**Westinghouse
Astronuclear
Laboratory**

WANL-TME- 269 2
JUNE 1970

DATA ITEM T-119

**PAX-G2 FISSION FLUX
DISTRIBUTION MEASUREMENTS**

FINAL TEST REPORT

MASTER

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Westinghouse Astronuclear Laboratory

Subcontract NP-1

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WANL-TME- 269 2
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ABSTRACT

An experiment was performed to assist in prescribing the R-1 fuel loading distribution. This experiment provided a measured radial fission density (detailed) distribution in the PAX-G2A reactor for use in power analysis calculations. The PAX-G2A reactor has an R-1 size core (larger than NRX-A/PAX-E series and no inner reflector) and a 60-degree mockup of the current R-1, 18-control drum configuration in the beryllium reflector. This reactor mockup differs from the earlier version PAX-G1A, as reported in WANL-TME-1917, principally by the redistribution of TaC uniformly to the core periphery instead of only to a radius of 36.4 cm. The experimental procedure utilized U-Al wires located at the core midplane to determine the measured radial fission density distributions and included the self-shielding effects of the U-Al wires previously measured and reported in WANL-TME-1911.

The comparison of the PAX-G2A to PAX-G1A fission distribution measurements shows the desirability of uniformly distributing the TaC shims to the core periphery. This uniform distribution is recommended for use in the R-1 design due to the small power perturbations caused at the core periphery.

The difference between the experimental and calculated fissions/gram at the core periphery is on the order of 25 percent. The scatter of the NC_i correction factors at the periphery is due to the fact that the measured data explicitly take into account effects of the irregular periphery and the interaction between elements, whereas the calculated fissions/gram use a model with a smooth periphery and homogenized fuel regions.

The calculated peripheral power scalloping due to the control drums can cause an azimuthal variation in the NC_i 's. A comparison of the NC_i 's from PAX-G0 and PAX-G2A indicates that PAX-G2A data are preferable in setting the preliminary R-1 loadings due to the fact that they apply more adequately to an 18-control drum system.

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1.0 INTRODUCTION

1.1 TEST IDENTIFICATION

1.1.1 Type of Report

This report is a complete Final Report.

1.1.2 Scope of Test Document

The applicable Scope of Test Document is Number 66DW-234.

1.1.3 Functional Category of Test

This is a Development test.

1.1.4 Contractor

The Westinghouse Astronuclear Laboratory (WANL/14683), under Subcontract NP-1, CY'70, is the contractor.

1.1.5 Test Facility

These tests were performed at the Westinghouse Astronuclear Experimental Facility, located at the Westinghouse Waltz Mill Site, February 16 through March 2, 1970.

1.2 PURPOSE

The purpose of these tests is to provide the radial fission density distribution at the core midplane in the 60° core sector opposite the R-1 mockup reflector sector. These data are to be presented in terms of fissions per gram of uranium, normalized to unity at the core center and are to be used by the Nuclear Design group as input to their calculational codes in order to help set the R-1 fuel loadings and to determine the effect of previous reclustering of fuel.

2.0 REFERENCES AND ASSUMPTIONS

2.1 REFERENCES

2.1.1 Specification

EC 677566 - Part I. Performance/Design and Qualification Requirements
Fuel Element for 677555A NERVA Nuclear Subsystem. 1/23/69.

2.1.2 Data Item Description

Form 9, Data Item Description, T-119, dated 4/2/69

2.1.3 Scope of Test Document

66DW-234 - PAX-G2 Detailed Power Measurements

2.1.4 Data Release Memorandum

- 51192 - PAX-G2 Detailed Power Measurements
- 51189 - Parts Inventory in the PAX-G2 Reactor
- 51163 - Parts Inventory in the PAX-G1 Reactor
- 51163A - Parts Inventory in the PAX-G1A Reactor
- 51163B - Parts Inventory in the PAX-G1B Reactor
- 51166 - PAX-G1 Shim Wire Inventory
- 51166A - PAX-G1 Shim Wire Inventory
- 51105 } - Flow Charts for an Integrated Nuclear and Radiation, Thermal
51105C } and Structural Analysis Procedure, and Identification and
Description of Computer Codes
- 51150A - Parts Inventory in the PAX-G0-A, -B, and -C Reactors
- 51150 - Parts Inventory in the PAX-G0 Reactor
- 51194 - Repeatability Check of Fission Distribution Measurement in
PAX-G2

52084 - Effect Of Shim Content And Distribution On The R-1 Drum Span And Power Distribution

