ORNL

**OAK RIDGE
NATIONAL
LABORATORY**

MARTIN MARIETTA

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

⑤

8/87 95 ②

5.31521

DR-0289-5

ORNL/TM-10422

**Measurements for the JASPER Program
Fission Gas Plenum Experiment**

F. J. Muckenthaler

**DO NOT MICROFILM
COVER**

MASTER

HH
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DO NOT MICROFILM
COVER

Printed in the United States of America. Available from
the U.S. Department of Energy
Technical Information Center
P.O. Box 62, Oak Ridge, Tennessee 37830

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

Engineering Physics and Mathematics Division

MEASUREMENTS FOR THE JASPER PROGRAM
FISSION GAS PLENUM EXPERIMENT

Report Written by:
F. J. Muckenthaler

Work Done by:

F. J. Muckenthaler
B. D. Rooney
J. D. Drischler
N. Ohtani*
J. L. Hull**
L. B. Holland**

Date Published: June 1987

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

*Japan Power Reactor and Nuclear Fuel Development Corporation
**Operations Division

DISCLAIMER

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

Prepared by the
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
operated by
Martin Marietta Energy Systems, Inc.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

HH 1
3
1
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

DISCLAIMER

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

TABLE OF CONTENTS

ABSTRACT	1
1. INTRODUCTION	1
2. INSTRUMENTATION	3
3. EXPERIMENTAL CONFIGURATION	5
3.1 Spectrum Modifier	5
3.2 Heterogeneous Fission Gas Plenum	6
3.3 Homogeneous Fission Gas Plenum	7
3.4 Stainless Steel Sheets	7
3.5 Aluminum	7
3.6 Stainless Steel Tubing	8
4. MEASUREMENTS	9
4.1 Spectrum Modifier (Item I)	9
4.2 8-cm Homogeneous Fission Gas Plenum (Item II)	9
4.3 20-cm Homogeneous Fission Gas Plenum (Item III)	10
4.4 8-cm Heterogeneous Fission Gas Plenum (Item IV)	10
4.5 20-cm Heterogeneous Fission Gas Plenum (Item V)	10
5. RESULTS	12
6. ANALYSIS OF EXPERIMENTAL ERRORS	13
REFERENCES	15
APPENDIX A. Experimental Program Plan for the Fission Gas Plenum Experiment	17
APPENDIX B. Tables of Data	21
APPENDIX C. List of Figures	41

ABSTRACT

The Fission Gas Plenum Experiment was conducted at the Oak Ridge National Laboratory Tower Shielding Facility during FY 1987 to: (1) provide data for verification of the assumptions and calculational methods used to determine the neutron leakage from the plenum, and (2) provide an uncertainty evaluation associated with the calculations. The Tower Shielding Reactor source was modified to represent the neutron spectrum leaving a typical liquid-metal-cooled reactor core along its axis. The experimental configurations resulted from the insertion of either a homogeneous or homogeneous-heterogeneous gas plenum combination into the iris of a concrete slab, with the only variable being the thickness of the plenum. Integral neutron fluxes were measured behind each of the configurations at specified locations, and neutron spectra were obtained behind selected mockups. The experimental data are presented in both tabular and graphical form.

This experiment is the second in a series of six experiments to be performed as part of a cooperative effort between the United States Department of Energy and the Japan Power Reactor and Nuclear Fuel Development Corporation. The research program is intended to provide support for the development of advanced sodium-cooled reactors.

1. INTRODUCTION

In September 1985, an agreement was signed between the United States Department of Energy and the Japanese Power Reactor and Nuclear Fuel Development Corporation (PNC) to perform a series of six experiments at the Oak Ridge National Laboratory's Tower Shielding Facility (TSF). The research program, entitled "JASPER" for Japanese-American Shielding Program of Experimental Research, is a cooperative effort designed to meet the needs of both participants. All of the experiments performed are planned jointly by ORNL and PNC representatives, and derived through an iterative process of submitted proposals and mutual agreement.

The first of these experiments¹ was completed in the fall of 1986. The second one, entitled The Fission Gas Plenum Experiment, was started in January 1987 and was designed to investigate neutron transmission through heterogeneous and homogeneous mockups of an upper gas plenum region designed for use with advanced reactor concepts. The planned program was comparatively short, consisting of only four separate investigations.

In this experiment, a spectrum modifier was used to alter the energy distribution of the TSF beam to provide a typical near-core neutron spectrum. For this, a modifier of iron, aluminum, boron, and a "radial blanket" of natural UO_2 was placed in the beam.

