest result. It should be emphasized that these differences in calculated total flux are due not only to the number of groups used in the calculations but also due to the fact that the GE-BRD 24- and ORNL 100-group Type-304 stainless steel cross section libraries come from different data sets.

Figure 3-6. Neutron Attenuation Through 2-1/2 feet of Sodium

Figure 3-7. Neutron Attenuation Through 2-1/2 feet of Sodium

Figure 3-8. Neutron Attenuation Through 18 inches of Type-304 Stainless Steel

Figure 3-9. Neutron Attenuation Through 18 inches of Type-304 Stainless Steel

Figure 3-10. Neutron Attenuation Through 18 inches of Type-304 Stainless Steel + 12 feet of Void

Figure 3-11. Neutron Attenuation Through 18 inches of Type-304 Stainless Steel + 12 feet of Void

3.3.3 1D-S_n Transport Calculations For Partial Axial Modifier, Full Axial Modifier, and Radial Modifier

Diffusion calculations reported in the last quarterly report¹⁴ were extended to the transport mode. In order to make comparisons with experimental Bonner ball response data given in Subsection 3.2, the mesh was extended to include a 12-foot void down beam from each of the three test assemblies considered. The three assemblies for which work was completed were (1) partial axial modifier (18 inches of Type-304 stainless steel), (2) complete axial modifier (18 inches of Type-304 stainless steel + 48 inches of Na + 1/8 inches of boral), and (3) radial modifier (4 inches of Type-304 stainless steel + 6 inches of Na + 1 inch of boral). The calculations were performed with the intent of geometrically transforming the results to account for the actual size of the TSR collimated neutron beam before direct comparison with experimental results. This transformation is discussed in Subsection 3.4.1. Figures 3-10 to 3-17 display the untransformed results of the calculations. Total flux, a 4-group summary of each 24-group calculation, and Bonner ball response for 3-, 6-, and 10-inch diameter Bonner balls are shown for an axial traverse out to 12 feet behind each assembly. In order to provide results that could be compared with experiment, it was necessary to make some reasonable assumptions with regard to buckling and void correction effects. The neutron beam modifier slabs used in the experiments consisted of square slabs of size 5 feet on a side. The buckling factor used in the calculations has the form:

$$B^2 = \left(\frac{\pi}{DY + 1.42/\Sigma_{tr}} \right)^2 + \left(\frac{\pi}{DZ + 1.42/\Sigma_{tr}} \right)^2$$

where $DY = DZ$ was set equal to 152.4 cm (5 feet). Reflector savings which might be provided by concrete surrounding the modifier slabs was neglected. The void correction used is the usual option available in the standard version of ANISN which follows the treatment given by Olsen.¹⁵ The half-height input to the program was 82.5 cm. This value was derived in the following way.

The buckling factor discussed above may be considered as appropriate to a cylinder which is equivalent to the square slabs in producing buckling effects. In the cylindrical case,

$$B^2 = \left(\frac{2.405}{R + 1.42/\Sigma_{tr}} \right)^2$$

If the above two expressions for B^2 are equated, R may be solved for and has the form:

$$R = \frac{2.405}{\sqrt{2} \cdot \pi} \left(DY + 1.42/\Sigma_{tr} \right) - 1.42/\Sigma_{tr}$$

or

$$R \cong \frac{2.405}{\sqrt{2} \cdot \pi} \quad DY = 82.5 \text{ cm.}$$

for $DY = 152.4 \text{ cm.}$

3.3.4 MORSE Monte Carlo Calculations for Partial Axial Modifier (18 Inches of Type-304 Stainless Steel)

The primary objectives of Monte Carlo calculations performed during the quarter were two-fold.

First, it was considered desirable to use a surface crossing estimation routine as well as a next flight estimation routine in MORSE in order to permit later comparisons of flux values internal to the Type-304 stainless steel with values obtained by using DOT III and also by using the GE version of ANISN.