2.1.5 Drawing

711J496 - Reactor/Vessel Assembly, R-1 PAX

711J498B - Segment, Reflector Assembly, R-1 PAX

100E511 - Aft End of PAX with R-1 Designation

982D265 - NSS - Radial Components Aluminum Structure, Study Layout Of

2.1.6 TME

WANL-TME-267, Revision H - Westinghouse Astronuclear Experimental Facility Reactor Operations Manual

WANL-TME-1911 - PAX-G0 Power Distribution Measurements, January 1970

WANL-TME-1917 - PAX-G1 Gross Power Measurements, January 1970

WANL-TME-1725- NRX-A6 Fuel Zoning and Power Distribution Analysis, P. J. Sipush, R. Rittenberger, E. Iwinski, June 1969, Figure 5-1

2.2 ASSUMPTIONS

2.2.1 Control Drum Positioning

The test results are not influenced by the positioning of NRX control drums 1 through 6, 11 and 12 between 111.2° and 115.2° during the tests as long as the 3 PAX/R-1 control drums (A, B, C) and NRX control drums 7 and 10 are at 115.0° .

2.2.2 Self-Shielding Factors

The U-Al wire self-shielding factors obtained in the PAX-G0B reactor are equally valid for the PAX-G2A reactor. These data have been reported in Section 4.3 of WANL-TME-1911.

3.0 TEST ARTICLE CONFIGURATION

3.1 DESCRIPTION OF TEST CONFIGURATION

The tests were performed in the 60° core sector opposite the R-1 mockup reflector sector in the PAX-G2A reactor. A plan view of the 60° core sector with the locations used for the measurements is shown in Figure 3-1. Descriptions of the components used for the measurements are as follows.

3.1.1 PAX-G2A Reactor

The PAX reactor, modified as shown in Figure 3-2 and designated PAX-G2A has been used to perform standard reactor experiments during the initial phases of the R-1 design program to support the release of R-1 graphite core fuel specifications and provide information on the adequacy of the control capability of the R-1 reflector system. Basically, the reactor has an R-1 size core (no inner reflector) and a 60-degree mockup of the R-1, 18-control drum configuration in the reflector.

The current R-1 reactor core design contains 1878 fueled and 349 unfueled elements. The PAX/R-1 also contains a total of 2227 elements, but the number of fueled elements is greater. This R-1 design calls for uranium loadings as high as 630 mg/cm³. In order to mockup the overall uranium content using available fuel (loadings less than 500 mg/cm³), approximately one-half of the central elements in PAX/R-1 are fueled. These are made from existing fuel elements by drilling and tapping the ends. To accommodate the increase in the total number of elements, an extension to the core support plate is inserted into the support plate region of the PAX/R-1 as seen in Figure 3-2. Approximately 245 kg of highly enriched uranium are contained in the PAX-G2A core.

The PAX-G2A reflector is obtained by replacing two 30° KIWI sectors of the 12-drum NRX configuration with a 60° R-1 reflector mockup segment. This reflector mockup segment is constructed of laminated beryllium slabs. The non-beryllium fraction in this segment is approximately 10% lower than that of the current R-1 reflector (Dwg. 982D265).

Figure 3-1. Plan View of 60° Core Sector Used for Detailed Fission Distribution Measurements in PAX-G2A Reactor

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Figure 3-2. PAX-G2A Reflector Assembly

Also, this mockup segment does not include the aluminum barrel between the core and beryllium which is in the present design. The lateral support hardware mocked up in the plunger holes is approximately 50% less than the material in the current R-1 reflector (Dwg. 982D265), mostly because the plunger holes are considerably smaller than in the present R-1 design. This reflector segment contains three control drums whose vanes are Cu-B^{10} , 100 mils thick, with a B^{10} surface concentration of 0.13 gram per square centimeter. The R-1 mockup control drums have a vane span of 120 degrees.

The PAX-G2A reactor build (including shim wire inventory, parts inventory, fuel element listing, and/or representative as-built weights) is detailed in Drawings 711J496 and 711J498B; DRM's 51189, 51166, 51166A, 51163, 51163A, 51163B, 51150 and 51150A.

3.1.2 Uranium-Aluminum Wires and Wire Holders

The fission density distribution within the PAX-G2A reactor was measured by irradiating one-inch long uranium-aluminum wires. These wires and the wire holders used to insert them into the fuel element coolant channels, have been used before and are described in Sections 3.1.2 and 3.1.3, respectively, of WANL-TME-1911.