The components used in the experimental mockups were heterogeneous and homogeneous combinations of stainless steel (SS), aluminum, and voids. The aluminum was used to mockup sodium in the plenum region. The heterogeneous plenums consisted of a 22-cm-diameter arrangement of 512 SS tubes passing through sheets of aluminum spaced to provide the proper void fraction. Thicknesses of nominally 8 and 20 cm were investigated.

The plenums were positioned in the iris of a concrete slab placed in the horizontal beam emerging from TSR-II, preceded by the SM. Streaming was investigated through spectral and integral neutron flux measurements behind the individual plenums as they were placed in the beam. Measurements were also made behind each plenum with Japanese CR-39 neutron dosimeters, but that data will not be included in this report. However, these measurements are included in the program plan (see Appendix A).

2. INSTRUMENTATION

The TSF Bonner ball detection system consists of a series of detectors (balls), each of which measures an integral of the neutron flux weighted by the energy-dependent response function for that ball. The detection device of a Bonner ball consists of a 5.1-cm-diameter spherical proportional counter filled with BF_3 gas ($^{10}\text{B}/\text{B}$ concentration = 0.96) to a pressure of 0.5 atmospheres. In order to cover a range of neutron energies, the counter is used bare, covered with cadmium, or enclosed in various thicknesses of polyethylene shells surrounded by cadmium, each detector being identified by the diameter of its shell. Bonner ball experimental results are predicted analytically by folding a calculated neutron spectrum with the Bonner ball response functions determined by Maerker et al.² and by C. E. Burgart et al.³

The NE-213 liquid scintillator spectrometer was used to measure neutron spectra from about 800 keV to 15 MeV. The pulse-height data obtained with the spectrometer were unfolded with the FERD code⁴ to yield absolute neutron energy spectra.

The spherical proton-recoil counters, filled with hydrogen to pressures of 1, 3, and 10 atmospheres, were used to obtain the neutron spectral distribution from about 50 keV to 1 MeV. Pulse-height data from the counters were unfolded with the SPEC-4 code,⁵ which uses the unfolded NE-213 neutron spectrum for the high energy input.

The measurements for each detector were referenced to the reactor power (watts) using as a basis the data from two fission chambers positioned along the reactor centerline. The response of these chambers as a function of reactor power level was established previously through several calorimetric measurements of the heat generated in the reactor during a temperature equilibrium (heat power run).

A Hornyak button consists of a disk of lucite containing very small particles of zinc sulfide dispersed uniformly in the disk. The button has a response that approaches that of a single collision dose. For this experiment, the button was 0.635 cm in diameter, 0.159 cm thick, and mounted on an RCA photomultiplier tube. Calibration procedure consisted of first exposing the scintillator to a 2 R/h gamma-ray dose

rate and adjusting the electronic gain to obtain approximately 40 counts per second for a pulse height discriminator setting (PHS) setting of 060 (600 millivolts). The button was then exposed to a known strength of a ^{252}Cf neutron source and the dose rate to count rate ratio obtained. However, for this experiment, it was necessary to obtain this neutron calibration ratio at a higher PHS of 350 (3.5 volts) to bias against the increased number of gamma-ray pulses resulting from a much more intense gamma-ray field where the experimental neutron measurements were made. This meant that the neutron energy bias level was also higher, introducing a discrepancy in describing the button response as that of a dosimeter. However, since the detector's purpose was to determine if neutron streaming effects were observable, the measurements were meaningful for relative comparisons and have been listed in this report as neutron dose rates.

3. EXPERIMENTAL CONFIGURATION

The experimental program plan (see Appendix A) called for neutron measurements to be made behind a series of mockups containing heterogeneous and homogeneous models of the upper fission gas plenum design being considered by U.S. and Japanese reactor designers for use in advanced LMFBR concepts. Two thicknesses were studied, 8 cm and 20 cm, preceded by a spectrum modifier in the TSR beam.

3.1 SPECTRUM MODIFIER

The spectrum modifier (SM) in this experiment was the same SM used in the first JASPER experiment, nominally 10 cm of iron followed by 10 cm of aluminum, 2.5 cm of boral, and 20.3 cm of a "radial blanket" placed in the TSR-II beam (see Figure 1). The iron component consisted of two slabs 5.16 and 5.11 cm thick, both 152.4 cm (60 in) on an edge. The three aluminum slabs totaled 9.17 cm in thickness, and the boral was 2.54 cm thick, all having the same edge length as the iron slabs. Composition of the iron, aluminum, and boral are given in Tables 1, 2, and 3, respectively. (Note: All tables are included in Appendix B.)

