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WANL-TME-1918
JANUARY 1970

DATA ITEM T-119

PAX-G1 REACTIVITY EFFECT
MEASUREMENTS (U)

FINAL TEST REPORT

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**WANL-TME-1918
JANUARY 1970**

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FINAL TEST REPORT

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ABSTRACT

(CRD) Two sets of reactivity measurements were made in the PAX-G1A reactor containing nuclear mockups of R-1 reactor components in order to verify analytical methods and to provide data for normalization of R-1 reactor predictions. The first of these measurements, a determination of the reactivity coefficient of "Q" material (zirconium), indicated a discrepancy between calculation and experiment. Accordingly, a study is underway to re-evaluate zirconium cross sections as well as the calculational model used to represent the experiment.

(U) The second set of measurements involved determination of the reactivity worth as a function of radius for a group of mockup support stem assemblies. For this set of measurements, the predictions were in excellent agreement with the experimental measurements.

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1.0 INTRODUCTION

1.1 TEST IDENTIFICATION

1.1.1 Type of Report

(U) This report is a complete Final Report.

1.1.2 Scope of Test Document

(U) The applicable Scope of Test Document Numbers are 66DW-291-0 and M56DW-292-1.

1.1.3 Functional Category of Test

(U) This is a Development test.

1.1.4 Contractor

(U) The Westinghouse Astronuclear Laboratory (WANL/14683), under Subcontract NP-1 CY¹ 69, is the contractor.

1.1.5 Test Facility

(U) These tests were performed at the Westinghouse Astronuclear Experimental Facility, located at the Westinghouse Waltz Mill Site, during May through July, 1969.

1.2 PURPOSE (U)

(CRD) Two different sets of data are contained in this document. The first set, the "Q" material (zirconium) reactivity coefficients, was performed in order to gather information which could be utilized to normalize predicted data for the R-1 fuel element design effort.

(U) The second set of data, the reactivity effects of the mockup support stems, was obtained in order to provide data which may be used to normalize similar R-1 support stem reactivity predictions.

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2.0 REFERENCES AND ASSUMPTIONS

2.1 REFERENCES

2.1.1 Specification

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

EC 677558 - Part I. Performance/Design and Qualification Requirements
Support Stem and Cluster Miscellaneous Hardware for NERVA Nuclear Subsystem 677555A, 1/23/69

2.1.2 Data Item Description

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

2.1.3 Scope of Test Document

66DW-291-0 - PAX-G2 "Q" Material Reactivity Measurement
M56DW-292-1 - PAX-G1 Support Stem Reactivity Measurement

2.1.4 Data Release Memorandum

51172 - "Q" Material Reactivity Coefficients in the PAX-G Reactor
51175 - Reactivity Measurements of Mockup Support Stems in the PAX-G1 Reactor
51186 - Chemical Analysis of WANEF Reactivity Materials
51166A - PAX-G1 Shim Wire Inventory
51166 - PAX-G1 Shim Wire Inventory
51163A - Parts Inventory in the PAX-G1A Reactor
51163 - Parts Inventory in the PAX-G1 Reactor
51162 - Inventory of Special Central Elements for the Support Stem
Assembly Experiment
51150A - Parts Inventory in the PAX-G0-A, -B, and -C Reactors
51150 - Parts Inventory in the PAX-G0 Reactor
51154 - PAX-G0-B Control Drum Worth Measurements
51105 - Flow Charts for an Integrated Nuclear and Radiation, Thermal and
Structural Analysis Procedure and Identification and Description of Computer Codes

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2.1.5 Drawing

- (U) 711J496 - Reactor/Vessel Assembly, R-1 PAX
711J498B - Segment, Reflector Assembly, R-1 PAX
711J489 - Cluster Assembly, Fuel, R-1 PAX
939J300 - Reactor, R-1 Study Layout, 2/28/68
939J535 - R-1 Reflector Study Layout, 5/15/68

2.1.6 External Document

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

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

2.2 ASSUMPTIONS

2.2.1 Axial Correction Factors (U)

- (CRD) The reactivity coefficients are axial averages and the weight for the actual 55.25" long wire lengths are corrected for the 52" long portion of the wire in the fuel elements by proportioning the measured weight by 52"/55.25".

2.2.2 Reactivity Effects of Chemical Impurities (U)

- (CRD) The impurities, as given in the chemical analysis in Table 3-1, either do not contribute any significant net reactivity change and may, therefore, be neglected, or are typical of reactor grade zirconium and should be included.

2.2.3 Reactivity Measurement Uncertainties (U)

- (CRD) The measurement uncertainties are involved only with the zirconium mass, period pickoff system and drum repositioning. Although changes in core temperature, humidity, etc., are unknown, they are assumed to be small and will thus be neglected.

2.2.4 Axial Leakage

- (U) Insertion of the wires into the coolant channels does not affect the axial leakage.

2.2.5 Reactor Equivalence

- (U) The PAX-G1A reactor, in which these measurements were made, is assumed to be a close enough approximation to the PAX-G2 reactor (in which the measurements were requested) for the "Q" material measurements to be applicable.

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2.2.6 Estimate of NbC Coating Weights (U)

(CRD) The niobium coatings on the 19 special central elements substituted during this experiment contain approximately 25 grams of NbC per element based on measured weights given in DRM 51162.

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3.0 TEST ARTICLE CONFIGURATION

3.1 TEST SET-UP

(U) Descriptions of the components used in the set-up are as follows.

