LIQUID METAL REACTOR PROGRAM

JASPER

USDOE/PNC Shielding Research Program

Technical Progress Report

February 1 - March 31, 1987

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INTRODUCTION

Previous reports (ORNL/LMR/AC-86/3-6) covered the measurements and results from the Radial Shield Attenuation Experiment. During this reporting period, the measurements for the Fission Gas Plenum Experiment were completed and the results are enclosed. The spectrum modifier (SM) was the same as SM1 in the previous experiment (Fe, Al, boral, and "radial blankets").

EXPERIMENTAL PROGRAM

Instrumentation

The instrumentation used in this experiment, except for the Hornyak button, has been described in reference 1. The Hornyak button consists of a disk of lucite containing very small particles of zinc sulfide dispersed uniformly throughout. The button has a response that closely approaches that of a single collision dose, but for this experiment its response was altered somewhat, as discussed below. For these measurements the button was 0.635 cm in diameter, 0.159 cm thick, and mounted on an RCA photomultiplier tube. Calibration procedures would normally consist of first exposing the scintillator to a 2 R/h gamma-ray dose rate and adjusting the gain of the amplifier to obtain approximately 40 counts per minute for a pulse height setting (PHS) of 60. The button would then be exposed to a known strength ^{252}Cf neutron source for the same PHS and the dose rate to count rate ratio obtained. However, for this series of measurements, a part of the calibration procedure was changed. The gain was adjusted using the Co60 source as described above, but the neutron calibration was done at a PHS of 350 instead of 60. This was necessary because measurements behind the mockups would be in a much higher gamma-ray field than 2 R/h, and the higher bias would be necessary to discriminate against the gamma-induced pulses. By the same token, raising the bias also discriminates against neutron pulses of similar magnitude, pulses that would be part of a true neutron dose rate measurement. At what neutron energy this new cut off occurs cannot be easily determined, thus making it difficult to provide absolute numbers for calculational comparisons. The measurements can, however, provide shape of the neutron distribution behind the mockups and, when normalized to data at 30 cm, can provide values for comparison to calculations. We recognize this difficulty, but, for the sake of continuity in discussing the results, the measurements are given in terms of dose rate per watt.

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Spectrum Modifier

A schematic of the SM is included as part of Figure 1. Analysis of the various materials that mock up the SM are given in previous reports.^{1,2}

Heterogeneous Fission Gas Plenums

The designs of the fission gas plenums shown in Figure 2 were based on a compromise between several different U.S. and Japanese reactor designs and the availability of stock stainless steel tubing. The tubing which was selected had a 7.93 mm OD and a wall thickness of 0.508 mm. A total of 512 tubes comprised the heterogeneous part of the plenum. With this many tubes, the volume fraction for SS was 16%, while that for sodium was 33%, and for air (void) it was 51%. Since fabricating plenums with sodium was not feasible for this program the sodium was replaced by aluminum. Two plenum thicknesses were studied, 8 cm and 20 cm. In the mockups, the SM and reactor are located to the right of the designs shown in Figure 2. A photograph of the 8-cm heterogeneous plenum in the mockup is given in Figure 3.

Homogeneous Fission Gas Plenums

The quantities of the Al and SS sheets mocking up the homogeneous plenums were based on the designs of the heterogeneous plenums, keeping the same SS, Al, and air (void) volume fractions. Designs for both the 8-cm- and 20-cm-thick plenums are shown in Figure 4. In the configuration, the SM and reactor are located to the right of the designs in Figure 4.

Measurements

All of the measurements listed in the experimental program plan (see Appendix A) were completed during this reporting period. Bonner ball measurements along centerline behind the SM were repeated at the start of this experiment (Item I of data plan) to verify the continuity in source term from the previous experiment. Results at 30 cm behind the SM are given in Table 1 for all five balls, while the measurements at 304.8 cm from the reactor are given in Table 2. Measurements with the Hornyak button were included in this experiment, with the results from a horizontal traverse at 2 cm behind the SM given in Table 3. A single measurement with this detector on centerline at 30 cm is contained in Table 4.

Similar measurements were made behind each of the gas plenums as they were placed in the configurations. These results are contained in the respective tables noted for the measurements behind the SM. Plots of the traverses obtained with the Hornyak button directly behind the plenums are given in Figures 5 and 6. In addition, results from horizontal traverses at 30 cm behind the mockups with the 5-in Bonner ball are given in Table

5. Neutron spectral measurements with the NE 213 and hydrogen counters behind the homogeneous plenum (Item III of data plan) are plotted in Figures 7 and 8, and listed in Tables 6 and 7. The same measurements behind the heterogeneous plenum (Item V) are plotted in Figures 9 and 10, and listed in Tables 8 and 9. The 3-, 5-, and 10-in Bonner ball measurements at the NE 213 locations are given in Table 10.