The UO_2 slabs representing the "radial blanket" had been fabricated for earlier experiments performed in the LMFBR program. They contain natural UO_2 pellets, 1.397 cm OD, enclosed in aluminum cylinders having an OD of 1.524 cm. Between the aluminum and the pellets there is a 0.00508 to 0.01016 cm void filled with argon. The cylinders are stacked side-by-side vertically, having a triangular pitch of 1.608 cm. The voids between the cylinders are filled with sodium. These rods are enclosed in iron vessels having an overall thickness of 11.05 cm and a length of 152.4 cm on each side.

Each of the two slabs used in this experiment contain 522 rods amounting to 64.6% of the volume of the slab. There are seven rows of rods with 74 and 75 rods per alternate row. The UO_2 density is 10.28 g/cm^3 (94% of theoretical). The volume of the aluminum cladding is 11.2% and that for the sodium is 23.3%, leaving a void volume between the pellet and the aluminum cylinder of 1%. The pellet stack length in each of the rods is approximately 121.9 cm. A schematic of the slab is

shown in Figure 2, with analyses of the UO_2 and aluminum given in Tables 4 and 5.

The spectrum modifier was surrounded by 20.3 cm (8 in) of lithiated paraffin followed by up to 152.4 cm (60 in) of concrete to minimize the neutrons scattering back into the slabs and to reduce the amount of background radiation reaching the detectors. The lithiated paraffin was shaped as small bricks 10.16 cm on edge and 20.3 cm long (4-in-facing x 8-in-long) and the concrete consisted of large blocks 61 cm on edge and 30.5 cm thick (24-in-facing x 12-in-thick). The composition of the lithiated paraffin and concrete blocks are presented in Tables 6 and 7 respectively.

3.2 HETEROGENEOUS FISSION GAS PLENUM

The designs of the heterogeneous gas plenums shown in Figure 3 were to be representative of actual plenums anticipated for use in advanced LMRs. The reference design suggested by the Japanese called for SS tubing having a 7.5 mm OD with a 0.42 mm wall thickness. Tubing having an OD of 7.93 mm with a wall thickness of 0.508 mm was available and this was used instead to save fabrication costs. With this tubing in the mockups, the volume fractions for SS, sodium, and air were calculated to be 16, 33, and 51% respectively. A total of 512 tubes were placed in each heterogeneous plenum. As was mentioned earlier, the sodium was replaced by aluminum, a material which attenuates neutrons about twice that for sodium. Thus, the aluminum volume in the plenum was half of that calculated for sodium.

Since the SS tubing penetrated the aluminum sheets in the heterogeneous region, it was necessary to add additional aluminum between the pins to maintain the above volume fractions. Calculations indicated that for each original sheet of aluminum, an additional plate 6.35 mm thick should be added. As the schematic (see Figure 3) indicates, the actual thickness of each plate was 6.53 mm.

As shown in Figure 3, the 22-cm-diam heterogeneous region was surrounded by an annular region, 61 cm OD, that was homogeneous in design but maintained the same respective volume fractions as in the heterogeneous region. Two plenum thicknesses were tested, nominally 8 cm and 20 cm.

3.3 HOMOGENEOUS FISSION GAS PLENUM

The structure of this plenum is based upon the volume fraction ratios of SS, sodium, and void established for the heterogeneous model above. Again, as stated in Section 3.2, aluminum replaced the sodium. The volume fractions for each material in the heterogeneous models were transformed into thin sheets of equal thickness and spaced throughout the homogeneous models, as shown in Figure 4. For aluminum, each sheet was 0.3175 cm thick (0.125 in), while for the SS sheets, the thickness was 0.302 cm (0.119 in). For the 8-cm plenum, the void thickness was 1.819 cm (0.716 in); for the 20-cm plenum, it was 1.331 cm (0.524 in). The plates were secured together with four SS bolts as shown. When placed in the beam, the plenums were oriented so that the source and SM were to the right of the plenums as they are displayed in the schematic. The plenums, both heterogeneous and homogeneous, were placed in the iris of a concrete slab (see Figure 5) when placed in the mockups. Two concrete slab thicknesses were used, 8 cm and 20 cm, and their composition is given in Table 7A. The 20-cm-thick slab contained two layers of wire mesh located 3.81 cm from the faces of the slab (see Figure 5). In the 8-cm-thick slab there was only one layer of wire mesh located midway between the faces of the slab.

3.4 STAINLESS STEEL SHEETS

The stainless steel sheets used in the homogeneous gas plenum models and in the homogeneous annulus of the heterogeneous models were 0.302 cm thick type 304 SS, (0.119 in), and their elemental composition is found in Table 8.