3.1.1 PAX-G1A Reactor (U)

(U) The modified PAX reactor, shown in Figure 3-1, and designated PAX-G1A 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 on the adequacy of the control capability of the R-1 reflector system. 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) A typical 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 as seen in Figure 3-1. Approximately 245 kg of highly enriched uranium are contained in the PAX-G1A core.

(CRD) The PAX-G1A reflector is obtained by replacing two 30 degree KIWI sectors of the 12 drum NRX configurations with a 60 degree R-1 reflector mockup segment. This reflector mockup segment is constructed of laminated beryllium slabs. The non-beryllium fraction in this segment is typical of the 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. These R-1 mockup control drums have a vane span of 120 degrees. Further details of the reactor components may be found in Appendix A of this document.

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Figure 3-1. PAX-G1A Reflector Assembly (U)

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3.1.2 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 3-2. 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 elapsed time between the start and stop trips. The start and stop trips have been positioned so that the scaler measures the elapsed time required for the reactor neutron level to increase by a factor of e^2 . Thus, we have the following equation:

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

where

$n(t)$ = level at time t

$n(0)$ = level at time 0

t = elapsed time

τ = reactor period

The elapsed time is thus equal to twice the reactor period since:

612650-198

Figure 3-2. Block Diagram of the Period-Pickoff Data Acquisition System

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

therefore

$$t/\tau = 2$$

$$t = 2\tau$$

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 elapsed 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.

3.1.2.1 Detector

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

3.1.2.2 High Voltage Supply

The high voltage supply is a Burgess U 200 battery.

3.1.2.3 Picoammeter

The picoammeter is an EG & G Model ME 920A, Serial Number 920161.

3.1.2.4 Level Trips

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

3.1.2.5 Scaler

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

3.1.2.6 Master Clock

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

3.1.2.7 Digital Printer

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

3.1.3 "Q" Material

The chemical analysis of the ingot, from which the 0.20" and 0.060" diameter "Q" material wires were fabricated, is given in Table 3-1.

3.1.4 Mockup Support Stem Hardware

Figure 3-3 shows the mockup support stem assembly hardware as detailed in drawing 711J489. Table 3-2 gives the average weights of each part used in the assembly, and Figures 3-4 and 3-5 show the complete assembly.

3.1.5 Modified Central Elements

Each support stem assembly was inserted into a modified graphite central element. The weights of these modified elements are given in Table 3-3.

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TABLE 3-1. "Q" MATERIAL CHEMICAL ANALYSIS*(U)

WAH CHANG ALBANY CORPORATION
A TELEDYNE COMPANY
P.O. BOX 480 - ALBANY, OREGON 97321 - TELEPHONE 503 926-4211

To	Westinghouse Electric Corporation	DATE	April 17, 1969
ADDRESS	Astronuclear Laboratory	DATE SHIPPED	April 15, 1969
	P.O. Box 10864	QUANTITY SHIPPED	As Listed
	Pittsburgh, Pennsylvania 15236	PRODUCTION ORDER NO	1958-1
		HEAT NO	352286-Zr

ATTENTION OF: Ron Shiroke

IN REGARD TO YOUR PURCHASE ORDER NO 59-NXD-04761
ITEM NO As Listed
DESCRIPTION Zirconium Wire
DIMENSIONS As Listed
SPECIFICATIONS Per Purchase Order
THE TEST REPORT FOLLOWS:

ZIRCONIUM INGOT		
HEAT NUMBER 352286-Zr		
ANALYSIS	IN	PPM
	Top	Bottom
Al	41	41
C	200	210
Cb	<100	<100
Cr	92	78
Cu	<25	<25
Fe	700	600
H		4.9
Hf	100	92
N	67	62
Ni	15	<10
O	930	930
Sn	25	25
Ta	<200	<200
Ti	<20	<20
W	<25	<25

HARDNESS IN BHN	
Range	149-163
Average	159

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ANALYSIS
CERTIFIED BY *Jack R. Sutherland*
R. Sutherland
Quality Assurance Department

(CRD) * "Q" material is an unclassified designation for zirconium.

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Figure 3-3. Mockup Support Stem Assembly Hardware (U)

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TABLE 3-2. WEIGHTS OF SUPPORT STEM ASSEMBLY HARDWARE (U)

<u>Description</u>	<u>Item No.*</u>	<u>Part No.</u>	<u>No. Weighed</u>	<u>Total Weight (grams)</u>
Support Stem Assembly	1	388D342G01	19	1919.2
Tie Rod Holder	2	388D343G01	19	925.0
Spacer	3	800C572H01	21	107.5
Split Washer	4	800C198H01	21 gps of 2	124.2
Spring Mockup	5	793C849H01	456	2426.0
Spring Mockup	6	793C848H01	30	322.5
Support Block	7	909E109H02	10	1348.2
Split Bushing	8	946C216H01	50 gps of 2	78.2
Plate Assembly	10	576F961H02		
Consists of:				
a. 1 Cluster Plate		909E529H01	19	636.0
b. 6 Orifice Jet Bushing		946C172H01		
		sub for 944C959	126	19.2
c. 6 Centering Bushing		388D341H01	18	450.2
Spacer	11	609B030	30	250.0
Jet Orifice	12	--	100	28.8
Spacer	14	800C576H01	21	46.0
Liner Collar Assembly	15	800C578G01	19	1992.2

* Obtained from Drawing No. 711J489, "Cluster Assembly, Fuel R-1 PAX"

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NOTE: All numbers refer to the item number
contained in Table 3-2.

