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MARTIN MARIETTA

**JASPER
USDOE/PNC Shielding
Research Program—Analysis of the
JASPER Fission Gas Plenum Experiment**

C. O. Slater

MASTER

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MARTIN MARIETTA ENERGY SYSTEMS, INC.
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DEPARTMENT OF ENERGY

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Engineering Physics and Mathematics

Liquid Metal Reactor Program

JASPER USDOE/PNC Shielding Research Program - Analysis of the JASPER Fission Gas Plenum Experiment

C. O. Slater

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Prepared for the
U.S. DOE Office of
Liquid Metal Converter Reactor

Prepared by the
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ABSTRACT

The results of the analysis of the Fission Gas Plenum Experiment are presented. This experiment is the second in a series of several experiments comprising a joint U.S. DOE-Japan PNC Shielding Research Program (JASPER). The four Fission Gas Plenum Experiment configurations, designed for the measurement of neutron streaming through the fission gas plenum region, were analyzed using Monte Carlo and two-dimensional discrete ordinates methods. Calculated results compared well with measured results in many cases, although results were consistently underpredicted for the shorter plenum configurations. Like the measured data, the calculated results indicated no significant streaming when results from the heterogeneous mockups were compared to those from the homogeneous mockups. An explanation is given as to why little streaming was observed. The Hornyak button dose rates were overpredicted because of a normalization problem with the response function but yielded horizontal traverse curves whose shapes agreed well with the measured shapes to the same extent as did those for the other integral detectors.

1. INTRODUCTION

The Fission Gas Plenum Experiment is the second of several experiments planned under the JASPER (Japanese-American Shielding Program of Experimental Research) program, which is a cooperative program between the U. S. Department of Energy and Japan's Power Reactor and Nuclear Fuel Development Company. It was designed to measure streaming in mockups of the fission gas plenum region of Liquid Metal Reactors (LMRs). A major goal of this experiment was to verify the accuracy of the calculated neutron leakage from a typical liquid metal fast reactor fission gas plenum. Having this information, one can then design adequate shielding to protect structural components (thus maximizing their lifetimes) and to reduce dose rates above the reactor top head to levels that allow access to the reactor building during operation. The resultant shielding design could have an impact on the reactor fuel-element length and the reactor vessel height. Overly conservative calculated neutron fluxes could lead to an overprediction of the shielding requirements and possibly to a significant increase in the vessel height. Costs are increased because of the extra steel required for the vessel, the increased weight to be transported, the increased sodium inventory, and the extra material required for other scaled-up components in the reactor building. Consequently, a reasonably accurate calculation of the neutron leakage from the plenum is highly desirable. The experiment provides a benchmark by which to judge the adequacy of the calculational methods. Measurements for the experiment were performed in early 1987;¹ this report presents the results of the analysis of this experiment.

2. DESCRIPTION OF THE EXPERIMENT

Both heterogeneous and homogeneous mockups of a given design are needed in order to measure neutron streaming in the plenum mockups. Therefore, the experimental mockups included heterogeneous designs with empty tubes^a parallel to the source beam and homogeneous designs with disks of material perpendicular to the source beam in order to eliminate any streaming paths parallel to the source beam. Two plenum lengths were considered (8 and 20 cm). One mockup, with a nominal length-to-diameter ratio (L/D) of 25, has an L/D representative of several LMR designs.² This mockup had an overall length of 20 cm. It is noted, however, that the Fast Test Reactor at the Fast Flux Test Facility has a plenum length of about 107 cm.³ The other mockup, with a nominal L/D of 10, is not typical of LMR designs, but based on data from Ref. 3, it was expected to show significant neutron streaming effects. By contrast, the same data predicted the first design would show little neutron streaming effects.

The experimental setup is as shown in Fig. 1. The plenum mockups are preceded by a spectrum modifier consisting of about 10 cm carbon steel, 9 cm aluminum, 2.5 cm boral, and 20 cm UO₂ blankets. All of this is positioned and centered in front of the wide-beam portal of the Tower Shielding Reactor II (TSR-II) at the ORNL Tower Shielding Facility (TSF). The homogeneous and heterogeneous plenum designs are shown in Figs. 2 and 3, respectively. The plenum mockups were circular and were placed into a circular tube which penetrated a concrete slab of the same thickness as the plenum mockup. Fig. 4 shows the concrete slab for the 20-cm plenum mockups.

Measurements were made with five different Bonner balls (3-, 5-, 8-, 10-, and 12-in.), a 0.635-cm-diameter $\times$ 0.159-cm-thick Hornyak button, and NE-213 and Benjamin spectrometers. Horizontal traverses were performed with the 5-in. Bonner ball and the Hornyak button behind each of the four plenum mockups. Fast-neutron spectra and 3-, 5-, and 10-in. Bonner ball measurements were made behind the homogeneous and heterogeneous mockups of the 20-cm plenum. All other measurements were made on centerline behind the configuration either at 30 cm from the configuration or 304.8 cm from the reactor center. The Experimental Program Plan is shown in Appendix A.

^a The fission gases in the tubes provide little shielding and are therefore treated as void.

Fig. 1. Arrangement of the spectrum modifier and the fission gas plenum mockups in the radiation beam of the Tower Shielding Reactor II.

Fig. 2. Homogeneous fission gas plenum mockups for Configurations II and III.

Fig. 3. Heterogeneous fission gas plenum mockups for Configurations IV and V.

Fig. 4. Concrete slab for the 20-cm-thick fission gas plenum mockups.

3. THE ANALYSIS

3.1 NEUTRON SOURCE

The neutron source was provided by the TSR-II with its wide-beam configuration as shown in Fig. 5. The calculational source was obtained from a previous analysis.⁴ In that analysis, the one-dimensional angular fluxes on the reactor's spherical surface, as determined by Maerker,⁵ were projected onto 2-D cylindrical end (as shown in Fig. 5) and side surfaces and were used as internal boundary sources for a DOT-IV⁶ calculation of neutron transport through a mockup of the reactor, its housing and collimator, and the spectrum modifier (without the UO_2 blankets). The boundary flux used as a source for calculations for this experiment was saved from the above DOT-IV calculation at the interface between the collimator and the spectrum modifier. This location is shown in Fig. 5 as the "beginning of the shield configuration." The boundary fluxes generated in the earlier analysis were for a 51-group structure. They were converted with lethargy weighting to the 61-group structure used in the present calculations.

