**Westinghouse
Astronuclear
Laboratory**

Mowery SNPO-C

WANL-TME-2703
AUGUST 1970

DATA ITEM T-119

**PAX-G2 CONTROL
DRUM SPANS**

FINAL REPORT

MASTER

DISCLAIMER

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

DISCLAIMER

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

Westinghouse Astronuclear Laboratory

Subcontract NP-1
CODE IDENT NO. 14683

WANL-TME-2703
AUGUST 1970

DATA ITEM T-119

PAX-G2 CONTROL

3#
DRUM SPANS. ↗

FINAL REPORT.

NOTICE

This report contains information of a preliminary nature and was prepared primarily for internal use at the originating installation. It is subject to revision or correction and therefore does not represent a final report. It is passed to the recipient in confidence and should not be abstracted or further disclosed without the approval of the originating installation or USAEC Technical Information Center, Oak Ridge, TN 37830.

APPROVED BY:

J. G. Gallagher, Manager
NERVA Design Engineering

INFORMATION CATEGORY

Unclassified

AUTHORIZED CLASSIFIER

7-9-70

DATE

PAGE BLANK

ABSTRACT

Control drum span measurements have been performed in support of the R-1 design on the PAX-G2A reactor, a nuclear mockup of an 18-drum R-1 design. 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 0.85, assuming a total delayed neutron fraction of 0.0070. This compares quite favorably to similar calculations for the PAX-G0B and PAX-G1A measurements of 0.89 and 0.86 respectively. Substantial drum interaction effects between the individual R-1 mockup drums were also demonstrated.

PAGE BLANK

TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
1.0	INTRODUCTION	1-1
1.1	TEST IDENTIFICATION	1-1
	1.1.1 Type of Report	1-1
	1.1.2 Scope of Test Document /Test Information Sheet	1-1
	1.1.3 Functional Category of Test	1-1
	1.1.4 Contractor	1-1
	1.1.5 Test Facility	1-1
	1.2 PURPOSE	1-1
2.0	REFERENCES AND ASSUMPTIONS	2-1
2.1	REFERENCES	2-1
	2.1.1 Specification	2-1
	2.1.2 Data Item Description	2-1
	2.1.3 Scope of Test Document/Test Information Sheet	2-1
	2.1.4 Data Release Memorandum	2-1
	2.1.5 TME	2-2
	2.1.6 Drawing	2-2
2.2	ASSUMPTIONS	
	2.2.1 Worths of Control Drums Not In Or Adjacent to the Test Sector	2-2
	2.2.2 Uncertainty Estimates	2-2

TABLE OF CONTENTS (continued)

<u>Section</u>		<u>Page</u>
3.0	TEST ARTICLE CONFIGURATION	3-1
3.1	REACTIVITY MEASURING SYSTEMS	3-1
3.2	AUTOMATED DRUM POSITION READOUT	3-1
3.3	PAX-G REACTOR DESCRIPTION	3-3
4.0	SUMMARY OF TESTS	4-1
4.1	NARRATIVE	4-1
4.2	TEST CONDITIONS	4-1
	4.2.1 Individual Drum Worths	4-1
	4.2.2 R-1 Mockup Drum Bank Worth	4-4
4.3	TEST RESULTS	4-6
	4.3.1 Individual Drum Worths	4-6
	4.3.2 R-1 Mockup Drum Bank Worth	4-6
4.4	COMPARISON WITH PREVIOUS RESULTS	4-7
5.0	ANALYSIS	5-1
5.1	PREDICTIONS	5-1
5.2	PREDICTIONS VERSUS MEASUREMENTS	5-1
5.3	COMPARISON OF EXPERIMENTAL CORRECTION FACTORS	5-3
6.0	CONCLUSIONS	6-1
APPENDIX		
A.	The PAX-G2A Control Drum Worth Measurement Experimental Procedure	A-1

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
3-1	Drum Interface Amplifier Schematic Diagram	3-2
3-2	PAX-G2A Reflector Assembly	3-4
4-1	PAX-G2A Reflector Geometry	4-2
4-2	Drum B Integral Drum Worth Curve in the PAX-G2A Reactor	4-8
4-3	Drum 7 Integral Drum Worth Curve in the PAX-G2A Reactor	4-9
4-4	Differential Control Drum Worth for Drum B in the PAX-G2A Reactor	4-10
4-5	Differential Control Drum Worth for Drum 7 in the PAX-G2A Reactor	4-11
4-6	Drum B Worth as a Function of Adjacent Drum Position in the R-1 Mockup Sector	4-13
4-7	R-1 Integral Drum Bank (Drums A, B, & C) Worth Curve in the PAX-G2A Reactor	4-15
5-1	Differential Control Drum Worth of Drum B Calculated Using the Shadowing Technique	5-2