Figure 3-4. Support Stem Assembly - Forward End (U)

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NOTE: All numbers refer to the item number
contained in Table 3-2.

Figure 3-5. Support Stem Assembly - Aft End (U)

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Table 3-3. Measured Weights of Referenced Fuel Elements (U)
(Modified Graphite Central Elements)

<u>Element No.</u>	<u>Weight (gm)</u>
UN-01-61256	577.0
UN-01-61267	574.7
UN-01-61278	572.2
UN-01-61199	576.5
UN-01-61219	575.0
UN-01-61252	576.0
UN-01-61259	575.0
UN-01-61210	576.5
UN-01-61253	572.5
UN-01-61241	576.2
UN-01-61350	575.0
UN-01-77092	570.0
UN-01-77085	569.8
UN-01-76584	571.9
UN-01-61186	573.6
UN-01-61345	576.0
UN-01-76783	573.1
UN-01-71780*	553.3
UN-01-71775*	556.0

* All elements except those noted by * are fully coated on the outside with NbC.

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4.0 SUMMARY OF TESTS

4.1 "Q" REACTIVITY MEASUREMENTS (U)

4.1.1 Narrative (U)

(CRD) Measurements are made of the reactivity change caused by the insertion (into the reactor core) of 546 zirconium wires ("Q" material) through standard WANEF techniques. Basically, the control drums are set at an angle such that the reactor is on a suitable positive period. This period is then measured through use of the period pickoff system and the reactor is shutdown. The period is then converted to a reactivity through use of the "in-hour" equation. The material which is to be measured (zirconium) is then inserted into the core in the proper positions. The reactor is again brought to critical with the control drums at the same angle as before. Again, a period is measured and converted into a reactivity. The difference between the two reactivities may then be attributed to the insertion of the material.

(U) Further details regarding these measurements are contained in Appendix B.

(U) An attempt was made to determine the self-shielding factor by measuring the reactivity coefficient for two different wire diameters. By extrapolating the results of reactivity coefficient vs. wire diameter to zero wire diameter, a measurement of the self-shielding should be obtained. Wire diameters of 0.060" and 0.020" were used.

4.1.2 Test Conditions (U)

(CRD) Since zirconium is a reasonably ductile metal and may be drawn into wire form, the zirconium was placed in the core through the simple expedient of placing suitably sized zirconium wires in the fuel element coolant channels. The wires were placed in one of two general locations--near the core center (clusters 000, (1-6)A1) as shown in Figures 4-1 and 4-2, and in the outermost (radial) 3-4 elements in front of the 60° R-1 mockup sector, as shown in Figures 4-3 and 4-4.

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Figure 4-1. Photo Showing the Larger Size "Q" Material
in Center of the PAX-G1A Core

Figure 4-2. Close-Up of the Larger Size "Q" Material
in Center of the PAX-G1A Core

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Figure 4-3. Photo Showing the Larger Size "Q" Material
in the Outer Periphery of the PAX-G1A Core

Figure 4-4. Close-Up of the Larger Size "Q" Material
in the Outer Periphery of the PAX-G1A Core

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(CRD) In the center clusters, wires were placed in channels 1, 3, 5, 6, 8-12, 14, 15, 17, and 19. In the peripheral measurements, only channels 1, 3, 8, 10, 12, 17, and 19 were utilized. In the few cases where a shim wire already existed in one of the designated channels, the zirconium wire was placed in channel 2.

4.1.3 Test Results

(U) The reactivity changes associated with this series of measurements may be found in Table 4-1. Upon inspection of this table, it may be seen that a number of corrections have been made to the measured reactivity changes. The first correction, the "R-1 Drum Correction", is based upon the fact that the R-1 drums cannot be set exactly at the specified point. Therefore, the algebraic sum of the deviations from the set point was multiplied by the appropriate differential drum bank worth, thereby converting the Angle Correction into a Reactivity Correction.

(U) The period pickoff reactivity correction was made by estimating the asymptotic period from the series of periods measured by the period pickoff system. Hence, the adjusted reactivity is the measured reactivity change plus the two reactivity corrections noted above.

(U) Once the actual reactivity change is available, the reactivity coefficient may be determined by dividing the reactivity change by the weight of the material required to produce that change. However, as only a certain fraction of that material is actually in the core, the reactivity coefficient must be adjusted to account for this fact, as shown in the far righthand column of Table 4-1.

4.2 MOCKUP SUPPORT STEM ASSEMBLY REACTIVITY MEASUREMENTS

4.2.1 Narrative

(U) Measurements were made of the reactivity worths associated with the mockup support stem assemblies (See Figure 4-5) in the PAX-G1A reactor. Basically, the measurements consisted of determining the reactivity effects caused by interchanging a group of 19 mockup support stem assemblies (including the special graphite central elements*) with 19 regular

*(CRD) These are solid graphite elements with a 0.421" hole drilled along the major axis.

