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Westinghouse
Astronuclear
Laboratory

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MASTER

DATA ITEM T-119
PAX-G1 REFLECTOR INTERCHANGE,
CONTROL DRUM SPAN, AND ALUMINUM
REFLECTOR BARREL EXPERIMENTS (U)
FINAL TEST REPORT

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DATA ITEM T-119

PAX-G1 REFLECTOR INTERCHANGE,
CONTROL DRUM SPAN, AND ALUMINUM
REFLECTOR BARREL EXPERIMENTS (U)

FINAL TEST REPORT

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ABSTRACT

Reflector reactivity experiments have been performed in support of the R-1 design on the PAX-G1, the first nuclear mockup of an 18-drum R-1 design. The first experiment determined the reactivity effects caused by interchanging a 60° reflector sector containing three R-1 type control drums for two 30° sectors, each of which contained one NRX type control drum. Analytical predictions of the worth of the interchange were in excellent agreement with the measurements.

The second experiment entailed various measurements of the control drum spans. Two different experimental procedures were employed, both of which yielded very nearly the same results. Comparison of analytical predictions with the experimental data yielded a drum span correction factor of 0.88. Substantial drum interaction effects between the individual R-1 mockup drums were also demonstrated.

The third experiment entailed the interchange of an aluminum reflector barrel mockup for a graphite lateral support mockup on the 60° R-1 mockup reflector sector. The effects of the liner segments interchange on the R-1 mockup control drums were also determined. In both cases, the analytical predictions were in good agreement with the experimental data.

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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 Numbers are 59DW-229-0, 59DW-230-2, and 59DW-290-1.

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'69, 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, during April through June, 1969.

1.2 PURPOSE

Three sets of data are presented in this document. The first set, the reactivity changes for the PAX/R-1 Reflector Sector Interchange, is to be used to provide information which may be used to normalize the R-1 reflector calculations.

The second set of data, the PAX-G1 control drum spans, is to be used to provide data which may be used to normalize the calculational technique used in estimating the control drum span for the three R-1 alternate reflector designs. Additionally, some data are provided which allow for the evaluation of a proposed technique to monitor reactor shutdown through subcritical multiplication measurements.

The third set of data, the reactivity measurements and control drum spans in the PAX-G1 Aluminum Barrel Reflector Mockup Experiment, provides data which may be used to normalize the reactivity and control drum span calculations. These calculations are needed to evaluate the neutronics of the aluminum barrel alternate reflector design.

2.0 REFERENCES AND ASSUMPTIONS

2.1 REFERENCES

2.1.1 Specification

CP 677559 - Part I. Performance/Design and Qualification Requirements

Reflector, Control Drums & Axial Support for NERVA Nuclear Subsystem 677555A, dated 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

59DW-229 - Reflector Interchange Experiment

59DW-230 - PAX-G1 Control Drum Spans

59DW-290 - Aluminum Barrel Experiment

2.1.4 Data Release Memoranda

51186 - Chemical Analysis of WANEF Reactivity Materials

51174 - Reactivity Changes for the PAX/R-1 Reflector Sector Interchange

51170-A - Reactivity Measurements in the PAX-G Aluminum Barrel Reflector Exp.

51170 - Reactivity Measurements in the PAX-G Aluminum Barrel Reflector Exp.

51167 - PAX-G1 Control Drum Spans

51166-A - PAX-G1 Shim Wire Inventory

51166 - PAX-G1 Shim Wire Inventory

51163-A - Parts Inventory in the PAX-G1A Reactor

51163 - Parts Inventory in the PAX-G1A Reactor

51057 - Nuclear Predictions for the PAX/R-1 Experimental Program

51154A - PAX-G0B Control Drum Worth Measurements

51150-A - Parts Inventory in the PAX-G0A, -B, and -C Reactors

51150 - Parts Inventory in the PAX-G0 Reactor

51105 - Flow Charts for an Integrated Nuclear and Radiation, Thermal

and Structural Analysis Procedure and Identification and Description of Computer Codes

51103 - Subcritical Measurements (R-1 Drum Worth)

2.1.5 TME

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

WANL-TME-1910, "PAX-G0 Control Drum Spans and Reactivity Coefficient Measurements"

2.1.6 Drawing

711J496	-	Reactor/Vessel Assembly, R-1 PAX
711J498B	-	Segment, Reflector Assembly, R-1 PAX
100E292	-	Segment, Liner
944C979	-	Rod, Poison Shipping

2.2 ASSUMPTIONS

2.2.1 Worths of Control Drums Not in Nor Adjacent to the Test Sector

The control drum worths for drums 11 through 6 reported in DRM 51154 are still valid since these drums are remote from the test sector.

2.2.2 Poison Wire Effects on Control Drum Worths

The presence of poison wires in accordance with the loading given in Table 4-1 does not affect the control drum worth.

2.2.3 Niobium Self-Shielding Factor

The self-shielding factor for 0.068" OD and 0.077" Nb wire is 0.82 (personal communication from the WANL Nuclear Design group) and is uniform throughout the core.

2.2.4 Niobium Reactivity Coefficient

The shape of the predicted Nb reactivity coefficient curve, as given in DRM 51157 (Figure 6-3) is assumed to be valid for all sectors, even though the reflector and the core fuel loading are not completely symmetrical.

2.2.5 Uncertainty Calculations

The 1σ uncertainties are the same as those reported in Section 4.3 of DRM 51154 since the instrumentation systems are basically the same for both reactors.

2.2.6 Effect of Aluminum Reflector Barrel Mockup Upon Control Drum Span

The aluminum liner segments reduce the R-1 mockup control drum spans by some percentage of the drum spans obtained with graphite liner segments. The percentage is constant throughout the entire drum span.

3.0 TEST ARTICLE CONFIGURATION

3.1 TEST SETUP

Reactivity measurements have been made with two systems: the period-pickoff system for reactivity coefficient measurements and the reactivity computer system for determining integral control drum worths. Figures 3-1 and 3-2 show block diagrams of the two systems. System and component descriptions are given in the following paragraphs.

3.1.1 Period-Pickoff System

The normal method for measuring the reactivity changes associated with reactor configuration changes at WANEF is to use positive period techniques. In using this method, the reactor period is determined for a given reactor configuration and then after a configuration change is made, a second period measurement is obtained at the same drum positions as the first. The two period measurements are then converted to reactivity using the "in-hour" relationship* and the difference in the two reactivity values constitutes the effect of the configuration change.

In order to accurately and efficiently measure the reactor periods, WANEF has designed and installed a reactor-period measuring system referred to as a period-pickoff system. A block diagram of the system is shown in Figure 3-1. Operation of the system originates with a Westinghouse compensated ion chamber which produces a signal proportional to the reactor neutron level. This signal is routed to a linear picoammeter located in the reactor control room. The linear picoammeter has been equipped with electronic trip circuits which, at preset levels, start and stop a scaler. This timing scaler measures the lapsed time between the start and stop trips. The start and stop trips have been positioned so that the scaler measures the lapsed time required for the reactor neutron level to increase by a factor of $2e$. Thus, we have the following equation:

$$n(t) = n(0) e^{t/\tau}$$

* The "in-hour" equations and values of the constants used therein are the same as those given in Appendix D of WANL-TME-1910.

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Figure 3-1. Block Diagram of the Period-Pickoff Data Acquisition System

Figure 3-2. Block Diagram of the EAI-PC12 Reactivity Computer Data Acquisition System

where

$n(t)$ = level at time t

$n(0)$ = level at time 0

t = lapsed time

τ = reactor period

The lapsed time is thus equal to twice the reactor period since

$$\frac{n(t)}{n(0)} = e^2 = e^{t/\tau}.$$

therefore

$$t/\tau = 2$$

and

$$t = 2\tau$$

As can be seen from the block diagram, the high level or stop trip not only stops the scaler but also issues a print signal to the scaler which, in turn, routes the lapsed time signal to the printer and at the same time upscales the linear picoammeter to the next higher range.

During normal reactor runs, an average of four to six period measurements are obtained, thereby providing enough period measurements for statistical determination of uncertainties.

Descriptions of the components of the period pickoff system are given in the following paragraphs.

3.1.1.1 Detector

The neutron detector is a Westinghouse WL-7741 ion chamber, Serial Number 634303 operated in the uncompensated mode. It was mounted inside a polyethylene cylinder 24" long, 5-1/2" diameter with a 3-1/8" diameter bore.

3.1.1.2 High Voltage Supply

The high voltage supply was a Burgess U 200 battery.