Figure 3-12. Calculated Bonner Ball Response for Axial Traverse Behind 18 inches of Type-304 Stainless Steel

Figure 3-13. Calculated Bonner Ball Response for Axial Traverse Behind 18 inches of Type-304 Stainless Steel

Figure 3-14. Neutron Attenuation Through Axial Modifier + 12 feet of Void

Figure 3-15. Calculated Bonner Ball Response for Axial Traverse Behind Axial Modifier

Figure 3-16. Neutron Attenuation Through W-Modifier + 12 feet of Void

Figure 3-17. Calculated Bonner Ball Response for Axial Traverse Behind W-Modifier

The second objective was to test the feasibility of using the GE-BRD 24-group cross section library in multigroup Monte Carlo calculations.

In order to expedite the use of a surface crossing estimator in the Monte Carlo analysis of this experiment, input data and routines prepared by ORNL for their 100-group Monte Carlo analysis of this experiment were modified to include surface crossing estimation and associated detectors for four region boundaries internal to the Type-304 stainless steel. The problem was set up in such a way that both surface crossing and next flight estimation were operative during a single computer run. Partial results of this calculation (done for 50,000 histories) are shown in Table 3-6.

Table 3-6
COMPARISON BETWEEN TWO MONTE CARLO CALCULATIONS OF NEUTRON FLUX
TRANSMITTED THROUGH THE PARTIAL AXIAL MODIFIER
(18 INCHES OF TYPE-304 STAINLESS STEEL)

Computer Run	Total Neutron Flux (n/cm ² ·min-watt)					
	Detector No. 1		Detector No. 2		Detector No. 3	
	x = 0.0 cm y = 0.0 z = 80.645		x = 0.0 cm y = 0.0 z = 233.04		x = 0.0 cm y = 0.0 z = 405.76	
	ϕ	F.S.D.*	ϕ	F.S.D.	ϕ	F.S.D.
ORNL 100-group P ₃ scattering matrix + ORNL point totals for Type-304 stainless steel (50,000 histories)	1.6283 + 3	0.03129	1.1953 + 2	0.02639	3.4275 + 1	0.03021
GE-BRD 24-group P ₃ scattering matrix + ORNL point totals for Type-304 stainless steel (50,000 histories)	2.3745 + 3	0.04511	1.7492 + 2	0.02474	5.0296 + 1	0.02607

*Fractional Standard Deviation

In order to accomplish the second objective, 100-group data for the towering shielding reactor (TSR) neutron source were collapsed to the 24-group structure corresponding to the BRD cross-section library. The 18-inch Type-304 stainless steel configuration was modeled by using the finite slab geometry option of MORSE and by locating detector points at 1 foot, 6 feet, and 12 feet on axis behind the back face of the slab. Figure 3-18 is a diagram of the geometry used in the calculation. It should be noted that source enhancement effects due to multiple scattering in the concrete collimator were neglected. The effects of concrete blocks surround the Type-304 stainless steel slabs and the effects of air attenuation were also neglected. Bonner ball response data which had been prepared initially for the 24-group 1D-S_n calculations discussed in Subsection 3.3.3 were used in the calculation for estimating the response of the 3-, 6-, and 10-inch diameter Bonner balls at the detector points. GE-BRD 24-group P₃ scattering matrices + ORNL "point" total cross sections for Type-304 stainless steel were used. The "point" total cross sections were incorporated in MORSE for use in sampling collision sites and in next-flight estimation; they were not used in calculating the uncollided flux since this component is a very small part of the total flux. Table 3-6 shows partial results of this calculation which was analogous to the 100-group calculation described above. Variance reduction techniques used in these two Monte Carlo calculations consisted of energy dependent path stretching and Russian roulette. Figures 3-19 and 3-20 display biasing and geometry parameters for the two Monte

Figure 3-18. TSR-II + 18 inches of Type-304 Stainless Steel + 12 feet of Void

INITIAL RANDOM NUMBER = P29482E2CA5D

NSPLT= 0. NKILL= 1 NPAST= 1 NOLEAK= 1 ICRAS= 0 MXPEG= 5 MAXGP=100

WEIGHT STANDARDS FOR SPLITTING AND RUSSIAN ROULETTE AND PATHLENGTH STRETCHING PARAMETERS

NGP1	NDG	NGP2	NRG1	NRPG	NRG2	WTPIH1	WTLOW1	WTAVE1	XNU
1	1	58	1	1	5	0.0	1.0000E-02	1.1000E-02	0.0
59	1	100	1	1	4	0.0	1.0000E-02	1.1000E-02	0.5000E 00
59	1	100	5	1	5	0.0	1.0000E-02	1.1000E-02	0.0