ANALYSIS

Attenuation Experiment

As stated in the previous progress report, configurations II.A and VI.A were recalculated with updated data and the results were in better agreement with experimental results. Fig. 11 shows a comparison of the calculated and measured neutron spectrum for Configuration VI.A. The spectrum measurement Configurations II.D and VI.F were also recalculated using source input from Configurations II.A and VI.A, respectively. Comparisons of calculated and measured spectra are shown in Figs. 12 and 13. The agreement is much better than that previously obtained. For Configuration II.D, the improvement is attributed mainly to the newer ^{11}B cross-section set mentioned in the previous progress report. The jump in the measured curve around 1.0 MeV is nearly matched by that in the calculated curve now, whereas there was a large discrepancy before (August-September 1986 progress report, ORNL/LMR/AC-86/6). This might be due to the lower ^{11}B total cross section immediately below 1.0 MeV (see Fig. 1 in the December 1986-January 1987 progress report, ORNL/LMR/AC-87/2). Neutron transmission through the steel and B₄C is overpredicted in the 3 to 10 MeV energy range, while it is almost uniformly underpredicted below 1.0 MeV. Thus, satisfactory agreement has been achieved for previously calculated configurations for which the results were not in close agreement with measured results.

In addition to the above configurations, calculations were performed for all Configurations IV and VII and for the remaining Configurations VI (for which the incorrect graphite density was used in earlier calculations). Fig. 14 shows the spectrum comparison for Configuration IV.C and Table 11 shows calculation-to-experiment ratios (C/E's) for the 3-, 5-, and 10-in. Bonner balls for several configurations. The spectrum agreement is good and the Bonner ball count rate agreement is generally good. Configurations IV.G, IV.H, and IV.I show evidence that a background radiation problem may be responsible for the poor agreement for these configurations. The calculated results agreed much better with those measurements that had a large background component subtracted than they did with those that didn't. The agreement with the *in situ* measurement results (Configurations IV.IA, IV.J, IV.K, IV.L, and IV.M) is generally very good and appears to improve with the number of sodium tanks included in the configurations. While this could be due to overprediction of the neutron transmission through sodium, the increase in the C/E per tank is relatively small; so any overprediction can be classified as slight. Certainly, the background problem was mostly eliminated with the *in situ*

measurements. The C/E's for Configurations VI and VII fluctuate with increasing configuration size. Background radiation effects are small compared to those for the large Configurations IV.

In summary, the use of the 61-group cross-section library with the newer Fe and ^{11}B cross-section sets and the corrected graphite density resulted in good agreement of most calculated results with measured results. The new ^{11}B cross sections had a large effect on Configuration II.D because of the large amount of B_4C present and because of the hard neutron spectrum emerging from the UO_2 blankets. Results from 1-D calculations showed little effect for the Alternate Shielding Materials Experiment configurations (which did not include the UO_2 blankets). Thus design calculations through thick B_4C regions might need to be reexamined only for those cases where the incident spectrum contains a significant source fraction above 0.1 MeV.

Gap Streaming Experiment

One-dimensional calculations were performed to try to determine a suitable spectrum modifier for the gap streaming experiment. The goal was to match as closely as possible a soft neutron spectrum found below the rotating shield plug in a fast reactor design and to limit the attenuation of the TSR-II source by the spectrum modifier to about 10^5 . This attenuation would allow measurements to be made behind shields which attenuate up to 10^4 .

A preliminary spectrum modifier design consisting of 45 cm of carbon steel plus 122 cm of sodium plus 20 cm of graphite plus 61 cm of sodium appears to give a satisfactory match with the design neutron spectrum as shown in Fig. 15. With carbon steel, the 10-in. Bonner ball count rate is attenuated by a factor of 1.3×10^5 by the spectrum modifier. Stainless steel attenuates about 1.4 to 1.5 times as much as carbon steel does. The graphite tends to make the agreement better at high energies and in the 10-1000 eV range. Without the graphite, the high-energy portion of the spectrum would be well below the design spectrum and that in the 10-1000 eV range would be shifted upward to compensate.

REFERENCES

1. D. T. Ingersoll et al. *Liquid Metal Reactor Program Technical Progress Report - JASPER Shielding Program*, ORNL/LMR/AC-86/3 (July 1986).
2. D. T. Ingersoll et al. *Liquid Metal Reactor Program Technical Progress Report - JASPER Shielding Program*, ORNL/LMR/AC-86/4 (September 1986).

Appendix A
Experimental Program Plan for the
Fission Gas Plenum Experiment

I. Spectrum Modifier

A. Spectrum Modifier (SM) (10cm Fe + 10cm Al + 2.5cm boron
+ 20.32cm Radial Blanket)

1. 0.635-cm Hornyak button horizontal traverse as close as possible behind SM
2. CR-39 dosimeter map directly behind SM
3. 3-, 5-, 8-, 10-, 12-in Bonner ball measurements on centerline:
 - a. at 30cm behind SM
 - b. at 304.8cm from reactor centerline (Foreground and Background)
4. 0.635-cm Hornyak button on centerline at 30cm behind SM