3.1.1.3 Picoammeter

The picoammeter was an EG&G Model ME 920A, Serial No. 920161.

3.1.1.4 Level Trips

The low and high level trips which provided the start and stop signals were Keithley Instruments, Inc., Model 4103, electronic trips.

3.1.1.5 Scaler

The scaler was a Computer Measurements Company (CMC) Model 306B, Serial Number 99020.

3.1.1.6 Master Clock

The master clock was a CMC Model 2602A, Serial Number 1.

3.1.1.7 Digital Printer

The digital printer was a CMC Model 400C, Serial Number 10135.

3.1.2 Analog Reactivity Computer System

A large portion of the reactivity and all of the drum worth measurements made at WANEF employ the use of an on-line analog reactivity computer system for which a block diagram is shown in Figure 3-2. This system provides both positive and negative reactivity measurements. These results can be directly obtained from a digital voltmeter or plotted using an X,T or strip chart recorder. The heart of the system is an EAI PC12 Multi-Purpose Analog Computer, a photograph of which is shown in Figure 3-3.

The EAI PC12 analog computer has been programmed to calculate reactivity directly from the signal of a neutron-sensitive ionization chamber. To accomplish the reactivity calculation, the analog computer has been programmed to solve the standard space-independent reactor kinetics equations which are assumed to describe the kinetic behavior of the reactor. Further description of the basic programming of this computer is given in WANL-TME-1910, Appendix D.

Figure 3-3. Photo of EAI Analog Computer

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The following components were used in the setup:

3.1.2.1 Detector

The neutron detector was a Neutronics Laboratories Model BR, Serial 158, ion chamber inside a polyethylene block 5-3/4" square, 8-1/2" long with a 3-1/2" diameter bore.

3.1.2.2 High Voltage Supply

An NJE Corporation Model S-325, Serial 15571-2, provides regulated high voltage to the ion chamber.

3.1.2.3 Analog Computer

An Electronic Associates, Inc., (EAI) Series PC12, Model 3.154, Serial 107, analog computer calculates reactivity from the input ion chamber current which is proportional to reactor neutron level.

3.1.2.4 Digital Voltmeter

An EAI Series 6000, Model 26.257/2.394, Serial 163, digital voltmeter displays the reactivity information.

3.1.2.5 X-Y Plotter

An EAI Series 1130, Model 99.663, Serial 227 X-Y plotter was operated in the X-time mode to record the reactivity information.

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3.1.3 PAX-G1 Reactor

(CRD) The PAX reactor, modified as shown in Figure 3-4 and designated PAX-G1, 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 fuel specifications and provide information of the adequacy of the control capability of the R-1 reflector system and hydrogen in the support stems. Basically, the reactor has a large core (no inner reflector) and a 60-degree mockup of the R-1, 18-control drum configuration in the reflector.

(CRD) The present 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/cm^3 . In order to mockup the overall uranium content using available fuel, (loadings less than 500 mg/cm^3), 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. Approximately 245 kg of highly enriched uranium are contained in the PAX-G1 core.

(CRD) The PAX-G1 reflector is obtained by replacing two 30-degree KIWI sectors of the 12-drum NRX configuration with a 60-degree R-1 reflector mockup sector. This reflector mockup sector is constructed of laminated beryllium slabs. The non-beryllium fraction in this segment is the same as that of the present R-1 reflector. The lateral support hardware is mocked up in the plunger holes by the same amount of material as in R-1. This reflector segment contains three control drums whose vanes are Al-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 only difference between the PAX-G1 and the -A modification is in the fuel loading in the reactor core.

References giving further details on the PAX-G1 and PAX-G1A reactors may be found in Appendix A.

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(CRD) Figure 3-4. PAX-G1A Reflector Assembly

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3.1.4 Aluminum Reflector Barrel Mockup

Aluminum liner segments (Drawing 100E292) were interchanged with the graphite liner segments at the positions indicated in Figure 3-5. The liner weights are given in Table 3-1.

3.1.5 Shipping Poison Wires

The poison wires (Drawing 944C979) consist of Type 304 stainless steel tubes filled with boron carbide and coated with a thin layer of polyethylene.

Not to scale

Figure 3-5. PAX-G1 Reflector Geometry

TABLE 3-1
LINER SEGMENT WEIGHTS ON THE 60° R-1
MOCKUP REFLECTOR SECTOR

<u>MATERIAL</u>	<u>TOTAL WEIGHT (Kg)</u>
Graphite	18.563
Aluminum	27.366

4.0 SUMMARY OF TESTS

4.1 REFLECTOR SECTOR INTERCHANGE

4.1.1 Narrative

In order to make initial reactivity effect measurements on an 18-drum R-1 reflector configuration, a 60° mockup reflector segment (containing 3 R-1 size control drums) was interchanged for two of the 30° reflector sectors (containing a total of 2 NRX size control drums). A determination was then made of the reactivity effect of this interchange and the reactor core was reshimmied to achieve the required delayed critical drum bank angle of $115^\circ \pm 1^\circ$. After reshimming, the reactor was given the designation PAX-G1.

4.1.2 Test Conditions

Prior to the actual interchange, shipping poison wires were inserted into the fuel element coolant channels into the positions listed in Table 4-1. Reflector sectors 8 and 9 were then removed and the 60° mockup R-1 reflector sector inserted in their place. Figure 4-1 contains a line drawing of the 60° mockup reflector sector in place. After removal of all of the shipping poison wires, niobium wires were removed to reshim the reactor in order to attain the required delayed critical drum bank angle of $115^\circ \pm 1^\circ$. DRM 51174 contains a listing of the positions from which the 350 niobium shim wires were removed (in order of their removal). Exact details on the steps involved in interchanging the reflector sectors may be found in Appendix B.

TABLE 4-1. LOCATION OF SHIPPING POISON WIRES

<u>Element Designation</u>	<u>Totals</u>
000 (B-6)	6
(1-6) A1 (B-6)	36
(1-6) B (1-2) (B-6)	72
(1-6) C (1-3) B	18
(1-6) C2C	<u>6</u>
	138

Note: All wires were placed in the central channel of the designated element.

Figure 4-1. PAX-G1 Reflector Geometry

4.1.3 Test Results

Table 4-2 contains a listing of the reactor operations data associated with each step of the reflector interchange procedure. There are two different methods of calculating the reactivity change attributable to the change in reflector sectors. These methods are given in the following paragraphs.

4.1.3.1 Calculated by the Change in Delayed Critical Drum Bank Positions

From Table 4-2, it may be seen that during the reactor run immediately before the sector interchange (PAX-G0C-142), all drums except two were at 180° . As drums 8 and 9 were found to be worth a total of \$1.07 (Table 1, DRM 51154A), use of the normalized integral worth curves indicates that if these two drums were to be rotated to 180° , an additional reactivity insertion would occur in the amount of

$$(\$1.07 \pm 0.01) \times (0.24 \pm 0.01 \%) = 25.7 \pm 0.1\% \quad (1)$$

If we add to this value the measured reactivity for this run (as given in Table 4.2), we then have a calculated reactivity for all 12 KIWI drums at 180° . This value is $35.5 \pm 0.4\%$. One may then argue that the reactivity change caused by substitution of the 60° mockup R-1 sector of two KIWI sectors is given by the difference between equation (1) and the reactivity measured in PAX-G1-1 as given below:

$$(35.5 \pm 0.4\%) - (7.6 \pm 0.4\%) = 27.9 \pm 0.6\% \quad (2)$$

4.1.3.2 Calculation by Removal of Nb Wires

From Table III in DRM 51174, the calculated reactivity change caused by removal of the Nb shim wires was $+37.7\%$. Assuming a typical self-shielding coefficient* of 0.82 and a reactivity coefficient correction¹ of 1.376 yields a true calculated change due to the Nb wire removal of

$$37.7\% \times (0.82 \pm 0.03) \times (1.376 \pm 0.22) = 42.5 \pm 7. \%$$

* See DRM 51174 for further details.