LIST OF TABLES

<u>Table</u>		<u>Page</u>
4-1	Individual Control Drum Worth Measurement	4-3
4-2	Comparison of Analog Reactivity Computer Data vs. Period Pickoff Data	4-5
4-3	Summary of Differential and Integral Drum Worths	4-12
4-4	HDRC Least Squares Fit Data	4-14

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/Test Information Sheet

The applicable Scope of Test Document Number is 59DW-232-2 and the applicable Test Information Sheet is DW-27.2.

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, during February and March, 1970.

1.2 PURPOSE

The PAX-G2 control drum span measurements provide data which will be used to support analysis normalization techniques. These data will support the nuclear design of the R-1 reflector assembly, and by providing experimental normalization factors to the analysis design techniques, assure that the control drum span design requirements are satisfied.

2.0 REFERENCES AND ASSUMPTIONS

2.1 REFERENCES

2.1.1 Specification

CP 677559 - Part 1. 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/Test Information Sheet

S/T 59DW-232-2 - PAX-G2 Control Drum Spans

TIS DW-27.2 - PAX-G2 Control Drum Worth Measurements

2.1.4 Data Release Memorandum

51612 - Neutron Transmission Measurements on NERVA Reactor Control Vanes

51511 - R-1 Effective Delayed Neutron Fraction and Prompt Neutron Lifetime

51245 - Test Reports on PAX Control Vanes

51198 - Hurst Data Reduction Code for a Hurst Fast Neutron Proportional Counter

51193 - PAX-G2 Control Drum Worth Measurements

51189 - Parts Inventory in the PAX-G2 Reactor

51186 - Chemical Analysis of WANEF Reactivity Materials

51167 - PAX-G1 Control Drum Spans

51166-A - PAX-G1 Shim Wire Inventory

51166 - PAX-G1 Shim Wire Inventory

51163-B - Parts Inventory in the PAX-G1B Reactor

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

51163 - Parts Inventory in the PAX-G1A Reactor

51154-A - 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
51105C } Structural Analysis Procedure and Identification and Description
of Computer Codes

2.1.5 TME

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

WANL-TME-1916, "PAX-G1 Reflector Interchange, Control Drum Span and Aluminum Reflector Barrel Experiments"

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

939J535 - R-1 Reflector (5/68)

2.2 ASSUMPTIONS

2.2.1 Worths of Control Drums Not In Or Adjacent to the Test Sector

The individual control drum worths for drums 11, 12, 1, 3, 4, 5, and 6 are assumed to be given by an average of the worths of drums 2, 7, and 10.

2.2.2 Uncertainty Estimates

The estimated ~~1~~ uncertainties are the same as those reported in DRM51154A since the instrumentation systems are basically the same for both reactors.

3.0 TEST ARTICLE CONFIGURATION

3.1 REACTIVITY MEASURING SYSTEMS

Reactivity measurements have been made with two systems: the period pickoff system for reactivity coefficient measurements and the reactivity computer systems for determining integral control drum worths. These two systems have been described in Section 3.1 of WANL-TME-1916, "PAX-G1 Reflector Interchange, Control Drum Span, and Aluminum Reflector Barrel Experiments." Further description of the basic programming of the reactivity computer is given in WANL-TME-1910, Appendix D, "PAX-G0 Control Drums Spans and Reactivity Coefficient Measurements." The period pickoff system was not changed, but minor changes were made in the reactivity computer. The time constant of the input amplifier was increased to 0.2 seconds to improve its operation at high gain and to provide some filtering of the signal to the servo-multiplier. Also, the gains of amplifiers 7 and 8 (see Figure D-1, WANL-TME-1910) were doubled to increase the input voltages supplied to the servo-multiplier. Additionally, the servo-multiplier was replaced with a functionally equivalent unit.