II. 8-cm Homogeneous Fission Gas Plenum (FGP) Mockup

A. SM + 8-cm Homogeneous FGP Mockup

1. 0.635-cm Hornyak button horizontal traverse as close as possible behind FGP mockup
2. CR-39 dosimeter map directly behind FGP mockup
3. 3-, 5-, 8-, 10-, 12-in Bonner ball measurements on centerline:
 - a. at 30cm behind FGP mockup
 - b. at 304.8cm from reactor centerline (Foreground and Background)
4. 0.635-cm Hornyak button on centerline at 30cm behind FGP mockup
5. 5-in Bonner ball horizontal traverse at 30cm behind FGP mockup

III. 20-cm Homogeneous Fission Gas Plenum Mockup

A. SM + 20-cm Homogeneous FGP Mockup

1. 0.635-cm Hornyak button horizontal traverse as close as possible behind FGP mockup
2. CR-39 dosimeter map directly behind FGP mockup
3. 3-, 5-, 8-, 10-, 12-in Bonner ball measurements on centerline:
 - a. at 30cm behind FGP mockup
 - b. at 304.8cm from reactor centerline (Foreground and Background)
4. 0.635-cm Hornyak button on centerline at 30cm behind FGP mockup
5. 5-in Bonner ball horizontal traverse at 30cm behind FGP mockup
6. NE-213 and Hydrogen counter spectrum measurements on centerline as close as feasible behind configuration
7. 3-, 5-, 10-in Bonner ball measurements on centerline at location of NE-213/H counter spectrum measurements

IV. 8-cm Heterogeneous Fission Gas Plenum Mockup

A. SM + 8-cm Heterogeneous FGP Mockup

1. 0.635-cm Hornyak button horizontal traverse as close as possible behind FGP mockup
2. CR-39 dosimeter map directly behind FGP mockup
3. 3-, 5-, 8-, 10-, 12-in Bonner ball measurements on centerline:
 - a. at 30cm behind FGP mockup
 - b. at 304.8cm from reactor centerline (Foreground and Background)
4. 0.635-cm Hornyak button on centerline at 30cm behind FGP mockup
5. 5-in Bonner ball horizontal traverse at 30cm behind FGP mockup

V. 20-cm Heterogeneous Fission Gas Plenum Mockup

A. SM + 20-cm Heterogeneous FGP Mockup

1. 0.635-cm Hornyak button horizontal traverse as close as possible behind FGP mockup
2. CR-39 dosimeter map directly behind FGP mockup
3. 3-, 5-, 8-, 10-, 12-in Bonner ball measurements on centerline:
 - a. at 30cm behind FGP mockup
 - b. at 304.8cm from reactor centerline (Foreground and Background)
4. 0.635-cm Hornyak button on centerline at 30cm behind FGP mockup
5. 5-in Bonner ball horizontal traverse at 30cm behind FGP mockup
6. NE-213 and Hydrogen counter spectrum measurements on centerline as close as feasible behind configuration
7. 3-, 5-, 10-in Bonner ball measurements on centerline at location of NE-213/H counter spectrum measurements

Table 1. Bonner ball measurements on centerline at 30 cm behind a series of configurations (Items I, II, III, IV, V)

Configuration ^a	Bonner ball count rates ($s^{-1}W^{-1}$)				
	3-inch diam ball	5-inch diam ball	8-inch diam ball	10-inch diam ball	12-inch diam ball
I	6.53 (2) ^b	3.12 (3) 3.21 (3)	2.18 (3)	1.16 (3)	5.28 (2)
II	5.85 (2)	2.21 (3)	1.41 (3)	7.23 (2)	3.58 (2)
III	3.07 (2)	1.09 (3)	6.98 (2)	3.53 (2)	1.74 (2)
IV	5.89 (2)	2.19 (3)	1.50 (3)	7.33 (2)	3.49 (2)
V	3.10 (2)	1.09 (3)	7.12 (2)	3.61 (2)	1.73 (2)

^aSee experimental program plan in Appendix A for description of configurations.

^bRead: 6.53×10^2 .

Table 2. Bonner ball measurements on centerline at 304.8 cm from the center of the reactor (Items I, II, III, IV, V).

Configuration ^a	Bonner ball count rates ($s^{-1}W^{-1}$)									
	3-inch Diam Ball		5-inch Diam Ball		8-inch Diam Ball		10-inch Diam Ball		12-inch Diam Ball	
	Foreground ^b	Background ^c	Foreground	Background	Foreground	Background	Foreground	Background	Foreground	Background
I	1.09 (2) ^d	2.04 (1)	4.61 (2)	5.07 (1)	3.20 (2)	2.58 (1)	1.59 (2)	1.20 (1)	7.37 (1)	5.24 (0)
II	1.05 (2)	1.36 (1)	3.10 (2)	2.76 (1)	1.83 (2)	1.25 (1)	9.40 (1)	5.79 (0)	4.56 (1)	2.58 (0)
III	4.29 (1)	4.20 (0)	1.33 (2)	8.66 (0)	8.56 (1)	4.12 (0)	4.38 (1)	1.95 (0)	2.19 (1)	8.77 (-1)
IV	1.01 (2)	1.46 (1)	3.13 (2)	2.97 (1)	1.91 (2)	1.37 (1)	9.15 (1)	6.19 (0)	4.44 (1)	2.51 (0)
V	4.49 (1)	4.29 (0)	1.38 (2)	8.79 (0)	8.64 (1)	4.17 (0)	4.53 (1)	1.96 (0)	2.22 (1)	8.77 (-1)

^aSee experimental program plan in Appendix A for description of configurations.