3.5 ALUMINUM

Two thicknesses of 6061-T6 aluminum, 0.3175 cm (0.125 in) and 0.653 cm (0.257 in), were used in the heterogeneous part of the plenums, while only the thinner plates were used in the homogeneous sections. The composition of the aluminum is given in Table 9.

3.6 STAINLESS STEEL TUBING

The stainless steel tubing was also type 304, and the analysis is given in Table 10. The tubing was 0.793 cm (0.312 in) OD, with a 0.0508-cm- (0.020-in-) thick wall.

4. MEASUREMENTS

4.1 SPECTRUM MODIFIER (ITEM I)

Since the spectrum modifier used in this experiment was the same one used in the prior experiment,¹ the only Bonner ball measurements included in this program plan were the 3-, 5-, 8-, 10-, and 12-in Bonner balls on centerline at 30 cm behind the SM, and at 304.8 cm from the reactor center. The results from this series of measurements can be found in Tables 11 and 12. Background runs were made with a shadow shield of lithiated paraffin (91.4 cm square x 40.64 cm thick) placed between the detector and configuration only when the detector was at the 304.8 cm location. These results are included in Table 12.

The program plan (see Appendix A) included horizontal traverses with the 0.635-cm-diam Hornyak button as close as feasible behind each mockup and on centerline at 30 cm beyond the configuration. The results from the traverse 2 cm behind the SM are given in Table 13. The measurement on centerline at 30 cm is given in Table 14.

4.2 8-CM HOMOGENEOUS FISSION GAS PLENUM (ITEM II)

As was mentioned earlier, the purpose of this experiment was to determine the extent of neutron streaming through SS tubing in the heterogeneous fission gas plenums. To make this determination, it was necessary to include measurements behind a homogeneous plenum which included the same volume fractions of SS, Al, and void as the heterogeneous model, and then compare the results. Such measurements were made with the 3-, 5-, 8-, 10-, and 12-in Bonner balls on centerline at 30 cm behind the 8-cm-thick homogeneous plenum and at 304.8 cm (both foreground and background) from the reactor center. These results are listed in Tables 11 and 12. Data from the 5-in Bonner ball horizontal traverse at 30 cm behind the plenum are listed in Table 15. A similar traverse with the 0.635-cm-diam Hornyak button was run 1.6 cm behind the plenum, and the data are given in Table 13. The single point measurement on centerline at 30 cm beyond the plenum with the button is given in Table 14.

4.3 20-CM HOMOGENEOUS FISSION GAS PLENUM (ITEM III)

Spectral measurements, with both the NE-213 and hydrogen counters, were made on centerline at 43.6 cm behind the plenum, a point 203.6 cm from the reactor center. The results are plotted in Figures 6 and 7, and listed in Tables 16 and 17. The 3-, 5-, and 10-in Bonner ball measurements at this same location are given in Table 18. The centerline measurements with the five Bonner balls at 30 cm behind the plenum are given in Table 11, while those at the 304.8 cm location (both foreground and background) are listed in Table 12. Data from the 5-in Bonner ball horizontal traverse 30 cm behind the plenum are included in Table 15. Results from a horizontal traverse with the Hornyak button 1.6 cm behind the plenum are listed in Table 13. The Hornyak button measurement on centerline at 30 cm behind the plenum is included in Table 14.

4.4 8-CM HETEROGENEOUS FISSION GAS PLENUM (ITEM IV)

A photograph of the fission gas plenum mockup is shown in Figure 8. Results from the five Bonner ball measurements on centerline at 30 cm behind this mockup are given in Table 11. The foreground and background measurements on centerline with the Bonner balls at 304.8 cm from the reactor center are listed in Table 12. Measurements from the 5-in ball traverse 30 cm behind the plenum are given in Table 15. Results from a similar traverse with the Hornyak button at 1.6 cm behind the plenum are part of Table 13. The data points were obtained every millimeter from centerline for the first 1.5 cm north, trying to detect peaks and valleys in the count rates as the detector moved across the first and second SS tube openings and the aluminum-SS structure in between. No peaks were observed, as shown by the data points in Figure 9. The numerical values for this traverse are listed in Table 13. The dose rate measurement with the Hornyak button on centerline at 30 cm is part of Table 14.