3.2 AUTOMATED DRUM POSITION READOUT

In order to reduce the number of hash marks manually recorded on the integral drum span curves as well as to increase the precision of the measurement, a small departure was made from previous practice. Since the position of the 3,R-1 mockup drums is determined through the use of potentiometers coupled to each drum, a Drum Interface Amplifier (see Figure 3-1) was constructed to allow use of the X-T recorder in an X-Y mode. This allowed data to be taken with direct calibration of drum position instead of time for each of the 3,R-1 mockup drums. In order to use this device with the NRX type drums, the installation of an additional potentiometer position indicator is required on each drum. One of these devices has been constructed and during the time of these measurements it

Figure 3-1. Drum Position Interface Amplifier Schematic Diagram

was mounted on drum 7. Therefore, the drum 7 data were taken with an automatically calibrated position axis, but the data for drums 2 and 10 required the usual manual addition of hash marks to record actual drum position during the measurement.

3.3 PAX-G REACTOR DESCRIPTION

The PAX-G reactor has been used to perform standard reactor experiments during the early phases of the R-1 design program to support the release of R-1 fuel specifications and provide information on the adequacy of the control capability of the R-1 reflector system.

The reference R-1 reactor core design* contains 1878 fueled and 349 unfueled elements having a hex shaped cross section approximately $3/4$ " across the flats and a length of approximately 52". The PAX-G reactor also contains a total of 2227 elements, but the number of fueled elements is greater. Although the R-1 design calls for uranium loadings as high as 630 mg/cm^3 , available elements have uranium loadings of less than 500 mg/cm^3 . Thus, in order to mockup the overall uranium content using available fuel, approximately one-half of the central elements in PAX-G are fueled. These fueled central elements were made from existing fuel elements by drilling and tapping each end. To accommodate the increase in the total number of elements from NRX PAX, an extension to the core support plate was inserted into the support plate region of the PAX-G as seen in Figure 3-2. The PAX-G core contains approximately 245 kg of highly enriched uranium.

The original PAX-G build (PAX-G0) had a reflector with 12 NRX type control drums in available KIWI reflector sectors.

The next major modification to the PAX-G reactor involved the replacement of two KIWI reflector sectors together with their associated control drums with a 60 degree R-1 reflector mockup segment containing 3 R-1 mockup control drums. This resulted in a reactor with a total of 13 control drums. The 60 degree reflector mockup sector is constructed from laminated beryllium slabs and contains the same non-beryllium fraction as that of the earlier R-1 reference design.* This mockup sector also contained mockup lateral support hardware,

*The April, 1968, R-1 reference design described in WANL Dwg. 939J535.

612397-3

Figure 3-2. PAX-G2A Reflector Assembly

as may be seen in Figure 3-2. This configuration, after suitable reshimming and reclustering of the core, was designated PAX-G1A. The conversion from PAX-G1A to PAX-G2A, the reactor in which the measurements reported in this document were made, involved the following changes from PAX-G1:

1. Substitution of Cu-B¹⁰ control vanes for the Al-B¹⁰ control vanes on the 3, R-1 mockup drums. *
2. Redistribution and addition of TaC shim elements and shim pencils.
3. Removal of 12 fueled centrals and replacement with TaC centrals.
4. Removal of all "X" material.
5. Reshimming to a θ_{DC} of $115^\circ \pm 1^\circ$ by the addition of Nb wire.

The PAX-G2A reactor build (including shim wire inventory, parts inventory, fuel element listing, and representative as-built weights) is detailed in WANL Drawings 711J496 and 711J498B, and DRM's 51612, 51245, 51189, 51186, 51166, 51166A, 51163, 51163A, 51163B, 51150 and 51150A.

* Both type of control vanes are 100 mils thick, with a B¹⁰ surface concentration of 0.13 gram per square centimeter and a vane span of 120 degrees around the control drums.

4.0 SUMMARY OF TESTS

4.1 NARRATIVE

A series of measurements was performed in the PAX-G2A reactor to determine the control characteristics of a 3 drum mockup of an 18-drum R-1 reflector design. (Figure 4-1 shows the relative geometry of the different drums and reflector.) Basically, the experiments determined the control drum span of drums 2, 7, 10, and B, and the control drum interaction effects between the central (drum B) and adjacent drums, (drums A and C) in the 60° mockup R-1 reflector sector. Additionally, a second method was used during the experiment to provide an independent check on some of the data. An attempt was also made to measure the span of the 3 mockup R-1 drum bank.

4.2 TEST CONDITIONS

4.2.1 Individual Drum Worths

During these experiments, two different techniques of measuring individual control drum spans were employed. The first was the usual WANEF method of measuring control drum spans. In this procedure, the drum whose worth is to be measured is placed initially at 180° and the remaining control drums are placed at the specified angles*(shown in Table 4-1) so that the reactor is on a reasonable period (> 20 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, which was used for check purposes only, entailed determining the delayed critical drum bank position with the control drum, whose worth was to be measured, 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 was determined. The specified drum was then moved to 90° and again the resultant excess

*Nearly identical to those used for the corresponding PAX-G1A control drum worth measurements.