TABLE 4-2
SUMMARY OF REACTIVITY CHANGES
ASSOCIATED WITH THE 60° MOCKUP R-1 REFLECTOR SECTOR INTERCHANGE

Run No. (PAX)	Date	NRX Drum* Bank Angle (NRX Drums) (degrees)	R-1 Mockup Drum Position (degrees)			Period τ (sec)	Reactivity ρ ρ	Comments
			Drum A (deg)	Drum B (deg)	Drum C (deg)			
G0-C-138	4/14/69	120.00	120.00 ₁	120.00 ₂		35.27	20.08	Basepoint with all 12 "KIWI" reflector sectors. Last run before reflector sector interchange.
G0-C-142	4/17/69	180.00	120.00 ₁	120.00 ₂		98.3	9.78	
			109.05 ₁	109.05 ₂		∞	0	
G1-1	4/17/69	180	180	180	180	135.2	7.58	Basepoint.
		180	153.8	155.2	154.2	∞	0	
G1-2	4/17/69	180	125.1	124.9	125.1	52.96	15.40	Removed 36 poison wires; 1 each from central coolant channel of (1-6)B(1-2)E; (1-6)C(1-3)B; (1-6)C2C.
		180	109.8	110.0	109.9	∞	0	
G1-3	4/21/69	180	85.2	85.0	85.1	75.20	11.99	Removed 36 poison wires; 1 each from central coolant channel of (1-6)B(1-2)(D,F,G).
		180	74.0	73.8	72.7	∞	0	
G1-5	4/21/69	180	45.2	45.1	45.3	53.09	15.37	Removed 36 poison wires; 1 each from central coolant channel of (1-6)B(1-2)(B-C); (1-6)A1(D,E)
		180	13.0	13.1	14.1	∞	0	
G1-6	4/22/69	119.00	179.8	178.4	182.2	58.94	14.29	Removed last 30 poison wires; 1 each from central coolant channel of (1-6)A1(F-C) 000(B-G)
		115.70	179.8	178.4	182.2	∞	0	
		150.01	1.0	0.9	1.3	∞	0	
G1-7	4/22	118.00	179.8	178.3	181.5	52.94	15.40	Remove first 30 Nb wires shown in Table 1 of DRM 51174.
		115.00	166.6	164.5	167.6	∞	0	
		123.40	115.1	115.1	115.1	∞	0	
G1-8	4/22/69	115.00	159.9	160.1	159.9	31.8	21.4	Remove next 176 Nb wires shown in Table 1 of DRM 51174.
		115.00	128.8	129.0	128.9	∞	0	

* Average setting for the 10 NRX type drums not in test sector.

1. Drum 8
2. Drum 9

** PAX-G0C-138 was the last run in the PAX-G0 series before the insertion of poison wires. PAX-G1-10 is the first run in PAX-G1 series after the removal of the final required increment of shim wires.

ρ estimated 1σ uncertainty = $\pm 0.39\%$
(WANL-TME-1910) (See Assumptions 2.2.5)

TABLE 4-2 (continued)
 SUMMARY OF REACTIVITY CHANGES
 ASSOCIATED WITH THE 60° MOCKUP R-1 REFLECTOR SECTOR INTERCHANGE

Run No. (PAX)	Date	NRX Drum* Bank Angle (NRX Drums) (degrees)	R-1 Mockup Drum Position (degrees)			Period τ (sec)	Reactivity ρ (β)	Comments
			Drum A (deg)	Drum B (deg)	Drum C (deg)			
G1-9	4/22/69	115.00	130.3	130.0	130.2	94.00	10.13	Removed next 94 Nb wires shown in Table I of DRM 51174.
		115.00	121.8	118.9	119.2	∞	0	
G1-10	4/23/69	115.00	125.2	125.0	125.0	9 .90	10.31	Removed last 50 Nb wires shown in Table I of DRM 51174.
		115.00	114.7	114.6	114.6	∞	0	

ρ estimated 1σ uncertainty = $\pm 0.39\beta$ (WANL-TME-1910)

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However, it is necessary to correct for the differences in delayed critical drum bank position between runs PAX-G0C-138 and PAX-G1-10. (PAX-G0C-138 was the last run in the PAX-G0 Series before the insertion of poison wires. PAX-G1-10 is the first run in PAX-G1 Series after the removal of the final required increment of shim wires.) In the vicinity of 117° , DRM 51154A gives a differential drum bank worth of 4.8¢/degree . For run PAX-G0C-138 the calculated excess reactivity for a delayed critical drum bank angle of 115.00° is given by

$$(120.00^\circ - 115.00^\circ) \times (4.8 \pm 0.4\text{¢/degree}) = 24 \pm 2\text{¢}$$

From Table 4-2, the measured reactivity was only $20.1\text{¢} \pm 0.4\text{¢}$. The delayed critical position then corresponds to an angle in excess of 114° , the value of which is given by

$$(24 \pm 2\text{¢}) - (20.1 \pm 0.4\text{¢}) = 4 \pm 2\text{¢} \quad (3)$$

DRM 51154A gives a value of 4.9¢/degree for the differential drum bank worth in the vicinity of 115° . Thus, the calculated delayed critical drum bank position is given by the sum of the reference angle, 115.00° , and a small correction factor as follows:

$$\begin{aligned} \theta_{DC} &= 115.00 + (4 \pm 2\text{¢})/4.9 \pm 0.4\text{¢/degree} \\ &= 115.8 \pm 0.4^\circ \end{aligned}$$

Again from Table 4-2, the reactivity difference between the actual drum bank position from run PAX-G1A-10 and the reference drum bank of 115° is given by the following equation: (In the vicinity of 115° , the differential drum bank worth of the 3 R-1 type drums as 1.1¢/degree .)

$$1/3^\circ \times (1.1 \pm 0.1\text{¢/degree}) = 0.37 \pm 0.4\text{¢} \quad (4)$$

As the removal of the Nb wires not only compensated for the reactivity effects of the sector interchange but also resulted in moving the delayed critical drum bank position from approximately 115.8° to slightly under 115° , the values given in equations (3) and (4) must be subtracted from the value calculated in equation (2). Thus, the reactivity change associated with the reflector sector interchange calculated through the removal of niobium wires is given by

$$(42.5 \pm 7\text{¢}) - (4 \pm 2\text{¢}) - (0.4 \pm .04\text{¢}) = 38 \pm 7\text{¢}$$

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4.2 CONTROL DRUM WORTHS

4.2.1 Narrative

A series of measurements was performed in the PAX-G1 reactor to determine the control characteristics of an 18-drum R-1 reflector design (See Figure 4-1). Basically, the experiments determined of the control drum span and the control drum interaction effects. Additionally, two other methods were used during the experiment to determine if the two methods produced essentially identical results.

4.2.2 Test Conditions

Table 4-3 lists the conditions under which the control drum worth measurements were obtained. Essentially, control drum span measurements were made under two methods. The first was the standard WANEF method of measuring control drum spans. In this procedure, the drum whose worth is to be measured, is placed at 180° and the remaining control drums are placed at an angle so that the reactor is on a reasonable period (approximately 30 seconds). When a reactor power level is reached which is consistent with the operating limits of the WANEF analog reactivity computer, the specified control drum is driven from 180° to 0° with the output of the computer being recorded as a function of drum position, thereby yielding the integral control drum span. The second method entailed determining the delayed critical drum bank position where the control drum whose worth was to be measured was positioned at 90° . After the delayed critical position for the remaining bank was determined, the specified control drum was rotated from 90° to 180° and the resultant excess reactivity measured by both the reactivity computer and by the period pickoff system. The specified control drum was then moved to 0° and a new critical drum bank angle reestablished. The specified drum was then moved to 90° and again the resultant excess reactivity measured with the period pickoff system. The sum of the two reactivities measured during these two steps was thus determined to be the total control drum span of that particular drum.

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The interaction effects for the R-1 mockup control drums were determined by measuring the integral control drum span of the central R-1 drum (drum B) as a function of the adjacent R-1 drums (drums A and C)*:

Further details regarding the exact procedures for these tests may be found in Appendix C of this document.

4.2.3 Test Results

Table 4-3 lists the control drum spans as determined by the two different methods described above for control drums A, B, C, 2, 7, and 10. Figures 4-2 and 4-3 show typical integral control drum worth curves for drums B and 7 while Figures 4-4 and 4-5 show the corresponding differential control drum worth curves. Table 4-4 shows a tabular summary of the measured differential and integral control drum worth curves. Figure 4-6 contains a graphical summary of the integral drum worth curves for control drum B as a function of the adjacent control drums, A and C. Table 4-5 contains least squares fit data from Figure 4-6.

* See Figure 4-1 for the location of these drums.