^bNeutron flux without shadow shield between detector and configurations.

^cNeutron flux with shadow shield between detector and configurations.

^dRead: 1.09×10^2 .

Table 3. Hornyak button traverses through horizontal midplane
1.6* cm behind a series of mockups (Items I, II, III, IV, V)

Distance from Centerline (cm)	0.635-cm-diam Hornyak button dose rate (erg/g·h·W)				
	Item I ^a	Item II ^a	Item III ^a	Item IV ^a	Item V ^a
71.2 S	6.39 (-2) ^b				
70					8.64 (-3)
69.6			9.41 (-3)		
65		4.21 (-2)		3.94 (-2)	
60	1.18 (-1)	5.74 (-2)	1.69 (-2)		
55					1.96 (-2)
50				8.33 (-2)	
45	2.14 (-1)	1.04 (-1)	3.41 (-2)		
40					3.73 (-2)
35				1.42 (-1)	
30	3.08 (-1)	2.08 (-1)	1.00 (-1)		
25					1.19 (-1)
22.5		2.60 (-1)	1.37 (-1)		
20				2.59 (-1)	
15	3.46 (-1)	2.74 (-1)	1.54 (-1)	2.66 (-1)	1.44 (-1)
13					1.47 (-1)
12.5				2.71 (-1)	
11					1.47 (-1)
10		2.84 (-1)	1.60 (-1)	2.73 (-1)	
9					1.52 (-1)
7					1.53 (-1)
5				2.80 (-1)	1.54 (-1)
2					1.55 (-1)
0	3.74 (-1)	2.85 (-1)	1.63 (-1)	2.84 (-1)	1.54 (-1)
.1				2.82 (-1)	1.56 (-1)
.2				2.80 (-1)	1.55 (-1)
.3				2.73 (-1)	1.53 (-1)
.4				2.83 (-1)	
.5				2.83 (-1)	1.55 (-1)
.6				2.83 (-1)	1.59 (-1)
.7				2.80 (-1)	1.53 (-1)
.8				2.76 (-1)	1.54 (-1)
.9				2.80 (-1)	1.56 (-1)
1.0				2.79 (-1)	1.57 (-1)
1.1				2.81 (-1)	1.56 (-1)
1.2				2.80 (-1)	1.57 (-1)
1.3				2.79 (-1)	
1.4				2.81 (-1)	
1.5				2.80 (-1)	
5				2.76 (-1)	1.53 (-1)
10		2.85 (-1)	1.61 (-1)	2.70 (-1)	1.50 (-1)
15	3.50 (-1)	2.77 (-1)	1.52 (-1)	2.69 (-1)	1.41 (-1)
20				2.62 (-1)	
22.5		2.53 (-1)	1.34 (-1)		
25					1.18 (-1)
26.5				2.33 (-1)	
30	2.78 (-1)	2.02 (-1)	9.81 (-2)		
31.5					8.22 (-2)
35				1.37 (-1)	
40					3.67 (-2)
45	1.93 (-1)	1.00 (-1)	3.18 (-2)		
50				8.62 (-2)	
55					1.94 (-2)
60	1.05 (-1)	5.43 (-2)	1.64 (-2)		
65		3.98 (-2)		3.90 (-2)	
69.6			9.22 (-3)		
70					8.77 (-3)
71.9 N	5.05 (-2)				

^aSee experimental program plan in Appendix A for description of configurations.

^bRead: 6.39×10^{-2} .

*Data run at 2.0 cm for Item I.

Table 4. Hornyak button measurements on centerline at 30 cm behind a series of mockups (Items I, II, III, IV, V)

Configuration ^a	0.635-cm-diam Hornyak button (erg/g·h·W)
I	2.21 (-1) ^b
II	1.50 (-1)
III	7.36 (-2)
IV	1.46 (-1)
V	6.88 (-2)

^aSee experimental program plan in Appendix A for description of configurations.

^bRead: 2.21×10^{-1} .

Table 5. 5-inch Bonner ball horizontal traverse through midplane at 30 cm behind a series of configurations (Items II, III, IV, V).