Figure 4-1. PAX-G1 Reflector Geometry

TABLE 4-1. INDIVIDUAL CONTROL DRUM WORTHS

Drums Measured	Drum Angle (Degrees)							Averaged Remaining Bank	Drum Spans* (¢)
	2	7	A	B	C	10	12		
B	116.50	116.50	116.54	180 ↓ 0	116.49	116.50	118.84	116.50	39.3
2	180 ↓ 0	117.50	116.51	116.50	116.49	117.50	117.80	117.50	54.1
7	117.50	180 ↓ 0	116.51	116.50	116.49	117.50	118.08	117.50	54.5
10	117.50	117.50	116.54	116.50	116.50	180 ↓ 0	117.74	117.50	54.1
A+B+C	106.58	105.94	180 ↓ 0	180 ↓ 0	180 ↓ 0	105.70	105.62	106.05	115.

*The reactivity values are for the drum changes indicated and were measured using the WANEF analog reactivity computer.

reactivity was measured with the period pickoff system and the analog computer. The sum of the two reactivities measured during these two steps was then added directly to give the total control drum span of that particular drum. Table 4-2 provides a summary of this data.

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

4.2.2 R-1 Mockup Drum Bank Worth

A measurement of the integral bank worth of the 3 R-1 mockup drum bank was attempted by two slightly different techniques. Both techniques used the first method described above except that all 3 of the R-1 mockup drums were treated as a unit and were driven simultaneously. The difference between the two bank techniques resulted from changes in the initial conditions.

The first integral drum bank worth technique placed the reactor on a positive period, then drove the bank in through use of the Multiple-In switch upon reaching a predetermined power level while the reactivity was recorded as a function of the position of drum C. **

The second bank technique allowed the reactor to reach delayed critical (drums A, B, and C at 180°) at a predetermined power level. After allowing sufficient time (>15 minutes) for the long-lived delayed neutron groups to approach equilibrium, the 3 drum bank was driven in with the Multiple-In switch and the reactivity was recorded as a function of the position of drum C.

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

*See Figure 4-1 for the relative control drum and reflector location.

**Drum C was chosen for position indication because it reached its FULL IN position intermediate in time between drums A and B when using the Multiple-In switch. Drums A and B were observed to be within 5° of the position drum C at all times.

TABLE 4-2. COMPARISON OF ANALOG REACTIVITY COMPUTER DATA
VS. PERIOD PICKOFF DATA

DRUM ANGLE (DEGREES)								ρ^*		
2	7	A	B	C	10	12	Average Remaining Bank	Reactivity Computer (ρ)	Period Pickoff System	
									(sec)	(ρ)
120.70	120.70	90.01	90.06	90.07	120.70	119.90	120.70		∞	0
			↓ 180					19.56	36.10	19.79
125.14	125.15	90.01	0	90.07	125.16	125.14	125.15		∞	0
			↓ 90.11					18.20	40.92	18.28
								37.76		38.07

*The reactivity values are for the drum changes indicated. Estimated 1 σ precision in each individual measurement $\pm 0.23\%$.

4.3 TEST RESULTS

This section contains tabulated values of all of the individual drum span and bank worth measurements. Representative integral and differential worth curves are also given. The complete set of data required in TIS-DW-27.2 (which includes all of the integral and differential drum span curves) may be found in DRM-51193.

4.3.1 Individual Drum Worths

Table 4-1 lists the control drum spans determined as described in Section 4-2 for control drums B, 2, 7, and 10. Figures 4-2 and 4-3 show typical integral control drum worth curves for drums B and 7. Differential control drum worth curves were obtained by manually differentiating the corresponding integral worth curves. Figures 4-4 and 4-5 show the differential control drum worth curves obtained for drums B and 7. Table 4-3 shows a tabular summary of the 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 4-4 contains least squares fitted data from Figure 4-6.

Comparison of the drum B integral drum span presented in Table 4-2 (37.8¢) with the corresponding value in Table 4-1 (39.3¢) indicates that the positive period and the analog reactivity computer integral drum worth techniques described in Section 4.2 yield slightly different net results. In accordance with the discussion presented in Section 3 of DRM 51167, this difference is not unreasonable and is a direct result of having different positions on the nearby drums for the two different techniques. However, it should be noted that reasonable agreement is obtained between individual measurements taken using both techniques when the same conditions are used.