TABLE 4-3. INDIVIDUAL CONTROL DRUM WORTHS

Drums Measured	Drum Angle (Degrees)								ρ^*			
	2	7	A	B	C	10	12	Remaining Bank	Reactivity Computer (ρ)		Period Pickoff System	
									Total	Partial	(sec)	(ρ)
A	116.50	116.50	90	116.58	116.57	116.50	119.24	116.50	41.91	22.00	∞	0
			180								29.96	22.19
	121.50	121.50	0	116.56	116.58	121.50	121.50	121.50			∞	0
			90								34.66	20.30
												42.49
B	116.50	116.50	116.61	90	116.52	116.50	118.84	116.50	40.64	20.76	∞	0
				180							33.23	20.84
	121.50	121.50	116.61	0	116.52	121.50	121.40	121.50			∞	0
				90							33.68	20.66
												41.50
C	116.90	116.90	116.55	116.56	90	116.90	115.00	116.90	41.80	21.57	∞	0
					180						31.52	21.52
	121.50	121.50	116.55	116.55	0	121.50	122.10	121.50			∞	0
					90						33.42	20.76
												42.28
2	90	117.50	116.52	116.50	116.51	117.50	117.80	117.50	55.27	26.54	∞	0
	180										21.95	26.51
	0	123.10	123.98	124.01	124.02	123.10	124.70	123.10			∞	0
	90										18.32	29.23
												55.73
7	117.50	90	116.55	116.56	116.52	117.50	118.08	117.50	55.43	28.08	∞	0
		180									19.75	28.08
	123.10	0	124.06	124.07	123.99	123.10	122.96	123.10			∞	0
		90									19.62	28.18
												56.26
10	117.50	117.50	116.56	116.55	116.43	90	117.74	117.50	55.09	26.24	∞	0
						180					21.98	26.49
	123.10	123.10	124.00	124.00	124.06	0	125.30	123.10			∞	0
						90					17.98	29.50
												55.99

* The reactivity values are for the drum changes indicated.

Figure 4-2. Drum B Integral Drum Worth Curve in the PAX-G1A Reactor

Figure 4-3. Drum 7 Integral Drum Worth Curve in the PAX-G1A Reactor

Figure 4-4. Differential Control Drum Worth for Drum B in the PAX-G1A Reactor

NS8932-1

Figure 4-5. Differential Drum Worth for Drum 7 in the PAX-G1A Reactor

TABLE 4-4. SUMMARY OF DIFFERENTIAL AND INTEGRAL DRUM WORTHS

(Degrees)	DRUM NUMBER						R-1 Drum Bank Worth	
	2	7	10	A	B	C	Differential (ℓ /degree)	Integral (ℓ)
175	0.01	0.04	0	0.06	0.04	0.04	0.14	1.4
165	0.08	0.1	0.07	0.11	0.09	0.11	0.31	4.5
155	0.19	0.22	0.08	0.18	0.16	0.17	0.51	9.6
145	0.26	0.25	0.35	0.25	0.21	0.22	0.68	16.4
135	0.31	0.36	0.33	0.25	0.22	0.27	0.74	23.8
125	0.39	0.40	0.35	0.32	0.30	0.29	0.91	32.9
115	0.40	0.44	0.44	0.37	0.33	0.32	1.02	43.1
105	0.49	0.50	0.49	0.31	0.34	0.39	1.04	53.5
95	0.44	0.46	0.42	0.37	0.35	0.34	1.06	64.1
85	0.48	0.43	0.47	0.35	0.34	0.38	1.07	74.8
75	0.42	0.44	0.44	0.38	0.34	0.31	1.03	85.1
65	0.46	0.49	0.45	0.28	0.33	0.31	0.92	94.3
55	0.37	0.37	0.42	0.30	0.29	0.36	0.95	103.8
45	0.41	0.33	0.35	0.23	0.25	0.20	0.68	110.6
35	0.31	0.29	0.34	0.19	0.21	0.20	0.60	116.6
25	0.24	0.24	0.23	0.14	0.15	0.14	0.43	120.9
15	0.18	0.13	0.18	0.07	0.08	0.10	0.25	123.4
05	0.09	0.06	0.09	0.04	0.04	0.03	0.11	124.5
Integral Drum Worth	55.30	55.50	55.00	42.00	40.80	41.80

Figure 4-6. Central Drum Worth as a Function of Adjacent Drum Position in the R-1 Mockup Sector

TABLE 4-5. LEAST SQUARES FIT DATA

PAX G-1A CONTROL DRUM WORTHS

GUESSED PARAMETER	CALCULATED PARAMETER	STD ERROR
GP1 7.50000000E-02	CP1 3.15128571E+01	2.5271455E-01
GP2 3.16900000E+01	CP2 7.63174603E-02	2.5996479E-03

VARF= 6.3867E-02 VARF1= 9.1278E-03

THE PROBLEM COMPLETED 1 ITERATION(S)

Y(OBS)	YCALC	P.C.FR	VAR(Y)	X(1)	X(2)	X(3)	X(4)	X(5)
3.3940E+01	3.3802E+01	4.0544E-01	3.3454E-02	3.0000E+01				
3.6260E+01	3.6092E+01	4.6354E-01	1.5206E-02	6.0000E+01				
3.6810E+01	3.7237E+01	-1.1591E+00	1.0644E-02	7.5000E+01				
3.8250E+01	3.8381E+01	-3.4360E-01	9.1238E-03	9.0000E+01				
3.9530E+01	3.9526E+01	9.6370E-03	1.0644E-02	1.0500E+02				
4.0940E+01	4.0671E+01	6.5714E-01	1.5206E-02	1.2000E+02				
4.2940E+01	4.2960E+01	-4.7686E-02	3.3454E-02	1.5000E+02				

BCC INPUT *ENDFILE*INPUT
 ERROR NUMBER 0065 DETECTED BY INPUTC AT ADDRESS 021651
 CALLED FROM OMNI AT 000167

ERROR SUMMARY
 ERROR TIMES
 0065 0001

Where the equation to be fitted is of the form $Y = A_0 + A_1 X$

where Y = worth of drum B in cents
 X = angular position of drums A and C in degrees
 A_0 = CP1 (from above)
 A_1 = CP2 (from above)

4.3 LINER SEGMENT INTERCHANGE

4.3.1 Narrative

In this series of experiments, four aluminum liner segments (used to mockup the aluminum reflector barrel) were substituted for four graphite liner segments (a mockup of the lateral support). The reactivity change resulting from this substitution was determined by the change in delayed critical drum bank position through the use of differential drum bank worth curves. The reactor was then reshimmed by removing niobium wires from the core to bring the delayed critical drum bank angle back to the required $115^{\circ} \pm 1^{\circ}$. A second value for the worth of the liner segment substitution was determined based upon calculations of the worth of the niobium shim wires removed.

Measurements were also made of selected individual control drum worths in order to determine what effects the liner segment substitution had upon the individual control drum spans.

4.3.2 Test Conditions

Figure 3-5 contains a line drawing showing the geometry in which the liner segment interchange occurred. Figures 4-7 and 4-8 show pictures taken of the 60° R-1 mockup reflector sector with the graphite and aluminum liner segments, respectively. DRM 51170 contains a listing of the niobium shim wires removed from the core after substitution of the aluminum liner segments in order to achieve a delayed critical drum bank angle of $115^{\circ} \pm 1^{\circ}$. Appendix D contains a more detailed description of the actual steps performed during this experiment.

Figure 4-7. View of 60° R1 Mockup Sector Showing Graphite Liner Segment

Figure 4-8. View - Aluminum Liner Segment

4.3.3 Test Results

Table 4-6 is a summary of the reactor run data taken during the liner segment interchange. Table 4-7 is a summary of the control drum worth data taken during the control drum worth measurements. The integral and differential drum worth curves actually obtained are similar in nature to those presented in Figures 4-2 through 4-5 of this report.

It should be noted that these control drum worth curves were taken in the same manner as in Section 4.2 of this report and thus a direct comparison can be made of the effects of the liner segments upon the control drum worths.

TABLE 4-6. SUMMARY OF REACTOR RUN DATA

Run No. (PAX-G1)	Date	Drum Positions (in degrees)					$T_{(sec)}$	$P_{(g)}$	Comments
		11-6 (average)	7, 10	A	B	C			
20	5/26/69	120.00	120.00	115.06	114.99	115.07	27.00	23.58	Basepoint.
		114.49	115.00	115.06	114.99	115.07	∞	0	(graphite liner segments in place)
21	5/26/69	125.00	125.00	115.05	114.99	115.01	42.52	17.83	Al liner segments in place in
		122.09	115.00	115.05	114.99	115.01	∞	0	60° sector.
22	5/27/69	117.00	117.00	115.01	115.00	114.99	62.86	13.65	Removed Nb wires for shimming
		116.01	115.00	115.01	115.00	114.99	∞	0	purpose.