4.5 20-CM HETEROGENEOUS FISSION GAS PLENUM (ITEM V)

The NE-213 fast neutron spectrometer was placed on centerline at 43.5 cm behind this gas plenum. As with the measurement behind the

20-cm homogeneous plenum, proximity of the detector to the gas plenum permitted only the foreground run. The spectrum is plotted in Figure 10 and the data contained in Table 19. The hydrogen counter low-energy spectra were obtained at the NE-213 location, and the results are plotted in Figure 11 and listed in Table 20. Data with the 3-, 5-, and 10-in Bonner balls at the same location are part of Table 18. The 3-, 5-, 8-, 10-, and 12-in ball data on centerline at 30 cm behind the plenum are in Table 11, and the measurements at 304.8 cm from the reactor are given in Table 12. The 5-in ball traverse data at 30 cm behind the mockup are listed in Table 15. Measurements from a similar traverse with the Hornyak button at 1.6 cm behind the plenum are given in Table 13. Again, measurements were made at millimeter increments along the traverse near the centerline in search of peaks and valleys but none were observed (see Figure 12). The Hornyak data on centerline at 30 cm behind the mockup are included in Table 14.

5. RESULTS

Measurements show that, within experimental error, there were no indications of neutron streaming through the voided SS tubing. Specifically, no spatial peaking of the neutron flux was observed at the exit of individual tubes, although this result may be somewhat affected by the relative sizes of the tubes and the Hornyak button detector. Additionally, however, no significant change in the magnitude of the centerline measurements was observed for any of the detectors when comparing the homogeneous and heterogeneous data. This may be due to the fact that the neutrons entering the plenum have a broad angular distribution and there was insufficient attenuation across the plenum region to demonstrate a perceptible amount of streaming. Careful analysis will be required to fully understand the measurements.

6. ANALYSIS OF EXPERIMENTAL ERRORS

The errors associated with the measurements are mainly due to uncertainties in the positioning of the detectors, their count rate statistics and calibrations, the reactor power determinations, and in the effects of the exposure of the configurations to the weather. Of these, the uncertainty due to changes in the weather is probably the hardest to estimate. The uncertainty lies in the amount of moisture that can collect between the slabs and in the lithiated paraffin surrounding them, even though some coverage was provided by a tarpaulin. For this experiment, the effect was assumed to be negligible.

The TSR-II power level for each measurement was determined from the output of two fission chambers located in the reactor shield along the midplane of the reactor. The response of these chambers to the reactor source was monitored prior to the experiment through the use of gold foils, and found to agree to within 5% with previous reactor power values. These detectors were calibrated on a daily basis using a ^{252}Cf source, with the calibration values lying within about a 6% spread ($\pm 3\%$ of an average value). During any one detector traverse in a given day, the variation in the reactor power indicated by the monitor outputs was, at most, about 3%; however, during the time that the experiment was being performed, the monitors indicated variations of about $\pm 5\%$. Thus, the uncertainty in the reactor power determination was assumed to be $\pm 5\%$.

Count-rate statistics are expressed in a manner specific to each detector. For the NE-213 measurements, counting statistics and unfolding errors are included in the unfolding of the pulse-height spectra using the FERD code, with the resulting flux expressed in terms of lower and upper limits that represent a 68% confidence interval. Similar errors are expressed in the tabular data for the hydrogen counter measurements unfolded using SPEC4. Neither of the spectra, NE-213 or hydrogen counter, reflects the error in determining the reactor power since this error is not included in the unfolding program.

The Bonner balls were calibrated on a daily basis using ^{252}Cf as a source, with the resulting count rates falling within about $\pm 3\%$ of an

average value obtained throughout the years. Movement of the Bonner balls along a traversing mechanism can vary the detector location with respect to the configuration several millimeters or more on either side of a straight line. For the measurements perpendicular to the configuration centerline at 30 cm behind the configurations, such variations in the detector position could amount to a change in the count rate of about 2%. For the measurements on centerline beyond the 30 cm point, the error in positioning several millimeters either side of the selected location would lie within the statistics of the measurement. Rather than calculate probable errors for each measurement in a series of measurements during a traverse, we prefer, in general, to quote a value for the error in the measurements for a given experiment. Thus, assuming an estimated upper limit for all the considerations, the errors assigned to the Bonner ball measurements should be less than $\pm 10\%$.

It is estimated that errors in measurements with the Hornyak button fall within this same range, even though the errors in calibration are slightly greater than for the Bonner balls.

REFERENCES

1. F. J. Muckenthaler et al., *Measurements for the JASPER Program Radial Shield Attenuation Experiment*, ORNL/TM-10371 (May 1987).
2. R. E. Maerker et al., *Calibration of the Bonner Ball Neutron Detectors Used at the Tower Shielding Facility*, ORNL/TM-3465 (June 1971).
3. C. E. Burgart and M. B. Emmett, *Monte Carlo Calculations of the Response Functions of Bonner Ball Neutron Detectors*, ORNL/TM-3739 (April 1972).
4. B. W. Rust, D. T. Ingersoll, and W. R. Burrus, *A User's Manual for the FERDO and FERD Unfolding Codes*, ORNL/TM-8720 (September 1983).
5. J. O. Johnson and D. T. Ingersoll, *User's Guide for the Revised SPEC-4 Neutron Spectron Unfolding Code*, ORNL/TM-7384 (August 1980).