4.3.2 R-1 Mockup Drum Bank Worth

Figure 4-7 shows the integral drum bank worth curve for the bank consisting of drums A, B, and C. Measurement precisions are indicated with the data. Although the measurements of the 3 R-1 drum integral bank worth yielded equivalent results with the two

different sets of initial conditions (positive period and constant power), portions of the data are felt to be of somewhat questionable validity, as indicated in Figure 4-7, because the voltage levels in the analog reactivity computer were close to, or outside of their dynamic range. This results from the large reactivity span which is being measured, ~ 1.15 , and the long time span, ~ 2.7 minutes, required to fully insert the 3 R-1 drums. At the present time, it is not clear that this problem can be resolved with the present drum drive and analog computer equipment. Values of the integral bank worths of 1.13 and 1.15 resulted from the first and second techniques described above, respectively.

The estimated 1σ precision in the bank worth measurements is $\pm \$0.05$. This value reflects the limited dynamic range of the analog computer.

4.4 COMPARISON WITH PREVIOUS RESULTS

In comparison with the corresponding PAX-G1A control drum span measurements, (See WANL-TME-1916) the individual PAX-G2A control drum spans have decreased approximately 1% per drum. This decrease may be attributed to the addition of TaC shims near the core periphery during the conversion to PAX-G2.

Reactivity
(ρ)

Figure 4-2. Drum B Integral Drum Worth Curve in the PAX-G2A Reactor

Figure 4-3 Drum 7 Integral Drum Worth Curve in the PAX-G2A Reactor

Figure 4-4 Differential Control Drum Worth for Drum B in the PAX-G2A Reactor

Figure 4-5. Differential Drum Worth for Drum 7 in the PAX-G2A Reactor

TABLE 4-3. SUMMARY OF DIFFERENTIAL AND INTEGRAL DRUM WORTHS

Angle (degrees)	Drum Number				R-1 Drum Bank Worth**	
	2	7	10	8	Differential* (¢/degree)	Integral* (¢)
175	0.01	0.01	0.01	0.02	0.09	0.0
165	0.09	0.11	0.08	0.12	0.30	2.0
155	0.16	0.17	0.18	0.16	0.42	5.9
145	0.26	0.27	0.25	0.20	0.67	11.7
135	0.31	0.32	0.31	0.26	0.64	18.1
125	0.40	0.37	0.39	0.32	0.98	26.2
115	0.40	0.43	0.41	0.29	0.95	36.0
105	0.43	0.44	0.45	0.33	0.97	45.3
95	0.46	0.44	0.43	0.35	0.98	53.3
85	0.44	0.44	0.44	0.33	0.94	64.4
75	0.45	0.45	0.46	0.32	0.93	73.7
65	0.41	0.38	0.39	0.29	0.83	83.0
55	0.41	0.40	0.41	0.26	0.80	91.2
45	0.35	0.35	0.34	0.25	0.68	98.7
35	0.29	0.31	0.32	0.19	0.51	104.2
25	0.26	0.23	0.24	0.12	0.41	109.0
15	0.15	0.26	0.16	0.09	0.30	112.3
5	0.13	0.07	0.15	0.02	0.12	115.0
Integral* Worth	54.1	54.5	54.1	39.3	115.3	

*Because of round-off errors, the Integral Worth may be slightly different from 10 times the sum of the Differential Worths. The estimated 1σ precision of the integral and differential measurements is $\pm 0.23\text{¢}$ and $\pm 0.0017\text{¢/}^\circ$, respectively, for the individual drum worths. The corresponding precisions for the bank worth measurements are estimated to be $\pm 5\text{¢}$ and $\pm 0.3\text{¢/}^\circ$.

**Drums 7 and 10 at 105.82° .

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

TABLE 4-4. HDRC* LEAST SQUARES FIT DATA

PAX G-2A CONTROL DRUM WORTHS

GUESSED PARAMETER	CALCULATED PARAMETER	STDE ERROR
CP1 3.20000000E+01	CP1 3.10000000E+01	4.4907312E-01
CP2 7.60000000E-02	CP2 7.15873016E-02	4.6195658E-03
VARF= 2.0167E-01 VARF1= 2.8810E-02		

THE PROBLEM COMPLETED 1 ITERATION(S)