Fig. 5. Schematic of the Tower Shielding Reactor (TSR-II) with its wide beam collimator.

An additional neutron source was provided by fissions induced in the UO_2 blankets which were components of the spectrum modifier. The calculated fission neutron source was obtained from the DOT-IV calculation by using multiple outer or source iterations.

3.2 DATA

Cross-section data from the recently developed VELM61 library⁷ was used for the analysis. Detector response functions were converted from the 51-group structure, but a collection of response functions are also available in a VELM61-related file. Ref. 7 lists the sources of most of the response function data. For the Hornyak button, a first-collision dose response function with an estimated energy cutoff was used. Response functions are given in Tables B1 to B6 in Appendix B. Note that normalization factors for these response functions are based on the units of the neutron flux. The neutron source is per minute per watt. Therefore, the Bonner ball count rates are multiplied by 0.0166667 to obtain count rates per second per watt and the Hornyak button dose is multiplied by 60.0 to obtain results with units ergs/g.h.W. Material composition data are shown in Table 1. They were derived mainly from the analyses given in Tables 1-10 of Ref. 1.

3.3 METHODS

Calculations were performed using the two-dimensional discrete ordinates computer code DOT-IV⁶ (subsequently renamed DORT) and the MORSE⁸ Monte Carlo computer code. In addition, several auxiliary computer codes were used to prepare input source or other data for the main calculations or to process output data from those calculations. Three codes (BSPRP2,⁹ VFL2BD,¹⁰ and BFXSCL¹¹) were used to prepare input source data for the DORT calculations while the DOMINO-II¹² code was used to prepare input source data for the MORSE calculations. Cross sections for DORT were prepared with the GIP¹³ code and those for MORSE were prepared with the XCHEKR⁸ code. Finally, detector responses were calculated using the DTWTPN¹⁴ and DSKTRN¹⁵ codes.

The codes used to prepare the DORT source input were written by the author and have been described elsewhere. However, brief descriptions of their use in the calculations for this experiment are given here. The BSPRP2 code is used to process boundary flux files to prepare source input for DOT-IV, while optionally changing the spatial mesh and/or quadrature from that for the input file. For this experiment, the code changed the spatial mesh only. The VFL2BD and BFXSCL codes prepare DORT source input using the boundary fluxes from DORT flux and moments files. The VFL2BD code was used when a DORT calculation through a configuration was followed by a DORT calculation through a void region behind the configuration. VFL2BD used boundary fluxes from the first DORT calculation as a source for the second DORT calculation. The BFXSCL code was used to apply MORSE streaming correction factors to the DORT boundary fluxes from the flux and moments file. The method used by BFXSCC to perform the streaming correction is as follows: First, MORSE and DORT fluxes and currents were binned

**Table 1. Compositions of Mixtures Used in the Calculations
for the Experimental Configurations**

Component	Atom Density ($b^{-1} \text{ cm}^{-1}$) by Mixture							
	Carbon Steel	Lithiated Paraffin	Block Concrete	UO ₂ Blanket Mixture	Plenum Concrete	Plenum SS304	Plenum Al	Boral
H		5.93-2 ^a	6.4-3		6.16-3			
Li-6		5.625-4						
Li-7		6.938-4						
B-10								5.13-3
B-11								2.077-2
C	9.82-4	3.34-2	1.01-2		1.08-2			6.45-3
O		1.13-2	4.48-2	2.962-2	4.52-2			
Na				5.589-3	8.28-5			
Mg			2.18-3		5.01-3		6.958-4	
Al			6.24-4	6.879-3	6.98-4		5.864-2	3.65-2
Si			4.35-3		2.08-3	7.773-4	3.937-4	
P					6.19-6			
S			5.78-5		9.68-5			
K			1.11-4		1.77-4			
Ca			9.89-3		9.60-3			
Cr						1.743-2	5.317-5	
Mn	1.55-3					1.296-3	3.256-5	
Fe	8.37-2		1.09-4	2.0-5	5.27-4	5.906-2	1.94-4	7.7-4
Ni				3.635-5		7.44-3		
Mo						1.138-4		
U-235				1.08-4				
U-238				1.47-2				

^aRead as 5.93×10^{-2} .

over space and energy. Second, one-dimensional angular fluxes were calculated for each different eta in the 2-D quadrature. The 1-D angular fluxes varied as a power of eta determined from the flux and current for a given energy and space bin. Third, a ratio of the MORSE-to-DORT angular flux was calculated. Fourth and finally, the ratio with a minimum value of 1.0 then multiplied the DORT angular fluxes having the same eta and belonging to the same space and energy bins. As with VFL2BD, these boundary fluxes were then used as input for a DORT calculation in the void region behind the configuration.

In the calculation of the detector responses, the DTWTPN and DSKTRN codes were used under different circumstances. The DTWTPN code is used to calculate responses for detectors located within the DORT geometry boundaries. Detector response functions are folded with the DORT fluxes to give point detector responses at each 2-D mesh point. The code assumes a spherical detector and the point detector responses are averaged over the hemisphere toward the source to calculate the integral detector response. The DSKTRN code is used for detectors located outside the 2-D geometry boundaries. Responses are calculated only at locations input by the user. Hence, for the Bonner balls, the locations input corresponded to the centers of detection¹⁶ of the individual balls.

3.4 RESULTS

DORT calculations were performed for the two homogeneous plenum mockups and for homogeneous models of the two heterogeneous mockups. MORSE calculations were performed for the two heterogeneous plenum mockups and the results were used to calculate streaming-corrected sources for DORT as described above. The sources were then used in DORT to calculate streaming-corrected fluxes behind the heterogeneous plenum mockups. Comparisons of calculated and measured results are given in the sections which follow.