ACKNOWLEDGEMENTS

The author is deeply indebted to D. T. Ingersoll and W. W. Engle, Jr. of ORNL's Engineering Physics and Mathematics Division, to D. E. Bartine of the Engineering Technology Division, to P. B. Hemmig of DOE/Washington, and to the JASPER working group from Japan, for their participation and assistance in formulating the Experimental Program Plan. Appreciation is expressed to E. R. Specht, Rockwell International; W. H. Harless, General Electric Company; R. K. Disney, Westinghouse-ARD; W. L. Bunch, Westinghouse-Hanford, for timely suggestions. Special thanks go to G. A. Russell and J. K. Ingersoll for their efforts in editing and preparation of this report.

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

APPENDIX B. TABLES OF DATA

LIST OF TABLES

- Table 1. Analysis of iron slabs used in spectrum modifier ($\rho = 7.86 \text{ g/cm}^3$)
- Table 2. Analysis of aluminum slabs used in spectrum modifier ($\rho = 2.70 \text{ g/cm}^3$)
- Table 3. Composition of boron slabs used in spectrum modifier
- Table 4. Composition of UO_2 radial blanket
- Table 5. Analysis of aluminum used in UO_2 radial blanket cladding
- Table 6. Composition of lithiated-paraffin bricks ($\rho = 1.15 \text{ g/cm}^3$)
- Table 7. Analysis of 61-cm x 61-cm x 30.5-cm concrete blocks used to surround configuration ($\rho = 2.4 \text{ g/cm}^3$)
- Table 7A. Analysis of concrete slabs used to contain the fission gas plenums ($\rho = 2.44 \text{ g/cm}^3$)
- Table 8. Analysis of type 304 stainless steel sheets used in fission gas plenums
- Table 9. Analysis of (6061-T6) aluminum sheets used in fission gas plenums ($\rho = 2.70 \text{ g/cm}^3$)
- Table 10. Analysis of type 304 stainless steel tubing used in fission gas plenums
- Table 11. Bonner ball measurements on centerline at 30 cm behind a series of configurations (Items I, II, III, IV, V)
- Table 12. Bonner ball measurements on centerline behind a series of configurations at 304.8 cm from the center of the reactor (Items I, II, III, IV, V)
- Table 13. Hornyak button traverses through horizontal midplane 1.6 cm behind a series of mockups (Items I, II, III, IV, V)
- Table 14. Hornyak button measurements on centerline at 30 cm behind a series of mockups (Items I, II, III, IV, V)
- Table 15. 5-inch Bonner ball horizontal traverse through midplane at 30 cm behind a series of configurations (Items II, III, IV, V)
- Table 16. Spectrum of high-energy neutrons ($>0.8 \text{ MeV}$) on centerline 43.6 cm beyond 20-cm homogeneous fission gas plenum (Item III): Run 7866A
- Table 17. 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
- Table 18. Bonner ball measurements on centerline at the same location as the NE-213 spectrometer (Items III, V)

Table 19. Spectrum of high-energy neutrons (>0.8 MeV) on centerline 43.5 cm beyond 20-cm heterogeneous fission gas plenum (Item V): Run 7865A

Table 20. 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

**Table 1. Analysis of iron slabs
used in spectrum modifier ($\rho = 7.86 \text{ g/cm}^3$)**

Element	wt %
Fe	98.4
C	.25
Cr	.15
Cu	.03
Mn	1.0
Mo	.02
Ni	.05
Si	.25

**Table 2. Analysis of aluminum slabs
used in spectrum modifier ($\rho = 2.70 \text{ g/cm}^3$)**

Element	wt %	ppm
Al	97.5	
Cr	.22	
Cu	.23	
Fe	.47	
Mg	.86	
Mn	.01	
Si	.63	
Ti	.042	
Zn	.07	
Li		3
Ni		50
Sn		<10
V		150

Table 3. Composition of boral slabs used
in spectrum modifier

Component	(B ₄ C - 40-43 vol % in B ₄ C-Al mixture)		
	Density (g/cm ³)	Elemental Composition (wt %)	With Al Cladding (wt %)
B ₄ C	2.3		
Al	2.70	65	~75
B		27.5	~19.6
C		7.5	~5.4