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TABLE 4-1. SUMMARY OF "Q" MATERIAL REACTIVITY COEFFICIENT MEASUREMENT RESULTS* (U)

Wire Diameter (in.)	Wire Mass (Kg)	Wire Location	Measured Reactivity Change (¢)	R-1 Drum ¹ Correction		Period Pickoff ² Reactivity Correction (¢)	Adjusted Reactivity Change (¢)	Reactivity Coefficient	
				Angle (deg.)	Reactivity (¢)			Measured (¢/Kg)	Length ³ Adjusted (¢/Kg)
0.060	10.151	periphery	+3.06	-.04	-.05	+ .10	+3.11 $\pm$ 0.55 ⁴	+0.31 $\pm$ 0.06	+0.33 $\pm$ 0.06
0.060	10.151	central	-2.84	+ .03	+ .04	+ .01	-2.79 $\pm$ 0.55	-0.28 $\pm$ 0.06	-0.27 $\pm$ 0.06
0.020	1.123	central	-0.44	-.06	-.08	+ .02	-0.50 $\pm$ 0.55	-0.45 $\pm$ 0.55	-0.47 $\pm$ 0.55

1. The R-1 drums are quite difficult to set exactly. Therefore, the total algebraic deviation from the desired set point is used as a small correction factor.
 2. Since the asymptotic period has not yet been reached, an estimate is made of the asymptotic period from the series of period measurements.
 3. Adjusted for the mass of wire actually in the 52" long fuel elements.
 4. All uncertainties are $\pm 1\sigma$. See Appendix D for further details.
- (CRD)* "Q" material is an unclassified designation for Zirconium.

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Figure 4-5. Support Stem Assembly Hardware (U)

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PAX-G tie rod assemblies. Separate measurements were also made of the reactivity effects of the mockup support stems* and liner tubes. In order to make a determination of possible radial effects, both types of measurements were made at two different radial locations, the first being located near the center of the core and the second being located near the periphery of the core.

(U) Further details regarding the exact procedure may be found in Appendix C.

4.2.2 Test Conditions

(U) The positions and data on the central elements involved in the measurements made in the peripheral portion of the core are given in Table 4-2. Table 4-3 gives the associated positions and central element data for the second set of measurements (which were made in the central region of the core).

(U) Prior to the support stem assembly hardware interchange, a base point reactivity run was made. Next, the support stem hardware was interchanged with the standard cluster hardware in those clusters in which the measurements were to be made. Where possible, the existing cluster hardware was used with the special support stem hardware. The only exception was the split washer (800C198H01) which was glued in the tie rod assembly and was not readily disassembled. Because of its distance from the core and small mass, spare washers of the same type were used instead of using the original components.

(U) After the modified clusters containing the support stem assemblies were reassembled and placed in the proper position in the reactor, another reactivity run was made. As the drums were set at the same angle as for the base point, the reactivity change was determined directly. Because of the time involved in the interchange, only one measurement could be made per day.

(U) On a different day, another base point was run. The support stem assembly (388D342G01), spacer (800C572H01), and liner collar assembly (800C578G01) were then removed and another reactivity run made. Again the drums were set at the same angle as before. After these data had been taken, the support stem assembly hardware was removed from the clusters and the reactor was returned to its original PAX-G1A configuration.

*(CRD) The mockup support stems are Inconel 718 and the liner tubes are 310 stainless steel.

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TABLE 4-2. CENTRAL ELEMENT DATA FOR PERIPHERAL CORE MEASUREMENTS (U)

Element Location	IN		OUT	
	Element Serial Number	Element Wt. (gms)*	Element Serial Number	Element Wt. (gms)
4J5A	UN-01-76584	571.9	01-02063	616.8
4J6A	UN-01-77092	570.0	01-02289	615.0
4J8A	UN-01-71780	553.3	01-06068	612.4
4P3A	UN-01-61210	576.5	01-09403	619.1
4P3U	UN-01-61350	575.0	01-01661	617.0
4P4A	UN-01-61267	574.7	01-02094	622.0
4P4U	UN-01-61278	572.2	01-03116	623.0
4P5A	UN-01-61186	573.6	01-01995	617.8
4P5U	UN-01-61256	577.0	01-01660	615.0
4P6A	UN-01-77085	569.8	01-09499	613.0
4P7A	UN-01-61252	576.0	01-02107	619.1
4P7U	UN-01-61199	576.5	01-02185	616.2
4P8A	UN-01-61345	576.0	01-09316	611.9
4P8U	UN-01-61259	575.0	01-09487	613.0
5P1A	UN-01-71775	556.0	01-03027	623.2
5P2A	UN-01-61219	575.0	01-03035	614.8
5P2U	UN-01-76783	573.1	01-02236	615.1
5P3A	UN-01-61253	572.5	01-03095	623.5
5P3U	UN-01-61241	576.2	01-02250	619.0
TOTAL WEIGHT <u>IN</u>		10,870.3	TOTAL WEIGHT <u>OUT</u>	11,726.9

*Includes NbC coatings

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TABLE 4-3. CENTRAL ELEMENT DATA FOR CENTRAL CORE MEASUREMENTS (U)