TABLE 4-7. INDIVIDUAL CONTROL DRUM WORTHS

Drums Measured	DRUM ANGLE (DEGREES)							Remaining Bank	ρ^* (%)
	2	7	A	B	C	10	12		
A	116.50	116.50	180 $\rightarrow$ 0	116.58	116.57	116.50	119.24	116.50	39.98
B	116.50	116.50	116.61	180 $\rightarrow$ 0	116.52	116.50	118.84	116.50	38.26
C	116.90	116.90	116.55	116.56	180 $\rightarrow$ 0	116.90	115.00	116.90	39.80
2	180 $\rightarrow$ 0	117.50	116.52	116.50	116.51	117.50	117.80	117.50	55.27
7	117.50	180 $\rightarrow$ 0	116.55	116.56	116.52	117.50	118.08	117.50	54.30
10	117.50	117.50	116.56	116.55	116.43	180 $\rightarrow$ 0	117.74	117.50	53.89

* The reactivity values are for the drum changes indicated. All measurements were made with the WANEF analog reactivity computer by rotating the drum whose worth was being measured from 180° to 0°.

5.0 ANALYSIS

5.1 PAX/R-1 REFLECTOR SECTOR INTERCHANGE

5.1.1 Predictions

The reactivity change associated with the exchange of the 60° R-1 Mockup Reflector Sector for two PAX/R-1 (KIWI) 30° reflector sectors was calculated with the EXTERMINATOR code. These multi-energy group problems were run in R- θ geometry with the control vanes represented explicitly. The two particular calculations involved in the interchange experiment were:

- 1) Test Sector Fuel and KIWI Reflector
- 2) Test Sector Fuel and Mockup Reflector

The reactivity difference between these two calculations is the worth of a full 360° reflector interchange. The reactivities at the 115° drum position for the above two calculations are \$1.93 and \$0.21, respectively. Thus, the worth of completely replacing the full 360° KIWI reflector with a full 360° R-1 Mockup Reflector is $\$0.21 - \$1.93 = -\$1.72$. The reactivity change associated with the 60° replacement was obtained from the 360° worth by multiplying by $60^\circ / 360^\circ$, assuming separability. This gives the predicted worth of the interchange to be $-\$0.29$.

5.1.2 Predictions Versus Measurements

As noted in Section 4.1.3, the reactivity change due to the substitution of the 60° mockup R-1 sector for the two KIWI sectors was determined experimentally by two methods. Using the change in the delayed critical drum bank positions, the interchange worth was determined to be -27.9% . Using the reactivity change associated with the niobium wire removal, the worth of the interchange was found to be -38% . Of the two values measured for the worth of this interchange, the value based upon the change in the delayed critical drum bank angle was considered the most accurate. This compares very favorably with the analytically predicted value of 29% . The value based upon the calculation of the reactivity change caused by removal of niobium wires is questionable due to the neutron self-shielding in the wires and the corresponding wire worth.

5.2 PAX-G1 CONTROL DRUM SPANS

5.2.1 Predictions

The Westinghouse Integrated Standard Design Method (WISDM)* was used to predict the PAX-G1 total control drum span. Sixteen energy group, regionwise spectral weighted cross sections were generated for each reactor region using the GAMBIT code. Using these cross sections as input, R-0 EXTERMINATOR calculations were performed at the 0° and 180° drum bank positions. These calculations represented the test sector core and the R-1 Mockup Reflector Sector. The predicted total control drum span was \$7.88.

5.2.2 Predictions Versus Measurements

The PAX-G1 drum span measurements clearly demonstrated the substantial drum interaction effect in the R-1, 18 drum design. As a function of the other two drum positions (drums A and C), the worth of the central drum (drum B) in the R-1 sector varied from 31.4 cents (drums A and C at 0°) to 45.2 cents (drums A and C at 180°) (See Figure 4-6). The validity of estimating the total drum span by using the average of the central drum B worth curve, the 90° bank position, was ascertained from integral drum worth data as obtained from Table 4-5. A differential worth curve for drum B shadowed by drums A and C from the individual differential worths for the 30° , 60° , 75° , 90° , 105° , 120° , and 150° A and C bank positions is given in Figure 5-1. The integral of this curve is equal to 38.3 cents which is the same worth as the central B drum with the A and C drums at 90 degrees as shown in Figure 4-6. Multiplying this single drum worth value of 38.3 cents by 18 drums gives the measured total drum span worth to be equal to \$6.9.

Comparison of this measurements with the predicted value of \$7.88 gives a calculated to experimental correction factor of 0.88.

*Details on the Westinghouse Integrated Standard Design Method (WISDM) and the computer codes referred to in this document may be found in DRM 51105.

Figure 5-1. Differential Control Drum Worth of Drum B Calculated Using the Shadowing Technique

5.3 ALUMINUM BARREL EXPERIMENT

5.3.1 Predictions

The reactivity and control drum changes associated with the interchange of the 60° aluminum liner segments for the standard graphite liner segments in PAX-G1 were calculated using results from R-6 EXTERMINATOR calculations run at the 0° and 180° drum bank positions.

In using the EXTERMINATOR, the predicted value for the PAX-G1 reactivity change between the graphite liner segments and the aluminum liner segments is a reactivity loss of 26 cents. The same problems give a decrease in the total control drum span of 60 cents for the full 360 degrees or a 10-cent change for a 60° sector. This corresponds to a 7.2-cent predicted worth for a drum rotation of 0° to 115° which was the measured drum integral.

5.3.2 Predictions Versus Measurements

The reactivity change due to the substitution of the four aluminum liner segments for the four graphite liner segments was determined experimentally by two methods. Using the change in the delayed critical drum bank position, the interchange of the segments was determined to be worth -24.3 cents. Using the reactivity change associated with the niobium wire removal, the worth of the aluminum for graphite segments interchange equals -31.8 cents. Of the two values measured for the worth of this interchange, the value based upon the change in the delayed critical drum bank angle was considered the most accurate. This compares very favorably with the analytically predicted value of -26 cents. The value based upon the calculation of the reactivity change caused by removal of niobium wires is questionable due to the neutron self-shielding in the wires and the corresponding wire worth.

The best corrected experimental value for the change in drum span (0° to 115°) is 7.5 cents. This agrees very well with the predicted loss in total drum span for a bank rotation from 0° to 115° of 7.2 cents for the 60-degree sector interchange.

6.0 CONCLUSIONS

6.1 PAX/R-1 REFLECTOR SECTOR INTERCHANGE

The good agreement between the experimental and measured values for the reactivity change associated with the reflector interchange lends support to the validity of the reflector model used in these predictions. An analytical model very similar to that used in these PAX/R-1 calculations will be used to predict the neutronic effects of the R-1 reflector design.

6.2 PAX-G1 CONTROL DRUM SPANS

The PAX-G1 control drum span measurements demonstrated the strong drum interaction effect in an 18 drum system. As noted in Section 5.2, the worth of the central B drum from 0° to 180° with the bank at 90° (the average value of the central B worth curve) is identical to that obtained by integrating the differential worth curve developed for drum B from the experimental drum shadowing data. Future experiments will have to be performed on R-1 criticals to demonstrate the reproducibility of the agreement on the value of the total control drum span obtained using these two different methods.

The drum span normalization factors (Experimental Drum Span/Predicted Drum Span) which were derived in PAX-G0 and PAX-G1 are in good agreement, being 0.90 and 0.88, respectively. The PAX-G1 value of 0.88 will be applied to all R-1 EXTERMINATOR drum span predictions.

6.3 PAX/R-1 ALUMINUM BARREL REFLECTOR EXPERIMENT

The good agreement between the experimental and measured values for the reactivity change associated with the aluminum for graphite sectors interchange lends support to the validity of the model used in these predictions. A similar model to that used in these PAX/R-1 calculations will be used to predict the neutronic characteristics of the R-1 aluminum cylinder reflector design.

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APPENDIX A

ACTUAL AND/OR REPRESENTATIVE AS-BUILT WEIGHTS
FOR THE PAX-G1 AND PAX-G1A REACTORS

The PAX-G1 reactor is described in Drawings 711J496 and 711J498B. The only differences between different members of the PAX-G1 series (PAX-G1, -G1A) of reactors are in the reactor cores. DRM's 51150, 51150A, 51163, 51163A, 51166, and 51166A contain actual and/or representative as-built weights of the reactor components and fuel element inventories. DRM 51186 contains the chemical analyses of the different shim wires. It should be noted that both the fuel and non-fuel element positions are in the PAX/R-1 notation, and are not in the R-1 notation. The only difference between the two notations is in the outer peripheral region of the core. In the former, the peripheral clusters are given J and K designations. In the latter, J and P notations are used. The former notations, however, correspond to the actual as-built conditions while the latter correspond to an R-1 Reference Design. Figures A-1 and A-2 contain a one-sector representation of the two different notations.