3.4.1 Detector Responses 30 cm Behind Configurations

Table 2 shows a comparison of calculated and measured detector responses 30 cm behind the configurations. For the heterogeneous configurations (IV and V) comparisons are shown for calculated results with and without streaming correction. It is noted that results for Configurations II and IV are underpredicted while those for Configurations III and V are slightly overpredicted. Even so, the calculated results, like the measured results, show little streaming through the plenum mockups (i.e. the results behind the heterogeneous mockups differ little from the results behind the corresponding homogeneous mockups). The calculations show slightly more streaming for the longer plenum mockup (3-4% increase compared to about 1% for the shorter plenum mockup). However, uncertainties in the MORSE calculations are of the same order. Thus streaming effects could be smaller or larger. The streaming issue will be examined later in this report. The Hornyak button results

do not compare favorably because of a problem in normalizing the response function so that it has the same energy cutoff as the measurement.

3.4.2 Bonner Ball Count Rates Behind Configurations at 304.8 cm from the TSR-II Core Center

Calculated Bonner ball count rates behind the configurations at 304.8 cm from the TSR-II core center are compared with measured count rates in Table 3. No streaming-corrected results were obtained for the two heterogeneous cases, but the streaming factors should be about the same as those at 30 cm. Note that again the results for the short plenum cases are underpredicted more so than those for the long plenum cases. The results from the homogeneous and heterogeneous mockups of a given plenum design again indicate little streaming exists. Except for the 3-in. Bonner ball results, the agreement is fair to good for Configurations II and IV and excellent for Configurations III and V. The 3-in Bonner ball count rate is most underpredicted for Configurations II and IV and most overpredicted for Configurations III and V. Thus, there is no clear trend. At the larger distances, count rates for detectors with a significant low-energy neutron contribution typically will be underpredicted because of unaccounted background contributions to the count rate.

3.4.3 Neutron Spectra Behind Configurations

Fast-neutron spectra ($E > 0.05$ MeV) were measured behind the 20-cm plenum mockups (Configurations III and V). The calculated and measured neutron spectra are compared in Fig. 6 for Configuration III, Fig. 7 for a homogeneous modeling of Configuration V, and Fig. 8 for a heterogeneous modeling of Configuration V. The shapes of the curves as well as the integrals of the spectra are in excellent agreement. The calculated flux integral increased about 5% due to streaming and uncertainty in the MORSE results.

3.4.4 Bonner Ball Count Rates at the Spectrum Measurement Locations

Calculated and measured 3-, 5-, and 10-in. Bonner ball count rates at the spectrum measurement locations behind Configurations III and V are compared in Table 4, results before and after streaming correction being shown for Configuration V. Again, the agreement is excellent and the Configuration V results show about a 4% increase with streaming correction.

3.4.5 5-in. Bonner Ball Count Rate Horizontal Traverses

Calculated and measured 5-in. Bonner ball count rates for horizontal traverses at 30 cm behind the configurations are shown in Figs. 9-12 for Configurations II, III, IV, and V, respectively. The respective calculation-to-experiment (C/E) ratio ranges are 0.77-0.88, 1.04-1.10, 0.79-0.92, and 1.04-1.14. Without streaming correction, the C/E ranges were 0.78-0.90 for Configuration IV and 1.01-1.13 for Configuration V. The worst results were generally at the outer edges of the traverses, being low for Configurations II and IV and high for Configurations III and V. The agreement is characterized as good to excellent.

Table 2. Calculated vs. Measured Detector Responses 30 cm Behind Fission Gas Plenum Experiment Configurations

Detector	Configuration ^a					
	II	III	IV ^b	V ^b	IV ^c	V ^c
3-in. Bonner ball						
Calc.	4.73(+2) ^d	3.25(+2)	4.73(+2)	3.25(+2)	4.81(+2)	3.35(+2)
Meas.	5.85(+2)	3.07(+2)	5.89(+2)	3.10(+2)	5.89(+2)	3.10(+2)
C/E ^e	0.81	1.06	0.80	1.05	0.82	1.08
5-in. Bonner ball						
Calc.	1.97(+3)	1.14(+3)	1.97(+3)	1.14(+3)	2.00(+3)	1.18(+3)
Meas.	2.21(+3)	1.09(+3)	2.19(+3)	1.09(+3)	2.19(+3)	1.09(+3)
C/E	0.89	1.05	0.90	1.05	0.90	1.08
8-in. Bonner ball						
Calc.	1.34(+3)	7.49(+3)	1.34(+3)	7.47(+2)	1.36(+3)	7.73(+3)
Meas.	1.41(+3)	6.98(+2)	1.50(+3)	7.12(+2)	1.50(+3)	7.12(+2)
C/E	0.95	1.07	0.89	1.05	0.91	1.09
10-in. Bonner ball						
Calc.	6.83(+2)	3.78(+2)	6.82(+2)	3.77(+2)	6.90(+2)	3.90(+2)
Meas.	7.23(+2)	3.53(+2)	7.33(+2)	3.61(+2)	7.33(+2)	3.61(+2)
C/E	0.94	1.07	0.93	1.04	0.94	1.08
12-in. Bonner ball						
Calc.	3.22(+2)	1.78(+2)	3.21(+2)	1.77(+2)	3.24(+2)	1.82(+2)
Meas.	3.58(+2)	1.74(+2)	3.49(+2)	1.73(+2)	3.49(+2)	1.73(+2)
C/E	0.90	1.02	0.92	1.02	0.93	1.05
Hornyak Button (270 keV cutoff)						
Calc.	2.40(-1)	1.31(-1)	2.49(-1)	1.30(-1)	2.50(-1)	1.34(-1)
Meas.	1.50(-1)	7.36(-2)	1.46(-1)	6.88(-2)	1.46(-1)	6.88(-2)
C/E	1.60	1.78	1.71	1.89	1.71	1.95

^aConfigurations:

II - 8-cm-thick homogeneous plenum mockup.

III - 20-cm-thick homogeneous plenum mockup.

IV - 8-cm-thick heterogeneous plenum mockup.

V - 20-cm-thick heterogeneous plenum mockup.

^bComparisons with DORT-calculated results (no streaming correction).

^cComparisons with streaming-corrected DORT-calculated results.

^dRead as 4.73×10^2 .

^eRatio of calculated result to measure result.