Element Location	IN		OUT	
	Element Serial Number	Element Wt. (gms) *	Element Serial Number	Element Wt. (gms)
000A	UN-01-61253	572.5	01-03043	616.3
1B1A	UN-01-61199	576.5	01-01088	617.0
2B1A	UN-01-71345	576.0	01-02202	619.0
3B1A	UN-01-61256	577.0	01-02087	622.0
4B1A	UN-01-61278	572.2	01-03024	621.0
5B1A	UN-01-71780	553.3	01-03010	621.0
6B1A	UN-01-61219	575.0	01-02119	622.0
1C1A	UN-01-76584	571.9	01-01674	617.0
2C2A	UN-01-61267	574.7	01-03000	619.0
3C2A	UN-01-61259	575.0	01-03112	621.0
4C2A	UN-01-61350	575.0	01-03004	622.0
5C2A	UN-01-61252	576.0	01-02092	623.0
6C2A	UN-01-77085	569.8	01-01680	619.0
1D3A	UN-01-61241	576.2	01-01654	616.0
2D3A	UN-01-77092	570.0	01-01651	617.0
3D3A	UN-01-61210	576.5	01-01679	617.0
4D3A	UN-01-76783	573.1	01-01123	615.0
5D3A	UN-01-71775	556.0	01-02085	620.0
6D3A	UN-01-61186	573.6	01-01201	619.0
TOTAL WEIGHT <u>IN</u>		10,870.3	TOTAL WEIGHT <u>OUT</u>	11,763.3

* Includes NbC coatings.

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(U) The measurements in the outer periphery were made in the same manner with one minor exception. As may be noticed from Section 3, all of the special support stem assembly hardware is designed for use with the PAX core support plate. Many of the clusters in the outer periphery, however, are designed for use with the core support plate extension ring. As a result, the tie rod holder*, split washer, three spring mockups*, and split bushing* were omitted from these clusters when necessary. The net result was to lower the affected cluster by some minor amount (less than 1/32") and to produce some uncertainty in the location of the bottom of the cluster. Because of the interlocking nature of the irregular clusters, as well as the filler strips and core bundling devices, it is not felt that appreciable displacements from the desired positions occurred.

4.2.3 Test Results

(U) Table 4-4 contains a summary of the experimental results for the measurement of the support stem reactivities while Table 4-5 contains a listing of the reactor operations data obtained during the course of these measurements.

* See DRM 51150, Sections C and D for more exact descriptions and part numbers.

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TABLE 4-4. MOCKUP SUPPORT STEM REACTIVITY WORTHS

	Position of Measurement in Core	
	Peripheral*	Central**
Reactivity change resulting from substitution of 19 mockup support stem assemblies for 19 regular cluster hardware assemblies	$-11.22 \pm 0.55\%$ ⁺	$-18.36 \pm 0.55\%$
Worth of 19 mockup support stem and liner tubes	$-0.65 \pm 0.55\%$	$-1.49 \pm 0.55\%$

* Exact positions are given in Table 4-2.

** Exact positions are given in Table 4-3.

+ All uncertainties are $\pm 1\sigma$.

TABLE 4-5. REACTOR OPERATIONS DATA FOR THE SUPPORT STEM ASSEMBLY MOCKUP EXPERIMENT (U)

Run No. PAX-G1A	Date	Comments	Drum Angle (Degrees)								Period (sec)	Reactivity (ρ)
			Drum Number									
			1-6	7	A	B	C	10	11	12		
25	6/4/69	Basepoint	121.00	121.00	115.03	114.98	115.03	121.00	121.00	121.00	22.97	25.86
26	6/4/69	19 mockup support stem assemblies in place	121.00	121.00	115.00	115.01	115.04	121.00	121.00	121.00	136.99	7.40
27	6/5/69	Basepoint	119.26	119.26	115.00	115.01	115.04	119.26	119.26	118.88	∞	0
			121.50	121.50	115.03	115.00	115.00	121.50	121.50	121.40	98.20	9.79
			114.26	114.26	115.03	115.00	115.00	119.26	119.26	118.60	∞	0
28	6/5/69	19 mockup support stems and liner tubes removed	121.50	121.50	115.03	115.04	115.01	121.50	121.50	121.50	81.65	11.28
			119.00	119.00	115.03	115.04	115.01	119.00	119.00	117.40	∞	0
58	7/25/69	Basepoint	122.00	115.00	114.98	115.01	114.99	115.00	122.00	122.00	29.00	22.62
59	7/25/69	19 mockup support stem assemblies in place	115.40	115.00	114.98	115.01	114.99	115.00	115.40	115.40	∞	0
			122.00	115.00	114.98	114.97	115.05	115.00	122.00	122.00	80.48	11.40
60	7/28/69	Basepoint	118.70	115.00	114.98	114.97	115.05	115.00	118.70	118.28	∞	0
			122.00	115.00	115.04	115.00	115.01	115.00	122.00	122.00	77.02	11.78
61	7/28/69	19 mockup support stem and liner tubes removed	118.70	115.00	115.03	115.00	115.02	115.00	118.70	117.50	∞	0
			122.00	115.00	114.98	115.02	115.03	115.00	122.00	122.00	71.61	12.43
			118.40	115.00	114.98	115.02	115.03	115.00	118.40	118.00	∞	0

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5.0 ANALYSIS (U)

5.1 "Q" REACTIVITY MEASUREMENTS (U)

(CRD) The reactivity worth of zirconium was calculated as a function of radius with the Westinghouse Integrated Standard Design Method (WISDM)* for the R-1 reactor configuration.** One-dimensional ANISN's in 16 energy groups were used to solve for the forward and adjoint fluxes. These fluxes were then used in the PERT-1D code to calculate the reactivity change of zirconium in β /kg as a function of radius. The resulting reactivity worth curve with the corresponding experimental data points is shown in Figure 5-1.