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LOOKING FORWARD

Figure A-1. PAX/R-1 Notation (U)

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Figure A-2. R-1 Core Notation (U)

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APPENDIX B

THE PAX/R-1 BERYLLIUM REFLECTOR SECTOR INTERCHANGE EXPERIMENTAL PROCEDURE

In accordance with WANEF procedures*, an Experimental Details Checklist (EDC) was written to set forth the details of interchanging one PAX/R-1 mockup sector containing three R-1 mockup drums, with two PAX/R-1 (KIWI) sectors containing a total of two NRX type control drums. Because of the sizable reactivity change associated with this interchange, procedures were also written for reshimming the reactor to the desired delayed critical drum bank angle of $115^{\circ} \pm 1^{\circ}$. Also included in this EDC is an evaluation of the nuclear hazards which could result from such procedures. Those portions of the experimental procedure applicable to this TME may be found in Part A of the EXPERIMENTAL DETAILS section of EDC 70. The body of EDC 70 is contained in this appendix.

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

WANEF
EXPERIMENTAL DETAILS CHECKLIST*

No. 70
Date 4/1/69

TITLE OF EXPERIMENT: PAX/R-1 Beryllium Reflector Sector Interchange Experiment

OBJECTIVES:

The objectives of this experiment are three-fold. The first is to determine the reactivity effects of interchanging two PAX/R-1 (KIWI) sectors containing two NRX PAX control drums with one PAX/R-1 mockup sector containing three R-1 mockup drums. The second is to reshim the core to a delayed critical drum bank angle of $115^{\circ} + 1^{\circ}$. The third is to replace the PAX/R-1 mockup sector with two KIWI type sectors to allow measurements to be made with a symmetrical reflector.

EQUIPMENT REQUIREMENTS:

1. The PAX-G reactor.
2. One R-1 mockup reflector sector.
3. Three R-1 type drums with Cu-B^{10} control plates, or alternate plates (modified NRX Al B¹⁰ plates) and their drive mechanisms.
4. The WANEF reactivity computer.
5. Special lifting fixtures and adapters for handling the KIWI and the R-1 mockup reflector sectors.
6. Two assembled NRX type reflector sectors (may be in the PAX-G reactor reflector).

HAZARDS CONSIDERATIONS:

The reactivity measurements to be conducted during the execution of this EDC involve interchanging beryllium reflector sectors on the PAX-G. This type of interchange falls within the limits set forth in the revised WANEF safety documents, and when the sector changes are made in accordance with the steps outlined below, no violation of any Operating Limit should occur. In formulating the steps in which the experiment is to be carried out, three areas considered were: 1) the reactivity effect of each step, 2) the possibility of a mechanical misalignment of a drum or sector, and 3) the "fat man" effects on an unreflected core while the sectors are being changed. Based upon a published prediction** it is estimated that a net change of -29% will occur when two 30° PAX/R-1 (KIWI) sectors are replaced with the 60° PAX/R-1 mockup sector with all control vanes in position. Thus, safety hazards are contingent on the following possibilities.

* In response to Scope of Test 59DW-229-0, "Reflector Interchange Experiment", by D. Mangan, et. c
** DRM No. 1057, "Nuclear Prediction for the PAX/R-1 Experimental Program", dated 12/2/68, by the Nuclear Design staff, page 3-4.

1. Since control drums in the R-1 mockup sector do not have a spring return feature similar to the existing PAX/NRX drums, the drums may be at some position other than "full-in" when installed into the sector.

2. The vanes may have been inadvertently omitted during assembly of the drum into the housing or, in the case of new vanes, the poison may have been inadvertently omitted during the manufacturing process.

3. A large hydrogenous mass, such as a person, may accidentally come in contact with the core at a time when a reflector sector is missing.

Avoidance of the first potential hazard, i.e., the R-1 drums not in a "full-in" position, is ensured under SOP 5.4.2.2.4 by requiring that the "..... Experimentalist will ensure that these drums are locked in the "full-in" (0 degrees) position", and that this information be recorded on the appropriate PRE-STARTUP/MANUAL CHANGE CHECKLIST before the interchange takes place.

Avoidance of the hazards due to the second possibility is ensured by the requirement in SOP 5.4.2.2.4 that poison wires of sufficient worth be inserted in the core to cover the estimated net reactivity change (assuming a reactivity increase of \$0.80 for each NRX type drum and \$0.60 for each R-1 type drum) prior to the interchange. Presence of poison in the vane will be demonstrated by a neutron transmission experiment, certification of the vane material, or prior use in PAX.

Avoidance of the hazards due to the third possibility, that of a large hydrogenous mass coming in contact with the side of the core during the interchange process is precluded since the pressure vessel must be in place for the R-1 mockup sector experiments. If the pressure vessel must be removed prior to, or during, the sector interchange procedure, a suitable physical barrier will be inserted in its place to prevent reflective material from coming in contact with the core.

Reshimming will take place in accordance with SOP 5.4, "Manual Reactivity Change Procedure".

From the above discussion, it may be seen that the performance of the experiment set forth in this EDC presents no unevaluated safety hazard.

EXPERIMENTAL DETAILS:

The reflector interchange will take place in one of the following sequences of steps:

A. Replacement of two KIWI type sectors with a 60° mockup R-1 sector.

1. A sufficient number* (151) of poison wires will be added to the core (see Appendix I) and a physical barrier will be installed (if necessary). A reactivity run will be made to verify that the required shutdown is available. A shutdown measurement will be made with drums 8 and 9 adjusted to obtain criticality with all remaining drums at 180° . If necessary, drum 2 and/or 3 may be adjusted in the event the criticality is reached while drums 8 and 9 are at 0° and the remaining bank is $<180^{\circ}$.
2. The drum drives will be disconnected from drums 8 and 9.
3. Sectors 8 and 9 will be unfastened from the remaining sectors so that they are free to be removed (i.e., the sections of the aft support ring will be disconnected and tie bolts removed).
4. The lifting fixtures will be attached to one of the sectors and it will be removed from the reactor by use of the overhead crane. The other sector will then be removed in a similar manner.
5. The new sector assembly will be lowered into position by the overhead crane and fastened in place. The physical barrier may then be removed, as desired. The drums** and drive mechanisms will then be installed.
6. The drums will be connected to the control circuitry and all electrical controls checked out with the reactor in BY-PASS condition.
7. A reactivity run will be made in order to verify the reactivity change associated with the sector interchange and to provide a basepoint for poison wire removal.
8. After the period is measured, the reactor operator will level off at a nominal power (approximately 10 watts) and will verify that each new drum can insert a negative reactivity by individually driving them in.
9. The PAX/R-1 (KIWI) drums will be driven either to 180° or until criticality is reached. In the event that criticality is not reached with the 10 NRX type drums at 180° , the reactor will be brought critical on the R-1 mockup drums. After a suitable power level is reached, the power will be leveled off and the NRX type drums will be scrambled and the shutdown measured.
10. The poison wires will be removed in increments of 50¢ or less until all poison wires have been removed. (The minimum shutdown of \$3.40 with personnel present will not be violated and will be monitored in accordance with the procedure in step 9, above.)
11. The core will then be reshimmed to the desired θ_{DC} in accordance with the sequence provided by the WANL Nuclear Design staff.

*The number of poison wires to be inserted will be determined by assuming a reactivity insertion of +60¢ for each inserted R-1 type drum, or 80¢ for each inserted NRX type drum. Credit will also be taken for the reactivity change associated with the actual sector(s). Based upon predicted values (DRM-1057, "Nuclear Predictions for the PAX/R-1 Experimental Program"), the replacement of two PAX (KIWI) sectors by one 60° mockup R-1 sector will be assumed to result in a -29¢ change until experimental data is available. Based on a typical worth of 1¢/wire, the change from two 30° sectors with 2 NRX type drums to one 60° sector with 3 R-1 type drums will require \$1.51 ($3 \times \$0.60 - \0.29) worth of wires (151 wires) to be inserted in the core. The reverse change would require an insertion of \$1.89 ($2 \times \$0.80 + \0.29), or 189 wires. This procedure then provides for the possibility of accidentally omitting the control vanes. If better experimental wire worth values become available, the number of wires will be recalculated according to these values.

NOTE: Before each drum is placed into the sector, it will be locked in the 0 degree position and this fact recorded by the Experimentalist on the PRE-STARTUP/MANUAL CHANGE CHECKLIST.