Table 4. Composition of UO_2 radial blanket

Component	vol %	Density (g/cm^3)
UO_2 (pellets)	64.6	10.28
Al (8001)	11.2	2.8
Na	23.2	0.92
Void	1.0	----

UO_2 content 88.18 wt %			
----------------------------------	--	--	--

Isotope %			
^{234}U	.0053	^{236}U	--
^{235}U	.713	^{238}U	99.28

Metallic Impurities in UO_2 (ppm)					
Al	<20	Cu	1	Na	<20
B	<1	F	<2	Ni	<10
Be	<2	Fe	<20	Pb	<4
Bi	<2	H_2O	2.1	Si	<20
C	<10	Li	<1	Sn	<2
Ca	<20	Mg	<10	Ta	<25
Cd	<.5	Mn	<4	Tu	<4
Cl	<3.3	Mo	<10	W	<25
Co	<2	N	54	Zr	<25
Cr	<10				

Table 5. Analysis of aluminum used in UO_2 radial blanket cladding

Element	wt %	ppm
Fe	.59	
Ni	1.13	
B		<6
Be		<20
Cd		<20
Co		<20
Cr		<6
Cu		52.9
Li		6
Ng		3.04
Mn		11.2
Mo		<6
Pb		<20
Si		27.5
Sn		<60
Ta		<2000
Ti		65.5
V		44.2
W		<60
Zr		<20

Table 6. Composition of lithiated-paraffin bricks ($\rho = 1.15 \text{ g/cm}^3$)

Component	wt%
$\text{C}_n\text{H}_{2n+2}$	60
Li_2CO_3	40

Table 7. Analysis of 61-cm x 61-cm x 30.5-cm concrete blocks used to surround configuration ($\rho = 2.4 \text{ g/cm}^3$)

Component	wt %	Component	wt %
Co ₃	41.9	Al ₂ O ₃	2.2
Ca	27.4	Fe ₂ O ₃	.60
SiO ₂	18.1	SO ₃	.32
H ₂ O	4.0	P ₂ O ₅	.035
Mg	3.66	K	.30
O ₂	1.4		

Table 7A. Analysis of concrete slabs used to contain the fission gas plenums ($\rho = 2.44 \text{ g/cm}^3$)

Element	wt %
Al ₂ O ₃	2.43
CaO	36.78
CO ₃	44.3
Fe ₂ O ₃	0.92
H ₂ O (Bound)	2.10
H ₂ O (Free)	0.26
K ₂ O	0.57
LOI*	35.62*
MgO	13.78
Na ₂ O	0.13
P ₂ O ₅	0.0285
SiO ₂	8.54
SO ₃	0.53

*Includes free and bound H₂O, CO₂, and SO₃ values shown in the table.

**Table 8. Analysis of type 304 stainless steel sheets
used in fission gas plenums**

Element	wt%
Co	<0.001
Cr	19.2
Cu	0.15
Fe	69.0
Mn	1.7
Mo	0.21
Ni	9.2
Si	0.46
Ti	<0.02

**Table 9. Analysis of (6061-T6) aluminum sheets
used in fission gas plenums ($\rho = 2.70 \text{ g/cm}^3$)**

Element	wt%
Al	major
Co	<0.001
Cr	0.17
Cu	0.28
Fe	0.42
Li	<0.001
Mg	1.04
Mn	0.11
Ni	<0.001
Si	0.68
SN	<0.001
Ti	0.025
V	<0.001
Zn	0.15

**Table 10. Analysis of type 304 stainless steel tubing
used in fission gas plenums**

Element	wt%
Co	<0.001
Cr	19.0
Cu	0.37
Fe	69.97
Mn	1.3
Mo	0.25
Ni	9.2
Si	0.45
Ti	<0.02

Table 11. 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 12. Bonner ball measurements on centerline behind a series of configurations 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 13. 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}

Table 14. 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 15. 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 16. 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 17. 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

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

Configurator ^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 19. 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)	4.89 (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)	1.43 (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)	9.45 (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)	5.02E (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 (-1)
1.500	15.000	2.63E (4)	2.09E (2)
3.000	10.000	8.49E (3)	1.15E (2)

Table 20. 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

 