(CRD) As the chemical analysis of the zirconium wire (See Table 3-1) used in this experiment showed the presence of hafnium as an impurity, a preliminary estimate was made to determine its effect on the measured worth of the wire. The amount of wire present in the PAX-G1 during testing was 10 kg. Based on the analysis report of 100 ppm (at the top) of hafnium in the wire, the maximum amount of hafnium present was 0.001 kg. Using a reactivity coefficient of -1.3β /kg with this mass of hafnium produces a negative reactivity worth of 0.13β . The measured worth of the 10 kgs of zirconium wire was 3β ; consequently, the presence of introduces an error of approximately 4 percent. Since this effect is small, hafnium was not included in the above described calculations.

5.2 MOCKUP SUPPORT STEM ASSEMBLY REACTIVITY MEASUREMENTS (U)

(CRD) The analysis of the mockup support stem assemblies was performed using WISDM. The support stem assemblies include support stems of Inconel 718 and liner tubes of 310 Stainless Steel whose major constituents are the elements iron, nickel, chromium, niobium, and molybdenum. The radial reactivity worth for each of these elements was calculated to evaluate the radial reactivity coefficient of the support stem assemblies. Initially, forward and

*Further details on WISDM and the computer codes referred to in this document may be found in DRM 51105.

**WANL Drawings 949J300, Reactor, R-1 Study Layout, 2/28/68; and 939J535, R-1 Reflector Study Layout, 5/15/68.

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Figure 5-1. "Q" Reactivity Coefficient Versus Radial Distance from the Core Center in the PAX-G1A Reactor (U)

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adjoint fluxes for the R-1 configuration were generated with the ANISN code and stored on magnetic tape. These fluxes were, in turn, used with the PERT-ID code to calculate the space dependent reactivity coefficient for each of the constituent materials in the support stem assemblies. The radial reactivity worth distribution for Fe, Ni, Cr, Nb, Mo, and C are presented in Figures 5-2 through 5-7, respectively.

(CRD) By multiplying the mass of each constituent material by its corresponding radial reactivity worth, the total reactivity worth for the substitution of 19 sets of support stem hardware for the regular cluster assemblies was calculated for the PAX-G1 core. In addition, the calculated worths for the removal of the 19 mockup support stem assemblies, spacers, and liner collar assemblies were ascertained for central and peripheral locations.

(U) Table 5-1 gives a comparison of the measured and calculated worths of the support stem assemblies.

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Figure 5-2. Radial Reactivity Worth of Fe in R-1 Reactor (U)

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Figure 5-3. Radial Reactivity Worth of Ni in R-1 Reactor (U)

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Figure 5-4. Radial Reactivity Worth of Cr in R-1 Reactor (U)

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NIOBIUM REACTIVITY WORTH, β /KG

Figure 5-5. Radial Reactivity Worth of Nb in R-1 Reactor (U)

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Figure 5-6. Radial Reactivity Worth of "X" Material* in R-1 Reactor (U)

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W59832

Figure 5-7. Radial Reactivity Worth of C in R-1 Reactor (U)

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Figure 5-8. Radial Reactivity Worth of a Single Support Stem Assembly in R-1 Reactor (U)

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TABLE 5-1

COMPARISON OF MEASURED AND CALCULATED REACTIVITY WORTH OF
SUPPORT STEM ASSEMBLIES (U)

<u>Type of Comparison</u>	<u>Core Location</u>	<u>Calculated Worth, ρ/kg</u>	<u>Measured Worth, ρ/kg</u>
19 mockup support stems and liner tubes	Core Central Region	-1.36	$-1.49 \pm 0.55^*$
19 mockup support stems and liner tubes	Core Peripheral Region	-0.83	-0.65 ± 0.55
Substitution of 19 mockup support stem assemblies for 19 regular cluster hardware assemblies	Core Central Region	-17.5	-18.36 ± 0.55
Substitution of 19 mockup support stem assemblies for 19 regular cluster hardware assemblies	Core Peripheral Region	-11.0	-11.22 ± 0.55

* All uncertainties are $\pm 1 \sigma$.

6.0 CONCLUSIONS

6.1 "Q" REACTIVITY MEASUREMENTS (U)

(CRD) The discrepancy noted between the calculated reactivity worth and measured worth for zirconium has prompted a study to re-evaluate the cross sections and the calculational model used to represent the experiment. From a preliminary investigation of the zirconium cross sections presently available on the GAM8 tape (WISDM), the resonance absorption is possibly too high and/or the resonance scattering too low. Based on the discrepancy observed, new zirconium material cross sections were developed by Reactor Physics and Math. A one-dimensional calculational model of the PAX/R-1 has been employed to evaluate this new cross section data. Two problems were run: one without zirconium and the other with 50 gm of zirconium smeared uniformly over the core. These new cross sections predict a value of -0.26¢/Kg for a PAX/R-1 core average zirconium reactivity coefficient, while that predicted by GAM8 was -1.7¢/Kg . The interpolated experimental value is approximately $+0.05\text{¢/Kg}$. GAM8, the standard design tape, is to be updated shortly to include these improved zirconium cross section data.

6.2 MOCKUP SUPPORT STEM ASSEMBLY REACTIVITY MEASUREMENTS (U)

(U) The calculated reactivity worths for the support stem assemblies measured in the PAX-G1A reactor as listed in Table 5-1 with the experimental results indicate good agreement between calculations and measurements. These worths will be used to predict the total reactivity worth of the support stem assemblies in the R-1 reactor.