B. Replacement of a 60° mockup R-1 sector by two KIWI type sectors.

1. A sufficient number (189) (see single asterisk on bottom of page 3) of poison wires will be added to the core (see Appendix I) and a physical barrier will be installed (if necessary). A reactivity run will be made to verify that the required shutdown is available.

2. All circuitry will be disconnected from the three R-1 drives.

3. The R-1 drive housings will be unfastened from the sector and the drive mechanisms and drums removed.

4. Suitable lifting fixtures will be attached to the 60° sector. Only the end tie rods will be removed.

5. If required, a physical barrier will be placed in position. The 60° sector may then be removed.

6. The two KIWI sectors will then be placed in position, one at a time.

7. The drums will be connected to the drum drives and checked out with the reactor in BY-PASS condition. Checks to be made include proper operation of the IN and OUT limit lights as well as scram times (per OLD, Section 3.22).

8. A reactivity run will be made in order to verify the reactivity change associated with the sector interchange and to provide a basepoint for poison wire removal. This will include a shutdown measurement.

9. After the period is measured, the reactor operator will level off at a nominal power (approximately 10 watts) and will verify that each new drum can insert a negative reactivity by individually driving them in.

10. The poison wires will be removed in increments of 50¢ or less until all poison wires have been removed. (The minimum shutdown of \$3.40 with personnel present will not be violated and will be monitored by shutdown measurements and/or suitable drum worth curves.)

11. The core will then be reshimmied to the desired θ_{DC} in accordance with the sequence provided by the WANL Nuclear Design staff.

DATA REQUIRED:

1. Weights and serial numbers (where applicable) of all parts used during assembly of the inserted sector.
2. Weights, locations, and serial numbers (where applicable) of all shim materials used to shim the core to the desired θ_{DC} ($115^\circ \pm 1^\circ$).
3. Differential poison wire worth curves*.

* Not required by T/S.

WRITTEN BY:	<u>I. W. Rowland</u>	I. W. Rowland	DATE	<u>3/1/69</u>
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APPENDIX I

Poison wires will be inserted in the following sequence clusters (6 wires/
1 cluster) in order to provide the required negative reactivity insertion:

(1-6) A1

(1-6) B(1-2)

(1-6) C(1-3)

APPENDIX C

THE PAX-G1 CONTROL DRUM WORTH MEASUREMENT EXPERIMENTAL PROCEDURES

In accordance with WANEF procedures*, an Experimental Details Checklist (EDC) was written to set forth the details of determining the control drum worths in the R-1 mockup reflector sector and the effect of the new sector upon the remaining 10 NRX type drums. In addition, an evaluation was performed of the nuclear hazards which might possibly result from such measurements. The experimental procedure** used in making the PAX-G1 control drum worth measurements may be found in the EXPERIMENTAL DETAILS section of EDC 75. The body is contained in this appendix.

- * For further details, see WANL-TME-267, Revision H, "Westinghouse Astronuclear Experimental Facility Reactor Operations Manual".
- ** Three minor changes were made to the experimental procedure as described in the EDC in order to better conform with the Scope of Test document. These changes are as follows:
 - A. Part 4 of the EQUIPMENT REQUIREMENTS section should be changed to read:
".other detector to be positioned horizontally on top of the reactor core and centered on the reactor core centerline."
 - B. 1. The first paragraph of Part A of the EXPERIMENTAL DETAILS section should be changed to read: ".extended centerline on top of the reactor core . . ."
 - 2. The existing Step 12 should be renumbered Step 19 and the following inserted after Step 11: "12-18. Repeat Steps 3 through 10, above."

WANEF
EXPERIMENTAL DETAILS CHECKLIST

No 75
Date 4/15/69

TITLE OF EXPERIMENT: PAX-G1 Control Drum Worths *

OBJECTIVES:

1. To determine the influence of the R-1 mockup sector reflector interchange on the 10 remaining PAX/R-1 (KIWI) drum worth.
2. To determine the worth of a central drum in the 60° R-1 mockup sector.
3. To determine shadowing interactions for certain specified configurations between adjacent drums in a 18 drum system.
4. To check the equivalence of positive period reactivity techniques and the WANEF reactivity computer method of measuring reactivity.
5. To provide further information on the suitability of subcritical multiplication reactivity monitoring techniques for measuring drum span.

EQUIPMENT REQUIREMENTS:

1. The WANEF analog reactivity computer with X-Y (or stripchart) recorder.
2. The WANEF period-pickoff measuring system.
3. The PAX-G1 reactor** shimmed to $\theta_{DC} = 115^\circ \pm 1^\circ$.
4. Two DAS pulse channels: One detector to be positioned horizontally at the reactor midplane next to the pressure vessel midway between drums 2 and 3, and the other detector to be positioned horizontally underneath the dome end of the reactor and centered on the reactor core centerline.
5. Six reactor assembly neutron "line" sources.

* In response to T/S 59DW-230-1, "PAX-G1 Control Drum Spans".

** I.E., including the 60° mockup reflector sector with 3 R-1 mockup drums and core reclustering assignments as required by NRD.

HAZARDS CONSIDERATIONS:

The techniques involved with drum worth measurements using the analog reactivity computer and positive-period techniques are the standard ones used previously at WANEF. When conducted in accordance with the requirements and limitations of SOP 5.2, "Reactor Operating Procedure", there will be no unevaluated safety hazard or any increase in the probability or consequences of those already evaluated.

EXPERIMENTAL DETAILS:

The drum worth measurements contained in this EDC consist of three groups, namely:

1. Subcritical $1/M$ measurements.
2. Regular integral drum worth measurements made with the analog reactivity computer.
3. Shadowed measurements performed on the central R-1 mockup drum.

The last two groups of measurements are relatively insensitive to prior irradiation history in view of WANEF's maximum power limitation. The same cannot be said for the first group, however. Thus, although the measurements can be performed in any order, consideration should be given to the performance of the subcritical measurements after the reactor has not been run for some time in order to ensure a reasonably constant (over the course of the measurements, e.g., one morning) background caused by photoneutrons, etc.

A. Subcritical $1/M$ Measurements

For these measurements, two DAS channels shall be used to accumulate $1/M$ count rate data. One of the detectors shall be placed midway between drums 2 and 3 and adjacent to the pressure vessel (+6'). The other detector will be placed at or near to the extended centerline underneath the dome end. The data will be taken in the following steps:

1. Insert 6 reactor assembly neutron "line" sources in cluster 000. These should be placed symmetrically about the centerline axis, if possible.
2. Obtain count rate* data on the two data channels.
3. Run the bank of 10 NRX type drums to a position such that the reactor is shutdown by approximately \$2.
4. Obtain count rate data on the two DAS channels.

* Count rate data should be taken in a series of 5 or more sequential one minute counts. To ensure reasonable statistics, a minimum of 10,000 counts in each channel is desirable.

5. Run drum A* out to 115° .
6. Obtain count rate data on the two data channels.
7. Run drum B out to 115° .
8. Obtain count rate data on the two data channels.
9. Run drum C out to 115° .
10. Obtain count rate data on the two data channels.
11. Shutdown the reactor and remove the neutron sources from cluster 000.
12. Remove the DAS detectors.

B. Integral and Differential Drum Worths

Integral drum worth measurements will be performed in the following manner:

1. The drum which is to be measured shall be placed at 90° and the remaining bank adjusted so that the reactor is just critical. The drum to be measured shall then be withdrawn to 180° . If necessary, the power may be reduced by scrambling one to two drums, waiting a suitable period of time, and then returning them to their immediate prior position.
2. When the reactor is on a relatively stable period, period measurements shall be taken until the power level is adequate for operation of the reactivity computer.
3. The drum to be measured will then be driven full in with the output of the reactivity computer recorded on a suitable recorder. Indications of the drum position shall be made at 10° intervals on the recorder trace.
4. The above three steps shall be repeated for each drum to be measured. Differential worths may then be obtained from the integral curves by numerical differentiation.

Measurements will be performed on drums 2, 7, 10, A, B, and C.

The drums in the 60° R-1 mockup sector are labeled A, B, and C in a clockwise sequence looking forward.

C. Shadowed Measurements in the R-1 Sector Central Drum

The sequence of steps for these measurements is the same as in section B but subject to the following restrictions:

1. Only the worth of drum B is to be measured.
2. The two outer drums, A and C, will be placed at the following angles:

- a. 30
- b. 60
- c. 75
- d. 90
- e. 105
- f. 120
- g. 150

A different angle will be picked for each measurement with the remaining 10 drum bank being adjusted for the desired period.