**Table 3. Calculated vs. Measured Bonner Ball Count Rates
Behind Fission Gas Plenum Experiment Configurations
at 304.8 cm from the TSR-II Core Center**

Detector	Configuration			
	II	III	IV	V
3-in. Bonner ball				
Calc.	6.86(+1) ^a	4.75(+1)	6.86(+1)	4.75(+1)
Meas.	9.14(+1)	3.87(+1)	8.64(+1)	4.06(+1)
C/E ^b	0.75	1.23	0.79	1.17
5-in. Bonner ball				
Calc.	2.36(+2)	1.32(+2)	2.36(+2)	1.32(+2)
Meas.	2.82(+2)	1.24(+2)	2.83(+2)	1.29(+2)
C/E	0.84	1.06	0.83	1.02
8-in. Bonner ball				
Calc.	1.49(+2)	7.97(+1)	1.49(+2)	7.96(+1)
Meas.	1.70(+2)	8.15(+1)	1.77(+2)	8.22(+1)
C/E	0.88	0.98	0.84	0.97
10-in. Bonner ball				
Calc.	7.46(+1)	4.00(+1)	7.46(+1)	3.99(+1)
Meas.	8.82(+1)	4.18(+1)	8.53(+1)	4.33(+1)
C/E	0.85	0.96	0.87	0.92
12-in. Bonner ball				
Calc.	3.51(+1)	1.90(+1)	3.51(+1)	1.90(+1)
Meas.	4.30(+1)	2.10(+1)	4.19(+1)	2.13(+1)
C/E	0.82	0.90	0.84	0.89

^aRead as 6.86×10^1 .

^bRatio of calculated result to measured result.

Fig. 6. Calculated versus measured $E > 0.05$ MeV neutron spectrum behind Configuration III.

Fig. 7. Calculated versus measured $E > 0.05$ MeV neutron spectrum behind Configuration V (no streaming correction).

Fig. 8. Calculated versus measured $E > 0.05$ MeV neutron spectrum behind Configuration V (with streaming correction).

3.4.6 Hornyak Button Dose Rate Horizontal Traverse

Hornyak button horizontal traverse measurements were made as close as feasible behind the configurations in order to try to detect significant changes in the response across the empty tubes with the heterogeneous cases and to establish baseline responses with the homogeneous cases. Since earlier results showed a large overprediction of the Hornyak button response, the cutoff for the response function was adjusted until there was agreement between the calculated and measured results on centerline for Configuration V. This was achieved by retaining the response function values for groups 1-16 of the 61-group structure and 0.535 times the response function for group 17 (see Table A6). Assuming a $1/E$ distribution of the flux in group 17, this effectively represents a 0.82 MeV cutoff of the response function compared to the 0.27 MeV cutoff used to obtain the results in Table 2. In reality, the response function for each group should be reduced in proportion to the proton-recoil-generated pulse heights with energies below the instrument bias setting. The conversion from count rate to dose rate introduces additional complications. The horizontal traverses obtained with the modified response function are shown in Figs. 13-16 for Configurations II-V, respectively. The calculated and measured curve shapes are in excellent agreement. The C/E ratio ranges are 0.84-0.94, 0.94-1.13, 0.86-0.96, and 1.00-1.19 for Configurations II-V, respectively. These ratios are comparable to the 5-in. Bonner ball count rate ratios for horizontal traverses.

Table 4. Comparison of Calculated and Measured Bonner Ball Count Rates at the Spectrum Measurement Locations Behind Configurations III and V

Detector	Count Rate ($S^{-1} W^{-1}$)		Ratio: $\frac{\text{Calculated}}{\text{Measured}}$ (C/E)
	Calculated	Measured	
Configuration III			
3-in.	2.43+2 ^a	2.34+2	1.04
5-in.	8.06+2	7.92+2	1.02
10-in.	2.65+2	2.58+2	1.03
Configuration V (Homogeneous Computational Model)			
3-in.	2.43+2	2.40+2	1.01
5-in.	8.05+2	8.23+2	0.98
10-in.	2.64+2	2.57+2	1.03
Configuration V (Heterogeneous Computational Model)			
3-in.	2.52+2	2.40+2	1.05
5-in.	8.38+2	8.23+2	1.02
10-in.	2.74+2	2.57+2	1.07

^aRead as 2.43×10^2 .

Fig. 9. Calculated versus measured 5-in. Bonner ball count rates ($s^{-1} \cdot W^{-1}$) for a horizontal traverse 30 cm behind Configuration II.

Fig. 10. Calculated versus measured 5-in. Bonner ball count rates ($s^{-1} \cdot W^{-1}$) for a horizontal traverse 30 cm behind Configuration III.

Fig. 11. Calculated versus measured 5-in. Bonner ball count rates (s⁻¹.W⁻¹) for a horizontal traverse 30 cm behind Configuration IV.

Fig. 12. Calculated versus measured 5-in. Bonner ball count rates (s⁻¹.W⁻¹) for a horizontal traverse 30 cm behind Configuration V.

Fig. 13. Calculated versus measured dose rates (erg/g.h.W) for a horizontal traverse 1.6 cm behind Configuration II.

Fig. 14. Calculated versus measured dose rates (erg/g.h.W) for a horizontal traverse 1.6 cm behind Configuration III.

Fig. 15. Calculated versus measured dose rates (erg/g.h.W) for a horizontal traverse 1.6 cm behind Configuration IV.

Fig. 16. Calculated versus measured dose rates (erg/g.h.W) for a horizontal traverse 1.6 cm behind Configuration V.

3.4.7 Analysis of Neutron Streaming

As mentioned in Section II, based on data from Ref. 3, significant streaming effects were predicted for the 8-cm-thick plenum mockup. The prediction was based on curves in Ref. 3 that give streaming factors versus a diameter-to-length ratio (D/L) for a fast reactor plenum. For the 8-cm-thick plenum and tube inner diameter of 0.6914 cm, D/L is about 0.086. For this D/L , Fig. 2 of Ref. 3 shows a streaming factor near 2.0, which is significant. Yet the measurements showed little streaming. A review of Boulette's report leads to the conclusion that the prediction of streaming for the 8-cm-thick plenum mockup resulted from a misinterpretation of the data. In his report, Boulette described Monte Carlo calculations on a unit cell from the Fast Test Reactor (FTR) fission gas plenum and on cells formed by proportionally expanding the cell radially while keeping the height constant at 106.68 cm (42 in.). His Figs. 2 (0.414 eV cut-off energy) and 9 (6.065 MeV cut-off energy) show streaming factors as a function of D/L where D is varied while L remains constant. In the present experiment L is varied while D remains constant to give different D/L . As a consequence, Boulette's data are not directly applicable to the experiment.