Distance from centerline (cm)	Bonner Ball count rates ($s^{-1}W^{-1}$)			
	Item II ^a	Item III ^a	Item IV ^a	Item V ^a
76.2 S				1.73 (2)
70	7.17 (2) ^b	2.09 (2)	7.02 (2)	
60	9.51 (2)	2.97 (2)	9.25 (2)	2.85 (2)
45	1.36 (3)	4.97 (2)	1.35 (3)	4.91 (2)
30	1.77 (3)	7.56 (2)	1.78 (3)	7.58 (2)
22.5	1.98 (3)	8.98 (2)	1.94 (3)	9.28 (2)
15	2.11 (3)	9.86 (2)	2.06 (3)	1.03 (3)
13				1.06 (3)
11				1.07 (3)
10	2.16 (3)	1.04 (3)	2.12 (3)	
5				1.12 (3)
0	2.30 (3)	1.10 (3)	2.18 (3)	1.13 (3)
10	2.21 (3)	1.05 (3)	2.19 (3)	1.08 (3)
15	2.11 (3)	1.03 (3)	2.13 (3)	1.03 (3)
22.5	1.97 (3)	9.01 (2)	1.88 (3)	
30	1.74 (3)	7.74 (2)	1.76 (3)	8.01 (2)
45	1.33 (3)	5.14 (2)	1.33 (3)	5.11 (2)
60	9.19 (2)	2.93 (2)	9.35 (2)	2.97 (2)
70	6.78 (2)		6.94 (2)	
76.2 N				1.72 (2)

^aSee experimental program plan in Appendix A for description of configurations.

^bRead: 7.17×10^2 .

Table 6. Spectrum of high-energy neutrons (>0.8 MeV)
on centerline 43.6 cm beyond 20-cm homogeneous fission
gas plenum (Item III): Run 7866A

Neutron Energy (MeV)	Flux (neutrons $\text{cm}^{-2}\text{MeV}^{-1}\text{kW}^{-1}\text{s}^{-1}$)		Neutron Energy (MeV)	Flux (neutrons $\text{cm}^{-2}\text{MeV}^{-1}\text{kW}^{-1}\text{s}^{-1}$)	
	Lower Limit	Upper Limit		Lower Limit	Upper Limit
8.11 (-1)	3.60 (4)	3.65 (4)	5.94 (0)	9.73 (2)	1.01 (3)
9.07 (-1)	3.70 (4)	3.73 (4)	6.25 (0)	7.94 (2)	8.42 (2)
1.01 (0)	3.35 (4)	3.38 (4)	6.56 (0)	6.72 (2)	7.11 (2)
1.11 (0)	2.95 (4)	2.97 (4)	6.84 (0)	5.78 (2)	6.05 (2)
1.20 (0)	2.61 (4)	2.63 (4)	7.24 (0)	4.57 (2)	4.78 (2)
1.31 (0)	2.33 (4)	2.35 (4)	7.74 (0)	3.38 (2)	3.61 (2)
1.41 (0)	2.11 (4)	2.12 (4)	8.24 (0)	2.56 (2)	2.75 (2)
1.51 (0)	1.91 (4)	1.93 (4)	8.76 (0)	1.98 (2)	2.11 (2)
1.61 (0)	1.72 (4)	1.74 (4)	9.26 (0)	1.50 (2)	1.62 (2)
1.71 (0)	1.57 (4)	1.58 (4)	9.74 (0)	1.08 (2)	1.18 (2)
1.81 (0)	1.45 (4)	1.47 (4)	1.03 (1)	7.74 (1)	8.60 (1)
1.93 (0)	1.38 (4)	1.39 (4)	1.08 (1)	5.84 (1)	6.58 (1)
2.10 (0)	1.30 (4)	1.32 (4)	1.12 (1)	4.55 (1)	5.21 (1)
2.30 (0)	1.16 (4)	1.17 (4)	1.18 (1)	3.84 (1)	4.41 (1)
2.50 (0)	9.71 (3)	9.81 (3)	1.24 (1)	3.40 (1)	3.80 (1)
2.70 (0)	7.90 (3)	8.01 (3)	1.32 (1)	2.12 (1)	2.41 (1)
2.90 (0)	6.41 (3)	6.51 (3)	1.40 (1)	8.55 (0)	1.02 (1)
3.10 (0)	5.05 (3)	5.16 (3)	1.48 (1)	3.35 (0)	4.09 (0)
3.30 (0)	3.99 (3)	4.07 (3)	1.56 (1)	1.69 (0)	2.12 (0)
3.50 (0)	3.24 (3)	3.34 (3)	1.65 (1)	1.13 (0)	1.51 (0)
3.71 (0)	2.82 (3)	2.90 (3)	1.75 (1)	7.38 (-1)	1.01 (0)
3.91 (0)	2.59 (3)	2.66 (3)	1.85 (1)	4.08 (-1)	6.10 (-1)
4.15 (0)	2.39 (3)	2.46 (3)	1.95 (1)	1.80 (-1)	3.17 (-1)
4.45 (0)	2.17 (3)	2.23 (3)	2.06 (1)	5.09 (-2)	1.14 (-1)
4.75 (0)	1.91 (3)	1.96 (3)	2.16 (1)	6.84 (-3)	2.85 (-2)
5.04 (0)	1.63 (3)	1.67 (3)	2.26 (1)	-2.92 (-3)	3.54 (-3)
5.35 (0)	1.36 (3)	1.40 (3)	2.35 (1)	-3.34 (-3)	-1.30 (-3)
5.65 (0)	1.16 (3)	1.20 (3)			