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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) 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 for 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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Figure A-2. R-1 Core Notation

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APPENDIX B

THE "Q" MATERIAL REACTIVITY COEFFICIENTS EXPERIMENTAL PROCEDURE (U)

(CRD) In accordance with WANEF procedures,* an Experimental Details Checklist (EDC) was written to set forth the details of measuring the reactivity coefficient of zirconium ("Q" material) as well as making an attempt to measure the self-shielding factor. This EDC also evaluates any nuclear hazards resulting from such measurement procedures.

(U) Those portions of the experimental procedure** applicable to this TME may be found in the EXPERIMENTAL DETAILS section of EDC 74. The body of EDC 74 is contained in this appendix.

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

(U)** In order to more closely conform to the intent of the Scope of Test and to make the necessary measurements within the available time, a few changes were made during the actual experiment. Part 2 in the EXPERIMENTAL DETAILS should read: "One to two Kg of "Q" material (.060" OD) will be placed in the vicinity of cluster 000 and a reactivity measurement made. NOTE: No existing shim wires need be removed during these measurements." Parts 5 and 6 were not done.

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WANEF
EXPERIMENTAL DETAILS CHECKLIST*

No. 74
Date 3/27/69

TITLE OF EXPERIMENT: "Q" Material Reactivity Coefficients

OBJECTIVE:

To provide experimental values for "Q" material reactivity coefficients in the PAX-G reactor.

EQUIPMENT REQUIREMENTS:

- 1) The PAX-G reactor shimmed to the desired drum angle.
- 2) 2 Kg .070" OD, 55-1/4" long "Q" material wires.
- 3) 2 Kg .060" OD, 2 Kg .040" OD, 2 Kg .020" OD; 55-1/4" long "Q" material wires.
- 4) The WANEF reactivity computer or other reactivity measuring device.

HAZARDS CONSIDERATIONS:

The techniques involved with reactivity coefficient measurements using wires will be the standard ones used previously at WANEF. When conducted in accordance with the requirements and limitations in SOP 5.5.4, "PAX In-Core Experiment", there will be no unevaluated safety hazard**.

Reactor operations will be carried out in accordance with SOP 5.2, "Reactor Operating Procedure". The installation and removal of experiments will be governed by SOP 5.4, "Manual Reactivity Change Procedure".

EXPERIMENTAL DETAILS:

- 1) A basepoint will be run with some convenient period (approximately 35 seconds).
- 2) One to two Kg of "Q" material (.070" OD) will be placed in the vicinity of cluster 000 and a reactivity measurement made. NOTE: No existing shim wires need be removed during these measurements.

* Written in request to T/S 66DW-291-0, "Q Coat Reactivity Coefficient Measurements in the PAX-G2 Reactor".

** "Q" material is a metal whose predicted worth is less than +1¢/kg.

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- 3) The "Q" material will be removed from the vicinity of cluster 000 and placed in the vicinity of cluster 4K4. A second reactivity measurement will then be made.
- 4) One to two Kg of .020" OD "Q" material will be placed in the vicinity of cluster 000 and a reactivity measurement made.
- 5) One to two Kg of .040" OD "Q" material will be placed in the vicinity of cluster 000 and a reactivity measurement made.
- 6) One to two Kg of .060" OD "Q" material will be placed in the vicinity of cluster 000 and a reactivity measurement made.

DATA REQUIRED:

- 1) "Q" material reactivity coefficients near the core center and at a radial location.
- 2) "Q" material self-shielding coefficients.
- 3) Chemical analysis of the "Q" material used.

WRITTEN BY:

J. W. Rowland

J. W. Rowland

DATE

3/25/69

SCIENTIST-IN-CHARGE:

F. S. Frantz

F. S. Frantz, Manager, WANE

DATE

3/27/69

MANAGER, NUCLEAR AND RADIATION DESIGN:

W. P. Kovacik

W. P. Kovacik

DATE

3/28/69

APPENDIX C

THE SUPPORT STEM REACTIVITY COEFFICIENT EXPERIMENTAL PROCEDURE

In accordance with WANEF procedures,* an Experimental Details Checklist (EDC) was written to set forth the details of measuring the reactivity effects caused by the introduction of 19 mockup support stem assemblies into the PAX-G1A reactor as well as evaluating any nuclear hazards resulting from such procedures. The experimental procedures** applicable to the TME may be found in the EXPERIMENTAL DETAILS section of EDC 79. The body of EDC 79 is contained in this appendix.

- * WANL-TME-267, Revision H, 'Westinghouse Astronuclear Experimental Facility Reactor Operations Manual.'
- ** The only change from the procedure set forth in the EDC was that steps 6-10 in the EXPERIMENTAL DETAILS section were performed before steps 1-5.

WANEF
EXPERIMENTAL DETAILS CHECKLIST

No. 79

Date 5/14/69

TITLE OF EXPERIMENT: Support Stem Reactivity Coefficient Measurement Experiment*

OBJECTIVES:

The objective of this experiment is to provide data which will be used to normalize similar R-1 support stem reactivity predictions.

EQUIPMENT REQUIREMENTS:

1. The PAX-G reactor shimmed to the desired delayed critical drum angle.
2. Nineteen sets of mockup support stem hardware, including specially modified central elements.
3. Clustering fixtures and associated hardware.
4. The WANEF reactivity computer or other suitable reactivity measuring device.