3. Only integral drum worth data is required.

DATA REQUIRED:

1. R-1 sector component weights.
2. Subcritical count rate data for 0, 1, 2, and 3 R-1 drums at 115° with the 10 remaining R-1 (KIWI) mockup drums at 0° .
3. Integral and differential drum worth measurements and their associated period measurements for selected drums.
4. Shadowed drum measurements for drum B for seven selected shadow angles.

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SCIENTIST-IN-CHARGE F. S. Frantz F. S. Frantz, Manager, WANEF DATE 4/15/69

MANAGER, NUCLEAR AND RADIATION DESIGN W. P. Kovacik W. P. Kovacik DATE 4/15/69

APPENDIX D

THE PAX-G1 LINER SEGMENT INTERCHANGE EXPERIMENTAL PROCEDURE

In accordance with WANEF procedures*, an Experimental Details Checklist (EDC) was written to set forth the details of interchanging four aluminum liner segments for four graphite liner segments. Because of the sizable reactivity change associated with the liner segment interchange, a procedure was also written for reshimming the reactor to bring the delayed critical drum bank angle to $115^{\circ} \pm 1^{\circ}$. In addition, an evaluation was made of the possible nuclear hazards resulting from such operations. These procedures and evaluations are found in EDC 77, the body of which is contained in this appendix.

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

WANEF
EXPERIMENTAL DETAILS CHECKLIST

No. 77
Date 5/2/69

TITLE OF EXPERIMENT: Liner Segment Interchange Experiment*

OBJECTIVES:

The objectives of this experiment are as follows:

1. To measure the reactivity change caused by interchanging graphite and aluminum liner segments on the 60° mockup sector.
2. To determine the effects of the above change on the integral and differential drum worths.

This data will then be used to normalize calculations involving an aluminum barrel reflector design.

EQUIPMENT REQUIREMENTS:

1. The PAX-G reactor with the 60° R-1 mockup sector installed.
2. The WANEF analog reactivity computer.
3. Four aluminum liner segments.

HAZARDS CONSIDERATIONS:

The reactivity measurements to be conducted during the execution of this EDC involve interchanging graphite and aluminum liner segments on the PAX-G reactor. This type of interchange falls within the limits set forth in the revised WANEF safety documents, and when the changes are made in accordance with the steps outlined below, no violation of any Operating Limit should occur. In formulating the steps in which the experiment is to be carried out, two areas considered were: 1) the reactivity effect of each step, and 2) the "fat man" effects on an unreflected core while the sectors are being changed. Based upon a prediction**, it is estimated that a net change of -25¢** will occur when four graphite liner segments are replaced with four aluminum liner segments. Thus, safety hazards are contingent on the following possibilities:

* In response to T/S 59DW-290-0.

** NRD-69-137, "PAX-G2 Aluminum Barrel (Scope of Test 59DW-290-0). This results from a -15¢ change resulting from the material interchange and a -10¢ change from the integral drum span for the three R-1 drums.

1. Since control drums in the R-1 mockup sector do not have a spring return feature similar to the PAX/NRX drums, the drums may be at some position other than "full-in" when the sector is removed and/or re-inserted into the reactor. Avoidance of this hazard, i.e., the R-1 drums not in a "full-in" position, is assured by requiring that the Experimentalist ensure that these drums are locked in the "full-in" (0 degrees) position, and that this information be recorded on the appropriate PRE-STARTUP/MANUAL CHANGE CHECKLIST before the interchange takes place.

2. A large hydrogenous mass, such as a person, may accidentally come in contact with the core at a time when a reflector sector is missing.

Avoidance of the hazards due to this second possibility, that of a large hydrogenous mass coming in contact with the side of the core during the interchange process, is precluded since the pressure vessel will be in place for the R-1 mockup sector experiments. If the pressure vessel must be removed during the sector interchange procedure, a suitable physical barrier will be erected in its place to prevent reflective material from coming in contact with the core.

Based upon a θ_{DC} of 115° and a conservative drum worth estimate of 50¢/NRX type drum (in the PAX-G reactor) for each of 10 drums, one may show from normalized drum worth curves that in the highly unlikely event that substitution of aluminum liner segments for graphite liner segments causes the R-1 drum to become worthless, the reactor will still maintain a \$3.60 shutdown.

Since the drum assemblies will not be dismantled during the experiment covered by this interchange, there is no chance for any of the control vanes to be omitted during assembly. Therefore, no poison wires will be added to the core.

Reshimming will take place in accordance with SOP 5.4, "Manual Reactivity Change Procedure". Reactor operations will be carried out in accordance with SOP 5.2, "Reactor Operating Procedures". The installation and removal of experiments will be governed by SOP 5.4, "Manual Reactivity Change Procedure" and SOP 5.5.4, "PAX In-Core Experiments".

From the above discussion, it may be seen that the experiment set forth in this EDC presents no unevaluated safety hazard when performed within the limitations defined above.

EXPERIMENTAL DETAILS:

In order to substitute aluminum liner segments for graphite liner segments in the 60° mockup reflector sector, the following steps will be performed.

1. Before any changes are made, a reactivity run will be made to establish a basepoint for the change. The R-1 mockup drum bank will be set at 115° and θ_{DC} will be measured by adjusting only the 10 drum NRX bank.
2. The Experimentalist will verify that the three R-1 drums are locked in the "full-in" position and record this information on the PRE-STARTUP/MANUAL CHANGE CHECKLIST.
3. The electrical connectors will be disconnected from the three R-1 drive mechanisms.
4. The lifting fixtures will be attached to the sector. If the readout potentiometers must be removed, care should be taken to record (before removal) the R-1 drum position readings so that the indicators may be properly reset.
5. The outside tie bolts and connecting plates on the 60° sector will be loosened and removed, as required.
6. A physical barrier capable of preventing full body contact with the side of the core must be in place while the reflector sector is out of the reflector. If the pressure vessel is to remain in place while the sector is out of the reflector, it will provide an acceptable barrier. If pressure vessel must be removed for any reason while the sector is out, a replacement barrier must be erected.
7. The sector may then be removed from the reactor and the liner segments interchanged.
8. The sector will then be placed back into position in the reflector, the lifting fixtures removed, electrical connectors attached, and the position indicator potentiometers reset. Each of the drums in the sector will then be checked out with the reactor in BY-PASS mode to verify proper operation.
9. A reactivity run will be made to determine the effect of the liner segment interchange. To do this, the R-1 mockup drum bank will be set at 115°. The reactor will then be brought to delayed critical with the 10 drum (NRX) bank at a suitable power level. The 10 drum NRX bank will be placed at the same position obtained in step 1 above. θ_{DC} will be re-established by adjusting the R-1 mockup drum bank. If criticality cannot be achieved with the R-1 mockup drum bank at 180°, the 10 drum NRX bank will

be moved until θ_{DC} is reached.

10. The reactor will be reshimmed to a $\theta_{DC} = 115^\circ \pm 1^\circ$ by removal of .068" OD Nb wires in a uniform manner.

11. Integral and differential drum worths of the three R-1 mockup drums should be measured.

To change from the aluminum to the graphite liner segments, the procedures will be as follows:

1. The reactor will be reshimmed by inserting .068" OD Nb wires into the positions from which they were removed in Step 10 above.

2. Steps 2 through 8 above will be repeated.

The net change caused by inserting the Nb wires and interchanging liner segments will be approximately 0%.

DATA REQUIRED:

1. Weights of the aluminum and graphite liner segments.
2. Reactivity effect of changing from graphite to aluminum liner segments in the 60° mockup sector.
3. Integral and differential drum worth measurements.
4. Positions and total weight of Nb wires removed in the shim procedure.

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MANAGER, NUCLEAR & RADIATION DESIGN W. P. Kovacik W. P. Kovacik DATE 5/6/69

TITLE PAX-G1 Reflector Interchange, Control Drum Span, and Aluminum Reflector Barrel Experiments	
DOCUMENT NO. WANL-TME-1916		DATE December, 1969
ABSTRACT Reactivity experiments have been performed on the PAX-G1 reactor in support of an 18 drum R-1 design. Measurements have been made on the reactivity changes resulting from the substitution of a 60° R-1 mockup reflector sector containing three R-1 type control drums for two 30° reflector sectors, each of which contained one NRX type drum. Additionally, measurements have been made of the control drum spans and interaction effects in the 60° mockup reflector sector. An additional experiment is reported in which measurements were made of the reactivity effects caused by interchanging aluminum and graphite liner segments.		
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