Y (OBS)	YCALC	P.C.EH	VAR(Y)	X
3.3700E+01	3.3148E+01	1.6391E+00	1.0563E-01	3.0000E+01
3.4800E+01	3.5295E+01	-1.4231E+00	4.8016E-02	6.0000E+01
3.6100E+01	3.6369E+01	-7.4524E-01	3.3611E-02	7.5000E+01
3.7100E+01	3.7443E+01	-9.2414E-01	2.8810E-02	9.0000E+01
3.8600E+01	3.8517E+01	2.1589E-01	3.3611E-02	1.0500E+02
4.0100E+01	3.9590E+01	1.2706E+00	4.8016E-02	1.2000E+02
4.1700E+01	4.1738E+01	-9.1355E-02	1.0563E-01	1.5000E+02

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)

*For further information on this computer code, see DRM 51198

Figure 4-7. R-1 Integral Drum Bank (Drums A, B, C)
Worth Curve in the PAX-G2A Reactor

5.0 ANALYSIS

5.1 PREDICTIONS

The WANL Integrated Standard Design Method (WISDM)* was used to predict the PAX-G2A 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-θ 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 \$7.84.

5.2 PREDICTIONS VERSUS MEASUREMENTS

The PAX-G2A drum span measurements clearly demonstrated the substantial drum interaction effect in the R-1, 18 drum design. As shown in Figure 4-6, the worth of the central drum (drum B) in the R-1 sector extrapolated from 31.0 cents to 43.8 cents for the cases where drums A and C were both at 0° and 180°, respectively. The validity of estimating the total drum span, by using the average of the central drum B worth curve with adjacent drums at the 90° position, was ascertained from integral drum worth data as obtained from Table 4-4. 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 36.9 cents which is within 0.2 of a cent of the worth shown for central drum B with A and C drums at 90 degrees as shown in Figure 4-6. Multiplying this single drum worth value of 36.9 cents by 18 drums gives the measured total drum span worth to be equal to \$6.64.

Comparison of this measurements with the predicted value of \$7.84 gives a calculated to experimental correction factor of 0.85.

*Details on the WANL 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 COMPARISON OF EXPERIMENTAL CORRECTION FACTORS

Since the experimental correction factors for PAX-G0B and PAX-G1A were reported in WANL-TME-1910 and WANL-TME-1916, respectively, the total delayed neutron fraction used in the drum span calculations was changed from .0071 to .0070 (DRM-51511). It was therefore necessary to adjust the previous PAX-G0B and PAX-G1A values for comparison with PAX-G2A. The previous PAX-G0B predicted drum span was \$6.94 and the measurement was \$6.26. Adjusting for the revised delayed neutron fraction results in a PAX-G0B prediction of \$7.04. The revised correction factor would then be \$6.26 divided by \$7.04 or 0.89. For the PAX-G1A the previous predicted drum span was \$7.88 and the measured was \$6.9. The adjusted PAX-G1A predicted drum span would now be \$8.00. The correction factor would therefore be \$6.9 divided by \$8.0 or 0.86. The PAX-G2A correction factor (0.85) calculated in Section 5.2 is thus in good agreement with the PAX-G0B and PAX-G1A values of 0.89 and 0.86, respectively.

6.0 CONCLUSIONS

The PAX-G2A control drum span measurements demonstrated the strong drum interaction effect in an 18 drum system. As noted in Section 5.1, the drum span of the central R-1 mockup drum (drum B) from 0° to 180° with the adjacent drums at 90° (the average value of the drum B worth curve) is similar 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-G0B, PAX-G1A and PAX-G2A are in good agreement, being 0.89, 0.86 and 0.85, respectively. Various analytical procedures (such as improvements in peripheral mesh spacing and accounting for self-shielding in the control vane cross sections) are presently being investigated to determine the feasibility of reducing the differences between the experimental and predicted drum spans.

APPENDIX A

THE PAX-G2A 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 PAX-G2A control drum worths in the R-1 mockup reflector sector and the effect of this special sector upon the remaining 10 NRX 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-G2A control drum worth measurements may be found in the EXPERIMENTAL DETAILS section of EDC 87, a copy of which is contained in this appendix.

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

**Minor changes were made to the experimental procedure as described in the EXPERIMENTAL DETAILS section of the EDC in order to provide better measurements. These changes are as follows:

- A. The excess reactivity and voltage specification in Sections 1 and 3 were relaxed to between +0 and +30 μ , and between +1 and +10 volts, respectively.
- B. The measurement described in Section 3 was also made with drums 7 and 10 at 105.82° (average.)
- C. Where available, calibrated position scales (through use of the Drum Interface Amplifier) were used with an X-Y recorder instead of manually recording positioning with hash marks on the recorder trace of an X-T recorder.
- D. The individual drum settings given in Table 1 were slightly adjusted to produce the required positive periods.