A unit cell from the heterogeneous mockups (Configurations IV and V) is somewhat larger than the Boulette's reference cell. The distance across the flats (rod pitch) is about 22% larger, while the fuel-pin outer diameter is about 36% larger, although the clad thickness is the same. Hence, this cell is not a proportional expansion of Boulette's reference cell. The experimental cell has void, clad, and sodium fractions of 0.554, 0.175, and 0.271,^b compared to 0.401, 0.187, and 0.413 for the reference cell. Hence, one would expect that the experiment should show more streaming than a proportionally expanded cell with comparable outer dimensions. Based on the 38% larger void fraction, one might estimate the streaming factor (S_2) for the experimental arrangement by selecting from Boulette's data the streaming factor (S_1) corresponding to the D/L for the tubes used in the experiment (i.e. $0.6914/106.68=0.0065$) and increasing the streaming contribution by 38% [i.e. $s_2=1.0+1.38(s_1-1.0)$], Boulette's Figs. 2 and 7 show no significant streaming for $D/L=0.0065$ and when the streaming is enhanced by 38%, it is still insignificant.

The above analysis is based on a plenum with a length comparable to the 100 cm length of the reference cell. However, since the streaming factor varies monotonically from 1.0 at the base of the plenum to the maximum factor at the top of the plenum, the streaming factor for any plenum of the same cross section but shorter in length would have to be smaller than the factor for the longer plenum. Consequently, insignificant streaming for the 106.68-cm-long plenum translates into insignificant streaming for the 20-cm- and 8-cm-long plenums. This is a possible explanation as to why streaming was not observed for the mockups used in the experiment.

^b The fractions are based on the tube diameter, wall thickness, and rod pitch. The region outside the tube is considered sodium, the wall cladding, and the inside void.

4. SUMMARY

The Fission Gas Plenum Experiment was analyzed using Monte Carlo and two-dimensional discrete ordinates methods. Calculated results were in reasonably good agreement with the measured results in most instances. The calculated results, like the measured results, showed very small streaming effects for the plenum mockups. The streaming issue was analyzed and a possible explanation was given for the insignificant streaming observed from the measurements. The results of both the analysis and the experiment reinforce Boulette's conclusion that the fission gas plenum region can be treated as homogeneous and calculated results can be used without streaming correction provided the fuel rods are small enough and the material fractions are nearly the same as those for the reference design.

APPENDIX A
The Experimental Program

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

APPENDIX B
Detector Response Functions

APPENDIX B

Detector Response Function

**Table B1. Response function for the 3-inch
Bonner ball units are: (counts·cm²/neutron)**

Group	Upper Energy(eV)	Response	Group	Upper Energy(eV)	Response
1	1.49183E+07 ^a	3.44697E-03	32	8.65168E+04	2.35597E-01
2	1.22140E+07	4.36603E-03	33	5.65622E+04	2.35627E-01
3	1.00000E+07	5.50542E-03	34	5.24752E+04	2.67017E-01
4	8.18730E+06	6.86520E-03	35	3.43067E+04	2.86389E-01
5	6.70320E+06	9.24655E-03	36	2.85011E+04	2.92975E-01
6	5.48811E+06	1.10363E-02	37	2.70001E+04	2.92975E-01
7	4.49329E+06	1.34927E-02	38	2.60584E+04	2.93010E-01
8	3.67879E+06	1.69485E-02	39	2.47875E+04	3.10526E-01
9	3.01194E+06	2.11139E-02	40	2.35786E+04	3.18793E-01
10	2.46597E+06	2.61091E-02	41	1.50344E+04	3.61398E-01
11	2.34570E+06	2.61091E-02	42	9.11882E+03	3.84520E-01
12	2.23130E+06	2.61100E-02	43	5.53084E+03	4.18671E-01
13	2.01897E+06	3.19913E-02	44	3.70744E+03	4.47832E-01
14	1.65299E+06	3.88334E-02	45	3.03539E+03	4.58543E-01
15	1.35335E+06	4.67488E-02	46	2.61259E+03	4.81026E-01
16	1.10803E+06	5.58410E-02	47	2.24867E+03	4.81064E-01
17	9.07180E+05	6.59897E-02	48	2.03468E+03	5.17541E-01
18	7.42735E+05	7.72032E-02	49	1.23410E+03	5.81143E-01
19	6.08101E+05	8.94339E-02	50	7.48518E+02	6.07197E-01
20	5.23397E+05	8.94340E-02	51	4.53999E+02	6.98568E-01
21	4.97870E+05	1.05238E-01	52	2.75364E+02	7.37472E-01
22	3.87742E+05	1.21833E-01	53	1.67017E+02	7.76309E-01
23	3.01974E+05	1.30279E-01	54	1.01301E+02	7.87411E-01
24	2.98491E+05	1.30279E-01	55	4.78512E+01	8.18826E-01
25	2.97211E+05	1.30279E-01	56	2.26033E+01	9.40486E-01
26	2.94518E+05	1.30279E-01	57	1.06770E+01	1.04548E+00
27	2.73237E+05	1.44599E-01	58	5.04348E+00	1.13840E+00
28	2.23708E+05	1.59121E-01	59	2.38237E+00	1.18443E+00
29	1.83156E+05	1.73593E-01	60	1.12535E+00	8.67016E-01
30	1.49956E+05	1.87971E-01	61 ^b	4.13994E-01	0.0
31	1.22773E+05	2.07011E-01			

^aRead as 1.49183×10^7 .

^bLower energy boundary is 1.0×10^{-5} eV.