E1 (MeV)	E2 (MeV)	Integral (neutrons $\text{cm}^{-2}\text{kW}^{-1}\text{s}^{-1}$)	Error (neutrons $\text{cm}^{-2}\text{kW}^{-1}\text{s}^{-1}$)
0.811	1.000	6.89E (3)	2.95E (1)
1.000	1.200	5.99E (3)	2.21E (1)
1.200	1.600	8.62E (3)	3.71E (1)
1.600	2.000	5.99E (3)	3.08E (1)
2.000	3.000	9.78E (3)	5.83E (1)
3.000	4.000	3.59E (3)	4.23E (1)
4.000	6.000	3.43E (3)	4.69E (1)
6.000	8.000	1.13E (3)	2.98E (1)
8.000	10.000	3.71E (2)	1.34E (1)
10.000	12.000	1.18E (2)	7.09E (0)
12.000	16.000	5.89E (1)	3.90E (0)
16.000	20.000	3.02E (0)	4.98E (-1)
1.500	15.000	2.63E (4)	2.41E (2)
3.000	10.000	8.52E (3)	1.32E (2)

Table 7. Neutron fluxes (50 keV - 1.4 MeV) on centerline
 43.6 cm beyond 20-cm homogeneous fission gas plenum
 (Item III): Runs 1550A, 1551A, 1551B

N	Energy Boundary (MeV)		Flux (Neutron cm ⁻² MeV ⁻¹ kW ⁻¹ s ⁻¹)	Error (%)
<u>Run 1551B</u>				
1	0.0526	0.0626	1.17E 06	1.16
2	0.626	0.0745	2.00E 06	0.61
3	0.0745	0.0864	1.16E 06	1.11
4	0.0864	0.1023	7.11E 05	1.44
5	0.1023	0.1202	6.79E 05	1.47
6	0.1202	0.1420	6.94E 05	1.25
7	0.1420	0.1659	4.74E 05	1.83
8	0.1659	0.1957	3.92E 05	1.87
9	0.1957	0.2314	3.29E 05	1.96
<u>Run 1551A</u>				
1	0.1665	0.1968	3.89E 05	0.99
2	0.1968	0.2314	3.23E 05	1.15
3	0.2314	0.2747	3.05E 05	1.04
4	0.2747	0.3223	2.66E 05	1.18
5	0.3223	0.3785	1.92E 05	1.46
6	0.3785	0.4434	1.40E 05	1.88
7	0.4434	0.5256	1.33E 05	1.61
<u>Run 1550A</u>				
1	0.3767	0.4512	1.60E 05	0.55
2	0.4512	0.5256	1.22E 05	0.79
3	0.5256	0.6186	1.07E 05	0.75
4	0.6186	0.7302	8.99E 04	0.77
5	0.7302	0.8605	6.04E 04	1.02
6	0.8605	1.0093	3.91E 04	1.45
7	1.0093	1.1860	2.92E 04	1.73
8	1.1860	1.4000	2.32E 04	1.86

Table 8. Spectrum of high-energy neutrons (>0.8 MeV)
on centerline 43.5 cm beyond 20-cm heterogeneous
fission gas plenum (Item V): Run 7865A

Neutron Energy (MeV)	Flux (neutrons $\text{cm}^{-2}\text{MeV}^{-1}\text{kW}^{-1}\text{s}^{-1}$)		Neutron Energy (MeV)	Flux (neutrons $\text{cm}^{-2}\text{MeV}^{-1}\text{kW}^{-1}\text{s}^{-1}$)	
	Lower Limit	Upper Limit		Lower Limit	Upper Limit
8.11 (-1)	3.57 (4)	3.61 (4)	5.94 (0)	9.79 (2)	1.01 (3)
9.07 (-1)	3.69 (4)	3.72 (4)	6.25 (0)	7.96 (2)	8.38 (2)
1.01 (0)	3.35 (4)	3.37 (4)	6.56 (0)	6.72 (2)	7.06 (2)
1.11 (0)	2.95 (4)	2.97 (4)	6.84 (0)	5.85 (2)	6.09 (2)
1.20 (0)	2.62 (4)	2.63 (4)	7.24 (0)	4.71 (2)	1.89 (2)
1.31 (0)	2.32 (4)	2.34 (4)	7.74 (0)	3.36 (2)	3.57 (2)
1.41 (0)	2.10 (4)	2.11 (4)	8.24 (0)	2.52 (2)	2.69 (2)
1.51 (0)	1.90 (4)	1.92 (4)	8.76 (0)	1.95 (2)	2.07 (2)
1.61 (0)	1.72 (4)	1.73 (4)	9.26 (0)	1.13 (2)	1.52 (2)
1.71 (0)	1.56 (4)	1.58 (4)	9.74 (0)	1.02 (2)	1.11 (2)
1.81 (0)	1.45 (4)	1.46 (4)	1.03 (1)	7.58 (1)	8.33 (1)
1.93 (0)	1.38 (4)	1.39 (4)	1.08 (1)	5.90 (1)	6.55 (1)
2.10 (0)	1.30 (4)	1.32 (4)	1.12 (1)	4.66 (1)	5.25 (1)
2.30 (0)	1.16 (4)	1.17 (4)	1.18 (1)	4.00 (1)	4.50 (1)
2.50 (0)	9.74 (3)	9.83 (3)	1.24 (1)	3.62 (1)	3.97 (1)
2.70 (0)	7.95 (3)	8.04 (3)	1.32 (1)	2.30 (1)	2.56 (1)
2.90 (0)	6.41 (3)	6.50 (3)	1.40 (1)	9.15 (0)	1.09 (1)
3.10 (0)	5.01 (3)	5.10 (3)	1.48 (1)	3.73 (0)	4.40 (0)
3.30 (0)	3.89 (3)	3.96 (3)	1.56 (1)	1.87 (0)	2.30 (0)
3.50 (0)	3.17 (3)	3.25 (3)	1.65 (1)	1.26 (0)	1.62 (0)
3.71 (0)	2.80 (3)	2.86 (3)	1.75 (1)	8.16 (-1)	1.08 (0)
3.91 (0)	2.60 (3)	2.66 (3)	1.85 (1)	4.48 (-1)	6.46 (-1)
4.15 (0)	2.45 (3)	2.51 (3)	1.95 (1)	1.95 (-1)	3.32 (-1)
4.45 (0)	2.24 (3)	2.29 (3)	2.06 (1)	5.48 (-2)	1.17 (-1)
4.75 (0)	1.92 (3)	1.96 (3)	2.16 (1)	7.25 (-3)	2.90 (-2)
5.04 (0)	1.60 (3)	1.64 (3)	2.26 (1)	3.24 (-3)	3.26 (-3)
5.35 (0)	1.35 (3)	1.38 (3)	2.35 (1)	3.63 (-3)	-1.53 (-3)
5.65 (0)	1.16 (3)	1.19 (3)			