NSOUR= 0 MFISTP= 0 NKCALC= 0 NORMF= 0

MEDIUM 7 BOUNDARY

1	0.0
2	0.15560D 02
1	0.23180D 02
2	0.30922D 02
1	0.38703D 02

VOID BEYOND Z= 0.46568D 02

REGION 1 Z BOUNDARY

1	0.0
2	0.15560D 02
3	0.23180D 02
4	0.30922D 02
5	0.38703D 02
6	0.46568D 02

FINITE SLAB GEOMETRY

X LOWER BOUNDARY = -0.7620D 02	X UPPER BOUNDARY = 0.7620D 02
Y LOWER BOUNDARY = -0.7620D 02	Y UPPER BOUNDARY = 0.7620D 02

NGFOM= 12712, NGLAST= 12711

Figure 3-19. Biasing and Geometry Parameters for 100-Group Monte Carlo Calculation
(18 inches of Type-304 Stainless Steel + 12 feet of Void)

INITIAL RANDOM NUMBER = B29482E2CA5D

NSPLT= 0 NKILL= 1 NPAST= 1 NOLEAK= 1 IEBIAS= 0 MXREG= 5 MAXGP= 24

WEIGHT STANDARDS FOR SPLITTING AND RUSSIAN ROULETTE AND PATHLENGTH STRETCHING PARAMETERS

NGP1	NDG	NGP2	NRG1	NDRG	NRG2	WTHI1	WTLOW1	WTAVE1	XNU
1	1	14	1	1	5	0.0	1.0000E-02	1.1000E-02	0.0
15	1	24	1	1	4	0.0	1.0000E-02	1.1000E-02	0.5000E 00
15	1	24	5	1	5	0.0	1.0000E-02	1.1000E-02	0.0

NSOUR= 0 MFISTP= 0 NKCALC= 0 NORMF= 0

MEDIUM Z BOUNDARY

1	0.0
2	0.155600 02
1	0.231800 02
2	0.309220 02
1	0.387030 02

VOID BEYOND Z= 0.465680 02

REGION Z BOUNDARY

1	0.0
2	0.155600 02
3	0.231800 02
4	0.309220 02
5	0.387030 02
6	0.465680 02

FINITE SLAB GEOMETRY

X LOWER BOUNDARY = -0.76200 02 X UPPER BOUNDARY = 0.76200 02
Y LOWER BOUNDARY = -0.76200 02 Y UPPER BOUNDARY = 0.76200 02

NGEOM= 3060, NGLAST= 3059

Figure 3-20. Biasing and Geometray Parameters for 24-Group Monte Carlo Calculation
(18 inches of Type-304 Stainless Steel + 12 feet of Void)

Carlo calculations. The path-stretching parameter, XNU, was assigned a value of 0.5 for all regions but only for particles having energies above 10 keV. Russian roulette was invoked for all regions for particles whose weight fell below 1.0×10^{-2} and a weight of 1.1×10^{-2} was assigned to surviving particles.

3.4 COMPARISONS BETWEEN EXPERIMENTAL AND CALCULATED DATA

The Bonner ball and hydrogen counter experimental data received from ORNL and discussed in Subsection 3-2 was used in making comparisons with calculated results for the partial axial modifier (18 inches of Type-304 stainless steel) and the radial modifier (4 inches of Type-304 stainless steel + 6 inches of Na + 1 inch of boral) configurations. Bonner ball response values for 3-, 6-, and 10-inch diameter balls, and neutron energy spectrum comparisons are presented in this section.

