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SAXTON PLUTONIUM PROGRAM

CRITICAL EXPERIMENTS FOR THE

SAXTON PARTIAL PLUTONIUM CORE

By *Pa*

E. G. Taylor

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IN NUCLEAR SCIENCE ABSTRACTS

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TABLE OF CONTENTS

	<u>Page No.</u>
LIST OF FIGURES	iv
LIST OF TABLES	v
ABSTRACT	vi
1. INTRODUCTION.	1
2. FACILITIES DESCRIPTION.	3
2.1 The Reactor Evaluation Center.	3
2.2 The CRX Reactor Facility	8
3. SUMMARY OF EXPERIMENTS.	24
REFERENCES	27
	<u>Appendices</u>
APPENDIX A - Single Region Experiments.	A
Attachment A "Core Tank Hardware & Fuel Specifications".	38
Attachment B "Buckling Data"	43
Attachment C "Relative Power Distributions".	87
Attachment D "Relative Fluxes"	90
Attachment E "Circumferential Thermal Fluxes About Fuel Rods".	95
APPENDIX B - Multi-Region Experiments	B
Attachment A "Power Scan Data"	24
Attachment B "Reactivity-Period Relationships"	49
Attachment C "Flux Data"	56
APPENDIX C - Measurement of Gamma-to-Fission Ratios by Gamma Ray Spectrometry to Relate Uranium/Plutonium Multizone Power Distributions.	C
APPENDIX D - Measurements Relating Power Sharing Between Plutonium and Uranium Fuel Rods.	D
APPENDIX E - Void Effects in Plutonium Criticals.	E
APPENDIX F - Noise Analysis Experiments	F
APPENDIX G - Pulsed Neutron Experiments	G

<u>Figure No.</u>	<u>LIST OF FIGURES</u>	<u>Page No.</u>
2.1	The Westinghouse Reactor Evaluation Center	4
2.2	Westinghouse Reactor Evaluation Center - Ground Floor Plan View	5
2.3	Cutaway of Assembly Areas.	6
2.4	WREC Control Room	7
2.5	CRX Moderator System	11
2.6	CRX Interlock System	13
2.7	CRX Reactor Console	14
2.8	CRX Reactor Core Tank and Structure.	15
2.9	CRX Core Loading Operation	16
2.10	19 x 19 Plutonium Core	17
2.11	Mixed Core (U outside with 7 x 7 Pu insert).	18
2.12	Variable Water Height Limiter (overflow pipe).	19
2.13	Plutonium Fuel Storage Rack.	20
2.14	Vertical Cross-Section of Core for Plutonium (or UO ₂) Fuel.	22

NOTE: Figures for Appendices are listed near the beginning of each Appendix.

<u>LIST OF TABLES</u>		
<u>Table No.</u>		<u>Page No.</u>
2.1	Operating Limitations	23
3.1	Measurement Program Summary	25

NOTE: Tables for Appendices are listed near the beginning of each Appendix.

ABSTRACT

Critical experiments with water moderated, single region and multi-region $\text{PuO}_2\text{-UO}_2$ fueled cores were performed in the CRX reactor critical facility at the Westinghouse Reactor Evaluation Center (WREC) at Waltz Mill, Pa. These experiments were carried out in support of the Saxton Plutonium Program for the Joint US-Euratom R&D Board under USAEC Contract Number AT(30-1)-3385, administered by the USAEC New York Operations Office. The purpose of the experiments was to verify the nuclear design of the Saxton partial plutonium core. Close agreement was found between predicted and measured nuclear characteristics.

From the experimental standpoint, this was the first time that plutonium had been used in a commercial-licensed facility and the first time that a facility had been licensed to operate solely on partial moderator (water) height control. The WREC experimental program was carried out between March 18, 1965 and June 9, 1965 using the same fuel rods that later were installed in Saxton.

1. INTRODUCTION

Critical experiments were carried out to verify the nuclear design of the Saxton partial plutonium core. This core consists of nine $\text{PuO}_2\text{-UO}_2$ /natural UO_2 assemblies in the central region, with 12 peripheral enriched UO_2 assemblies. Large uncertainties existed in important design parameters because of the lack of experimental data applicable to plutonium fueled systems at the design enrichment. Parameters of interest included installed reactivity, power sharing between different fuels, local power peaking effects, and control rod and soluble poison worth. Consequently, the critical experiments program was design-oriented to determine whether or not the nuclear design could satisfactorily meet the desired performance.

This report covers the efforts of a large number of people who worked in separate groups on various parts of the program. The work of each group is described in detail in Appendices. While these Appendices contain only the experimental work done, EURAEC-1490 (WCAP-3385-51) entitled Nuclear Design of the Saxton Partial Plutonium Core, compares analysis to experiments.

To achieve a clean lattice, control rods were eliminated from the system. The operation of the facility was accomplished entirely by controlling the moderator (water) height. In the past, the critical facility had been operated on partial moderator height control; however, criticality had always been established first by safety rod withdrawal. The elimination of control rods from the system provided a high degree of experimental flexibility. A total of 232 reactor runs with 288 source range startups were made with no safety incidents and with only five unprogrammed shutdowns due to electronic failures (all period system noise). A total of 166 fuel loading changes were made in a variety of single region and multi-region cores.

While the object of the critical experiments program was to verify the Saxton nuclear design, a number of experiments of fundamental significance were carried out; for example:

- a. Buckling measurements were made in five different $\text{PuO}_2\text{-UO}_2$ critical lattices covering a wide range of H/Pu ratios. These results are important from the standpoint of improving analysis methods in plutonium fueled systems.
- b. Buckling measurements were made in three different UO_2 critical lattices. These experiments provide the basis for checking existing methods of analysis in more highly enriched criticals.
- c. Power distribution and reactivity measurements were made in a large number of multi-region cores of both fuel types. The measurement of power in multi-region cores required the development of experimental techniques. The experimental results provide a good test of the analysis methods and of nuclear cross sections.
- d. Control rod worth and soluble poison measurements were made in single region and multi-region cores.
- e. Power peaking effects were investigated near water slots. The results of these experiments confirmed that water slot power peaking is an important consideration in utilizing plutonium in a thermal reactor.

Much care was devoted to safety and to minimizing radiation exposures. With frequent air and smear surveys, stringent permissible contamination level limits, and with thorough personnel indoctrination, no contamination or radiation incidents occurred during the period. The plutonium fuel rods were received, unloaded, stored, irradiated for experimental purposes, handled daily during fuel loading changes, and shipped out with no person receiving more than the permissible 1.25 rem per quarter dose limit.

2. FACILITIES DESCRIPTION

2.1 The Reactor Evaluation Center

The Westinghouse Reactor Evaluation Center (WREC) is located at the Atomic Power Division Waltz Mill Site, about thirty (30) miles south-east of Pittsburgh, Pennsylvania. Figure 2.1 is an aerial view of the WREC with some adjoining facilities on the Waltz Mill Site.

There are presently two operating reactors at the WREC: The Critical Experiment Station (CES), AEC Reactor Facility License No. CX-11, and the Critical Reactor Experiment (CRX), AEC Facility License No. CX-6. The CES is a 10 Kwt irradiation and training facility and was only used to irradiate some foils and fuel rods for determination of the gamma-to-fission ratios during the plutonium experiments. The CRX facility is the reactor that was used in this program and is described in the next section. Figure 2.2 is a floor plan of the WREC showing the reactors, control rooms, laboratories and offices. Figure 2.3 is a cross-section through the two reactor assembly areas. Figure 2.4 shows the control room area with both reactor consoles, the CRX reactor being in the foreground.

Additional facilities at the WREC include an electronics shop, an experimental fabrication machine shop, a semi-hot lab for handling contaminated materials, and standard counting room equipment. Special experimental equipment includes:

- a. A semi-automatic fuel rod and wire scanner for axial and/or radial flux scans with digital tape output.
- b. A 400 channel analyzer with peripheral equipment.

Figure 2.1 - The Westinghouse Reactor Evaluation Center

Figure 2.2 - Westinghouse Reactor Evaluation Center (WREC)
Ground Floor Plan View

8-23-63

Figure 2.3 - CUTAWAY OF ASSEMBLY AREAS (Not To Scale)

Figure 2.4 - WREC Control Room

- c. A neutron pulser.
- d. An analogue computer for reactivity measurements.

2.2 The CRX Reactor

As mentioned in the Introduction, the CRX reactor facility was modified to eliminate control rods from the system. The following describes some of the considerations used in the design and safety analysis for operating the CRX reactor with partial moderator level control.

A need has been repeatedly evident in the past to use the moderator of a critical assembly as the primary control to approach and achieve criticality.

Use of the moderator as the basic control device is a requirement for the study of cores which have nonhomogeneous fuel enrichments, dimensions, and cladding. Partial moderator height experiments accordingly have been performed on the CRX reactor in the past in support of such efforts. Criticality has been first achieved by movement of control rods, followed by the exchange of reactivity between control rods and moderator until the rods were withdrawn from the active core.

To achieve "clean" lattices in rodded cores, complicated efforts of design and fabrication are necessary. Fueled followers (for control rod water slots) have been used to ensure core uniformity. These followers classically create bottom reflector problems because the fuel protrudes into the lower reflector flux peak. Also, coupling of control material and fuel represents a potential source of weakness in the combined structure. Penetration of the bottom core plate for the follower section could open a potential path for the absorber to fall through the core unless prevented by mechanical design features.

These problems and others were solved by meticulous design of modifications to remove the control rods and to control reactivity solely by moderator level adjustments.

It is important to remember that a critical assembly is different from reactor systems in general, and particularly, from power reactors. By definition, critical facilities are used to investigate those characteristics that are the predetermined technical specifications for most nuclear reactors. In critical facility work, core size is a variable, as are the corollary measurements and buckling, reflector saving, power distribution and other parameters found in typical nuclear fission systems.

Public health and safety in critical facilities are best ensured by limiting the allowable fission product inventory and by reducing the probability of an accident which would cause either a temporary high radiation field or release of fuel. In water moderated critical assemblies, provision for dumping the moderator has long been recognized as a backup for shutdown in case there is failure of the other shutdown system. If all else should fail and if the critical assembly should undergo a vast excursion, moderator would be boiled from the core and inherently would cause shutdown.

The ramp rate obtained from moderator control is one continuous variable, while the ramp rates of control rods vary with radial location; thus, for a given core, the operator does not have to concern himself with different ramps at his fingertips. There is only one method of adding reactivity and any mechanical failure in the moderator fill system (leak, pipe failure, etc.) results in a loss of moderator with attendant reduction in reactivity.

When using moderator control, the starting point for shutdown is always a k-eff of approximately 1.00. In any potential ramp (or step) accident, the feedback from the moderated (albeit controlled) upper portion of a rodded core is of tremendous significance to the total core power output. Elimination of this available power source provides an added safety factor. This has been accomplished by the addition of a remotely controlled, variable position overflow system. Control of this system is interlocked into the reactor instrumentation and is dependent upon source multiplication in the establishment of a just critical configuration. Figure 2.5 is a block diagram of the CRX moderator handling system incorporating these features.

The moderator dump mode is a straight 6-inch dump line from the critical assembly reflector region controlled by a fast action normally open, spring-loaded valve. Response time of this valve is less than 200 milliseconds from initiation of a signal at the console to initial diaphragm movement within the valve body (equivalent to initiation of movement of a control rod). A second dump mode is similar. However, it is a 4-inch line rather than 6-inch.

The rate of insertion of negative reactivity by the 6-inch dump line is a variable, highly dependent on the critical moderator height, which in turn, is highly dependent on the fuel loading. It is interesting to note that the bigger the core, the more rapid the insertion of negative reactivity.

It has been argued that with a high moderator height, the moderator reactivity differential is low and one has no rapid means of negative reactivity insertion. This argument is easily and effectively countered by the very fact

CRX MODERATOR SYSTEM

Figure 2.5 - CRX Moderator System

that, under such circumstances, fast insertion of positive reactivity is even less possible. The maximum possible rate of insertion of moderator is approximately one-tenth the dumping rate.

The average dumping rate is about two centimeters a second. The negative reactivity insertion of ten seconds duration varies from approximately a dollar for the top twenty centimeters, typically four dollars at normal operating heights, to twenty dollars at lower operating heights in the largest cores. These values are, of course, checked in the performance of the initial reactivity studies.

Figure 2.6 is a block diagram of the CRX safety interlock system as modified for partial moderator level control. Figure 2.7 is a view of the CRX reactor console. Figure 2.8 is a picture of the CRX reactor core tank and structure with the cover plates partially removed to show the water baffle around the core lattice. Figure 2.9 shows plutonium fuel being loaded into a 19 x 19 lattice. Figure 2.10 is a 19 x 19 loaded plutonium core with cover plates installed. Figure 2.11 is a mixed core, a 19 x 19 uranium outside core with a 7 x 7 plutonium insert. Figure 2.12 shows the variable water height limited overflow pipe with float switch interlocks. Figure 2.13 shows the plutonium fuel in upright storage racks with limiting slab geometry.

The nuclear instrumentation system for the CRX is standard with BF_3 detectors and count rate instrumentation used for the startup range and several ion chambers coupled into linear or logarithmic amplifiers with appropriate period and level scrams in the operating range.

CRX INTERLOCK SYSTEM

Figure 2.6 - CRX Interlock System

Figure 2.7 - CRX Reactor Console

Figure 2.8 - CRX Reactor Core Tank and Structure

Figure 2.9 - CRX Core Loading Operation

Figure 2.10 - 19 x 19 Plutonium Core

Figure 2.11 - Mixed Core (U outside with 7 x 7 Pu insert)

Figure 2.12 - Variable Water Height Limiter (overflow pipe)

Figure 2.13 - Plutonium Fuel Storage Rack

Figure 2.14 is a vertical cross-section of the core as used with the plutonium fuel. A complete description and specification of the fuel is contained in Appendix A. Table 2.1 is a list of parameters establishing the operating limitations of the CRX reactor as licensed to operate under the plutonium license.

A complete and thorough description of the reactor and system is contained in References 1 and 2.

TABLE 2.1
OPERATING LIMITATIONS

<u>Parameter</u>	<u>Maximum</u>	<u>Minimum</u>
Power (automatic scram)	2.2 kw	-
Power (steady state)	2.0 kw	-
Reactivity Addition Rate (S.M.* < 20)	\$0.1/sec	-
Reactivity Addition Rate (S.M. > 20)	\$0.035/sec	-
Period Scram (automatic)	-	3 sec
Period Scram (mandate to operator)	-	5 sec
Shutdown margin with highest worth rod fully withdrawn	-	\$1.0
Shutdown for assembly area entry	-	\$4
Shutdown Response Time (seconds)	.500	-
Step (credible experimental insertion or failure)	< \$1**	-
Temporary Reactivity Mode Addition	\$0.25	-
k-excess (cold clean)	\$2.00***	-
Neutron Source	-	10 ⁵ N/S
Prompt Neutron Generation Time ("l")	-	10 ⁻⁶ sec

*Source Multiplication.

**\$1 minus the period scram set point (in \$).

***Assured by moderator overflow.

3. SUMMARY OF EXPERIMENTS

At the outset of the Saxton Plutonium Program, it was decided to conduct a series of critical experiments to verify the nuclear design of the Saxton partial plutonium core. Although there were some data on plutonium systems, there was none in the area of the Saxton fuel, 6.6 w/o PuO_2 in natural UO_2 , which was established as the enrichment required for the program.

A standard series of measurements as outlined in Table 3.1 was proposed and approved. First, a series of single region UO_2 and single region PuO_2 fueled experiments were planned. Then, the multi-region $\text{Pu-UO}_2/\text{UO}_2$ cores were to be studied. The results of these experiments are reported in Appendices A and B respectively.

The standard measurement technique for determining flux profiles is to scan the fuel rod for fission product decay gammas. In multi-region cores, a problem was recognized in that the two different fuels had different fission product spectra and the time dependent gamma activities would be different. This would make power distribution scans in multi-region cores meaningless unless a normalizing factor could be determined to correlate the gamma decay activity of the two fuels. Two different techniques were proposed and both developed in an attempt to obtain a double check on the data. Appendix C reports the measurements of gamma-to-fission ratios (UO_2 to $\text{PuO}_2\text{-UO}_2$) by gamma ray spectrometric techniques. Appendix D reports on measurements relating power sharing between Pu and U fuel rods through the use of heating rates.