E1 (MeV)	E2 (MeV)	Integral (neutrons $\text{cm}^{-2}\text{kW}^{-1}\text{s}^{-1}$)	Error (neutrons $\text{cm}^{-2}\text{kW}^{-1}\text{s}^{-1}$)
0.811	1.000	6.86E (3)	2.53E (1)
1.000	1.200	5.99E (3)	1.90E (1)
1.200	1.600	8.60E (3)	3.21E (1)
1.600	2.000	5.98E (3)	2.65E (1)
2.000	3.000	9.79E (3)	3.92E (1)
3.000	4.000	3.54E (3)	3.65E (1)
4.000	6.000	3.46E (3)	4.06E (1)
6.000	8.000	1.14E (3)	2.60E (1)
8.000	10.000	3.59E (2)	1.17E (1)
10.000	12.000	1.18E (2)	6.24E (0)
12.000	16.000	6.28E (1)	3.51E (0)
16.000	20.000	3.27E (0)	4.86E (0)
1.500	15.000	2.63E (4)	2.69E (2)
3.000	10.000	8.49E (3)	1.15E (2)

Table 9. Neutron spectrum (50 keV - 1.4 MeV) on centerline
 43.5 cm beyond 20-cm heterogeneous fission gas plenum
 (Item V): Runs 1548A, 1549A, 1549B

N	Energy Boundary (MeV)		Flux (Neutron cm ⁻² MeV ⁻¹ kW ⁻¹ s ⁻¹)	Error (%)
<u>Run 1549B</u>				
1	0.0533	0.0626	1.57E 06	1.10
2	0.0626	0.0739	1.92E 06	0.79
3	0.0739	0.0869	1.16E 06	1.17
4	0.0869	0.1038	6.77E 05	1.66
5	0.1038	0.1206	6.84E 05	1.85
6	0.1206	0.1430	7.01E 05	1.40
7	0.1430	0.1673	4.49E 05	2.20
8	0.1673	0.1973	3.97E 05	2.14
9	0.1973	0.2328	3.39E 05	2.24
<u>Run 1549A</u>				
1	0.1687	0.1986	3.99E 05	1.04
2	0.1986	0.2328	3.27E 05	1.21
3	0.2328	0.2712	3.12E 05	1.22
4	0.2712	0.3182	2.78E 05	1.18
5	0.3182	0.3780	1.97E 05	1.37
6	0.3780	0.4421	1.45E 05	1.91
7	0.4421	0.5232	1.35E 05	1.68
<u>Run 1548A</u>				
1	0.3818	0.4478	1.65E 05	0.58
2	0.4478	0.5232	1.28E 05	0.70
3	0.5232	0.6175	1.12E 05	0.66
4	0.6175	0.7306	9.39E 04	0.69
5	0.7306	0.8532	6.26E 04	1.01
6	0.8532	1.0040	4.21E 04	1.26
7	1.0040	1.1832	3.08E 04	1.52
8	1.1832	1.4000	2.42E 04	1.67

Table 10. Bonner ball measurements on centerline at the same location as the NE-213 spectrometer (Items III, V)

Configuration ^a	Distance behind plenum (cm)	Bonner ball count rates ($s^{-1}W^{-1}$)		
		3-inch diam ball	5-inch diam ball	10-inch diam ball
		Foreground ^b	Foreground	Foreground
III	43.6	2.34 (2) ^c	7.92 (2)	2.58 (2)
V.	43.5	2.40 (2)	8.23 (2)	2.57 (2)

^aSee experimental program plan in Appendix A for description of configurations.