3.4.1 Transformed 1D-S_n Bonner Ball Response Results

Inspection of the figures presented in Subsection 3.3.3 shows that the untransformed one dimensional S_n, P₁ transport results do not agree very well with the experimental data. This disagreement can largely be attributed to geometrical effects. Because one-dimensional calculations are relatively inexpensive to perform, it was deemed worthwhile to attempt to find a way of geometrically transforming the calculated results to a form more closely resembling the actual TSR neutron beam geometry than was possible in the basic 1D-S_n calculation. This was done by noting that the buckling factor and void correction half-height used in the calculations (derived on the basis of the size of the square modifier slabs) actually correspond to a disk source of considerably larger radius than that of the TSR neutron source (82.5 cm as compared to 19.67 cm for the radius of the TSR beam). The necessary transformation factors for flux and Bonner ball responses were then calculated according to a scheme based on a formula given for the flux at a point due to an isotropic disk source with slab shield.¹⁸ The ratio of the group flux due to the actual TSR source disk to the ANISN-calculated group flux is given by:

$$\frac{\phi_d(E_n)}{\phi_D(E_n)} \equiv T_n = \frac{\pi}{2} \left[1 - \frac{\mathcal{E}_1(b_1 \sec \theta_1)}{\mathcal{E}_1(b_1)} \right] / \left[1 - \frac{\mathcal{E}_1(b_1 \sec \theta_2)}{\mathcal{E}_1(b_1)} \right]$$

where

T_n = flux transformation factor for energy group E_n

E_n = n th energy group

$$b_1 = \sum_{i=1}^N \mu_i(E_n) t_i$$

$\mu_i(E_n)$ = macroscopic cross section of i th shield slab for n th energy group (cm^{-1})

t_i = thickness of i th shield slab (cm)

N = number of shield slabs

θ_1 = half-angle subtended at the detector point or mesh interval of interest by actual TSR source disk

θ_2 = half-angle subtended at the detector point or mesh interval of interest by buckling — related large source disk

$$\mathcal{E}_1(b) = \int_b^{\infty} \frac{e^{-x}}{x} dx, \quad \text{exponential integral function}$$

The factor of $\pi/2$ was included to transform the 1D-S_n results from radial average to centerline (axial) value. The transformation factor, T, for the total flux at a given mesh interval was then calculated by weighting the group transformation factors with the group fluxes, i.e.,

$$T = \frac{\sum_n (T_n \cdot \Phi(E_n))}{\sum_n \Phi(E_n)}$$

where $\Phi(E_n)$ is the 1D-S_n calculated flux for the nth energy group at the mesh interval of interest.

Similarly, the transformation factor, R, for Bonner ball response at the mesh interval of interest is given by:

$$R = \frac{\sum_n (T_n \cdot \Phi(E_n) \cdot R(E_n))}{\sum_n (\Phi(E_n) \cdot R(E_n))}$$

where

$$R(E_n) = \text{Bonner ball response for the } n \text{ th energy group (counts/incident neutron } -\text{cm}^{-2}\text{)}.$$

To facilitate the calculation of these transformation factors, the exponential integral function, $E_1(b)$, was approximated for numerical computation by modifying a FORTRAN subroutine given by DeBeer.¹⁷ The (multiplicative) transformation factors computed by this method are tabulated in Tables 3-7 and 3-8. The 1D-S_n data corrected in this way are plotted in Figures 3-21 to 3-26 which also show experimental and Monte Carlo results. It should be noted that background count rates have been subtracted from foreground count rates before plotting the experimental data. The agreement with experimental results is reasonable but not exceptionally good. However, the slope of curves of transformed 1D-S_n data compared to experimental data is consistent with underestimating the anisotropic, forward peaked, nature of the collimated TSR neutron beam. The ratio of buildup factors for the two different size source disks is therefore probably space and energy dependent and different from the value of 1.0 assumed in the formula for T_n .

The transformation factors calculated on a group-wise basis were used for the neutron energy spectra comparisons shown in Figures 3-27 and 3-28 for a detector location 1 foot behind the 18 inches of Type-304 stainless steel partial axial modifier and 1 foot behind the radial modifier. The spectrum comparisons extend to a high energy limit of only about 1 MeV corresponding to the upper energy limit of hydrogen counter data. The higher energy NE213 data were not available for the 1-foot locations (the closest axial position for the NE213 spectrometer was 47-11/16 inches from the back face of the Type-304 stainless steel).