TABLE 3.1

MEASUREMENT PROGRAM SUMMARY

Single-Region Experiments PuO ₂ -UO ₂ Fuel		Multi-Region Experiments ³ PuO ₂ -UO ₂ Inside, UO ₂ Outside	
<u>0.56-Inch Lattice</u> a. Cylindrical core-critical rods b. Buckling by fuel rod scans (19 x 19 core) c. Power map, foil traverses-U238, Au, Dy (19 x 19 core) d. Water slot in center-reactivity, power map ² e. Aluminum slab in center-reactivity, power map f. Five control rods in center-reactivity, power map (21 x 21 core) g. Moderator temperature coefficient h. Vipac vs pelletized fuel-reactivity, power map i. 3 x 3 UO ₂ insert-reactivity, power map, flux-Dy j. Fuel rod circumferential flux-Dy wire k. Pulsed neutron experiments-clean and borated l. Boron worth to 50 ppm (19 x 19 core) m. Boron worth to 337 ppm (21 x 21 core) n. Borated core buckling (21 x 21 core) o. Noise analysis (19 x 19 core)		<u>0.795-Inch Lattice</u> a. Cylindrical core-critical rods b. Buckling by fuel rod scans (12 x 12 core) c. Power map <u>0.52-Inch Lattice</u> a. Cylindrical core-critical rods b. Buckling by fuel rod scans (22 x 23 core) c. Pulse neutron experiments (23 x 23 core) <u>0.735-Inch Lattice</u> a. Cylindrical core-critical rods b. Buckling by fuel rod scans (13 x 13 core) <u>1.04-Inch Lattice</u> ⁴ a. Cylindrical core-critical rods b. Buckling by fuel rod scans (11 x 11 core)	
<u>UO₂ Fuel</u> <u>0.56-Inch Lattice</u> a. Cylindrical core-critical rods b. Buckling by fuel rod scans (19 x 19 core) c. Power map, foil traverses-U238, Au (19 x 19 core) d. Water slot in center-reactivity, power map e. Aluminum slab in center-reactivity, power map f. Five control rods in center-reactivity, power map (21 x 21 core) g. Moderator temperature coefficient h. 3 x 3 PuO ₂ -UO ₂ insert-reactivity, power map i. 7 x 7 PuO ₂ -UO ₂ insert-reactivity j. Fuel rod circumferential flux-Dy wire k. Pulsed neutron experiments 1. U-238 foils counted for fission activity and Np-239 decay 2. Power measurements by fuel rod scans 3. Carried out in 0.56-inch lattice 4. Not part of the Saxton Plutonium Program. Included to complete the summary of the buckling data available		<u>0.795-Inch Lattice</u> a. Cylindrical core-critical rods b. Buckling by fuel rod scans (13 x 14 core) c. Power map <u>0.52-Inch Lattice</u> ⁴ a. Cylindrical core-critical rods b. Buckling by fuel rod scans (cylindrical core)	
		<u>Clean</u> a. Fuel substitution in steps to the reference core (11 x 11 PuO ₂ -UO ₂ , 19 x 19 core)-reactivity b. Power map, foil traverses-U238, Dy c. Aluminum slab at boundary-reactivity, power map d. Water slot-reactivity, 3 positions (11 x 11 PuO ₂ -UO ₂ , 21 x 21 core) e. Five control rods-reactivity, 5 positions (11 x 11 PuO ₂ -UO ₂ , 21 x 21 core) f. Five control rods at fuel interface-power map g. Moderator temperature coefficient h. Pulse neutron experiments (11 x 11 PuO ₂ -UO ₂ in 19 x 19 and 21 x 21 cores) i. Noise analysis <u>Borated Core</u> a. Fuel and boron addition in steps to the reference core (19 x 19 PuO ₂ -UO ₂ , 27 x 27 overall, 1453 ppm boron) - reactivity b. Power map, foil traverses-U238, Dy c. Water slot experiment at fuel interface-reactivity, power map d. Aluminum slab experiment at fuel interface-reactivity, power map e. L-shaped UO ₂ inserts in PuO ₂ -UO ₂ region simulating Saxton design-Manganese wire activation at design flux-wire locations and core power map (1425 ppm boron) f. 3 x 3 UO ₂ insert in PuO ₂ -UO ₂ region (1425 ppm boron) reactivity, power map	
		<u>UO₂ Inside, PuO₂-UO₂ Outside</u> <u>Clean</u> a. Fuel substitution in steps to inverted reference core (11 x 11 UO ₂ inside, 19 x 19 overall) b. Power map, foil traverses-U238, Dy c. Water slot-reactivity, 3 positions (11 x 11 UO ₂ , 21 x 21 core) d. Five control rods, 3 positions (11 x 11 UO ₂ , 21 x 21 core) e. Pulse neutron experiments (11 x 11 UO ₂ , 21 x 21 core) <u>Borated Core</u> a. Quarter-core step change in fuel position from 2-region core to inverted 2-region core-reactivity b. Full core change to inverted reference configuration (19 x 19 UO ₂ , 27 x 27 overall, 1252 ppm boron) c. Power map, foil traverses-U238, Dy	

Appendix E reports the reactivity effects of voids on the operating characteristics of plutonium cores.

A small number of noise analysis experiments were performed and are reported in Appendix F.

An attempt was made to use pulse neutron techniques for determining core shutdown characteristics but recent developments and analyses show that the coupling between the reflector and the reactor make it nearly impossible to measure the fundamental neutron decay mode. Comparison of shutdown reactivities obtained by pulsed neutron techniques with measurements by partial moderator height shows a thirty (30) percent difference. Appendix G contains a typical comparison of these data.

All water height data reported in all appendices were analyzed using relative differences only. For obtaining absolute water heights in relation to the bottom of the fuel, the following correction should be applied:

$$H_{\text{corr}} = .997 (H_{\text{raw}} + 1.91) \text{ cm.}$$

The seven appendices are written by several different persons and the authors are so indicated at the beginning of each appendix. The work was performed by the staff of the WREC as augmented by persons from the Atomic Power Division at Forest Hills, Pa.

REFERENCES

1. "Safety Report for the CRX Reactor," WCAP-1316, As Amended.
2. USAEC Facility License No. CX-6 through Amendment 12 dated March 12, 1965.

Appendix A

APPENDIX A

SINGLE REGION EXPERIMENTS

by

H. I. Sternberg

APPENDIX A

TABLE OF CONTENTS

	<u>Page No.</u>
LIST OF FIGURES	ii
LIST OF TABLES	iv
ABSTRACT	v
1.0 INTRODUCTION	1
2.0 FULLY REFLECTED JUST CRITICAL CONFIGURATIONS	3
3.0 LATTICE BUCKLING AND REFLECTOR SAVINGS	4
4.0 RELATIVE POWER DISTRIBUTIONS	6
5.0 RELATIVE FLUXES BY FOIL ACTIVATION	14
6.0 MODERATOR REACTIVITY WORTHS	19
7.0 REACTIVITY WORTHS OF PERTURBATIONS TO UNIFORM CRITICAL LATTICES	26
8.0 TEMPERATURE COEFFICIENT.	28
9.0 CIRCUMFERENTIAL THERMAL FLUX AT FUEL ROD SURFACES.	29
10.0 REFERENCES	36
ATTACHMENT A - Core Tank Hardware and Fuel Specifications	38
ATTACHMENT B - Buckling Data	43
ATTACHMENT C - Relative Power Distributions	87
ATTACHMENT D - Relative Fluxes.	90
ATTACHMENT E - Circumferential Thermal Fluxes About Fuel Rods	95

LIST OF FIGURES

<u>Figure No.</u>		<u>Page No.</u>
1	Water Slot Power Scan Core Diagram	8
2	Aluminum Plate Power Scan Core Diagram	9
3	Control Rod Power Scan Core Diagram	10
4	Power Distribution Through a Water Slot.	11
5	Power Distribution Through an Aluminum Plate	12
6	Power Distribution Through Control Rods	13
7	Relative Fast Flux in a 19 x 19 Core	16
8	Relative Resonance Flux in a 19 x 19 Core.	17
9	Relative Flux Shape in a 19 x 19 Core by Gold and Dysprosium Foil Activation	18
10	Differential Moderator Worth Curve (UO_2)	21
11	Differential Moderator Worth Curve (PuO_2-UO_2).	22
12	Integral Moderator Worth Curve (UO_2)	23
13	Integral Moderator Worth Curve (PuO_2-UO_2).	24
14	Installed Reactivity Curve	25
15	Circumferential Thermal Flux about a UO_2 Fuel Rod Next to the Reflector	30
16	Circumferential Thermal Flux about a PuO_2-UO_2 Fuel Rod Next to an Aluminum Plate	31
17	Circumferential Thermal Flux about an Unperturbed UO_2 Fuel Rod .	32
18	Circumferential Thermal Flux about a PuO_2-UO_2 Fuel Rod Next to the Reflector	33
19	Circumferential Thermal Flux about a PuO_2-UO_2 Fuel Rod Next to a Water Hole	34
20	Circumferential Thermal Flux about an Unperturbed PuO_2-UO_2 Fuel Rod	35

LIST OF FIGURES (CONT'D)

<u>Figure No.</u>		<u>Page No.</u>
A-1	Core Tank Top View	39
A-2	Core Tank Side Elevation	40
A-3	Core Plate Layout	41
B-1	0.792" Lattice Core Diagram (UO_2 Buckling)	47
B-2	0.56" Lattice Core Diagram ($\text{PuO}_2\text{-UO}_2$ & UO_2 Buckling)	51
B-2A	Longitudinal Power Shape, 0.56" UO_2 Lattice.	52
B-3	0.792" Lattice Core Diagram ($\text{PuO}_2\text{-UO}_2$ Buckling).	56
B-4	Longitudinal Power Shape, 0.56" $\text{PuO}_2\text{-UO}_2$ Lattice	61
B-5	0.56" Lattice Core Diagram ($\text{PuO}_2\text{-UO}_2$ Borated Buckling)	65
B-6	0.735" Lattice Core Diagram ($\text{PuO}_2\text{-UO}_2$ Buckling).	69
B-7	0.52" Lattice Core Diagram ($\text{PuO}_2\text{-UO}_2$ Buckling)	73
B-8	1.04" Lattice Core Diagram ($\text{PuO}_2\text{-UO}_2$ Buckling)	77
B-9	0.56" Lattice Core Diagram ($\text{PuO}_2\text{-UO}_2$ Buckling Repeat).	82
B-10	0.52" Lattice Core Diagram (UO_2 Buckling)	86
C-1	Relative Power Distribution Core Diagram	89
D-1	Foil Locations in the 19 x 19 UO_2 Core	93
D-2	Foil Locations in the 19 x 19 $\text{PuO}_2\text{-UO}_2$ Core.	94
E-1	Rod Locations ($\text{PuO}_2\text{-UO}_2$) for Circumferential Thermal Flux Measurement.	98
E-2	Rod Locations (UO_2) for Circumferential Thermal Flux Measurement.	99

LIST OF TABLES

<u>Table No.</u>		<u>Page No.</u>
1	Experiment Index	2
2	Fully Reflected Just Critical Configurations	3
3	Buckling and Reflector Savings	5
4	Relative Power Distributions	7
5	Reactivity Worths of Perturbations to Uniform Critical Lattices	27
A-1	Fuel Rod Specifications.	42
B-1	0.792" Lattice UO_2 Buckling Data	45
B-2	0.56" Lattice UO_2 Buckling Data.	48
B-3	0.792" Lattice PuO_2-UO_2 Buckling Data.	53
B-4	0.56" Lattice PuO_2-UO_2 Buckling Data	57
B-5	0.56" Lattice PuO_2-UO_2 Borated Buckling Data	62
B-6	0.735" Lattice PuO_2-UO_2 Buckling Data	66
B-7	0.52" Lattice PuO_2-UO_2 Buckling Data	70
B-8	1.04" Lattice PuO_2-UO_2 Buckling Data	74
B-9	0.56" Lattice PuO_2-UO_2 Repeat Buckling Data.	78
B-10	0.52" Lattice UO_2 Buckling Data	83
C-1	Relative Power Points	88
D-1	UO_2 Relative Fluxes.	91
D-2	PuO_2-UO_2 Relative Fluxes	92
E-1	Circumferential Relative Fluxes (UO_2).	96
E-2	Circumferential Relative Fluxes (PuO_2)	97

ABSTRACT

The data and results of the single region UO_2 and $\text{PuO}_2\text{-UO}_2$ critical experiments performed under the Saxton Plutonium Program are given in this report. These results include experiments made to determine critical configurations, bucklings, power distributions, flux shapes, reactivity worths of various perturbations and temperature coefficients.

1.0 INTRODUCTION

A series of critical experiments was carried out at the Westinghouse Reactor Evaluation Center (WREC) as part of the Saxton Plutonium Program. These experiments were performed with two different fuels. One type of fuel was the conventional Saxton UO_2 fuel (5.74 w/o U-235). The other fuel was mixed-oxide ($\text{PuO}_2\text{-UO}_2$) containing 6.6 w/o PuO_2 .

This report describes the single region UO_2 and $\text{PuO}_2\text{-UO}_2$ experimental data and results. An outline of the single region experiments is provided in Table I. The table also serves as an index for the material in this report.

TABLE I
EXPERIMENT INDEX

Experiment	Fuel	Lattice Pitch* (inches)	Core Configuration	Results	Experiment Description and Data
Criticality	UO ₂	0.52 ^Δ	Cylindrical	Table II Page 3	
		0.56	Cylindrical		
		0.792	Cylindrical		
	PuO ₂ -UO ₂	0.52 ⁺	Cylindrical		
		0.56	Cylindrical		
		0.735	Cylindrical		
		0.792	Cylindrical		
1.04 ^Δ	Cylindrical				
Buckling	UO ₂	0.52 ^Δ	449 Rods (Cylindrical)	Attachment B, Table B-10, Page 65 Page 42 Table B-2, Page 46 Table B-1, Page 44 Pages 4 and 5 Table B-7, Page 59 Tables B-4 and B-9 Pages 52 and 63 Table B-5, Page 55 Table B-6, Page 57 Table B-3, Page 50 Table B-8, Page 61	
		0.56	19x19 Square		
		0.792	13x14 Rectangle		
	PuO ₂ -UO ₂	0.52	22x23 Rectangle		
		0.56	19x19 Square		
		0.56 (Borated)	21x21 Square		
		0.735	13x13 Square		
		0.792	12x12 Square		
		1.04 ^Δ	11x11 Square		
Power Shapes	UO ₂	0.56	Through a Water Slot in the Center of a 19x19 Square Core	Attachment C, Page 67 Pages 6-13	
	PuO ₂ -UO ₂	0.56			
	UO ₂	0.56	Through an Aluminum Plate in the Center of a 19x19 Square Core		
	PuO ₂ -UO ₂	0.56			
	UO ₂	0.56	Through a row of 5 Ag-In-Cd Control Rods in the Center of a 21x21 Square Core		
	PuO ₂ -UO ₂	0.56			
Thermal Flux Shapes	UO ₂	0.56	Across the Center of a 19x19 Square Core	Attachment D, Page 70	
	PuO ₂ -UO ₂	0.56			
Fast Flux Shapes	UO ₂	0.56	Across the Center of a 19x19 Square Core	Pages 14-17	
	PuO ₂ -UO ₂	0.56			
Resonance Flux Shapes	UO ₂	0.56	Across the Center of a 19x19 Square Core		
	PuO ₂ -UO ₂	0.56			
Moderator Reactivity Worth Curves	UO ₂	0.56	All	Pages 18-23	
	PuO ₂	0.56	All		
Reactivity Worths	UO ₂	0.56	OF: A water slot (19x19 Core) An aluminum plate (19x19 Core) Control rods (21x21 Core)	Pages 24-25	
	PuO ₂ -UO ₂	0.56	A water slot (19x19 Core) An aluminum plate (19x19 Core) Control rods (21x21 rods)		
	PuO ₂ -UO ₂	0.56	Boron - 25 and 50 ppm (19x19 Core) 228, 309, and 337 ppm (21x21 Core)		
Temperature Coefficient	UO ₂	0.56	19x19 Square	Page 26	
	PuO ₂	0.56	19x19 Square		
Circumferential Thermal Flux at Fuel Rod Surface	UO ₂		19x19 Next To: 1) Reflector 2) Aluminum Plate 3) Other Fuel	Pages 27-33	Attachment E, Page 76
	PuO ₂ -UO ₂		1) Water Hole 2) Reflector 3) Other Fuel		
FUEL ROD SPECIFICATIONS AND CORE HARDWARE					Attachment A, Pages 36-41

* All pitches are square.

+ 0.56" Pitch has the same H/Pu ratio as in the plutonium fueled section of the Saxton reactor at power.

Δ Not part of the Saxton Plutonium Program.

2.0 FULLY REFLECTED JUST CRITICAL CONFIGURATIONS

Table 2 is a list of the extrapolated number of fuel rods needed to achieve criticality in a fully inundated cylindrical core.