**Table B2. Response function for the 5-inch
Bonner ball units are: (counts·cm²/neutron)**

Group	Upper Energy(eV)	Response	Group	Upper Energy(eV)	Response
1	1.49183E+07 ^a	1.20669E-01	32	8.65168E+04	1.24045E+00
2	1.22140E+07	1.55406E-01	33	5.65622E+04	1.24045E+00
3	1.00000E+07	1.98617E-01	34	5.24752E+04	1.23913E+00
4	8.18730E+06	2.47835E-01	35	3.43067E+04	1.24014E+00
5	6.70320E+06	3.09156E-01	36	2.85011E+04	1.24050E+00
6	5.48811E+06	3.50826E-01	37	2.70001E+04	1.24050E+00
7	4.49329E+06	4.11506E-01	38	2.60584E+04	1.24051E+00
8	3.67879E+06	4.80385E-01	39	2.47875E+04	1.24352E+00
9	3.01194E+06	5.59548E-01	40	2.35786E+04	1.24466E+00
10	2.46597E+06	6.44104E-01	41	1.50344E+04	1.25469E+00
11	2.34570E+06	6.44104E-01	42	9.11882E+03	1.26085E+00
12	2.23130E+06	6.44116E-01	43	5.53084E+03	1.26951E+00
13	2.01897E+06	7.27626E-01	44	3.70744E+03	1.27670E+00
14	1.65299E+06	8.07973E-01	45	3.03539E+03	1.27971E+00
15	1.35335E+06	8.84056E-01	46	2.61259E+03	1.28640E+00
16	1.10803E+06	9.55019E-01	47	2.24867E+03	1.28641E+00
17	9.07180E+05	1.01825E+00	48	2.03468E+03	1.29539E+00
18	7.42735E+05	1.07318E+00	49	1.23410E+03	1.30011E+00
19	6.08101E+05	1.12007E+00	50	7.48518E+02	1.29933E+00
20	5.23397E+05	1.12007E+00	51	4.53999E+02	1.30253E+00
21	4.97870E+05	1.16393E+00	52	2.75364E+02	1.28078E+00
22	3.87742E+05	1.19619E+00	53	1.67017E+02	1.25907E+00
23	3.01974E+05	1.20946E+00	54	1.01301E+02	1.22880E+00
24	2.98491E+05	1.20946E+00	55	4.78512E+01	1.23420E+00
25	2.97211E+05	1.20946E+00	56	2.26033E+01	1.21012E+00
26	2.94518E+05	1.20946E+00	57	1.06770E+01	1.14298E+00
27	2.73237E+05	1.22429E+00	58	5.04348E+00	1.05082E+00
28	2.23708E+05	1.23395E+00	59	2.38237E+00	9.13886E-01
29	1.83156E+05	1.23969E+00	60	1.12535E+00	5.47689E-01
30	1.49956E+05	1.24235E+00	61	4.13994E-01	0.0
31	1.22773E+05	1.24263E+00			

^aRead as 1.49183×10^7 .

^bLower energy boundary is 1.0×10^{-5} eV.

**Table B3. Response function for the 8-inch
Bonner ball units are: (counts·cm²/neutron)**

Group	Upper Energy(eV)	Response	Group	Upper Energy(eV)	Response
1	1.49183E+07 ^a	4.32326E-01	32	8.65168E+04	7.23162E-01
2	1.22140E+07	5.39716E-01	33	5.65622E+04	7.23108E-01
3	1.00000E+07	6.67276E-01	34	5.24752E+04	6.69284E-01
4	8.18730E+06	7.86112E-01	35	3.43067E+04	6.43675E-01
5	6.70320E+06	9.07761E-01	36	2.85011E+04	6.35525E-01
6	5.48811E+06	9.90151E-01	37	2.70001E+04	6.35525E-01
7	4.49329E+06	1.06950E+00	38	2.60584E+04	6.35489E-01
8	3.67879E+06	1.14893E+00	39	2.47875E+04	6.17751E-01
9	3.01194E+06	1.24834E+00	40	2.35786E+04	6.10005E-01
10	2.46597E+06	1.33619E+00	41	1.50344E+04	5.78153E-01
11	2.34570E+06	1.33619E+00	42	9.11882E+03	5.64949E-01
12	2.23130E+06	1.33620E+00	43	5.53084E+03	5.46305E-01
13	2.01897E+06	1.39025E+00	44	3.70744E+03	5.32917E-01
14	1.65299E+06	1.41070E+00	45	3.03539E+03	5.28635E-01
15	1.35335E+06	1.40779E+00	46	2.61259E+03	5.20655E-01
16	1.10803E+06	1.38552E+00	47	2.24867E+03	5.20642E-01
17	9.07180E+05	1.34711E+00	48	2.03468E+03	5.08575E-01
18	7.42735E+05	1.29615E+00	49	1.23410E+03	4.85726E-01
19	6.08101E+05	1.23801E+00	50	7.48518E+02	4.75849E-01
20	5.23397E+05	1.23801E+00	51	4.53999E+02	4.50639E-01
21	4.97870E+05	1.16242E+00	52	2.75364E+02	4.31711E-01
22	3.87742E+05	1.08623E+00	53	1.67017E+02	4.12817E-01
23	3.01974E+05	1.04936E+00	54	1.01301E+02	4.01933E-01
24	2.98491E+05	1.04936E+00	55	4.78512E+01	3.85773E-01
25	2.97211E+05	1.04936E+00	56	2.26033E+01	3.62747E-01
26	2.94518E+05	1.04936E+00	57	1.06770E+01	3.30363E-01
27	2.73237E+05	9.89887E-01	58	5.04348E+00	2.94710E-01
28	2.23708E+05	9.34528E-01	59	2.38237E+00	2.50440E-01
29	1.83156E+05	8.84565E-01	60	1.12535E+00	1.47271E-01
30	1.49956E+05	8.39646E-01	61	4.13994E-01	0.0
31	1.22773E+05	7.87488E-01			

^aRead as 1.49183×10^7 .

^bLower energy boundary is 1.0×10^{-5} eV.