3.1.3 NC-8010 Counting System

The U-235 wire fission product activity was counted on the 2π gas-flow proportional detector. The system is completely automated for efficiency and for reducing errors involved in handling large volumes of data. The NC-8010 beta counting system was built to WANEF specifications by the Nuclear-Chicago Corporation, and uses solid-state circuitry. It is described in detail in Section 3.1.4 of WANL-TME-1911.

4.0 SUMMARY OF TESTS

4.1 NARRATIVE

The detailed mapping of the fission density distribution at core midplane of the PAX-G2A reactor was carried out in the 60° core sector opposite the R-1 mockup reflector sector. The sector map required eight reactor runs. The eight reactor runs were inter-related by placing U-Al wires in the same central cluster element coolant channels. Each run was normalized to unity for the central cluster position and, in turn, all eight runs were combined for the final plot shown in Figure 4-1. The U-Al wires were positioned using the special U-Al wire holders in the central coolant channel of each fuel element except those elements containing tie rods. Additional wires were also placed in coolant channels 1, 3, 8, 12, 17 and 19 of the peripheral elements (peripheral elements being all elements in the G1, H, J, and P clusters). The detailed mapping involved the use of approximately 1300 U-Al wires.

The tests were carried out in accordance with procedures identified in Appendix A.

All of the tests were performed with the cold critical reactor at room temperature and with the PAX/R-1 control drums (A,B,C) and NRX control drums 7 and 10 set at 115.0°. All of the remaining control drums were positioned between 114.5° and 115.2° except for NRX control drum 12 which was positioned between 111.2° and 114.0°

Data from the NC-8010 counting system, used to count the beta radiation emitted by the fission products from the irradiated U-Al wires, were reduced to units of fission density relative to 1.0 at the core centerline by the CDC-6600 computer using the WANEF passive data reduction program as described in DRM 51105C. Essentially, this data reduction program corrects each piece of data from the NC-8010 system for counter background and for resolving time losses, normalizes the results to unity at the core center location, averages the results of multiple measurements on each wire, looks up the core radial and azimuthal position from a master tape, and provides computer-printed tables and plots of the analyzed data.

4.2 TEST RESULTS

Plots of the normalized radial fissions per gram distribution data appear in Figures 4-1 and 4-2. These distribution data include the effect of the change in self-shielding of the U-Al wires as a function of radius as described in Section 4.3 of WANL-TME-1911. Tabulated data in the form required for the PFENCER code (DRM 51105) have been provided in DRM 51192. The individual components contributing to the overall uncertainty of each measurement are shown in Table 4-1.

Figure 4-1. PAX-G2A Fission Density Distribution

Figure 4-2. PAX-G2A Detail of Fission Density Distribution

TABLE 4-1
FISSION DENSITY UNCERTAINTY

Uncertainty Contribution	1 σ Uncertainty (percent)
1. Reproducibility (based on DRM-51194)	± 0.4
2. Resolving time corrections	± 0.1 to ± 0.5
3. Self-shielding corrections (based on PAX-GOB measurements)	± 0.0 to ± 1.5
4. Variations in PAX reactor	± 0.5
Total (Root Mean Square of Listed Uncertainties)	± 0.6 to ± 1.7

5.0 ANALYSIS

5.1 PAX-G2A POWER PREDICTIONS

A detailed neutronic analysis was performed to predict the PAX-G2A power measurements. These calculations were identical to those performed for PAX-G1A (WANL-TME-1917) except that they incorporated a uniform TaC distribution to the core periphery, niobium number density adjustment to incorporate measured wire worths and replacement of "X" wires with niobium wires. An r, θ diffusion theory EXTERMINATOR calculation was run to predict the neutron fluxes in the R-1 test sector for a drum position of 115° . GAMBIT neutron cross sections used as input to this calculation were based on the "as-built" test sector inventory (from the AMDS program) for PAX/G1A with the modifications previously mentioned. The EXTERMINATOR fluxes were then used as input to the PFENCER-1 calculation which evaluates a fission/gram distribution at every channel location. EXTERMINATOR, GAMBIT, AMDS, and PFENCER-1, -2, are computer codes used by Nuclear Design and documented in DRM-51105.

5.2 CENTRAL CHANNEL DATA

The relatively small scatter in the data was smoothed by doing a least squares fit out to a radius of about 35.0 cm. A fourth order polynomial fit using the OMNIFIT (DRM 51105) code was found to be adequate. These smoothed data are then used in all subsequent power calculations rather than the individual measurements. Figure 5-1 shows the data and the corresponding fit for the PAX-G2A configuration. The 1σ variation of the data about this curve is 0.00485 or about 0.5 percent, giving some insight to the degree of experimental uncertainty. The same least squares analysis was performed on the PAX-G1A channel 10 data. The corresponding value for PAX-G1A was 0.6 percent.