TABLE 2

Fully Reflected Just Critical Configurations

Fuel	Pitch* (inch)	No. of Fuel Rods Required for Criticality	Moderator Temperature (°C)
5.74 w/o U-235 SS Clad	0.52 ⁺	447	17.6
	0.56	339	17.3
	0.792	173	17.3
6.6 w/o PuO ₂ Zr-4 Clad	0.52	472	24.0
	0.56	337	17.5
	0.735	151	28.0
	0.792	133	17.0
	1.04 ⁺	117	20.0

*All pitches are square.

+Not part of the Saxton Plutonium Program.

3.0 LATTICE BUCKLING AND REFLECTOR SAVINGS

Critical buckling measurements were made for five lattice pitches fueled with 6.6 w/o $\text{PuO}_2\text{-UO}_2$ and three lattice pitches using 5.74 w/o UO_2 fuel.

The $\text{PuO}_2\text{-UO}_2$ fueled 0.56 inch lattice buckling was measured in two separate experiments as a check on the precision of the measurements. This lattice was used for the two measurements and for a majority of the critical experiment program since this pitch contains the same H/Pu ratio as the Saxton reactor at power. The buckling was also measured in a borated configuration containing 337 ppm boron in the 0.56 inch lattice.

The results of the buckling experiments are listed in Table III. Attachment B lists the data, the method of calculation and a description of the experiments.

TABLE III
BUCKLING AND REFLECTOR SAVINGS

Lattice Loading	Critical No. of Fuel Rods	Critical Buckling		Reflector Savings		Water Temperature (°C)	Critical Water Height (cm.)
		Total (cm ⁻²) x 10 ³	Axial	Radial (cm.)	Axial (cm.)		
UO ₂ , 5.74 w/o U-235, SS Clad							
0.52" Pitch ⁺	449 (cylindrical)	11.76 ± 0.18	0.904 ± 0.01	13.73 ± 0.19	8.49 ± 0.27 (Bott.) 2.36 ± 0.27 (Top)	19.2	93.63
0.56" Pitch	361 (19x19)	12.71 ± 0.14	1.13 ± 0.01	14.31 ± 0.25	8.77 ± 0.14 (Bott.) 2.65 ± 0.05 (Top)	18.0	82.05
0.792" Pitch*	182 (13x14)	13.68 ± 0.19	1.05 ± 0.01	12.43 ± 0.41	7.78 ± 0.08 (Bott.) 0.21 ± 0.04 (Top)	17.3	88.96
<hr/>							
PuO ₂ -UO ₂ , - 6.6 w/o PuO ₂ , Zr-4 Clad							
0.52" Pitch	506 (22x23)	10.88 ± 0.13	1.07 ± 0.01	15.76 ± 0.44 (22 Rods) 14.51 ± 0.37 (23 Rods)	8.56 ± 0.29 (Bott.) 4.86 ± 0.29 (Top)	25.8	82.90
0.56" Pitch ^A	361 (19x19)	12.21 ± 0.11	1.14 ± 0.01	14.82 ± 0.17	7.97 ± 0.57 (Bott.) 4.67 ± 0.15 (Top)	17.0	80.80
	361 (19x19)	12.09 ± 0.15	1.11 ± 0.01	15.37 ± 0.28	8.22 ± 0.34 (Bott.) 4.36 ± 0.34 (Top)	15.75	81.79
0.56" Pitch 337 ppm Boron	441 (21x21)	11.23 ± 0.10	0.964 ± 0.01	13.98 ± 0.18	8.38 ± 0.15 (Bott.) 4.99 ± 0.15 (Top)	18.0	88.06
0.735" Pitch	169 (13x13)	15.96 ± 0.19	1.61 ± 0.01	12.78 ± 0.25	6.83 ± 0.17 (Bott.) 3.27 ± 0.17 (Top)	24.1	68.41
0.792" Pitch	144 (12x12)	15.93 ± 0.22	1.34 ± 0.01	12.90 ± 0.20	6.47 ± 0.12 (Bott.) 3.05 ± 0.12 (Top)	16.1	76.76
1.04" Pitch ⁺	121 (11x11)	12.84 ± 0.14	1.25 ± 0.01	12.27 ± 0.10	6.23 ± 0.09 (Bott.) 3.09 ± 0.09 (Top)	19.9	79.50

Notes:

1. All pitches are square.
2. Water heights are referenced to the bottom of the fuel.
3. Bottom axial reflector is water and aluminum; top axial reflector is air and fuel.
4. One-quarter inch thick aluminum grid plate at 45.7 cm. from bottom of the fuel.
5. Errors are ± one standard deviation.
6. *Core was irradiated on a positive period. Positive reactivity was 0.156% Δk/k.
7. ^ATwo separate experiments performed.
8. ⁺Not part of the Saxton Plutonium Program, but included for completeness.

4.0 RELATIVE POWER DISTRIBUTIONS

Table IV lists the relative power, produced in the fuel rods, through an unperturbed reference core, a water slot, an aluminum plate, and a row of 5 control rods. The rod numbers in the table are shown on the core loading diagrams in Figures 1-3. Plots of the relative power shapes are shown in Figures 4-6.

From the table it can be seen that power peaking in the fuel next to the water slot is 5.9% higher in the mixed-oxide fuel than in the UO_2 fuel. Power peaking in the fuel next to the aluminum plate is 1.2% higher in the mixed-oxide fuel than in the UO_2 fuel.

The following information is applicable to Table IV:

- (1) All lattice pitches were 0.56" square.
- (2) The water slot was formed by omitting five fuel rods from the center of a 19 x 19 core. The five remaining holes were in a line parallel to one side of the core with the third hole at the core center (Fig. 1).
- (3) The aluminum plate was positioned vertically between core plates in the space left by the five water holes described in (1). The purpose of the plate was to displace water with aluminum. Plate dimensions were one-quarter inch thick by 2.80 inches wide (Fig. 2).
- (4) The control rods were inserted in the water holes of (1). There were five control rods of 0.403 inch diameter composed of an unclad alloy of 80% Cd, 15% In, and 5% Ag (Fig. 3). An additional row of fuel was added in this experiment to form a 21 x 21 square core.

TABLE IV

Relative Power Distributions

Rod Number (From Boundary)	1	2	3	4	5	6	7	8	9	10	Critical Water Height (cm)	Moderator Temperature (°C)
Uranium Core Water Slot	-	-	1.0	-	1.1500	-	1.3071	1.4554	1.9257	-	78.33	18.4
Plutonium Core Water Slot	-	-	1.0	1.0687	-	1.2196	1.3019	1.4750	2.0385	-	74.22	15.4
Uranium Core Aluminum Plate	-	-	1.0	-	1.1587	-	1.2995	1.4138	1.6550	-	85.73	18.0
Plutonium Core Aluminum Plate	-	-	1.0	1.0617	1.1466	-	1.2840	-	1.6748	-	81.36	16.0
Uranium Unperturbed Reference	-	-	1.0	-	1.1551	-	1.3052	1.3255	-	-	81.94	18.4
Plutonium Unperturbed Reference	-	-	1.0	1.0786	1.1616	1.2295	1.2786	1.2945	1.3358	-	80.75	17.0
Uranium Core Control Rods	-	0.9846	-	1.0	-	1.1322	-	1.1411	-	0.8618	87.38	18.0
Plutonium Core Control Rods	1.5768	0.9754	0.9452	1.0	-	1.1213	1.1557	1.1634	1.1053	0.9607	77.34	15.4
Uranium Unper- turbed Refer- ence	-	0.9490	-	1.0	-	1.1659	-	1.2801	-	1.3316	51.0	16.1
Plutonium Unperturbed Reference (PDQ)	1.5880	0.9159	0.9233	1.0	1.0763	1.1430	1.1986	1.2425	1.2741	1.2932	-	-

Relative Power Notes: (1) Accuracy = $\pm 1.4\%$ (2 Standard Deviations).(2) PuO_2 - UO_2 pelletized fuel with Zr-4 Clad.

FIGURE-1 WATER SLOT POWER SCAN

FIGURE-2 ALUMINIUM PLATE POWER SCAN

FIG.-3 CONTROL ROD POWER SCAN

RELATIVE POWER SHAPES THROUGH A WATER SLOT

FIGURE 4

5.0 RELATIVE FLUXES BY FOIL ACTIVATION

Relative fast, resonance and thermal fluxes were measured by means of foils. The relative flux shapes are shown plotted as a function of core position in Figures 7-9.

The fast flux was measured by gamma counting bare irradiated U-238 foils. The gammas given off are a result of fission product decay. Since U-238 can only be fissioned by neutrons with energies above 1 Mev, the gamma emission is directly proportional to the greater than 1 Mev neutron flux. Thermal neutron capture is insignificant since gamma emission occurs almost immediately after capture.

By counting the same U-238 foils, three days later, the relative resonance flux was obtained. Resonance capture in ${}_{92}\text{U}^{238}$ leads to ${}_{94}\text{Pu}^{239}$ buildup in 2.3 days.

The 104 kev X-ray emitted during the formation of ${}_{94}\text{Pu}^{239}$ was counted. This leads to a measure of the resonance flux. Any thermal neutron capture contribution is insignificant since the gamma emission occurs almost immediately after capture.

Thermal flux shapes were determined using bare gold and bare dysprosium foils. Gamma emission from these foils are due to activation by essentially

thermal neutrons. Thus gamma counting leads to a measure of the thermal flux seen by the foils. It should be pointed out, however, that no cadmium covered foil measurements were made. Thus, the measured flux is somewhat epithermal.

The relative flux shapes in UO_2 and $\text{PuO}_2\text{-UO}_2$ are compared and shown in Figures 7-9. A tabulation of the relative flux values and the position of the foils in the core may be found in Attachment D.

RELATIVE FAST FLUX
IN A 19X19 CORE
MEASURED WITH U238 FOILS

FIGURE 7

• $\text{PuO}_2\text{-UO}_2$ CORE
x UO_2 CORE

RELATIVE FAST FLUX

1.2
1.0
0.8
0.6
0.4
0.2

RELATIVE RESONANCE FLUX
IN A 19X19 CORE
MEASURED WITH U238 FOILS

FIGURE 8

6.0 MODERATOR REACTIVITY WORTHS

During the initial criticality experiments, axial reflector savings (λ_A) and $\delta\rho/\delta H$ measurements at the just critical moderator height were made. A linear plot of moderator height vs. $(\delta\rho/\delta H)^{-1/3}$ was then made for each type of fuel, as shown below.

From these plots, a differential moderator height curve was drawn for the UO_2 and mixed oxide fuels in the fuel region. The LEOPARD^{/1} and AIM-5^{/2} codes were used to calculate $\delta\rho/\delta H$ in the reflector region. The differential worth curves for the UO_2 and mixed oxide fuels are shown in Figures 10 and 11. Subsequent $\delta\rho/\delta H$ data obtained during the critical experiment program are plotted on the curves.

By integrating the area under the differential worth curves, total worth curves were constructed. These curves are shown in Figures 12 and 13.

From the total worth curves, the maximum quantity of reactivity, fully inundated, was determined for each fuel type. For various critical moderator heights, the reactivities were read from the total worth curves. These reactivities were subtracted from the fully flooded reactivity. Thus, the resultant numbers represented the maximum installed reactivity available above the just critical condition. The installed reactivities were converted from dollars to per cent

using calculated β_{eff} 's of 0.00795 and 0.0034 for the UO_2 and mixed-oxide cores respectively. A curve of installed reactivity vs. just critical moderator height is shown in Figure 14. The reactivity worth of a core change can be determined by knowing the critical water height for the unperturbed and perturbed core and taking the difference in their available reactivities. The installed reactivity curve shows the available reactivity for UO_2 and $\text{PuO}_2\text{-UO}_2$ cores is approximately the same for equal water heights.

DIFFERENTIAL MODERATOR WORTH
CURVE
5.742 W/O UO₂ CRITICAL
EXPERIMENTS

7.0 REACTIVITY WORTHS OF PERTURBATIONS TO UNIFORM CRITICAL LATTICES

Table V is a list of the reactivity worths of different perturbations to uniform critical lattices. The worths were obtained from the installed reactivity curves (page 25) by subtracting the installed reactivity at the perturbed moderator height from the installed reactivity at the unperturbed moderator height. Reactivity corrections for differences in temperature between perturbed and unperturbed moderator heights were neglected.

The following information is applicable to Table V:

- (1) All lattice pitches were 0.56" square.
- (2) The water slot was formed by omitting five fuel rods from the center of a 19 x 19 core. The five remaining holes were in a line parallel to one side of the core with the third hole at the core center (Fig. 1).
- (3) The aluminum plate was positioned vertically between core plates in the space left by the five water holes described in (1). The purpose of the plate was to displace water with aluminum. Plate dimensions were one-quarter inch thick by 2.80 inches wide (Fig. 2).
- (4) The control rods were inserted in the water holes of (1). There were five control rods of 0.403 inch diameter composed of an unclad alloy of 80% Cd, 15% In, and 5% Ag (Fig. 3). An additional row of fuel was added in this experiment to form a 21 x 21 square core.

TABLE V

Reactivity Worths of Perturbations to Uniform Critical Lattices

Perturbation	5.74 w/o U-235			6.6 w/o PuO ₂			Boron
	Aluminum Plate	Water Slot	Control Rods	Aluminum Plate	Water Slot	Control Rods	
Core Configuration	19x19	19x19	21x21	19x19	19x19	21x21	
Unperturbed Critical Moderator Height (cm)	81.94	81.94	51.0	80.75	80.75	50.38	81.34 (19x19) 50.38 (21x21)
Unperturbed Water Temperature (°C)	18.4	18.4	16.1	17.0	17.0	15.4	16.9 (19x19) 15.4 (21x21)
Perturbed Critical Moderator Height (cm)	85.73	78.33	87.38	81.36	74.22	77.34	87.77 (25 ppm, 19x19) 97.83 (50 ppm, 19x19) 70.78 (228 ppm, 21x21) 83.00 (309 ppm, 21x21) 88.06 (337 ppm, 21x21)
Perturbed Water Temperature (°C)	18.0	18.4	18.0	16.0	15.4	15.4	16.9 (19x19) 18.0 (21x21)
Reactivity Worth ($\Delta k/k$, %)	-0.27	+0.26	-4.50	-0.04	+0.49	-3.92	-0.39 (25 ppm, 19x19) -0.79 (50 ppm, 19x19) -3.38 (228 ppm, 21x21) -4.36 (309 ppm, 21x21) -4.64 (337 ppm, 21x21)

8.0 TEMPERATURE COEFFICIENT

The temperature coefficient of reactivity was calculated from the installed reactivity curves (page 25) using the critical moderator height at room temperature and an elevated temperature after heating. The data and results are shown below for both fuel types.

<u>UO₂ Fuel</u>		
<u>Temperature</u>	<u>Height</u>	<u>Δk/k (From Curve)</u>
72.85°C	87.45 cm.	0.56%
61.97°C	85.21 cm.	0.61%
18.0 °C	81.94 cm.	0.85%

$$\alpha = \frac{-0.05\%}{10.88^\circ\text{C}} \times \frac{5}{9} = \underline{\underline{-2.55 \times 10^{-5}/^\circ\text{F at } 154^\circ\text{F}}}$$

$$\alpha = \frac{-0.24\%}{43.97^\circ\text{C}} \times \frac{5}{9} = \underline{\underline{-3.03 \times 10^{-5}/^\circ\text{F at } 103.98^\circ\text{F}}}$$

<u>PuO₂-UO₂ Fuel</u>		
<u>Temperature</u>	<u>Height</u>	<u>Δk/k (From Curve)</u>
58.5°C	85.78 cm.	0.66%
17.0°C	80.80 cm.	0.98%

$$\alpha = \frac{-0.32\%}{41.5^\circ\text{C}} \times \frac{5}{9} = \underline{\underline{-4.28 \times 10^{-5}/^\circ\text{F at } 99.86^\circ\text{F}}}$$

where α = temperature coefficient in both cases

The above coefficients are overall temperature coefficients since all the materials in the core were at the same temperature when measurements were made. Care should be used in analyzing these results, as the pitch of the fuel rods at the elevated temperature is governed by the expansion of the aluminum grid plates.

9.0 CIRCUMFERENTIAL THERMAL FLUX AT FUEL ROD SURFACES

The change in the relative thermal flux around the surface of fuel rods, due to different perturbations, was measured with dysprosium wire.

For the UO_2 fuel, the relative thermal flux was measured circumferentially about fuel rods next to the following perturbations.

- (1) The reflector (Fig. 15).
- (2) An aluminum plate (Fig. 16).
- (3) Surrounded by fuel (reference case, Fig. 17).

For the $\text{PuO}_2\text{-UO}_2$ fuel, the relative thermal flux was measured circumferentially about fuel rods next to the following perturbations:

- (1) The reflector (Fig. 18).
- (2) A single water hole (Fig. 19).
- (3) Surrounded by fuel (reference case, Fig. 20).