Table B4. Response function for the 10-inch
Bonner ball units are: (counts·cm²/neutron)

Group	Upper Energy(eV)	Response	Group	Upper Energy(eV)	Response
1	1.49183E+07 ^a	5.78909E-01	32	8.65168E+04	2.93774E-01
2	1.22140E+07	7.00540E-01	33	5.65622E+04	2.93744E-01
3	1.00000E+07	8.39563E-01	34	5.24752E+04	2.64298E-01
4	8.18730E+06	9.46618E-01	35	3.43067E+04	2.50817E-01
5	6.70320E+06	1.04564E+00	36	2.85011E+04	2.46583E-01
6	5.48811E+06	1.10765E+00	37	2.70001E+04	2.46583E-01
7	4.49329E+06	1.12520E+00	38	2.60584E+04	2.46564E-01
8	3.67879E+06	1.14494E+00	39	2.47875E+04	2.37427E-01
9	3.01194E+06	1.18825E+00	40	2.35786E+04	2.33527E-01
10	2.46597E+06	1.21060E+00	41	1.50344E+04	2.17585E-01
11	2.34570E+06	1.21060E+00	42	9.11882E+03	2.11135E-01
12	2.23130E+06	1.21060E+00	43	5.53084E+03	2.02107E-01
13	2.01897E+06	1.18985E+00	44	3.70744E+03	1.95759E-01
14	1.65299E+06	1.13338E+00	45	3.03539E+03	1.93728E-01
15	1.35335E+06	1.06010E+00	46	2.61259E+03	1.89962E-01
16	1.10803E+06	9.77055E-01	47	2.24867E+03	1.89956E-01
17	9.07180E+05	8.90321E-01	48	2.03468E+03	1.84405E-01
18	7.42735E+05	8.03759E-01	49	1.23410E+03	1.74474E-01
19	6.08101E+05	7.22208E-01	50	7.48518E+02	1.70306E-01
20	5.23397E+05	7.22208E-01	51	4.53999E+02	1.59811E-01
21	4.97870E+05	6.33772E-01	52	2.75364E+02	1.52531E-01
22	3.87742E+05	5.56978E-01	53	1.67017E+02	1.45263E-01
23	3.01974E+05	5.22467E-01	54	1.01301E+02	1.53973E-01
24	2.98491E+05	5.22467E-01	55	4.78512E+01	1.47152E-01
25	2.97211E+05	5.22467E-01	56	2.26033E+01	1.37944E-01
26	2.94518E+05	5.22467E-01	57	1.06770E+01	1.25359E-01
27	2.73237E+05	4.72399E-01	58	5.04348E+00	1.11704E-01
28	2.23708E+05	4.29645E-01	59	2.38237E+00	9.48862E-02
29	1.83156E+05	3.93889E-01	60	1.12535E+00	5.57627E-02
30	1.49956E+05	3.63828E-01	61	4.13994E-01	0.0
31	1.22773E+05	3.31231E-01			

^aRead as 1.49183×10^7 .

^bLower energy boundary is 1.0×10^{-5} eV.

**Table B5. Response function for the 12-inch
Bonner ball units are: (counts·cm²/neutron)**

Group	Upper Energy(eV)	Response	Group	Upper Energy(eV)	Response
1	1.49183E+07 ^a	6.49921E-01	32	8.65168E+04	1.04217E-01
2	1.22140E+07	7.59764E-01	33	5.65622E+04	1.04205E-01
3	1.00000E+07	8.80156E-01	34	5.24752E+04	9.25298E-02
4	8.18730E+06	9.49120E-01	35	3.43067E+04	8.73151E-02
5	6.70320E+06	1.00639E+00	36	2.85011E+04	8.56888E-02
6	5.48811E+06	1.03164E+00	37	2.70001E+04	8.56888E-02
7	4.49329E+06	9.82518E-01	38	2.60584E+04	8.56817E-02
8	3.67879E+06	9.46892E-01	39	2.47875E+04	8.22045E-02
9	3.01194E+06	9.37486E-01	40	2.35786E+04	8.07355E-02
10	2.46597E+06	9.07035E-01	41	1.50344E+04	7.47647E-02
11	2.34570E+06	9.07035E-01	42	9.11882E+03	7.23805E-02
12	2.23130E+06	9.07025E-01	43	5.53084E+03	6.90539E-02
13	2.01897E+06	8.39170E-01	44	3.70744E+03	6.67362E-02
14	1.65299E+06	7.47313E-01	45	3.03539E+03	6.59969E-02
15	1.35335E+06	6.52418E-01	46	2.61259E+03	6.46295E-02
16	1.10803E+06	5.60876E-01	47	2.24867E+03	6.46273E-02
17	9.07180E+05	4.77474E-01	48	2.03468E+03	6.26265E-02
18	7.42735E+05	4.03667E-01	49	1.23410E+03	5.91022E-02
19	6.08101E+05	3.41116E-01	50	7.48518E+02	5.76349E-02
20	5.23397E+05	3.41116E-01	51	4.53999E+02	5.39610E-02
21	4.97870E+05	2.80599E-01	52	2.75364E+02	5.14557E-02
22	3.87742E+05	2.33218E-01	53	1.67017E+02	4.89548E-02
23	3.01974E+05	2.13122E-01	54	1.01301E+02	5.85788E-02
24	2.98491E+05	2.13122E-01	55	4.78512E+01	5.59386E-02
25	2.97211E+05	2.13122E-01	56	2.26033E+01	5.24039E-02
26	2.94518E+05	2.13122E-01	57	1.06770E+01	4.75951E-02
27	2.73237E+05	1.86116E-01	58	5.04348E+00	4.23861E-02
28	2.23708E+05	1.64528E-01	59	2.38237E+00	3.59796E-02
29	1.83156E+05	1.47465E-01	60	1.12535E+00	2.11053E-02
30	1.49956E+05	1.33807E-01	61	4.13994E-01	0.0
31	1.22773E+05	1.19694E-01			

^aRead as 1.49183×10^7 .

^bLower energy boundary is 1.0×10^{-5} eV.