5.3 LOCAL FISSION PERTURBATIONS

In order to obtain the proper effect of the central unfueled element on the local power in the central region ($0 < r < 35$ cm), a local power perturbation is superimposed on the channel 10 data. Figure 5-2 shows the local perturbation that was applied to the PAX-G2A channel 10 data. This variation corresponds to that used for NRX-A6 (WANL-TME-1725) with an

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Figure 5-1. PAX-G2A Radial Fissions/GM Distribution

Figure 5-2. R-1 Central Element Power Perturbation

approximate 25 percent reduction due to the reduced mass of carbon associated with R-1 central element. This procedure was followed because these data will be applied to the R-1 design.

5.4 COMPARISON OF EXPERIMENT AND CALCULATIONS

The fission/gram distribution calculated by PFENCER-1 and the experimental data were directly compared to one another in a PFENCER-2 calculation. PFENCER-2 then computes an experimental correction factor, NC_i , which is simply the ratio of the measured to calculated fissions/gram for every channel normalized to unity at the core centerline. Figure 5-3 shows the radial variation of this correction factor for channel 10 as a function of radial position. This information is also shown for each element location on a sector drawing in Figure 5-4.

In order to detect any anomalies in the data, the NC_i correction factors obtained from the PAX-G2A and PAX-G0 experiments were compared, see Figure 5-5. The gross radial shapes of the two sets of NC_i 's were found to be in very close agreement. In particular, the average NC_i 's for the outer row, second row from the edge, third row from the edge, etc., were computed for each configuration and found to agree within one percent. Also, the variations of the NC_i correction factor from the centerline out to a radius of about 35 cm are in very good agreement.

Variations were noted, however, in the azimuthal variation of the NC_i 's. Figure 5-6 is a plot of the ratio of the PAX-G2A NC_i 's to the PAX-G0 NC_i 's for the outer row of fuel elements (channel 10) as a function of azimuthal position. As indicated, it appears that four elements are affected by the larger amount of beryllium in the KIWI sectors relative to the R-1 mockup sector. In addition to this effect, however, there is an apparent cyclic behavior of this ratio. It doesn't appear that any physical characteristics of either assembly such as notches in the Be plates, tie bolts, etc., can explain this variation. The frequency of this cyclic behavior does correspond to the azimuthal power scalloping in the PAX-G0 (12 drum) assembly. The location of the PAX-G0 drums is also indicated in Figure 5-6. It appears that this type of difference in the ratio of the NC_i 's could be caused

Figure 5-3. PAX-G2A Central Channel Radial NC_i Variation

Figure 5-4. PAX-G2A Central Channel Radial NC_i Distribution

Figure 5-5. Ratio of the PAX-G2A to PAX-G0 Normalization Coefficients

Figure 5-6. Ratio of PAX-G2A NC_i 's to PAX-G0 NC_i 's for Outer Row of Elements Versus Azimuthal Position

by an overprediction of the scalloping effect in the PAX-G0 configuration by the EXTERMINATOR calculation. This possibility is currently being investigated. The effect, of course, would also be present in the PAX-G2A calculation; however, the scalloping in this case is only about 4 percent due to the 18 drum design in comparison to 18 percent for a 12 drum system and, therefore, is not easily detected in this analysis. Consequently, the NC_i correction factors for elements adjacent to the filler strips obtained from the PAX-G0 experiments should not, therefore, be applied to an 18 drum system.

5.5 COMPARISON OF PAX-G1 and PAX-G2 FISSION MEASUREMENTS

A comparison of PAX-G1 and PAX-G2A fission distribution measurements was made for channel 10 locations. Figure 5.7 shows the results of this comparison. The maximum difference between the two measurements is 5.0 percent at the core periphery. This difference is due to the redistribution of the TaC in the PAX-G2A. PAX-G1A had TaC uniformly distributed to a radius of 36.4 cm; PAX-G2A has the TaC uniformly distributed to the core periphery. The effects of TaC on power distribution (DRM-52084) was calculated by the use of ANISN calculations and the test results show good agreement with these calculations. The effects of uniformly distributing \$3.0 of TaC to the core periphery is about .3 percent at the core periphery; the effects of uniformly distributing \$3.0 of TaC to a radius of 36.4 cm is about 5.0 percent at the core periphery. Consequently, the total predicted change in the power distribution for this redistribution of TaC shims from PAX-G1A to PAX-G2A would be -4.7 (5.0 - 0.3). This agrees well with the peripheral power depression noted in Figure 5.7.