The results are shown in the indicated figures. Core maps of the fuel loadings are included in Attachment E.

The following increases in thermal flux from the low to the peak flux about the fuel rods may be inferred from the figures:

<u>Perturbation</u>	UO_2	$\text{PuO}_2\text{-UO}_2$
	<u>Peak Flux/Low Flux</u>	<u>Peak Flux/Low Flux</u>
Reflector	$66 \pm 2\%$	$111 \pm 3\%$
Water Hole	-	$47 \pm 2\%$
Aluminum Plate	$28 \pm 1\%$	-
All Fuel Reference	0%	0%

FIGURE 15
CIRCUMFERENTIAL FUEL ROD
FLUX ADJACENT TO THE REFLECTOR
(UO_2 FUEL).

FIGURE 18
CIRCUMFERENTIAL FUEL ROD FLUX
ADJACENT TO THE REFLECTOR
($\text{PO}_2\text{-UO}_2$ FUEL)

10.0 REFERENCES

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ATTACHMENTS

ATTACHMENT A

Core Tank Hardware

Figure A-1 is a photograph of a typical core loading as seen from the top of the core tank. The fuel rods can be seen projecting vertically through the fuel rod holes in the top core plate. Figure A-2, which is a side elevation of the core tank, reveals that there are two additional grid plates below the top grid plate supporting the fuel rods in their vertical position.

The fuel rod holes in the aluminum grid plates are 0.397 ± 0.002 inches in diameter with additional holes of 0.193 ± 0.001 inches in diameter in the middle core plate, for water circulation. The layout of these holes is shown in Figure A-3. The three grid plates are supported at each corner with $7/16$ " SS support rods which are covered with $5/8$ " aluminum pipe. The grid plates with their support rods make up the grid structure.

The grid structure rests on a one inch thick aluminum slab the same size as the bottom grid plate. The one inch slab is supported on $2-1/2$ " thick aluminum feet which stand on a 2" thick by 6 foot diameter aluminum slab. The 6 foot diameter slab supports an approximately four foot diameter tank which surrounds the grid structure and prevents water waves.

Fuel Specifications

The specifications for the five different types of fuel rods designed for Saxton and available for the critical experiments are tabulated in Table A-1. Of the $\text{PuO}_2\text{-UO}_2$ fuel available, only the pelletized zircaloy clad fuel was used in the experiments in this report.

Figure A-1

Core Tank - Top View

FIGURE A-2 - CORE TANK-SIDE ELEVATION

TOP AND BOTTOM CORE PLATE

$A = \text{PITCH}$

FUEL ROD HOLES = 0.397 ± 0.002 " DIA.

MIDDLE CORE PLATE

$A = \text{PITCH}$
 $B = \frac{1}{2}A$

FUEL ROD HOLES = 0.397 ± 0.002 " DIA.
 CIRCULATION HOLES = 0.193 ± 0.001 " DIA.

FIGURE A-3 CORE PLATE LAYOUT

TABLE A-1
Fuel Rod Specifications

	UO_2 Rods* (Pelletized)	PuO_2-UO_2 Rods* (Pelletized)	PuO_2-UO_2 Rods (Vibratory Compacted)	PuO_2-UO_2 Rods (Pelletized)	PuO_2-UO_2 Rods (Vibratory Compacted)
Enrichment	5.74 w/o U-235 in UO_2	6.6 w/o PuO_2 in UO_2	6.6 w/o PuO_2 in UO_2	6.6 w/o PuO_2 in UO_2	6.6 w/o PuO_2 in UO_2
Pellet Diameter	0.357 inch	0.3374 inch	_____	0.3558 inch	_____
Clad O.D.	0.391 inch	0.391 inch	0.391 inch	0.391 inch	0.391 inch
Clad I.D.	0.361 inch	0.3445 inch	0.3445 inch	0.3610 inch	0.3610 inch
Clad Material	304 SS	Zircaloy 4	Zircaloy 4	304 SS	304 SS
% Theoretical Density	93.0	94.0	87.0	94.0	87.0
Fuel Length	36.6 inch	36.6 inch	36.6 inch	36.6 inch	36.6 inch

Theoretical Density of UO_2 = 10.96 grams/cc

Theoretical Density of PuO_2 = 11.46 grams/cc

*Used in the experiments covered by this report.

UO_2

UO_2 weight/rod = 604.250 grams/rod

Weight fraction of U metal = 0.8813

Weight Percent of U-235 = 5.742

U metal = 532.526 grams/rod

U-235 = 30.578 grams/rod

PuO_2-UO_2

Type Fuel (Clad-Fuel)	PuO_2-UO_2 Weight/Rod (gms/rod)	PuO_2 Weight/Rod (gms/rod)	Pu Metal (gms/rod)	Pu-239 (gms/rod)	Pu-240 (gms/rod)	Pu-241 (gms/rod)	Pu-242 (gms/rod)
Zirc-Pellets	546.576	36.074	31.815	28.789	2.727	0.283	0.013
SS-Pellets	608.707	40.175	35.432	32.062	3.037	0.315	0.014
Zirc-Vipac	535.059	35.314	31.145	28.183	2.669	0.277	0.012
SS-Vipac	587.534	38.777	34.199	30.947	2.931	0.304	0.014

Weight Percent of PuO_2 = 6.60

Weight Fraction of Pu Metal = 0.8820

Weight Percent of Pu-239 = 90.49

Weight Percent of Pu-240 = 8.57

Weight Percent of Pu-241 = 0.89

Weight Percent of Pu-242 = 0.04

ATTACHMENT B

Buckling Data

Buckling data were obtained by gamma scanning irradiated fuel rods from the critical cores whose buckling was under investigation. The irradiated fuel rods were gamma counted at four heights along their length in the initial experiments. In later experiments fuel rods were counted at six heights along their length. The data at each height from all the rods counted provided a radial power shape for radial buckling calculations. For axial buckling measurements, two irradiated fuel rods in each core were gamma counted every two centimeters along their length.

The gamma counting included all gamma ray emission above one-half Mev. The total counts obtained were corrected automatically for decay and wait time by the rod scanning apparatus. This was accomplished by using a fuel rod from the same core in a second monitor channel. This monitor channel was programmed to stop the counting equipment after counting a certain number of preset counts from the monitored fuel rod. Since this fuel rod decays at the same rate as those being scanned, the scanned rods yield total counts corrected for decay, wait time and count time. Total counts need only be corrected for dead-time and background to enable a power plot to be made.

Axial and radial bucklings were calculated, from the data, by means of the DARED³ code. The code normalizes and fits the data to either a cosine or Bessel function. DARED makes use of either a COFIT or JOFIT subroutine for this purpose. From the fitting, the code obtains an extrapolated power length. The extrapolated lengths were corrected by hand for dead-time with the formula⁴ shown below. The extrapolated lengths were then divided into π or J_0 to obtain the buckling.

$$H_C = H_O \left[1 - \frac{(\text{Peak Count/sec.})}{1000} \times 0.00025 \right]$$

where, H_C = extrapolated length corrected for dead time

H_O = extrapolated length from DARED

Tables B-1 through B-10 describe the core configurations, data and results of the buckling measurements. The data for each measurement is tabulated on the page following the description and results of that measurement.

Additional measurements and calculations were made on the 0.56 inch lattice as a check on the precision of the measurements. The additional measurements and computations included:

- (1) Radial buckling by U-238 foils in the UO_2 core.
- (2) Radial buckling by U-238 foils in the $\text{PuO}_2\text{-UO}_2$ core.
- (3) Calculations of the radial buckling at each of four planes in the UO_2 core.
- (4) Calculations of the radial buckling at each of six planes in the $\text{PuO}_2\text{-UO}_2$ core.

The additional measurements and calculations in the UO_2 and $\text{PuO}_2\text{-UO}_2$ cores are found in Tables B-2 and B-4 respectively. Longitudinal power shapes and peak to average power for the 0.56 inch lattice are given in Figures B-2A and B-4 for UO_2 and $\text{PuO}_2\text{-UO}_2$ cores, respectively.

TABLE B-1

DATE: March 19, 1965.

CONFIGURATION

FUEL: 5.74 W/O U235 in UO₂.

PITCH: 0.792" square.

CORE GEOMETRY: 13 x 14 rectangle (figure B-1).

MODERATOR TEMP: 17.3°C.

EXCESS REACTIVITY: 0.00156 (ΔK/K).

MODERATOR HEIGHT: 88.96 Centimeters.

BORON: ZERO PPM.

RESULTS

ROD SCAN					
Direction	Planes	H _o (cm.)	H _c (cm.)	B _c ² (cm ⁻²)	
13 rod dimension	{ Average of planes at 35, 40, 50 and 55 cm. }	38.535	38.437	0.00668	
14 rod dimension		40.835	40.731	0.00595	
Axially	{ Average of 2 axial measurements }	96.953	96.798	0.00105	
				0.01368	TOTAL

RADIAL SCANS

Ro	35 Cm. Plane		40 Cm. Plane		50 Cm. Plane		55 Cm. Plane		Rod No.	35 Cm. Plane		40 Cm. Plane		50 Cm. Plane		55 Cm. Plane	
	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)		Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)
2	2.6	20,400	2.6	20,070	2.6	19,580	2.6	17,990	17	3.4	20,510	3.4	20,980	3.4	20,140	3.4	19,060
3	2.7	21,320	2.6	21,380	2.6	20,130	2.6	19,350	18	3.5	21,770	3.5	21,780	3.4	20,980	3.4	19,750
4	2.6	18,860	2.6	18,880	2.7	18,400	2.7	17,310	19	3.5	25,960	3.5	25,860	3.5	24,950	3.5	23,260
5	2.7	27,590	2.7	27,670	2.7	26,440	2.7	25,120	20	3.5	26,710	3.6	27,200	3.6	26,230	3.6	24,600
6	2.8	27,130	2.7	26,700	2.8	26,690	2.8	24,280	21	3.6	24,410	3.6	24,020	3.6	23,210	3.6	21,720
7	2.8	23,670	2.8	23,350	2.8	22,900	2.8	21,600	22	3.6	19,760	3.7	19,560	3.7	19,010	3.7	17,620
8	2.8	18,930	2.8	19,020	2.9	18,710	2.9	17,420	4	3.7	27,330	3.7	27,480	3.7	26,410	3.7	24,800
9	2.9	20,920	2.9	21,200	2.9	20,470	2.9	19,410	23	3.7	20,920	3.8	20,030	3.8	19,190	3.8	18,080
10	2.9	21,600	2.9	22,010	3.0	21,300	2.9	19,890	24	3.8	21,190	3.8	21,020	3.8	20,330	3.9	19,250
Background	3.0	210	3.0	200	3.0	190	3.0	240	25	3.9	25,470	3.9	25,210	3.9	24,210	4.0	22,960
11	3.1	27,670	3.1	27,670	3.1	26,200	3.1	24,820	26	3.9	27,800	3.9	28,010	4.0	26,480	3.9	24,950
12	3.1	24,410	3.1	24,390	3.1	23,370	3.1	22,070	27	4.0	26,810	3.9	26,550	4.0	25,900	4.0	23,900
13	3.1	19,730	3.2	20,050	3.2	19,270	3.2	18,040	28	4.0	25,360	4.0	25,250	4.0	24,550	4.1	23,410
14	3.3	24,870	3.2	24,210	3.2	23,280	3.2	21,720	29	4.0	23,120	4.1	23,710	4.1	22,670	4.1	21,640
15	3.2	14,230	3.2	14,350	3.2	13,800	3.2	12,870	4	4.1	27,590	4.2	27,370	4.1	25,990	4.2	24,790
16	3.3	16,850	3.4	17,060	3.3	16,300	3.3	14,820	Background	4.2	200	4.1	180	4.2	200	4.2	190

AXIAL SCANS

ROD 26			ROD 11			ROD 26			ROD 11		
Count Time (secs)	Plane Position (cm)	Total Count (counts)	Count Time (secs)	Plane Position (cm)	Total Count (counts)	Count Time (secs)	Plane Position (cm)	Total Count (counts)	Count Time (secs)	Plane Position (cm)	Total Count (counts)
4.3	2	8,740	5.4	2	8,600	4.5	96	190	5.6	80	8,250
4.3	6	12,160	5.3	6	11,830	4.5	92	470	5.6	76	11,890
4.3	10	15,570	5.4	10	15,260	4.5	88	1,010	5.6	72	14,740
4.3	14	18,670	5.4	14	18,080	4.5	84	4,680	5.6	68	17,310
4.3	18	21,000	5.4	18	20,960	4.5	80	8,360	5.6	64	20,250
4.4	22	23,680	5.4	22	23,110	4.5	76	11,790	5.7	60	22,740
4.9	26	25,010	5.4	26	25,110	4.5	72	15,070	5.6	56	24,320
4.3	30	26,620	5.4	30	26,140	4.5	68	17,950	5.4	52	25,710
	34	27,360	5.5	34	26,920	4.5	64	20,520	5.7	48	26,290
	38	27,640	5.4	38	27,210	4.5	60	22,860	5.7	44	25,170
4.3	42	26,400	5.4	42	26,390	4.5	56	24,790	5.7	40	27,480
4.3	46	26,070	5.4	46	25,200	4.5	52	25,910	5.7	36	27,430
4.3	50	26,420	5.5	50	26,220	4.6	50	26,420	5.7	32	26,680
4.4	54	25,430	5.4	54	24,770	4.6	48	26,740	5.7	28	25,410
4.4	58	24,150	5.4	58	23,040	4.6	44	25,590	5.7	24	24,320
4.4	62	21,690	5.4	62	21,130	4.6	40	27,350	5.8	20	22,090
4.4	66	19,360	5.4	66	18,980	4.6	36	27,580	5.8	16	19,630
4.4	70	16,390	5.5	70	15,850	4.6	32	27,530	5.7	12	16,760
4.4	74	13,310	5.5	74	13,090	4.6	28	25,950	5.7	8	13,490
4.4	78	9,950	5.5	78	9,690	4.6	24	24,630	5.8	4	10,450
4.4	82	6,480	5.6	82	6,410	4.6	20	22,400			
4.5	86	2,250	5.6	86	2,240	4.6	16	19,650			
4.4	90	680	5.6	90	620	4.6	12	16,960			
4.4	94	220	5.6	92	440	4.7	8	13,940			
4.5	98	200	5.5	88	940	4.6	4	10,300			
4.4	100	180	5.6	84	4,590						

NOTE: Sodium Iodide Crystal Detector Used for the Scanning

FIGURE B-1 LOOSE LATTICE CONFIGURATION
FOR UO_2

TABLE B-2

DATE: March 24, 1965.

CONFIGURATION

FUEL: 5.74 W/O U235 in UO₂.

PITCH: 0.56" square.

CORE GEOMETRY: 19 x 19 square (figure B-2).

MODERATOR TEMP: 18.0°C.

EXCESS REACTIVITY: 0.0.

MODERATOR HEIGHT: 82.05 centimeters.

BORON: ZERO PPM.