Table B6. Response function for the Hornyak button
(270 keV cutoff) units are: (ergs.cm²/g.neutron)

Group	Upper Energy(eV)	Response	Group	Upper Energy(eV)	Response
1	1.49183E+07 ^a	6.20000E-07	32	8.65168E+04	0.00000E+00
2	1.22140E+07	5.80065E-07	33	5.65622E+04	0.00000E+00
3	1.00000E+07	5.42000E-07	34	5.24752E+04	0.00000E+00
4	8.18730E+06	5.03007E-07	35	3.43067E+04	0.00000E+00
5	6.70320E+06	4.68005E-07	36	2.85011E+04	0.00000E+00
6	5.48811E+06	4.36003E-07	37	2.70001E+04	0.00000E+00
7	4.49329E+06	4.19996E-07	38	2.60584E+04	0.00000E+00
8	3.67879E+06	3.89995E-07	39	2.47875E+04	0.00000E+00
9	3.01194E+06	3.49997E-07	40	2.35786E+04	0.00000E+00
10	2.46597E+06	3.12000E-07	41	1.50344E+04	0.00000E+00
11	2.34570E+06	3.12000E-07	42	9.11882E+03	0.00000E+00
12	2.23130E+06	3.11998E-07	43	5.53084E+03	0.00000E+00
13	2.01897E+06	2.96999E-07	44	3.70744E+03	0.00000E+00
14	1.65299E+06	2.67000E-07	45	3.03539E+03	0.00000E+00
15	1.35335E+06	2.44030E-07	46	2.61259E+03	0.00000E+00
16	1.10803E+06	2.21954E-07	47	2.24867E+03	0.00000E+00
17	9.07180E+05	2.01000E-07	48	2.03468E+03	0.00000E+00
18	7.42735E+05	1.77006E-07	49	1.23410E+03	0.00000E+00
19	6.08101E+05	1.58000E-07	50	7.48518E+02	0.00000E+00
20	5.23397E+05	1.58000E-07	51	4.53999E+02	0.00000E+00
21	4.97870E+05	1.39212E-07	52	2.75364E+02	0.00000E+00
22	3.87742E+05	1.24004E-07	53	1.67017E+02	0.00000E+00
23	3.01974E+05	1.18000E-07	54	1.01301E+02	0.00000E+00
24	2.98491E+05	1.18000E-07	55	4.78512E+01	0.00000E+00
25	2.97211E+05	1.18000E-07	56	2.26033E+01	0.00000E+00
26	2.94518E+05	1.18000E-07	57	1.06770E+01	0.00000E+00
27	2.73237E+05	7.93368E-11	58	5.04348E+00	0.00000E+00
28	2.23708E+05	0.00000E+00	59	2.38237E+00	0.00000E+00
29	1.83156E+05	0.00000E+00	60	1.12535E+00	0.00000E+00
30	1.49956E+05	0.00000E+00	61 ^b	4.13994E-01	0.00000E+00
31	1.22773E+05	0.00000E+00			

^aRead as 1.49183×10^7 .

^bLower energy boundary is 1.0×10^{-5} eV.

REFERENCES

1. F. J. Muckenthaler, et al., *Measurements for the JASPER Program Fission Gas Plenum Experiment*, ORNL/TM-10422, June 1987.
2. D. T. Ingersoll and N. Ohtani, "JASPER: A Joint U. S. -Japan Program of Experimental Shielding Research," *Proceedings of the Topical Conference on Theory and Practices in Radiation Protection and Shielding*, pp. 346-353, April 22-24, 1987, Knoxville, Tennessee.
3. E. T. Boulette, *Streaming Analysis for the FTR Fission Gas Plenum Region*, HEDL-TME-72-52, May 1972.
4. C. O. Slater, *Analysis of the ORNL/TSF Alternate Shielding Materials Experiment*, ORNL/TM-10183, April 1987.
5. R. E. Maerker and F. J. Muckenthaler, *The Absolute Neutron Spectrum Emerging Through the Large Beam Collimator from the TSR-II Reactor at the Tower Shielding Facility*, ORNL/TM-5183, 1976.
6. W. A. Rhoades and R. L. Childs, *An Updated Version of the DOT4 One- and Two-Dimensional Neutron/Photon Transport Code*, ORNL-5851, July 1982.
7. C. Y. Fu and D. T. Ingersoll, *VELM61 and VELM22: Multigroup Cross-Section Libraries for Sodium-Cooled Reactor Shield Analysis*, ORNL/TM-10302, April 1987.
8. M. B. Emmett, *The MORSE Monte Carlo Radiation Transport Code System*, ORNL-4972, 1975.
9. C. O. Slater, "BSPRP2 - A computer program to prepare source input from DOT-IV "BNDRYS" - formatted multiple boundary source data sets," ORNL internal memorandum, May 14, 1985.
10. VFL2BD is the Cray computer version of the IBM code VFL2BDRY written by the author to copy boundary fluxes from a DOT-IV flux and moments file and create a top or bottom boundary source file for a follow-on DOT calculation in a void region following the 2-D R-Z mockup. The boundary source may also be used as an internal source in a bootstrap case.
11. BFXSCL is the Cray computer version of the IBM code BFLXSCL written by the author and described in: C. O. Slater, *Analysis of Phase I of the HTGR Bottom Reflector and Core Support Block Neutron-Streaming Experiment*, ORNL/TM-9252, p. 13, July 1984.
12. M. B. Emmett, *DOMINO-II, A General Purpose Code for Coupling DOT-IV Discrete Ordinates and Monte Carlo Radiation Transport Calculations*, ORNL-4853, 1973.

13. W. A. Rhoades, "The GIP Program for Preparation of Group-Organized Cross Section Libraries," pp. 53-56 in RSIC Computer Code Collection Document PSR-75, January 23, 1976.
14. DTWTPN is the Cray computer version of the IBM code DOTWRTPN written by the author and described briefly on p. 26 of Ref. 11.
15. DSKTRN is the Cray computer version of the IBM code DISKTRAN written by the author and described in: C. O. Slater, S. N. Cramer, and D. T. Ingersoll, *Analysis of the ORNL/TSF GCFR Grid-Plate Shield Design Confirmation Experiment*, ORNL-5551, August 1979, Appendix C. The version presented starts the calculation at the detector and works back to the source. The present version starts the calculation at the source and works out to the detectors; the input is different from that shown.
16. R. E. Maerker, F. J. Muckenthaler, R. L. Childs, and M. L. Gritzner, *Final Report on a Benchmark Experiment for Neutron Transport in Thick Sodium*, ORNL-4880, 1974.

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