SECURITY CLASS UNCLASSIFIED	EXPERIMENTAL DETAILS CHECKLIST Westinghouse Astronuclear Laboratory Experimental Facility	EDC No. 87	Rev.
		Date 2/13/70	
		SHEET 1 OF 7	
Title PAX-G2 Control Drum Worth Measurements		S/T 59DW-232-2 TIS 27	
DOCUMENT REFERENCES (DWGNO/PART NO/COMPUTER CODES/DRMS/MTLS SPECS/CORRESPONDENCE)			
1. NRD-70-11	2. WANL-TME-1916	3. WANL-TME-267, Rev. H	
4.	5.	6.	

1. Objectives 2. Equipment Requirements 3. Hazards Considerations 4. Experimental Details
5. Data Required

1. OBJECTIVES

1. To determine the worth of a central drum in the 60° R-1 mockup sector.
2. To determine shadowing interactions for certain specified configuration between adjacent drums in an 18-drum system.
3. To verify the equivalence of positive period reactivity techniques and the WANEF reactivity computer method of measuring reactivity.
4. To determine the effects of the PAX-G2 conversion upon integral drum spans.
5. To attempt to measure the integral bank worth of the three R-1 mockup drums.

2. EQUIPMENT REQUIREMENTS

1. The analog reactivity computer with X-T recorder.
2. The WANEF "period-pickoff" reactivity measuring system.
3. The PAX-G2 reactor shimmed to $\theta_{DC} = 115^\circ \pm 1^\circ$, as specified in Reference 1 (re-distribution of TaC and X material replaced by Nb) and with CuB¹⁰ vanes on the mockup R-1 drums in the 60° test sector.

J. W. Rowland Prepared By F. S. Frantz, Manager, WANEF Approved, Scientist in-Charge W. P. Kovacic Approved, Manager, NRD	2/13/70 Date 2/13/70 Date 2/16/70 Date	INFORMATION CATEGORY UNCLASSIFIED CLASSIFICATION AUTHORIZED CLASSIFIER DATE	SECURITY CLASS UNCLASSIFIED
--	---	---	--------------------------------

SECURITY CLASS UNCLASSIFIED	EXPERIMENTAL DETAILS CHECKLIST CONTINUATION SHEET	EDC No. 87 REV SHEET <u>2</u> OF <u>7</u>
------------------------------------	--	--

3. HAZARDS CONSIDERATIONS

The techniques for performing drum worth measurements using the analog reactivity computer and positive-period techniques are the standard ones used previously at WANEF and documented in Reference 2, "PAX-G1 Reflector Interchange, Control Drum Span, and Aluminum Reflector Barrel Experiments."

4. EXPERIMENTAL DETAILS

All control drum worths shall be measured with the analog reactivity computer except as otherwise noted. The data to be taken will be broken down into three different groups, as described below:

1. Measurement of the integral drum span shall be made for control drums, 2, 7, 10, and B* in a manner which will allow comparison with prior measurements (Reference 2). Briefly, the control drum whose worth is to be measured is placed in a FULL OUT condition ($\sim 180^\circ$) with the rest of the control drums set at predetermined angles as specified in Table 1. Based upon the requirement that the reactor be shimmed to a delayed critical drum bank angle of $115 \pm 1^\circ$, these control drum settings will then place the reactor on a positive period corresponding to an excess reactivity of between $+10\%$ and $+25\%$. When the output voltage of amplifier number 9 in the reactivity computer reaches a value of between 3 and 6 volts, the drum whose worth is to be measured will be driven FULL IN with the output of the computer being recorded on an X-T recorder. Indications shall be made on the recorder trace at 10° decrements of the drum position.

2. Measurements of the integral drum span shall be made for control drum B (central drum of the R-1 test sector) in the same manner as described above except that the integral drum span of control drum B shall be measured for each of the following positions of the two adjacent drums (drums A and C): 30° , 60° , 75° , 90° , 105° , 120° , and 150° . Additionally, a check shall be made through positive period measurements of the worth of control drum B where drums A and C are both at 90° . This shall be done in the following manner:

*Figure 1 shows the relative location of the different control drums.