RESULTS

ROD SCAN				
Direction	Planes	Ho (cm.)	Hc (cm.)	Bc ² (cm ⁻²)
North-South	{ Average of planes at 35, 40, 50 and 55 cm. }	40.793	40.712	0.00595
East-West		41.954	41.870	0.00563
Axially	{ Average of 2 axial measurements }	93.644	93.457	0.00113
				0.01271 TOTAL

North-South	35 cm.	40.472		0.00603
	40 cm.	40.203		0.00611
	50 cm.	41.868		0.00563
	55 cm.	40.822		0.00592
East-West	35 cm.	41.570		0.00571
	40 cm.	41.815		0.00564
	50 cm.	41.589		0.00571
	55 cm.	42.851		0.00538

U 238 FOIL

North-South	Mid-plane	41.743	0.00566
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TABLE B-2

POWER SCAN DATA FOR BUKKLING
0.56" Pitch, 5.74 w/o UO₂

RADIAL SCANS

Rod No.	35 cm. Plane		40 cm. Plane		50 cm. Plane		55 cm. Plane		Rod No.	35 cm. Plane		40 cm. Plane		50 cm. Plane		55 cm. Plane	
	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)		Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)
19	4.2	27,030	4.2	25,970	4.2	24,560	4.3	22,510	31	5.1	25,350	5.1	24,640	5.1	22,660	5.3	21,070
21	4.2	30,580	4.2	29,520	4.3	28,000	4.3	25,850	30	5.4	27,100	5.3	26,090	5.4	24,740	5.4	22,720
23	4.3	33,330	4.3	32,150	4.3	30,040	4.3	27,950	19	5.4	26,740	5.4	26,160	5.4	24,490	5.4	22,550
1	4.3	34,950	4.3	34,210	4.3	32,300	4.4	30,120	25	5.8	33,450	5.9	33,310	5.8	30,760	5.8	28,190
3	4.3	24,800	4.4	24,750	4.3	22,640	4.4	21,130	16	6.0	26,940	5.9	26,660	5.9	24,650	6.1	23,040
5	4.4	29,430	4.4	28,600	4.4	26,410	4.4	24,300	19	6.1	30,788	6.0	26,340	6.1	24,770	6.0	22,500
7	4.4	32,390	4.4	31,750	4.4	28,750	4.5	27,240	14	6.1	33,210	6.2	30,820	6.1	28,460	6.2	26,230
9	4.4	33,120	4.4	32,870	4.4	30,510	4.5	28,260	12	6.1	33,210	6.1	33,450	6.1	30,220	6.1	28,130
11	4.5	33,860	4.5	33,030	4.6	30,690	4.5	27,790	10	6.2	33,980	6.2	33,450	6.2	30,810	6.2	28,660
13	4.6	32,480	4.6	31,870	4.6	29,200	4.6	27,040	8	6.2	33,590	6.2	32,740	6.0	29,950	6.2	27,610
19	4.5	26,440	4.6	26,310	4.6	24,800	4.6	22,530	6	6.3	30,940	6.2	29,860	6.3	28,090	6.3	25,940
15	4.7	28,880	4.6	28,060	4.7	26,640	4.7	24,530	4	6.4	27,210	6.4	27,180	6.3	24,360	6.4	23,110
17	4.7	25,580	4.6	24,820	4.6	22,830	4.7	21,310	2	6.5	26,020	6.4	24,890	6.5	24,080	6.3	21,410
26	4.9	32,550	4.8	32,310	4.8	29,830	4.9	27,920	24	6.4	33,550	6.4	33,360	6.4	30,390	6.4	28,370
27	4.9	32,550	4.9	32,300	4.9	29,800	5.0	27,340	22	6.5	32,640	6.4	31,390	6.5	29,380	6.5	27,400
28	5.0	30,680	4.9	29,610	5.0	28,060	5.0	26,300	20	6.5	28,750	6.5	28,140	6.6	26,450	6.6	24,680
19	5.0	27,060	5.0	26,450	5.1	24,900	5.1	22,680	19	6.7	26,850	6.6	26,700	6.6	24,640	6.6	22,530
29	5.0	28,910	5.1	28,600	5.1	26,380	5.0	24,220	18	7.1	26,320	7.1	25,720	7.0	24,110	7.0	22,120
33	5.3	35,930	5.3	34,690	5.3	32,550	5.3	29,780	Background	7.1	120	7.2	150	7.2	160	7.2	160
32	5.3	25,420	5.3	25,030	5.1	32,270	5.1	21,300									

AXIAL SCANS

ROD 10			ROD 34			ROD 10			ROD 34		
Count Time (secs)	Plane Position (cm)	Total Count (counts)	Count Time (secs)	Plane Position (cm)	Total Count (counts)	Count Time (secs)	Plane Position (cm)	Total Count (counts)	Count Time (secs)	Plane Position (cm)	Total Count (counts)
2.2	2	11,510	2.8	2	9,510	2.3	96	210	3.0	96	210
2.2	6	15,970	2.8	6	13,020	2.3	92	230	3.0	92	340
2.3	10	20,340	2.9	10	16,460	2.3	88	600	2.9	88	550
2.2	14	23,150	2.8	14	19,270	2.3	84	1,120	3.0	84	910
2.2	18	26,760	2.9	18	20,850	2.3	80	3,410	3.0	80	2,810
2.2	22	28,750	2.8	22	23,690	2.4	76	9,840	3.0	76	7,860
2.3	26	31,040	2.9	26	25,510	2.3	72	13,880	3.0	72	11,560
2.2	30	32,340	2.9	30	27,010	2.3	68	17,940	3.0	68	14,880
2.2	34	32,710	2.8	34	27,650	2.3	64	21,770	3.0	64	17,880
2.3	38	33,320	2.9	38	27,460	2.3	60	24,370	3.0	60	20,870
2.3	42	31,260	2.8	42	25,720	2.3	56	27,130	3.0	56	22,610
2.3	46	29,400	2.9	46	24,050	2.4	52	29,430	3.0	52	24,670
2.3	50	30,350	2.9	50	24,740	2.3	48	30,720	3.0	48	24,920
2.3	54	28,440	2.9	54	23,600	2.3	44	28,100	3.0	44	23,440
2.3	58	25,920	2.9	58	21,590	2.4	40	32,350	3.0	40	27,240
2.3	62	23,430	2.9	62	19,300	2.4	36	33,090	3.0	36	27,070
2.3	66	19,550	2.8	66	15,760	2.4	32	32,680	3.0	32	27,540
2.3	70	16,220	2.9	70	13,280	2.4	28	31,770	3.0	28	26,190
2.2	74	11,880	2.9	74	9,680	2.4	24	30,870	3.0	24	25,070
2.3	78	6,720	2.7	78	5,420	2.4	20	28,090	3.1	20	23,140
2.3	82	1,640	2.9	82	1,420	2.4	16	24,660	3.0	16	20,480
2.3	86	780	2.9	86	690	2.4	12	21,570	3.0	12	17,610
2.3	90	460	2.9	90	440	2.4	8	17,690	3.0	8	14,490
2.3	94	230	2.9	94	210	2.4	4	4,400	3.0	4	11,270

NOTE: Sodium Iodide Crystal Detector Used for the Scanning

U238 FOIL, BUCKLING DATA (UO2 CORE)

<u>FOIL #</u>	<u>COUNTS</u>	<u>FOIL WEIGHT</u>
21	21,167	
36	14,280	0.1052
18	15,601	0.1115
19	16,748	0.1128
20	16,691	0.1073
21	17,846	0.1114
22	18,451	0.1142
23	18,949	0.1146
24	17,030	0.1042
10	16,500	0.1034
21	15,371	
25	15,594	0.1031
26	15,454	0.1058
27	15,877	0.1125
21	13,594	
28	13,499	0.1053
29	13,138	0.1120
30	12,155	0.1110
21	12,395	
31	10,797	0.1113
32		
33	8,522	0.1054
37	8,499	0.1114
21	11,507	
38	7,533	0.1072
39	6,775	0.1050
21	10,508	
40	6,095	0.1122
41	4,276	0.1018
42	3,515	0.1054
21	9,716	
43	2,819	0.1126
44	2,097	0.1060
21	9,084	

- NOTES: (1) Counting times were 15 seconds per foil with a 45 second interval between counts.
(2) Foils positioned between fuel rods at mid-plane (figure B-2).
(3) Background = 45 counts in 15 seconds.

FIGURE B-2 TIGHT LATTICE CONFIGURATION
FOR UO₂ & PUO₂-UO₂ CORES

TABLE B-3

DATE: April 20, 1965.

CONFIGURATION

FUEL: 6.6 W/O PuO₂ in UO₂ pellitized (Zr clad).

PITCH: 0.792" square.

CORE GEOMETRY: 12 x 12 square (figure B-3).

MODERATOR TEMP: 16.1 C.

EXCESS REACTIVITY: 0.0.

MODERATOR HEIGHT: 76.76 Centimeters.

BORON: ZERO PPM.

RESULTS

POWER SCAN				
Direction	Planes	Ho (cm.)	Hc (cm.)	² Bc (cm-2)
NE - SW	{ Average of 2 counts of the sum over planes at 10, 18, 26 34, 52 and 60 cm. }	36.801	36.553	0.00739
NW - SE		37.277	37.027	0.00720
Axially	{ Average of 2 axial measurements }	86.283	85.705	<u>0.00134</u> 0.01593 TOTAL

TABLE B-3

POWER SCAN DATA FOR BUCKLING
0.792" Pitch, 6.6 w/o PuO₂

RADIAL SCANS

Rod No.	10 cm. Plane		18 cm. Plane		26 cm. Plane		34 cm. Plane		52 cm. Plane		60 cm. Plane	
	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)
4	3.9	17,560	3.9	23,940	3.9	28,950	3.9	30,640	4.0	25,840	3.9	20,230
2	3.9	14,690	3.9	20,280	4.0	24,240	4.0	25,560	4.0	20,460	3.9	16,760
6	4.1	19,280	4.0	26,480	4.1	31,420	4.1	33,360	4.1	28,340	4.0	22,090
Background	4.1	290	4.1	250	4.1	250	4.1	240	4.1	240	4.1	260
8	4.1	19,050	4.2	26,400	4.2	30,730	4.2	33,040	4.2	27,830	4.2	21,580
10	4.2	16,270	4.2	22,180	4.2	26,020	4.3	28,370	4.3	23,360	4.3	18,760
12	4.3	16,460	4.3	22,270	4.4	26,760	4.3	27,730	4.3	23,910	4.3	19,050
11	4.3	14,730	4.4	20,250	4.4	24,050	4.4	25,710	4.4	21,690	4.4	17,180
9	4.4	17,890	4.4	24,830	4.5	29,270	4.5	31,200	4.5	26,170	4.4	20,910
8	4.5	18,890	4.5	26,060	4.5	31,720	4.4	32,770	4.5	28,170	4.5	21,790
7	4.6	19,420	4.5	26,460	4.6	31,870	4.5	33,770	4.6	28,600	4.6	22,580
Background	4.6	340	4.7	250	4.6	230	4.6	250	4.6	230	4.6	250
5	4.4	18,850	4.3	25,910	4.7	30,340	4.8	33,400	4.4	27,410	4.7	22,100
3	4.7	16,060	4.7	22,160	4.7	26,200	4.7	27,730	4.7	23,610	4.7	18,680
1	4.7	16,460	4.8	22,890	4.9	27,530	4.8	28,500	4.8	24,000	4.8	18,270
13	4.9	14,550	4.9	20,120	4.9	23,810	4.9	25,640	5.0	21,350	4.9	16,900
15	5.0	17,760	5.0	24,400	5.0	28,650	5.0	30,750	5.1	26,510	5.1	20,910
17	5.1	19,610	5.2	26,980	5.1	31,340	5.2	34,070	5.0	27,880	5.0	22,490
19	5.2	17,660	5.2	24,270	5.2	28,590	5.2	30,710	5.2	25,690	5.2	20,480
21	5.3	15,020	5.2	20,170	5.3	23,920	5.3	25,270	5.3	21,350	5.3	16,970
20	5.4	16,090	5.4	22,380	5.5	26,870	5.1	27,490	5.4	23,290	5.4	18,840
18	5.4	18,760	5.5	26,080	5.5	30,870	5.6	32,820	5.6	27,630	5.5	21,680
16	5.6	18,840	5.6	26,350	5.6	30,920	5.6	32,920	5.6	27,760	5.7	22,160
14	5.7	15,850	5.7	22,370	5.7	26,100	5.8	28,540	5.7	23,710	5.7	18,450
8	6.0	18,900	6.0	26,340	6.0	31,290	5.9	32,220	6.0	27,970	6.0	22,370
Background	6.3	210	6.2	240	6.2	200	6.2	220	6.3	240	6.3	240

SECOND COUNT

1	11.5	16,730	11.6	23,090	11.6	27,570	11.6	29,040	11.6	24,210	11.7	18,990
3	11.6	16,330	11.8	23,020	11.8	26,930	11.8	28,270	11.9	24,200	11.9	19,020
5	11.8	18,830	12.0	26,080	11.7	30,340	11.9	32,990	12.0	28,070	11.9	21,840
7	12.0	19,370	12.0	27,000	12.2	32,140	12.2	34,250	12.0	28,410	12.1	22,580
9	—	—	12.0	24,310	12.0	27,000	12.3	31,290	12.4	26,840	12.5	21,290
11	12.1	14,860	12.2	20,420	12.4	24,400	12.4	26,060	12.3	21,340	12.3	17,190
1	12.7	16,840	12.7	23,210	12.5	27,140	12.7	29,290	12.6	24,010	12.7	19,240
14	12.7	16,210	12.8	22,550	12.7	26,350	12.9	28,420	12.8	23,560	12.8	18,640
16	13.0	18,890	13.0	26,340	13.0	31,430	12.8	32,690	13.0	27,450	13.1	22,030
18	13.2	18,990	13.3	26,550	13.2	31,120	13.2	33,260	13.1	27,520	13.2	21,750
20	13.3	16,220	13.5	22,810	13.5	26,430	13.4	27,950	13.3	23,440	13.4	18,700
1	14.0	16,790	14.0	32,320	14.2	27,660	14.1	29,340	14.1	24,550	14.0	19,210
Background	14.2	240	14.4	220	14.4	170	14.5	220	14.5	230	14.6	220
21	16.7	15,250	16.4	20,580	16.5	24,290	16.4	26,030	16.5	21,730	16.6	17,010
19	17.0	18,140	16.6	24,730	16.8	29,710	16.7	30,870	16.8	25,940	16.6	20,280
17	16.9	19,610	16.9	27,160	17.0	32,130	17.1	34,610	17.1	28,730	17.0	22,620
15	17.0	17,750	17.2	24,730	17.3	29,800	17.0	31,010	17.3	26,520	17.3	20,710
13	17.2	14,630	17.5	20,320	17.7	24,700	17.8	26,180	17.9	22,330	17.8	17,350
12	17.9	16,550	17.9	32,190	17.9	26,960	18.1	29,180	18.1	24,540	18.4	19,470
Background	18.3	210	18.4	190	18.3	220	18.4	210	18.2	200	18.3	220
10	18.6	16,610	18.5	22,380	18.4	26,840	18.6	28,490	18.6	23,850	18.7	18,720
8	19.0	19,130	19.0	27,110	18.9	31,100	19.2	34,010	19.0	28,090	19.1	22,460
6	19.1	19,560	19.2	27,210	19.3	32,140	19.5	34,910	19.3	28,720	19.4	22,200
4	19.4	17,950	19.6	24,550	19.4	29,150	19.5	31,040	19.5	26,060	19.4	20,310
2	19.7	14,890	19.9	20,620	19.7	24,080	19.9	25,890	19.8	21,870	20.0	17,160
1	19.9	16,770	20.0	22,990	20.2	27,900	20.0	29,260	20.2	24,410	20.2	19,320
Background	20.2	200	20.4	190	20.5	190	20.5	180	20.4	200	20.8	210

TABLE B-3 (continued)

AXIAL SCANS

ROD 4			ROD 15		
Count Time (secs)	Plane Position (cm)	Total Counts (counts)	Count Time (secs)	Plane Position (cm)	Total Counts (counts)
6.8	2	9,920	7.4	2	10,240
6.8	6	13,430	7.4	6	13,840
6.7	10	17,550	7.3	10	17,480
6.8	14	21,470	7.3	14	21,230
6.8	18	24,080	7.3	18	24,390
6.8	22	26,990	7.4	22	26,970
6.8	26	29,020	7.4	26	29,890
6.8	30	30,020	7.4	30	30,460
6.9	34	31,450	7.4	34	30,990
6.9	38	30,910	7.5	38	31,200
6.8	42	29,020	7.4	42	30,040
6.8	46	25,880	7.5	46	26,130
6.8	50	26,720	7.4	50	26,550
6.8	54	24,700	7.4	54	24,760
6.9	58	22,090	7.5	58	22,770
6.9	62	18,630	7.5	62	18,830
6.9	66	15,250	7.5	66	15,170
6.9	70	10,870	7.5	70	11,030
6.9	74	6,130	7.5	74	6,080
7.0	78	1,270	7.6	78	1,280
7.0	82	670	7.6	82	630
6.9	86	450	7.5	86	480
7.0	90	370	7.6	90	390
6.9	94	230	7.7	94	260
7.1	98	360	7.6	98	360
7.1	100	420	7.7	100	370
7.1	104	570	7.7	104	570
7.2	108	820	7.8	108	900
7.0	112	3,110	7.8	112	3,210
7.1	116	8,840	7.8	116	9,030
7.1	120	13,280	7.1	120	13,530
7.2	124	17,130	7.8	124	17,150
7.1	128	20,530	7.9	128	21,090
7.2	132	24,060	7.8	132	23,770
7.1	136	25,440	7.8	136	26,410
7.2	140	26,830	7.9	140	26,840
7.2	144	28,710	8.0	144	29,020
7.3	148	30,750	8.0	148	31,000
7.1	152	30,830	7.9	152	30,940
7.2	156	30,790	7.9	156	31,060
7.3	160	30,110	8.0	160	29,910
7.2	164	27,770	7.9	164	28,020
7.2	168	25,430	7.9	168	25,860
7.2	172	22,730	8.0	172	23,080
7.2	176	19,430	8.0	176	19,740
7.3	180	15,670	7.9	180	15,670
7.3	184	10,290	8.1	184	11,590

TABLE B-4

DATE: April 15, 1965.