^bNeutron flux without shadow shield between detector and configurations (no background runs were made).

^cRead: 2.34×10^2 .

Table 11. Calculation-to-Experiment Ratios for the 3-, 5- and 10-in. Bonner Ball Count Rates Close Behind or Inside Several Configurations.

Configuration	Detector Location	Count Rate Ratios		
		3-in. BB	5-in. BB	10-in. BB
II.A	30 cm	0.90	0.90	0.90
II.D	spectrum	0.69	0.80	0.86
IV.B	30 cm	0.90	0.86	0.84
IV.C	30 cm	0.89	0.88	0.94
IV.C	spectrum	0.78	0.82	0.85
IV.D	30 cm	0.91	0.88	0.86
IV.E	30 cm	0.94	0.90	0.89
IV.F(no background)	30 cm	0.83	0.79	0.80
IV.F(with background)	72.4 cm	0.86	0.84	0.85
IV.G(no background)	30 cm	0.61	0.59	0.60
IV.G(with background)	53.6 cm	0.70	0.70	0.73
IV.H(no background)	30 cm	0.40	0.41	0.45
IV.H(with background)	52.1 cm	0.60	0.62	0.70
IV.I(no background)	30 cm	0.24	0.23	0.23
IV.I(with background)	49.5 cm	0.54	0.49	0.54
IV.IA	in situ	0.80	0.79	0.79
IV.J	in situ	0.89	0.87	0.95
IV.K	in situ	0.83	0.83	0.86
IV.L	in situ	0.88	0.84	0.88
IV.M	in situ	0.92	0.93	0.95
VI.A	30 cm	0.94	0.89	0.88
VI.A	spectrum	0.80 ^a	0.80	0.74
VI.B	30 cm	0.93	0.88	0.84
VI.C	30 cm	0.90	0.87	0.82
VI.D	30 cm	0.95	0.91	0.88
VI.E	30 cm	0.91	0.88	0.88
VI.F	30 cm	0.92	0.90	0.86
VI.F	spectrum	0.74	0.81	0.85
VII.A	30 cm	0.89	0.82	0.80
VII.B	30 cm	0.82	0.73	0.71
VII.C	30 cm	0.76	0.75	0.72
VII.D	30 cm	0.82	0.80	0.73

^aThe 4-in. Bonner ball was used for Configuration VI.A.

Figure 1. Schematic of SM (Fe + Al + boral + radial blankets) and fission gas plenums (Items I-V). Note: Lithiated paraffin covers lateral sides of the configuration.

Heterogeneous Gas Plenum Inserts

Figure 2. Schematic of heterogeneous fission gas plenums (Items IV, V).

Figure 3. Photograph of 8-cm heterogeneous fission gas plenum mockup (Item IV).

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Homogeneous Gas Plenum Inserts

Figure 4. Schematic of homogeneous fission gas plenums (Items II, III).

Figure 5. Dose rate profile for Hornyak button measurements along horizontal traverse 1.6 cm beyond 8-cm heterogeneous fission gas plenum (Item IV).

Figure 6. Dose rate profile for Hornyak button measurements along horizontal traverse 1.6 cm beyond 20-cm heterogeneous fission gas plenum (Item V).

Figure 7. Spectrum of high-energy neutrons (>0.8 MeV) on centerline 43.6 cm beyond 20-cm homogeneous fission gas plenum (Item III): Run 7866A.

Figure 8. Neutron spectrum (50 keV - 1.4 MeV) on centerline 43.6 cm beyond 20-cm homogeneous fission gas plenum (Item III): Runs 1550A, 1551A, 1551B.

Figure 9. Spectrum of high-energy neutrons (>0.8 MeV) on centerline 43.5 cm beyond 20-cm heterogeneous fission gas plenum (Item V): Run 7865A.

Figure 10. Neutron spectrum (50 keV - 1.4 MeV) on centerline 43.5 cm beyond 20-cm heterogeneous fission gas plenum (Item V): Runs 1548A, 1549A, 1549B.

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Figure 11. Calculated versus measured $E > 50$ keV neutron flux behind Configuration VI.A of the penetration experiment.

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Figure 12. Calculated versus measured $E > 50$ keV neutron flux behind Configuration II.D of the penetration experiment.

Figure 13. Calculated versus measured $E > 50$ keV neutron flux behind Configuration VI.F of the penetration experiment.

Figure 14. Calculated versus measured $E > 50$ keV neutron flux behind Configuration VI.G of the penetration experiment.

Figure 15. Comparison of the modified TSR-II spectrum behind 45 cm of carbon steel plus 122 cm of sodium plus 20 cm of graphite plus 61 cm of sodium with the neutron spectrum below the rotating shield plug in the Japanese fast breeder reactor.