APPENDIX C

LIST OF FIGURES

- Figure 1. Schematic of SM (Fe + Al + boral + radial blankets) and fission gas plenums (Items I-V). Note: Lithiated paraffin covers lateral sides of configuration.
- Figure 2. Schematic of radial blanket slab containing UO_2 .
- Figure 3. Schematic of heterogeneous fission gas plenums (Items IV, V).
- Figure 4. Schematic of homogeneous fission gas plenums (Items II, III).
- Figure 5. Schematic of concrete slab enclosure for 20-cm-thick fission gas plenums.
- Figure 6. Spectrum of high-energy neutrons (>0.8 MeV) on centerline 43.6 cm beyond 20-cm homogeneous fission gas plenum (Item III).
- Figure 7. 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 8. Photograph of 8-cm heterogeneous fission gas plenum mockup (Item IV).
- Figure 9. Dose rate profile for Hornyak button measurements along horizontal traverse 1.6 cm beyond 8-cm heterogeneous fission gas plenum (Item IV).
- Figure 10. Spectrum of high-energy neutrons (>0.8 MeV) on centerline 43.5 cm beyond 20-cm heterogeneous fission gas plenum (Item V): 7865A.
- Figure 11. 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.
- Figure 12. Dose rate profile for Hornyak button measurements along horizontal traverse 1.6 cm beyond 20-cm heterogeneous fission gas plenum (Item V).

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

THEORETICAL DENSITY = 10.96 g/cc
 ACTUAL DENSITY (0.94 THEO.) = 10.28 g/cc

Figure 2. Schematic of radial blanket slab containing UO_2 .

Figure 3. Schematic of heterogeneous fission gas plenums (Items IV, V).

ORNL-DWG 87-6827

Homogeneous Gas Plenum Inserts

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

Figure 5. Schematic of concrete slab enclosure for 20-cm-thick fission gas plenums.

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

Figure 7. 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.

ORNL-PHOTO 1432-87

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

Figure 9. Dose rate profile for Hornyak button measurements along horizontal traverse 1.6 cm beyond 8-cm heterogeneous fission gas plenum (Item IV).

Figure 10. 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 11. 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.

Figure 12. Dose rate profile for Hornyak button measurements along horizontal traverse 1.6 cm beyond 20-cm heterogeneous fission gas plenum (Item V).

ORNL/TM-10422
DISTRIBUTION CATEGORY

INTERNAL DISTRIBUTION

1. D. G. Cacuci	33. C. O. Slater
2. R. L. Childs	34. R. C. Ward
3. J. D. Drischler	35. C. R. Weisbin
4. M. B. Emmett	36. L. R. Williams
5-8. W. W. Engle, Jr.	37. A. Zucker
9. C. Y. Fu	38. P. W. Dickson, Jr.
(Consultant)
10. G. F. Flanagan	39. G. H. Golub
(Consultant)
11. L. B. Holland	40. R. M. Haralick
(Consultant)
12. J. L. Hull	41. D. Steiner
(Consultant)
13-17. D. T. Ingersoll	42-43. Central Research Library
18. J. E. Jones, Jr.	44. Y-12 Technical Library
Document Reference Section
19. F. C. Maienschein	45-46. Laboratory Records
Department
20. J. J. Manning	47. Laboratory Records ORNL, RC
21-25. F. J. Muckenthaler	48. ORNL Patent Office
26. F. R. Mynatt	49. Engineering Physics
Information Center
27. J. V. Pace, III	50-54. EPMD Reports Office
28. R. W. Peelle	
29. W. A. Rhoades	
30. B. D. Rooney	
31. R. W. Roussin	
32. R. T. Santoro	

EXTERNAL DISTRIBUTION

55. Office of the Assistant Manager for Energy Research and Development, Oak Ridge Operations, Department of Energy, P.O. Box E, Oak Ridge, TN 37830.
56. J. E. Brunings, Program Manager, SAFR, Rocketdyne Division, Rockwell International Corp., 6633 Canoga Avenue, Canoga Park, CA 91304.
57. W. L. Bunch, Westinghouse-Hanford, 400 Area Trailer 1, Richland, WA 99352.
58. R. K. Disney, Westinghouse Electric Company, P.O. Box 158, Madison, PA 15663.
59. A. R. Gilchrist, Manager, Prism Technology Program, Nuclear Systems Technology Operation, General Electric Co., P.O. Box 3508, Sunnyvale, CA 94088.

- 60. W. H. Harless, General Electric Company, P.O. Box 3508, Sunnyvale, CA 94088.
- 61. P. B. Hemmig, Advanced Technology Development, Office of Technology Support Programs, U.S. Department of Energy, Washington, DC 20545.
- 62. R. J. Neuhold, Director, Advanced Technology Development, U.S. Department of Energy, Washington, DC 20545.
- 63. E. R. Specht, Rockwell International, 6633 Canoga Avenue, Canoga Park, CA 91304.
- 64-150. Given distribution as shown in TID-4500, I ~~nd~~