CONFIGURATION

FUEL: 6.6 W/O PuO₂ in UO₂ pelletized (Zr clad).
 PITCH: 0.56" square.
 CORE GEOMETRY: 19 x 19 square (figure B-2).
 MODERATOR TEMP: 17.0°C.
 EXCESS REACTIVITY: 0.0.
 MODERATOR HEIGHT: 80.80 Centimeters.
 BORON: ZERO PPM.

RESULTS

POWER SCAN

Direction	Planes	Ho (cm.)	Hc (cm.)	Bc (cm-2)
North-South	Sum of six planes at 10, 18, 26, 34, 52 and 60 cm.	42.104	41.851	0.00563
East-West		42.841	42.584	0.00544
Axially	Average of 2 axial measurements	93.503	92.942	0.00114
				0.01221 TOTAL

North-South	10 cm.	39.420		0.00635
	18 "	41.528		0.00572
	26 "	41.642		0.00569
	34 "	39.532		0.00632
	52 "	40.846		0.00592
	60 "	40.022		0.00616
East-West	10 "	41.896		0.00562
	18 "	41.780		0.00565
	26 "	44.178		0.00506
	34 "	46.372		0.00459
	52 "	42.288		0.00552
	60 "	41.798		0.00565

<u>U238 FOIL</u>				
North-South	Mid-plane	40.747		0.00594
East-West	" "	41.548		0.00572

TABLE B-4 (continued)
 POWER SCAN DATA FOR BUCKLING
 0.56" Pitch, 6.6 w/o PuO₂

RADIAL SCANS

Rod No.	10 cm. Plane		18 cm. Plane		26 cm. Plane		34 cm. Plane		52 cm. Plane		60 cm. Plane	
	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)
35	—	—	3.2	18,910	3.2	21,750	3.2	23,600	3.2	21,500	3.1	18,170
18	3.2	8,400	3.2	11,600	3.2	13,400	3.2	14,590	3.2	13,280	3.2	11,350
20	3.2	9,860	3.3	13,680	3.2	15,560	3.3	16,860	3.2	14,720	3.2	12,670
22	3.3	10,900	3.3	14,870	3.2	17,130	3.3	18,450	3.3	16,780	3.3	14,060
24	3.3	11,200	3.3	15,400	3.3	18,320	3.3	19,040	3.3	17,430	3.3	14,170
25	3.3	11,520	3.3	15,200	3.4	18,900	3.3	19,690	3.3	17,670	3.4	15,180
27	3.4	10,890	3.4	14,590	3.3	17,430	3.4	19,190	3.4	16,830	3.4	14,080
29	3.4	9,940	3.4	13,170	3.4	15,690	3.4	16,870	3.4	14,910	3.4	12,500
35	3.4	12,970	3.4	17,910	3.5	21,170	3.4	22,800	3.5	20,920	3.5	17,930
31	3.5	8,430	3.4	11,580	3.5	13,470	3.5	14,500	3.5	13,170	3.5	11,170
Background	3.5	250	3.5	240	3.5	210	3.5	230	3.6	240	3.5	230
30	3.5	8,680	3.6	12,400	3.6	14,920	3.5	15,510	3.6	14,030	3.6	11,730
28	3.6	10,430	3.6	14,230	3.6	16,610	3.6	18,030	3.6	15,840	3.6	13,680
26	3.6	11,150	3.6	15,240	3.6	17,890	3.6	19,080	3.6	16,940	3.6	14,750
10	3.7	11,280	3.7	15,560	3.6	17,930	3.6	19,430	3.7	17,710	3.7	15,230
23	3.7	11,150	3.7	14,870	3.7	17,840	3.7	18,900	3.7	16,780	3.7	14,250
21	3.8	10,430	3.7	14,270	3.7	16,870	3.8	17,850	3.8	15,890	3.8	13,610
19	3.8	8,910	3.8	12,330	3.8	14,350	3.8	15,640	3.8	14,030	3.8	11,990
36	3.8	8,710	3.8	11,510	3.8	13,800	3.8	14,740	3.8	13,400	3.9	11,640
35	3.9	13,770	3.8	18,170	3.9	22,090	3.9	23,200	3.9	21,120	3.9	18,030
Background	3.9	230	3.9	250	3.9	220	3.9	210	3.9	220	3.9	250
3	3.9	8,600	3.9	11,310	3.9	13,560	3.9	14,770	3.9	13,170	3.9	11,230
5	4.0	9,770	4.0	13,240	4.0	15,920	4.0	16,630	4.0	15,040	4.0	12,820
7	4.0	10,770	4.0	14,880	4.1	17,980	4.0	18,650	4.1	16,960	4.0	14,050
9	4.1	11,230	4.1	15,370	4.1	18,140	4.0	18,910	4.1	17,470	4.1	14,770
12	4.1	11,140	4.1	15,240	4.1	17,480	4.1	18,970	4.1	16,850	4.2	14,750
14	4.1	10,210	4.1	14,120	4.1	16,540	4.2	18,020	4.2	16,220	4.2	13,760
16	4.2	9,220	4.2	12,330	4.2	15,030	4.2	16,350	4.3	14,100	4.3	12,180
17	4.3	8,350	4.3	11,490	4.3	13,500	4.3	14,730	4.3	13,300	4.3	11,180
15	4.3	9,910	4.3	13,590	4.4	15,820	4.3	17,170	4.4	15,500	4.4	13,080
13	4.4	11,240	4.3	14,530	4.5	18,520	4.4	19,560	4.5	17,080	4.4	14,360
11	4.5	11,470	4.5	15,340	4.5	18,520	4.4	19,510	4.5	17,850	4.4	14,960
8	4.5	11,030	4.5	15,120	4.5	17,680	4.5	19,430	4.5	16,650	4.5	14,640
6	4.6	10,370	4.6	14,150	4.6	16,540	4.5	18,160	4.6	16,370	4.6	13,780
4	4.6	9,010	4.6	12,630	4.6	14,590	4.6	16,060	4.6	13,880	4.6	11,960
35	4.6	13,530	4.7	18,590	4.6	21,870	4.7	23,870	4.6	21,340	4.7	18,490
Background	4.6	240	4.7	210	4.7	240	4.7	220	4.7	210	4.7	240
35	5.9	13,370	5.9	18,350	5.9	21,270	5.9	22,500	5.9	20,650	6.0	8,980

TABLE B-4 (continued)

AXIAL SCANS

ROD 10			ROD 14		
Count Time (secs)	Plane Position (cm)	Total Counts (counts)	Count Time (secs)	Plane Position (cm)	Total Counts (counts)
2.5	2	7,230	2.6	2	6,560
2.5	6	9,070	2.6	6	8,020
2.5	10	11,380	2.6	10	10,340
2.5	14	13,770	2.6	14	12,140
2.5	18	15,320	2.7	18	14,440
2.5	22	17,040	2.7	22	15,760
2.5	26	17,779	2.7	26	16,600
2.5	30	19,130	2.7	30	17,390
2.5	34	19,800	2.7	34	18,320
2.5	38	19,860	2.6	38	17,990
2.5	42	19,350	2.7	42	17,320
2.5	46	16,400	2.7	46	14,810
2.5	50	18,100	2.7	50	16,200
2.5	54	17,620	2.7	54	15,760
2.5	58	15,960	2.7	58	14,440
2.5	62	13,850	2.7	62	13,050
2.5	66	12,320	2.7	66	11,140
2.5	70	10,000	2.7	70	9,000
2.5	74	7,756	2.7	74	6,950
2.5	78	4,600	2.7	78	4,240
2.5	82	1,170	2.7	82	1,130
2.5	86	620	2.7	86	600
2.6	90	440	2.7	90	450
2.1	92	330	2.7	94	270
2.5	92	390	2.3	98	240
2.5	88	520	2.7	96	270
2.5	84	770	2.7	92	410
2.5	80	2,790	2.7	88	510
2.6	76	6,410	2.7	84	730
2.6	72	8,950	2.7	80	2,550
2.6	68	11,350	2.7	76	5,560
2.6	64	13,440	2.7	72	8,080
2.6	60	15,150	2.7	68	10,150
2.5	56	16,260	2.7	64	12,120
2.6	52	17,810	2.7	60	13,850
2.6	50	18,270	2.8	56	15,180
2.6	48	17,420	2.7	52	16,170
2.6	44	18,680	2.8	50	16,490
2.6	40	19,780	2.7	48	15,830
2.6	36	19,840	2.8	44	17,260
2.6	32	19,300	2.7	40	17,790
2.6	28	18,430	2.7	36	17,850
2.6	24	17,140	2.8	32	18,050
2.6	20	16,440	2.8	28	17,100
2.6	16	14,380	2.7	24	15,940
2.5	12	12,120	2.7	20	14,580
2.6	8	10,100	2.8	16	13,050
2.5	4	7,510	2.7	12	11,240
			2.8	8	9,160
			2.8	4	7,030

U 238 FOIL, BUCKLING DATA (PuO₂ - UO₂ CORE)

NORTH - SOUTH

<u>FOIL #</u>	<u>COUNTS</u>	<u>FOIL WT. (GMS.)</u>
29	38,426	
38	26,409	0.1072
37	29,666	0.1125
33	29,671	0.1117
32	28,332	0.1054
29	34,349	0.1060
31	29,570	0.1070
30	30,964	0.1073
29	31,979	
28	33,804	0.1068
27	36,889	0.1143
26	35,165	0.1069
25	35,029	0.1062
29	29,049	
10	35,314	0.1112
29	28,077	
24	33,956	0.1103
23	33,352	0.1054
24	32,613	
29	25,935	
22	30,551	0.1109
21	27,246	0.1034
20	26,799	0.1090
19	24,099	0.1060
29	23,796	
18	22,036	0.1072
36	19,910	0.1054
35	18,735	0.1046
45	17,097	0.1036
29	21,855	
46	16,650	0.1081
47	15,054	0.1064
48	12,883	0.1054
49	10,663	0.1077
29	20,295	

- Notes: 1) Counting times were 30 seconds per foil with a 20 second interval between counts.
- 2) Foils positioned between fuel rods at mid-plane (figure B-2).
- 3) Background = 1341 counts in 30 secs.

EAST - WEST

<u>FOIL #</u>	<u>COUNTS</u>	<u>FOIL WT. (GMS.)</u>
5	28,965	
58	21,257	0.1124
57	21,874	0.1078
1	21,952	0.1072
2	22,355	0.1058
5	26,665	
3	23,208	0.1077
4	24,138	0.1060
5	25,956	0.1062
6	27,928	0.1118
7	29,501	0.1150
8	29,707	0.1134
9	29,160	0.1092
5	23,740	
10	26,962	0.1038
11	28,280	0.1098
12	26,208	0.1058
13	25,101	0.1038
5	22,062	
14	25,948	0.1154
15	23,956	0.1126
16	21,466	0.1070
17	20,540	0.1122
5	20,758	
50	17,705	0.1062
51	16,279	0.1054
52	15,694	0.1058
53	15,037	0.1058
5	19,319	
54	13,891	0.1094
55	11,599	0.1031
56	9,583	0.1068
5	18,542	

- 1) Counting times were 30 seconds per foil with a 30 second interval between counts.
- 2) Foils positioned between fuel rods at mid-plane (figure B-2).
- 3) Background = 295 counts in 30 secs.

TABLE B-5

DATE: May 11, 1965.

CONFIGURATION

FUEL: 6.6 W/O PuO₂ in UO₂ pellitized (Zr clad).

PITCH: 0.56" square.

CORE GEOMETRY: 21 x 21 square (figure B-5).

MODERATOR TEMP. 18.0°F.

EXCESS REACTIVITY: 0.0.

MODERATOR HEIGHT: 88.06 Centimeters.

BORON: 337 PPM.

RESULTS

POWER SCAN				
<u>Direction</u>	<u>Planes</u>	<u>H_o</u> <u>(cm.)</u>	<u>H_c</u> <u>(cm.)</u>	<u>B_c²</u> <u>(cm⁻²)</u>
North-South	{ Sum of six planes at 10, 18, 26, 34, 52 and 60 cm.	43.880	43.80	0.005144
East-West		43.981	43.902	0.005121
Axially	{ Average of 2 axial measurements }	101.40	101.19	<u>0.000964</u> 0.01123
				TOTAL

TABLE B-5 (continued)

POWER SCAN DATA FOR BUCKLING
0.56" Pitch, 6.6 w/o PuO₂, 337 ppm Boron

RADIAL SCANS

Rod No.	10 cm. Plane		18 cm. Plane		26 cm. Plane		34 cm. Plane		52 cm. Plane		60 cm. Plane	
	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)
Background	—	—	3.6	460	3.7	400	3.7	440	3.7	470	3.7	460
36	3.7	14,860	3.7	20,090	3.8	24,120	3.7	26,610	3.7	25,330	3.7	22,910
35	3.8	15,330	3.8	21,410	3.9	25,530	3.8	27,940	3.9	27,880	3.8	24,920
26	3.9	15,920	3.9	21,480	3.9	26,320	4.0	28,760	3.9	28,090	3.9	25,480
17	3.9	11,180	4.0	15,460	4.0	18,160	4.0	20,170	4.0	19,850	4.1	17,640
34	4.1	10,760	4.0	14,880	4.1	18,010	4.0	19,780	4.2	19,340	4.1	17,640
31	4.1	12,830	4.1	17,760	4.2	21,570	4.2	23,390	4.2	22,840	4.2	20,670
33	4.2	11,230	4.2	15,430	4.2	18,320	4.3	20,280	4.3	19,590	4.3	17,510
36	4.3	14,410	4.3	19,992	4.3	24,020	4.3	26,170	4.4	25,910	4.4	23,570
32	4.4	12,280	4.4	16,710	4.4	19,740	4.4	21,870	4.4	21,230	4.5	19,450
20	4.5	12,920	4.5	17,950	4.5	21,650	4.5	23,990	4.5	22,900	4.6	21,150
21	4.5	14,010	4.6	19,050	4.5	22,610	4.6	25,430	4.7	24,740	4.6	22,360
16	4.6	11,850	4.6	16,470	4.7	19,840	4.7	21,740	4.8	21,400	4.7	19,280
19	4.7	11,930	4.8	16,080	4.7	19,740	4.8	21,700	4.8	21,370	4.8	19,530
18	4.8	10,690	4.9	15,080	4.8	18,120	4.8	19,750	4.9	19,640	4.9	17,770
36	4.9	14,600	4.9	20,100	4.9	24,450	4.9	26,550	5.0	26,130	5.0	23,710
Background	5.1	450	5.1	430	5.0	410	5.0	400	5.1	430	5.1	400
13	5.1	14,750	5.1	19,770	5.1	24,050	5.2	26,000	5.2	25,590	5.2	23,350
15	5.2	12,870	5.3	17,940	5.3	21,590	5.2	23,530	5.3	22,860	5.2	20,260
12	5.3	15,160	5.3	20,660	5.4	25,190	5.4	27,800	5.4	27,070	5.4	24,310
14	5.5	13,810	5.5	19,280	5.4	22,720	5.5	25,420	5.5	24,640	5.5	22,570
11	5.6	15,660	5.6	21,750	5.6	26,160	5.6	28,780	5.5	27,390	5.6	25,030
28	5.6	15,260	5.6	21,090	5.7	25,060	5.7	27,670	5.7	26,870	5.8	24,650
36	5.8	14,420	5.7	20,040	5.9	24,200	5.8	26,630	5.7	25,740	5.8	23,750
27	5.9	15,590	5.9	21,090	5.9	25,780	5.9	28,320	5.9	27,750	6.0	25,210
23	6.0	15,230	6.0	21,030	6.1	25,610	6.1	28,110	6.1	29,960	6.1	24,570
24	6.2	15,860	6.2	21,500	6.2	26,060	6.1	28,170	6.2	27,380	6.2	25,290
22	6.2	14,430	6.3	20,380	6.2	24,240	6.3	26,690	6.3	26,160	6.3	23,130
30	6.3	14,250	6.4	19,250	6.4	22,910	6.4	25,310	6.5	25,140	6.4	22,430
29	6.5	14,560	6.5	20,230	6.5	24,300	6.5	26,940	6.5	25,480	6.6	23,650
36	6.6	14,550	6.7	20,190	6.6	24,580	6.6	26,940	6.8	26,000	6.7	23,940
25	6.8	16,030	6.7	21,500	6.8	26,040	6.8	28,670	6.9	28,400	6.8	25,510
5	6.7	14,000	6.9	19,910	7.0	23,930	6.8	25,850	6.9	25,710	7.0	23,910
1	7.0	11,200	7.0	15,110	7.0	17,850	7.0	19,940	7.1	19,510	7.1	17,550
4	7.0	13,460	7.1	18,770	7.1	22,720	7.1	24,870	7.3	24,670	7.2	22,270
2	7.2	11,890	7.3	16,520	7.3	19,700	7.3	21,950	7.4	21,420	7.3	18,770
3	7.4	13,000	7.3	17,590	7.4	21,600	7.6	23,950	7.5	23,270	7.5	21,000
36	7.6	14,770	7.7	20,490	7.6	24,360	7.6	26,690	7.7	26,120	7.7	23,620
6	7.6	14,770	7.7	20,920	7.8	24,860	7.7	27,070	7.9	27,710	7.9	25,030
10	7.8	16,050	7.8	21,960	8.0	26,750	7.9	28,030	8.0	28,570	8.0	25,800
7	8.0	15,520	8.1	21,280	8.1	26,060	8.2	28,480	8.2	27,800	8.2	25,040
8	8.2	15,760	8.3	22,120	8.2	26,180	8.4	28,890	8.3	28,250	8.3	25,200
9	8.3	15,900	8.3	21,640	8.5	26,350	8.4	28,670	8.5	28,110	8.5	25,950
36	8.6	14,620	8.5	20,340	8.5	24,540	8.7	27,040	8.6	26,240	8.6	23,490
Background	8.6	390	8.7	350	8.7	370	8.7	370	8.8	350	8.8	360