SECURITY CLASS

UNCLASSIFIED

Figure 1. PAX-G2 Reflector Geometry

TABLE 1. PAX-G2 CONTROL DRUM POSITION SETTINGS
FOR WORTH MEASUREMENTS OF DRUMS 2, 7, 10 AND B

Drums Measured	Drum Angle (Degrees)							Remaining Bank
	2	7	A	B	C	10	12	
B	116.50	116.50	116.61	180→0	116.52	116.50	118.84	116.50
2	180→0	117.50	116.52	116.50	116.51	117.50	117.80	117.50
7	117.50	180→0	116.55	116.56	116.52	117.50	118.08	117.50
10	117.50	117.50	116.56	116.55	116.43	180→0	117.74	117.50

SECURITY CLASS

UNCLASSIFIED

EXPERIMENTAL DETAILS CHECKLIST
CONTINUATION SHEET

EDC No.

87

REV

SHEET 5 OF 7

a. With control drums A, B, and C at 90° , the remaining 10-drum bank shall be positioned to achieve delayed critical. All drums in positions in this 10-drum bank should be within $\pm 1^\circ$ of the 10-drum average position.

b. Drum B will then be rotated to the FULL OUT position and the resultant positive period measured.

c. Delayed critical will be reestablished under the conditions noted in step a, above, except that drum B will be positioned FULL IN.

d. Control drum B will then be rotated to 90° and the resultant positive period measured.

The sum of the two partial drum worths determined above may then be compared to the corresponding total drum worth measured with the WANEF analog reactivity computer.

3. A measurement of the integral worth of the three-drum bank (drums A, B, and C) will be attempted on a "best efforts" basis. The technique to be employed will be that described under 1, above, except that control drums A, B, and C will be set at 180° , drums 7 and 10 at 90° , and the remaining drums will be adjusted* to produce a reactor period corresponding to between $+15\%$ and $+30\%$.

5. DATA REQUIRED

A typical data sheet to be used for the collection of the reactor operating parameters associated with each drum worth curve is attached to this EDC. The following data should be reported:

1. Integral drum worth measurements for drums 2, 7, 10, and B.
2. Positive period measurements for drum B.
3. Shadowed drum measurements for drum B for seven selected shadow angles.
4. Integral worth measurements for the R-1 mockup drum bank.

* Each of these drums should be adjusted to within $\pm 1^\circ$ of the 8-drum bank average for the drums outside the R-1 test sector.

SECURITY CLASS

UNCLASSIFIED

SECURITY CLASS UNCLASSIFIED	EXPERIMENTAL DETAILS CHECKLIST CONTINUATION SHEET	EDC No. 87
		REV
		SHEET <u>6</u> OF <u>7</u>

5. Differential worth data for all integral worth measurements taken in steps 1 and 4, above.

6. Drum positions for all 13* drums for each drum and bank worth measurement.

The type of detectors used and their locations relative to the reactor shall be documented. Photographs of the detectors in position shall be taken.

* Only the average bank position need be reported for drums 1, 3, 4, 5, 6, 11, and 12.

SECURITY CLASS UNCLASSIFIED

WANEF DATA SHEET - CONTROL DRUM WORTH

Reactor Designation _____ Test Request _____ EDC _____

Title of Test _____ Sheet _____ of _____

Drum Measured	Drum Angle (degrees)							Remaining Bank (Avg)	Reactivity Computer (¢)		Period Pickoff System	
	2	7	A	B	C	10	12		Partial	Total	Period (sec)	(¢)

Data taken by _____ Date ____ / ____ / ____

Sample Control Drum Worth Data Sheet

TITLE	
	PAX-G2 Control Drum Spans	
DOCUMENT NO.		DATE
WANL-TME-2703		July, 1970
ABSTRACT <p>Measurements have been made of the control drum spans and some of their interaction effects in the PAX-G2A reactor in support of an 18 drum R-1 design.</p> <p>An attempt was also made to measure the integral span of the mockup R-1 three drum bank. This measurement yielded only marginal results.</p>		
Fold --- or Cut	DATA ITEM NO.	SECURITY CLASSIFICATION OF DOCUMENT
	T-119	Unclassified
	CDRL LINE NO.	TOTAL NO. OF PAGES
	N/A	35
KEY WORDS <p>Drum Bank Worth Measurements PAX/R-1 Control Drum Span 18 Drum System Control Drum Interactions</p>		
AUTHOR/EDITOR		PREPARING DEPT.
J. W. Rowland and R.V. Rittenberger		WANEF
W Form 59943 DOCUMENT INFORMATION SUMMARY		

 Fold

or Cut