Figure 5.7. Comparison of PAX-G2A to PAX-G1A Fission Distribution Measurements

6.0 CONCLUSIONS

The difference between the experimental and calculated fissions/gram at the core periphery is on the order of 25 percent. The scatter of the NC_i correction factors at the periphery is due to the fact that the data explicitly take into account effects of the irregular periphery and the interaction between elements; whereas the calculated fissions/gram uses a model with a smooth periphery and homogenized fuel regions.

The calculated peripheral power scalloping due to the control drums can cause an azimuthal variation in the NC_i 's. A comparison of the NC_i 's from PAX-G0 and PAX-G2A indicate that PAX-G2A data are preferable in setting the preliminary R-1 loadings due to the fact that they apply more adequately to an 18 control drum system.

The comparison of the PAX-G2A to PAX-G1A fission distribution measurements, Figure 5.7, shows the desirability of uniformly distributing the TaC shims to the core periphery. This uniform distribution is recommended for use in the R-1 design due to the small power perturbations caused at the core periphery.

APPENDIX A

THE PAX-G GROSS AND DETAILED FISSION FLUX DISTRIBUTION EXPERIMENTAL PROCEDURE

In accordance with WANEF procedures*, an Experimental Details Checklist (EDC) was written to set forth the details of experimental procedures to be used in making the gross and detailed fission flux distribution measurements as well as the U-Al self-shielding measurements in the PAX-G reactor as well as evaluating any nuclear hazards resulting from such an operation. Those portions of the experimental procedure applicable to the TME may be found in Parts 1 and 7 of the EXPERIMENTAL DETAILS section of EDC-67. The body of EDC-67 is contained in Appendix A of WANL-TME-1911. The locations actually used are given in the revised Table 2 included here.

* WANL-TME-267, Revision H, "Westinghouse Astronuclear Experimental Facility Reactor Operations Manual."

TABLE A-1. DETAILED POWER DISTRIBUTION LOCATIONS*

Sector	Row	Cluster	Channel	Element							
				Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
5	A	1	10 ↓							B-D	E-G
4	B	2								B-D	E-G
5	B	1								B-D	E-G
4	C	2-3		B	C	D	E	F	G		
5	C	1		B	C	D	E	F	G		
4	D	2-4								B-D	E-G
5	D	1								B-D	E-G
4	E	3-5		B	C	D	E	F	G		
5	E	1-2		B	C	D	E	F	G		
4	F	3-6		B	C	D	E	F	G		
5	F	1-2		B	C	D	E	F	G		
4	G	3-7		B	C	D	E	F	G		
5	G	1-2		10	B	C	D	E	F	G	
5	G	1		1, 3, 8, 12, 17, 19	B	C	D	E			
5	G	1		1, 3, 8	F		G				
5	G	1		12, 17, 19		F	G				
4	H	3-6	1, 3, 8, 10, 12, 17, 19	B	C	D	E	F	G		
4	H	7-8	↓	B	C	D	E			G	F
5	H	1-2			C		E	F	B	D	G
4	J	3-4			C		E	F	G	B	D
4	J	5-6		B	C	D	E	F	G	K	M
4	J	7-8		B		D		F	G	C	E
4	P	3		K		D	E	F	B	N	L
4	P	4		B	C	D	E	F	G	H	L
4	P	5		J	C	D	E	F	G	K	L
4	P	6		B	C	D			G	F	E
4	P	7			C	D	E	F	G	H	L
4	P	8		B	C	D	E	F	G	K	M
5	P	1		B	C	D			G	E	F
5	P	2		B		D	E	F		G	J
5	P	3		1, 3, 8, 10, 12, 17, 19	B					D	
5	P	3		10, 19				K	E	N	L
5	J	3		1, 3, 8, 10, 12, 17, 19				C			D

* All core locations refer to the R-1 core as shown in drawing 100E511 (aft end of PAX with R-1 designation).

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	PAX-G2 Fission Distribution Measurements	
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ABSTRACT <p>An experiment was performed using U-Al wires located at core midplane to provide detailed measured radial fission density distributions in the PAX-G2A reactor for use in power analysis calculations. Comparisons of the calculated and measured radial fission density distributions show generally good agreement except at the core periphery. These comparisons will be utilized in the analytical calculations used to prescribe the R-1 fuel loading specification.</p>		
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