3.4.2 Monte Carlo Results

Bonner ball responses calculated for the 18-inch Type-304 stainless steel case as described in Subsection 3.3.4 have been plotted in Figures 3-21 to 3-23. It is encouraging to note that the 24-group data agree reasonably well with the experimental data. The 24-group response values are seen to be consistently higher than the 100-group values by a factor of about 1.3 for the 3-inch diameter Bonner ball and a factor of about 1.6 for the 6- and 10-inch diameter Bonner balls. Monte Carlo-calculated neutron energy spectra comparisons with experimental data are shown in Figures 3-29 and 3-30 for the 24- and 100-group 18-inch Type-304 stainless steel calculations. As in the 1D-S_n calculated vs experiment spectrum figures, the comparisons extend to a high energy limit of only about 1 MeV corresponding to the upper energy limit of the hydrogen counter data.

Table 3-7
FLUX TRANSFORMATION FACTORS, T, FOR 1D-S_n
TRANSPORT CALCULATIONS

Calculation Done for	<u>Distance of Center of Detection Behind Slabs (ft)</u>			
	0	1	6	12
18-in. Type-304 Stainless Steel	1.2386*	0.7122	0.1569	0.1082
Axial Modifier	0.4354	0.3361	0.1689	0.1225
Radial Modifier	0.2557	0.1789	0.1043	0.0944

*Note: These values of T are to be multiplied times the appropriate fluxes given in Figures 3-10, 3-14, and 3-16 to get the transformed flux values.

Table 3-8
BONNER BALL RESPONSE TRANSFORMATION
FACTORS, R, FOR 1D-S_n TRANSPORT CALCULATIONS

Calculation Done for	<u>Distance of Center of Detection Behind Slabs (ft)</u>			
	0	1	6	12
3-in. Ball				
18-in. of Type-304 stainless steel	1.3597*	0.8756	0.1934	0.1158
Axial Modifier	0.4645	0.3509	0.1670	0.1233
Radial Modifier	0.3069	0.2069	0.1090	0.0960
6-in. Ball				
18-in. of Type-304 stainless steel	1.2243	0.6965	0.1619	0.1051
Axial Modifier	0.4299	0.3321	0.1696	0.1224
Radial Modifier	0.2565	0.1800	0.1045	0.0946
10-in. Ball				
18-in. of Type-304 stainless steel	1.1619	0.6282	0.1503	0.1046
Axial Modifier	0.4042	0.3189	0.1759	0.1192
Radial Modifier	0.2361	0.1693	0.1029	0.0944

*Note: These values of R are to be multiplied times the appropriate Bonner ball responses given in Figures 3-12, 3-15, and 3-17 to get the transformed Bonner ball response values.

Figure 3-21. Calculated and Measured 3-inch Bonner Ball Response Behind 18 inches of Type-304 Stainless Steel

Figure 3-22. Calculated and Measured 6-inch Bonner Ball Response Behind 18 inches of Type-304 Stainless Steel

Figure 3-23. Calculated and Measured 10-inch Bonner Ball Response Behind 18 inches of Type-304 Stainless Steel

Figure 3-24. Calculated and Measured 3-inch Bonner Ball Response Behind Radial Modifier

Figure 3-25. Calculated and Measured 6-inch Bonner Ball Response Behind Radial Modifier

Figure 3-26. Calculated and Measured 10-inch Bonner Ball Response Behind Radial Modifier

Figure 3-27. Comparison of Unfolded Hydrogen Counter Spectra with Transformed 1D-S_n Calculations for 18 inches of Type-304 Stainless Steel

Figure 3-28. Comparison of Unfolded Hydrogen Counter Spectra with Transformed 1D-S_n Calculations for Radial Modifier

Figure 3-29. Comparison of Unfolded Hydrogen Counter Spectra with MORSE 24-Group Calculations for 18 inches of Type-304 Stainless Steel

Figure 3-30. Comparison of Unfolded Hydrogen Counter Spectra with MORSE 100-Group Calculations for 18 inches of Type-304 Stainless Steel

4. ADMINISTRATIVE

4.1 TRIPS

M. L. Weiss and D. R. Wilkins to ORNL, August 2 to 4, 1972.

W. H. Harless to ORNL, September 20 to 28, 1972.

4.2 VISITS

D. R. Riley, RDT, Chief, Core Design Branch, on August 17, 1972.

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