TABLE B-5 (Continued)

AXIAL SCANS

ROD 36			ROD 36 (cont.)			ROD 26			ROD 26 (cont.)		
Count Time (secs)	Plane Position (cm)	Total Counts (counts)	Count Time (secs)	Plane Position (cm)	Total Counts (counts)	Count Time (secs)	Plane Position (cm)	Total Counts (counts)	Count Time (secs)	Plane Position (cm)	Total Counts (counts)
2.9	2	8,780	3.1	64	21,790	3.2	2	9,590	3.5	64	22,850
2.9	6	11,390	3.1	60	23,160	3.3	6	12,430	3.5	60	25,000
2.9	10	14,430	3.1	56	24,460	3.3	10	15,990	3.5	56	26,570
2.9	14	17,210	3.1	52	25,370	3.3	14	18,660	3.5	52	27,340
2.9	18	20,220	3.1	50	25,620	3.3	18	21,490	3.5	50	27,600
2.9	22	22,300	3.1	50	25,630	3.3	22	23,820	3.5	48	27,070
2.9	26	23,830	3.1	48	24,590	3.3	26	26,150	3.5	44	28,020
2.9	30	25,260	3.1	44	25,720	3.3	30	27,290	3.5	40	28,700
2.9	34	26,520	3.1	40	26,700	3.3	34	28,490	3.5	36	28,430
2.9	38	26,730	3.2	36	26,710	3.3	38	28,560	3.5	32	27,970
2.9	42	26,350	3.1	32	25,360	3.3	42	28,830	3.6	28	26,840
2.9	46	22,690	3.2	28	24,590	3.4	46	24,960	3.6	24	25,030
3.0	50	25,620	3.2	24	22,870	3.3	50	27,600	3.6	20	22,920
3.0	54	25,560	3.2	20	21,200	3.4	54	27,610	3.6	16	20,440
3.0	58	24,070	3.2	16	18,700	3.4	58	26,010	3.6	12	17,220
3.0	62	22,510	3.2	12	15,900	3.3	62	23,650	3.6	8	14,010
3.0	66	20,300	3.2	8	13,040	3.4	66	21,680	3.6	4	10,560
2.9	70	17,480	3.2	4	9,640	3.4	70	19,350			
3.0	74	15,180				3.4	74	16,350			
3.0	78	12,350				3.4	78	13,210			
3.0	82	8,900				3.4	82	9,740			
3.0	86	5,130				3.4	86	5,570			
3.0	90	1,420				3.4	90	1,460			
3.1	92	1,010				3.4	92	1,030			
3.0	88	2,750				3.4	88	2,850			
3.1	84	7,260				3.5	84	7,740			
3.0	80	10,570				3.5	80	11,400			
3.1	76	14,210				3.4	76	14,870			
3.1	72	16,570				3.5	72	18,070			
3.1	68	19,370				3.5	68	20,810

FIGURE B-5 BORATED $\text{PUO}_2\text{-UO}_2$ CONFIGURATION

TABLE B-6

DATE: June 9, 1965.

CONFIGURATION

FUEL: 6.6 W/O PuO₂ in UO₂ pellitized (Zr clad).

PITCH: 0.735" square.

CORE GEOMETRY: 13 x 13 square (figure B-6).

MODERATOR TEMP: 24.1°C.

EXCESS REACTIVITY: 0.0.

MODERATOR HEIGHT: 68.41 centimeters.

BORON: ZERO PPM.

RESULTS

POWER SCAN				
<u>Direction</u>	<u>Planes</u>	<u>Ho</u> <u>(cm.)</u>	<u>Hc</u> <u>(cm.)</u>	<u>Bc²</u> <u>(cm⁻²)</u>
NW-SE	$\left\{ \begin{array}{l} \text{Average} \\ \text{of two counts} \\ \text{summed over} \\ \text{six planes at} \\ \text{10,18,26,34,52} \\ \text{and 60 cm.} \end{array} \right\}$	37.070	36.996	0.00721
NE-SW		37.260	37.185	0.00714
Axially	$\left\{ \begin{array}{l} \text{Average} \\ \text{of 2 axial} \\ \text{measurements} \end{array} \right\}$	78.538	78.302	0.00161
				0.01596 TOTAL

TABLE B-6 (continued)

POWER SCAN DATA FOR BUCKLING

0.735" Pitch, 6.6 x/o PuO₂

RADIAL SCANS (first count)

Rod No.	10 cm. Plane		18 cm. Plane		26 cm. Plane		34 cm. Plane		52 cm. Plane		60 cm. Plane	
	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)
10	3.5	16,927	3.5	23,552	3.5	26,253	3.5	27,575	3.5	19,150	3.5	12,417
1	3.6	17,475	3.5	23,807	3.5	27,100	3.6	28,023	3.6	19,598	3.6	12,484
3	3.6	15,286	3.6	20,842	3.6	24,159	3.6	25,207	3.6	17,172	3.6	11,220
5	3.7	18,482	3.7	24,594	3.7	28,445	3.7	29,102	3.7	20,357	3.7	13,156
7	3.8	19,495	3.7	26,021	3.8	30,355	3.8	30,664	3.8	21,718	3.8	13,937
9	3.9	18,340	3.8	24,608	3.8	28,146	3.9	29,474	3.9	20,472	3.9	13,178
11	3.9	15,478	3.9	20,971	3.9	24,585	3.9	24,861	3.9	17,150	4.0	11,316
13	3.9	16,922	3.9	22,995	4.0	27,111	4.0	27,392	4.0	19,407	4.0	12,256
2	4.1	14,582	4.1	19,620	4.1	22,486	4.1	23,044	4.2	16,040	4.1	10,335
4	4.1	16,911	4.2	23,378	4.2	26,735	4.2	27,200	4.2	19,458	4.2	12,564
6	4.2	18,609	4.3	25,801	4.3	29,497	4.3	30,781	4.3	20,972	4.3	13,625
8	4.4	18,947	4.3	25,792	4.4	29,865	4.4	30,529	4.4	21,674	4.3	13,338
7	4.5	19,669	4.5	26,482	4.5	30,396	4.5	30,957	4.4	21,436	4.5	13,853
12	4.5	14,362	4.6	19,631	4.5	22,062	4.6	22,577	4.6	16,059	4.6	10,519
14	4.6	17,113	4.7	23,277	4.6	26,627	4.6	27,366	4.6	19,167	4.7	12,240
16	4.7	15,257	4.7	21,016	4.7	24,124	4.7	25,371	4.7	17,118	4.8	11,351
18	4.8	18,039	4.8	24,921	4.9	28,900	4.8	29,006	4.8	20,531	4.9	13,189
21	4.9	18,005	5.0	25,125	4.9	28,463	4.9	29,169	5.0	20,665	4.9	12,832
23	5.0	15,219	5.0	21,268	5.1	24,694	5.1	25,243	5.1	17,562	5.1	11,194
25	5.1	17,030	5.1	23,277	5.1	26,523	5.1	27,390	5.2	19,656	5.2	12,635
7	5.2	19,445	5.2	26,435	5.2	30,407	5.2	30,924	5.2	21,707	5.2	14,048
15	5.4	14,760	5.4	19,817	5.4	22,790	5.3	22,755	5.5	16,609	5.4	10,403
17	5.4	16,979	5.4	22,959	5.4	26,566	5.5	27,302	5.5	19,291	5.5	12,215
19	5.5	18,571	5.5	25,584	5.5	29,834	5.6	31,006	5.5	21,012	5.6	13,768
20	5.6	18,466	5.7	25,632	5.7	29,555	5.7	30,370	5.7	21,179	5.7	13,658
22	5.8	16,975	5.8	23,162	5.8	26,594	5.8	27,680	5.9	19,185	5.9	12,592
24	5.9	14,417	5.9	19,161	5.9	22,610	5.9	22,659	5.9	15,915	6.0	10,285
7	6.0	19,133	6.1	26,817	6.1	30,400	6.0	30,912	6.1	22,178	6.1	13,925
10	6.2	17,206	6.1	22,793	6.2	26,407	6.1	27,568	6.1	19,067	6.2	12,279
1	6.2	17,148	6.2	23,312	6.3	27,337	6.3	28,181	6.3	19,489	6.4	12,394
3	6.5	15,712	6.4	21,030	6.4	24,354	6.5	25,174	6.5	17,680	6.5	11,286
5	6.5	18,375	6.5	24,371	6.6	28,683	6.6	29,497	6.5	20,593	6.7	13,511
9	6.7	18,182	6.7	25,000	6.7	28,599	6.7	29,262	6.7	20,226	6.7	13,046
11	6.8	15,422	6.8	20,941	6.8	24,416	6.9	24,872	6.9	17,744	6.7	11,067
13	6.9	17,014	6.9	23,541	7.0	27,267	7.0	27,661	7.0	19,709	7.0	12,379
2	7.0	14,515	7.1	19,926	7.1	22,801	7.2	23,368	7.2	16,453	7.2	10,355
4	7.2	16,925	7.3	23,571	7.3	26,731	7.2	27,367	7.4	19,253	7.4	12,476
6	7.3	18,572	7.4	25,758	7.5	30,225	7.4	30,504	7.4	21,278	7.4	13,520
8	7.4	18,753	7.6	25,686	7.6	29,449	7.6	30,394	7.6	21,523	7.6	13,703
12	7.6	14,365	7.7	19,572	7.7	22,316	7.6	22,877	7.8	16,419	7.8	10,642
14	7.8	16,713	8.0	23,707	7.9	26,985	7.8	27,659	7.9	19,251	8.0	12,432
7	8.0	19,385	8.1	26,308	8.0	30,296	8.0	30,901	8.2	22,286	8.2	14,035
16	8.2	15,451	8.2	21,048	8.3	24,695	8.3	25,403	8.2	17,673	8.3	11,242
18	8.4	18,142	8.3	24,473	8.3	28,532	8.5	29,424	8.3	20,444	8.4	13,193
21	8.6	10,512	8.6	25,193	8.5	28,986	8.6	29,415	8.6	20,473	8.7	13,212
15	8.6	14,390	8.7	19,362	8.7	22,578	8.7	23,373	8.8	16,180	8.8	10,383
25	8.9	16,959	8.9	23,646	9.0	27,130	9.0	27,824	9.0	19,623	8.9	12,430
23	9.1	15,621	9.2	21,561	9.1	24,231	8.9	24,611	9.1	17,564	9.2	11,120
17	9.4	17,444	9.2	23,462	9.2	26,790	9.2	27,394	9.4	19,662	9.4	12,515
19	9.4	19,051	9.5	26,069	9.4	29,940	9.4	30,768	9.5	21,587	9.5	13,620
20	9.6	18,961	9.7	25,758	9.6	30,550	9.7	29,492	9.7	21,456	9.7	13,821
22	9.8	17,186	9.9	23,243	9.8	26,796	9.9	27,727	9.9	18,951	9.9	12,397
24	10.0	14,305	10.1	29,586	10.1	22,256	10.1	23,012	10.2	16,495	10.1	10,577
7	10.3	19,431	10.4	27,082	10.3	30,371	10.3	31,183	10.4	21,865	10.5	14,195
Background	10.4	15	10.5	19	10.5	17	10.6	14				

TABLE B-6 (continued)

AXIAL SCANS

ROD 7			ROD 10		
Count Time (secs)	Plane Position (cm)	Total Counts (counts)	Count Time (secs)	Plane Position (cm)	Total Counts (counts)
2.7	2	10,556	3.1	2	9,807
2.7	6	14,969	3.0	6	12,852
2.7	10	19,005	3.1	10	16,629
2.7	14	22,333	3.1	14	20,150
2.7	18	25,768	3.1	18	22,830
2.7	22	28,261	3.1	22	24,792
2.8	26	30,223	3.1	26	26,134
2.7	30	30,981	3.1	30	27,527
2.8	34	30,587	3.1	34	27,090
2.8	38	30,098	3.1	38	26,216
2.7	42	27,927	3.1	42	24,560
2.8	46	23,607	3.2	46	21,496
2.7	50	22,172	3.1	50	20,212
2.8	54	20,162	3.1	54	17,429
2.8	58	16,108	3.2	58	14,237
2.8	62	11,402	3.1	62	10,184
2.8	66	6,326	3.2	66	5,566
2.8	70	1,066	3.2	70	1,020
2.8	74	458	3.2	74	416
2.8	78	235	3.2	78	249
2.8	82	167	3.2	82	159
2.8	86	110	3.1	86	107
2.8	90	66	3.2	90	73
2.9	92	53	3.3	92	67
2.8	88	95	3.2	88	97
2.9	84	108	3.2	84	121
2.9	80	183	3.2	80	198
2.9	76	340	3.3	76	324
2.9	72	650	3.3	72	662
2.9	68	3,027	3.3	68	2,694
2.9	64	9,333	3.3	64	8,087
2.9	60	14,143	3.3	60	12,454
2.9	56	18,183	3.3	56	16,058
2.9	52	21,665	3.3	52	19,278
2.9	50	22,975	3.3	50	20,206
3.0	48	23,456	3.3	48	20,908
2.9	44	26,603	3.3	44	23,665
3.0	40	28,871	3.3	40	25,669
2.9	36	29,675	3.4	36	27,641
3.0	32	30,801	3.3	32	27,127
2.9	28	30,181	3.4	28	26,872
2.9	24	28,608	3.4	24	25,796
3.0	20	27,210	3.4	20	24,258
3.0	16	24,459	3.4	16	21,752
3.0	12	20,969	3.4	12	18,643
3.0	8	16,720	3.4	8	14,865
3.0	4	12,206	3.4	4	11,094

FIGURE B-6 0.735" $\text{PuO}_2\text{-UO}_2$ LATTICE

TABLE B-7

DATE: June 8, 1965.

CONFIGURATION

FUEL: 6.6 W/O PuO₂ in UO₂ pellitized (Zr clad).

PITCH: 0.52" square.

CORE GEOMETRY: 22 x 23 rectangle (figure B-7).

MODERATOR TEMP: 25.8°C.

EXCESS REACTIVITY: 0.0

MODERATOR HEIGHT: 82.90 centimeters.

BORON: ZERO PPM.