HAZARDS CONSIDERATIONS:

The technique involved with reactivity coefficient measurements will be the standard ones used previously at WANEF. When conducted in accordance with the requirements and limitations in SOP 5.5.4, "PAX In-Core Experiments", there will be no unevaluated safety hazards nor will there be any increases in the probability or consequences of those already analyzed.

Reactor operations will be carried out in accordance with SOP 5.2, "Reactor Operating Procedure" and the Operating Limits Document. The installation and removal of experiments will be governed by SOP 5.4, "Manual Reactivity Change Procedure".

* Written in response to T/S 56DW-292-0.

EXPERIMENTAL DETAILS:

The experiment will be performed in the following steps:

1. A basepoint will be run by setting the R-1 mockup drums to 115° and adjusting the 10 drum (NRX) bank to obtain $\theta_{DC} \cdot \theta_T$ on the 10 drum (NRX) bank should be chosen to yield approximately 20% supercritical*.

2. The support stem mockup hardware (with special graphite central elements) should be placed in the following locations:

P1 A
 P2 A, - U
 P3 A, - U
 P4 A, - U
 P5 A, - U
 P6 A
 P7 A, - U
 P8 A, - U
 J (3-6) A
 J8 A

3. A reactivity run will be made by adjusting the R-1 mockup drums to 115° and θ_T as obtained in step 1. above. θ_{DC} shall then be obtained with the 10 drum (NRX) bank.

4. The support stems and liner tubes will then be removed and a reactivity measurement made as in step 3. above.

5. The support stem mockup hardware will be removed and the clusters returned to their original configuration.

6. Step 1. will be repeated.

7. The support stem mockup hardware (with special graphite central elements) shall be placed in the following locations:

000
 (1-6) B1
 (1-6) C2
 (1-6) D3

8-10. Steps 3 through 5 above will be repeated.

* Nuclear Design predicts that the insertion of the 19 special support stem mockup hardware assemblies and modified central elements should be worth -8.6% at the outer periphery and -13.7% near the core center.

DATA REQUIRED:

1. Actual or representative weights of all support stem mockup hardware.
2. Reactivity effects caused by support stem mockup hardware interchange.

WRITTEN BY: J. W. Rowland J. W. Rowland DATE 5/15/69

SCIENTIST-IN-CHARGE F. S. Frantz F. S. Frantz, Manager, WANEF DATE 5/20/69

MANAGER, NUCLEAR AND RADIATION DESIGN W. P. Kovacik W. P. Kovacik DATE 5/27/69

APPENDIX D

REACTIVITY UNCERTAINTY ESTIMATES

From the typical uncertainties involved in measuring positive periods, it is estimated that the uncertainty in each series of period measurements corresponds to $\sigma_t = \pm 0.1\%$.

From the manufacturer's literature, the repeatability of the NRX position indicators is 1.2 minutes for each of the 10 NRX type drums. In addition to this, experience has shown that there is an additional uncertainty of $\pm 0.01^\circ$ per drum involved with the actual positioning of the drum to a specified angle. In the vicinity of 115° the NRX drum bank is worth 4.9¢/degree*, vector addition of the uncertainties multiplied by the differential bank worth gives a positioning uncertainty of $\sigma_{NRX} = \pm 0.35\%$.

From the manufacturer's specifications, the repeatability of the R-1 position indicators is $\pm 0.02^\circ$ (1.2 minutes). Although these drums are nearly impossible to set to an exact predetermined position, the fact that they have a digital readout allows the operator to easily record their exact position in order that an appropriate correction factor may be applied at a later date. The linearity of the position indicator pots is $\sim 0.05\%$. However, since in this experiment the R-1 drums were set at very nearly the same position every time, this error is not applicable and thus will be omitted. WANL-TME-1916 gives the differential R-1 drum bank worth as 0.91¢/degree. Combining the R-1 position indicator uncertainties through vector addition and multiplying it by the differential drum bank worth gives a value of $\sigma_{R-1} = \pm 0.14\%$, attributable to the uncertainty in the R-1 drum bank position.

Because all of the above reactivity errors are independent of each other, they may be combined in the standard manner as shown below:

$$\begin{aligned}\sigma_{\text{total}}^2 &= \sigma_{NRX}^2 + \sigma_{R-1}^2 + \sigma_t^2 \\ &= (0.35)^2 + (0.14)^2 + (0.1)^2 \\ \sigma_{\text{total}} &= \pm 0.39\%\end{aligned}$$

* DRM-51154, "PAX-GOB Control Drum Worth Measurements"

Thus, one may say that based on the above mentioned assumptions, the uncertainty associated with each reactivity measurement is $\pm 0.39\%$. As the uncertainties associated with the weights are negligible in comparison to the reactivity uncertainty, the former will be neglected.

Because each reactivity measurement consists of two reactor runs, a base point as well as the actual measurement, the actual uncertainty, σ_p , for each set of measurements is given by

$$\begin{aligned}\sigma_p &= \sqrt{(0.39)^2 + (0.39)^2} \\ &= \pm .55\%\end{aligned}$$

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ABSTRACT A series of measurements have been performed on the PAX-G1A reactor, a nuclear mockup of an 18 drum R-1 design, to determine the reactivity effects of "Q" material and of mockup support stem assemblies. Measurements of the "Q" material reactivity coefficient indicated a considerable discrepancy between experimental values and analytical predictions. Measurements of the reactivity effects of the mockup support stem assemblies produced excellent agreement between the experimental measurements and the analytical predictions.			
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