RESULTS

POWER SCAN				
Direction	Planes	Ho (Cm.)	Hc (cm.)	Bc ² (cm ⁻²)
North-South	{ Sum of six planes at 10, 18,26,34,52 and 60 cm. }	44.913	44.886	0.00490
East-West		44.844	44.817	0.00491
Axially	{ Average of 2 axial measurements }	96.263	96.070	0.00107
				0.01088 TOTAL

TABLE B-7 (continued)

POWER SCAN DATA FOR BUCKLING
0.52" Pitch, 6.6 w/o PuO₂

RADIAL SCANS

Rod No.	10 cm. Plane		18 cm. Plane		26 cm. Plane		34 cm. Plane		52 cm. Plane		60 cm. Plane	
	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)
10	7.6	13,732	7.6	18,384	7.7	22,113	7.6	23,282	7.7	21,342	7.7	18,606
22	7.9	17,440	8.0	23,391	8.1	28,551	8.1	30,854	8.1	27,912	8.1	24,146
24	8.2	9,420	8.3	13,283	8.3	15,328	8.3	16,566	8.3	15,148	8.4	13,316
26	8.4	10,556	8.5	14,423	8.6	17,269	8.6	18,843	8.6	16,963	8.6	14,603
28	8.6	11,863	8.8	16,032	8.7	18,902	8.9	20,562	8.9	19,353	9.0	16,847
30	9.1	13,045	9.1	17,874	9.1	21,070	9.2	22,791	9.3	20,809	9.3	17,942
32	9.4	13,258	9.4	18,396	9.5	22,160	9.5	23,612	9.5	21,509	9.6	18,974
33	9.6	13,043	9.7	17,807	9.8	21,582	9.8	23,471	9.8	21,781	9.8	18,813
35	10.0	12,559	10.0	17,560	10.1	20,811	10.1	22,568	10.2	21,090	10.2	18,291
10	10.4	13,453	10.3	18,362	10.3	21,766	10.3	23,387	10.5	21,651	10.5	18,944
37	10.8	12,297	10.7	16,369	10.9	19,648	10.8	20,900	10.9	19,472	11.1	17,244
39	11.1	10,812	11.2	14,446	11.3	17,805	11.4	19,450	11.5	17,601	11.5	15,002
41	11.5	9,402	11.5	12,470	11.5	14,747	11.6	16,193	11.7	15,206	11.8	13,488
42	11.9	10,098	11.9	13,601	12.2	16,653	12.1	17,837	12.0	16,277	12.3	14,403
1	12.4	10,530	12.3	13,863	12.4	16,600	12.4	18,253	12.5	16,755	12.5	14,337
3	12.6	10,210	12.8	14,189	12.6	16,367	12.8	17,824	13.0	16,644	13.0	14,358
5	12.9	11,317	13.2	15,745	13.3	19,109	13.3	20,557	13.4	18,937	13.5	16,284
7	13.8	12,779	13.7	17,181	13.7	20,737	13.8	22,252	13.7	20,240	14.0	17,910
9	14.1	12,987	14.0	17,682	14.1	21,251	14.2	22,921	14.3	21,349	14.4	18,420
10	14.4	13,234	14.6	18,338	14.8	21,859	14.8	23,649	14.8	21,667	14.9	18,645
12	15.1	13,637	15.3	18,337	15.2	21,502	15.3	23,157	15.3	21,208	15.2	18,132
14	15.5	12,694	15.5	17,137	15.8	20,775	15.9	22,513	15.7	20,345	16.1	18,218
16	16.1	11,650	16.2	15,719	16.5	18,912	16.3	20,184	16.6	18,830	16.7	16,713
18	16.6	10,386	16.8	14,089	16.8	16,699	17.1	18,123	17.1	16,803	17.2	14,550
20	17.2	10,392	17.4	14,166	17.3	16,800	17.5	18,190	17.4	16,572	17.6	14,220
21	17.8	17,846	17.9	23,947	17.9	28,537	18.0	31,426	18.1	29,057	18.3	25,377
10	18.6	13,667	18.7	18,585	18.7	21,901	18.9	23,895	18.7	21,414	18.9	18,601
40	19.3	10,263	19.1	13,556	19.5	16,358	19.3	17,279	19.7	16,283	19.7	14,147
38	20.0	11,696	19.7	15,574	20.0	18,335	20.0	20,152	20.3	18,746	20.2	15,901
36	20.3	12,001	20.5	16,859	20.8	19,986	20.8	22,000	21.0	20,601	21.0	17,540
34	21.3	13,005	21.5	17,699	21.6	21,314	21.7	23,303	21.9	21,543	22.0	18,896
31	22.2	13,428	22.4	18,223	22.3	21,500	22.4	23,339	22.6	21,386	22.8	18,777
29	22.8	12,192	23.0	17,301	23.2	20,010	23.5	21,952	23.4	19,798	23.5	17,668
27	23.6	11,170	23.7	15,360	23.8	18,294	24.3	19,777	24.1	18,337	24.3	15,941
25	24.6	9,955	24.7	13,579	24.7	16,170	25.4	17,573	25.4	16,281	25.7	14,025
23	25.6	9,952	25.7	13,452	25.7	15,753	26.0	17,468	26.0	16,333	26.4	14,334
19	26.8	9,669	26.6	13,455	26.6	15,750	27.2	17,480	21.4	15,618	27.1	13,485
10	27.4	13,527	27.6	18,293	28.0	21,851	28.2	23,816	27.7	21,210	28.4	18,605
17	28.4	10,921	28.8	14,957	29.1	17,581	29.4	19,642	29.6	17,659	29.8	15,446
15	29.8	12,013	30.0	16,539	30.4	19,473	30.1	21,020	30.6	19,623	30.5	16,992
6	31.5	12,711	30.8	16,471	31.1	19,526	31.2	21,015	31.6	19,539	32.0	17,142
2	32.1	9,754	32.2	13,292	32.4	15,671	32.8	17,257	33.0	15,867	33.3	14,057
4	33.2	10,968	33.6	15,076	34.1	17,963	34.1	19,192	34.1	17,580	34.5	15,377
11	35.1	13,547	35.5	18,497	35.4	21,662	35.6	23,660	35.6	21,624	36.0	18,497
13	36.5	13,266	36.7	17,770	37.2	21,402	37.2	23,007	37.3	21,215	37.5	18,041
8	37.9	12,720	38.0	17,501	38.1	20,724	38.5	22,570	39.3	21,325	38.9	18,317
10	39.1	13,250	40.2	18,440	40.2	21,725	40.8	24,083	40.7	21,494	40.9	18,403
Background	41.1	42	42.2	42	42.3	60	42.5	60	42.4	48	43.6	45

AXIAL SCANS

ROD 12			ROD 34		
Count Time (secs)	Plane Position (cm)	Total Counts (counts)	Count Time (secs)	Plane Position (cm)	Total Counts (counts)
2.8	2	8,276	4.2	2	8,100
2.8	6	9,911	4.3	6	10,233
2.8	10	13,099	4.3	10	12,957
2.8	14	15,387	4.3	14	15,334
2.8	18	17,549	4.4	18	17,645
2.8	22	19,162	4.3	22	19,687
2.8	26	20,708	4.4	26	21,159
2.8	30	21,320	4.4	30	21,730
2.9	34	22,513	4.4	34	23,031
2.8	38	22,371	4.4	38	23,135
2.8	42	21,941	4.5	42	22,475
2.9	46	18,906	4.5	46	19,233
2.9	50	20,777	4.5	50	21,437
2.9	54	20,243	4.5	54	21,180
2.9	58	18,248	4.5	58	19,313
2.9	62	17,137	4.5	62	17,179
2.9	66	14,776	4.5	66	15,310
3.0	70	12,547	4.5	70	12,791
3.0	74	10,030	4.6	74	10,349
3.0	78	7,039	4.6	78	7,153
3.0	82	3,236	4.6	82	3,380
3.0	86	715	4.7	86	709
3.0	90	381	4.7	90	355
3.0	92	238	4.7	92	249
3.1	88	542	4.7	88	465
3.1	84	1,379	4.7	84	1,449
3.1	80	5,530	4.8	80	5,766
3.1	76	8,657	4.7	76	8,860
3.1	72	11,287	4.8	72	11,646
3.2	68	13,978	4.7	68	14,096
3.1	64	16,005	4.9	64	16,542
3.1	60	17,956	4.8	60	18,432
3.2	56	19,732	4.9	56	20,360
3.2	52	20,358	4.9	52	21,613
3.2	50	21,013	4.9	50	21,872
3.2	48	20,464	4.9	48	20,572
3.2	44	21,600	4.9	44	22,049
3.3	40	22,795	5.0	40	23,524
3.9	36	22,694			
4.0	32	22,469			
4.0	28	21,664			
4.0	24	20,434			
4.0	20	18,543			
4.1	16	16,761			
4.0	12	14,570			
4.1	8	11,808			
4.1	4	8,865

FIGURE B-7 0.52" $\text{PuO}_2\text{-UO}_2$ LATTICE

TABLE B-8

DATE: June 16, 1965.

CONFIGURATION

FUEL: 6.6 W/O PuO₂ in UO₂ pellitized (Zr clad).

PITCH: 1.04" square.

CORE GEOMETRY: 11 x 11 square (figure B-8).

MODERATOR TEMP: 19.9°C.

EXCESS REACTIVITY: 0.0.

MODERATOR HEIGHT: 79.50 centimeters.

BORON: ZERO PPM.

RESULTS

POWER SCAN				
<u>Direction</u>	<u>Planes</u>	<u>Ho</u> <u>(cm.)</u>	<u>Hc</u> <u>(cm.)</u>	<u>Bc²</u> <u>(cm⁻²)</u>
North-South	$\left\{ \begin{array}{l} \text{Sum of six} \\ \text{planes at 10,} \\ \text{18,26,34,52} \\ \text{and 60 cm.} \\ \text{over 3 rows} \\ \text{of fuel} \end{array} \right\}$	41.586	41.462	0.00574
East-West		41.155	41.073	0.00585
Axially	$\left\{ \begin{array}{l} \text{Average} \\ \text{of 2 axial} \\ \text{measurements} \end{array} \right\}$	88.998	88.820	0.00125
				0.01284 TOTAL

TABLE B-8 (continued)
POWER SCAN DATA FOR BUCKLING
1.04" Pitch; 6.6 w/o PuO₂

RADIAL SCANS

Rod No.	10 cm. Plane		18 cm. Plane		26 cm. Plane		34 cm. Plane		52 cm. Plane		60 cm. Plane	
	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)
20	2.8	13,867	2.8	19,627	2.8	23,764	2.8	25,741	2.8	22,673	2.8	18,727
1	2.8	9,132	2.8	12,458	2.8	15,375	2.8	16,631	2.8	14,689	2.8	12,009
4	2.8	11,479	2.8	16,156	2.8	19,278	2.8	20,974	2.8	18,655	2.9	15,491
13	2.8	13,538	2.9	19,525	2.8	23,028	2.9	25,319	2.9	22,149	2.9	18,083
29	2.9	13,876	2.9	19,360	2.9	23,326	2.9	25,153	2.9	22,583	2.9	18,333
37	2.9	11,368	2.9	16,223	2.9	19,193	2.9	21,178	2.9	18,524	2.9	15,454
34	2.9	12,618	2.9	17,923	2.9	21,367	2.9	23,200	2.9	20,747	2.9	16,695
7	3.0	12,666	3.0	17,840	2.9	21,431	3.0	23,741	3.0	20,796	3.0	17,130
20	3.0	14,242	3.0	19,495	3.0	23,419	3.0	25,482	3.0	22,769	3.0	18,805
23	3.0	11,671	3.0	16,069	3.0	19,507	3.0	21,027	3.0	18,531	3.0	15,176
10	3.0	11,308	3.0	15,939	3.0	18,777	3.0	20,789	3.1	18,503	3.0	14,986
12	3.1	13,720	3.0	18,874	3.1	23,101	3.1	24,659	3.1	21,843	3.1	18,016
14	3.1	13,404	3.1	18,746	3.1	22,789	3.1	24,722	3.1	21,625	3.1	17,703
16	3.1	11,311	3.1	16,084	3.2	19,194	3.1	20,772	3.1	18,175	3.1	14,829
15	3.2	12,710	3.2	17,889	3.2	21,531	3.2	23,348	3.2	20,884	3.1	16,765
19	3.2	13,607	3.2	19,157	3.2	23,273	3.2	24,947	3.2	22,329	3.2	18,389
20	3.2	14,155	3.2	19,432	3.2	23,557	3.2	25,558	3.2	22,463	3.2	18,601
18	3.2	12,770	3.3	18,196	3.3	21,873	3.2	23,534	3.2	20,864	3.3	17,391
17	3.2	11,537	3.3	15,963	3.3	19,394	3.3	20,746	3.3	18,700	3.3	15,359
6	3.3	12,488	3.3	17,423	3.3	21,576	3.3	22,916	3.3	20,533	3.3	16,836
11	3.3	12,527	3.3	17,730	3.3	21,521	3.3	23,294	3.3	20,664	3.3	16,748
3	3.3	11,209	3.3	15,863	3.4	18,806	3.4	20,514	3.4	18,470	3.4	15,346
21	3.4	13,780	3.4	19,420	3.4	23,470	3.4	25,583	3.4	22,557	3.4	18,532
8	3.4	12,733	3.4	17,475	3.4	21,653	3.4	23,541	3.4	20,661	3.4	17,068
26	3.5	11,348	3.5	15,860	3.5	19,010	3.5	21,019	3.5	18,750	3.4	15,173
24	3.5	10,030	3.5	14,025	3.5	16,613	3.5	18,127	3.5	16,007	3.4	12,767
38	3.5	11,203	3.5	15,743	3.5	19,379	3.5	20,731	3.5	18,732	3.5	15,017
33	3.6	12,735	3.5	17,790	3.5	21,149	3.6	23,396	3.6	20,860	3.6	17,114
2	3.6	9,871	3.6	14,006	3.6	17,103	3.6	18,373	3.6	16,263	3.6	13,265
20	3.6	14,055	3.6	19,624	3.6	23,561	3.6	25,604	3.6	22,826	3.6	19,007
5	3.6	11,084	3.6	14,627	3.7	19,445	3.7	21,014	3.7	18,560	3.7	15,415
36	3.7	11,482	3.7	16,109	3.7	18,981	3.7	20,895	3.7	18,720	3.7	15,262
31	3.7	12,630	3.7	17,605	3.7	21,649	3.7	23,034	3.7	20,610	3.7	17,030
30	3.7	13,355	3.7	18,948	3.8	22,963	3.8	24,822	3.7	22,105	3.8	18,053
32	3.8	11,167	3.8	16,001	3.8	19,284	3.8	20,975	3.8	18,650	3.7	14,852
35	3.8	12,761	3.8	18,077	3.8	21,538	3.8	23,009	3.8	20,590	3.8	16,894
22	3.9	13,079	3.8	18,327	3.8	21,650	3.8	23,829	3.9	21,292	3.9	17,316
28	3.9	13,421	3.9	18,831	3.9	22,870	3.9	24,639	3.9	21,728	3.9	18,031
25	4.0	9,281	3.9	12,986	3.9	15,232	3.9	16,542	3.9	15,008	3.9	11,887
27	3.9	12,538	3.9	17,538	3.9	21,522	4.0	23,248	4.0	21,065	3.9	16,564
20	4.0	14,067	4.0	19,916	3.9	23,495	4.0	25,861	4.0	22,734	4.0	18,492

TABLE B-8 (continued)

AXIAL SCANS

ROD 38			ROD 20		
Count Time (secs)	Plane Position (cm)	Total Counts (counts)	Count Time (secs)	Plane Position (cm)	Total Counts (counts)
2.5	2	5,771	2.7	2	7,404
2.5	6	8,642	2.6	6	10,340
2.5	10	11,143	2.7	10	14,042
2.5	14	13,361	2.6	14	16,841
2.5	18	15,196	2.6	18	19,479
2.5	22	17,159	2.7	22	21,542
2.5	26	18,573	2.7	26	23,469
2.5	30	19,552	2.7	30	24,324
2.5	34	20,208	2.7	34	25,339
2.5	38	20,149	2.7	38	25,407
2.5	42	20,232	2.7	42	25,079
2.5	46	18,513	2.7	46	23,486
2.5	50	18,074	2.7	50	22,971
2.5	54	17,363	2.7	54	21,990
2.5	58	15,240	2.7	58	19,617
2.6	62	13,800	2.7	62	17,175
2.6	66	11,592	2.7	66	14,166
2.5	70	8,724	2.7	70	11,303
2.5	74	5,876	2.7	74	7,556
2.5	78	2,460	2.7	78	3,055
2.5	82	448	2.7	82	517
2.6	86	271	2.7	86	300
2.6	90	180	2.7	90	180
2.6	92	117	2.7	92	146
2.5	88	179	2.7	88	212
2.6	84	332	2.7	84	365
2.5	80	845	2.7	80	1,055
2.6	76	4,639	2.7	76	5,661
2.5	72	7,487	2.7	72	9,374
2.6	68	10,082	2.7	68	12,886
2.5	64	12,491	2.7	64	15,909
2.6	60	14,723	2.7	60	18,439
2.6	56	16,555	2.7	56	21,005
2.5	52	18,236	2.7	52	22,597
2.5	50	18,354	2.7	50	23,167
2.6	48	19,074	2.7	48	23,111
2.6	44	19,544	2.7	44	24,574
2.6	40	20,379	2.7	40	25,319
2.5	36	20,245	2.7	36	25,838
2.6	32	19,799	2.7	32	24,921
2.6	28	19,151	2.7	28	24,274
2.6	24	17,640	2.7	24	22,514
2.6	20	16,498	2.7	20	20,534
2.6	16	14,463	2.7	16	17,857
2.6	12	12,115	2.7	12	15,290
2.6	8	10,020	2.8	8	12,360
			2.8	4	8,854

FIGURE B-8 1.04" $\text{PuO}_2\text{-UO}_2$ LATTICE

TABLE B-9

DATE: June 3, 1965.

CONFIGURATION

FUEL: 6.6 W/O PuO₂ in UO₂ pellitized (Zr clad).

PITCH: 0.56" square.

CORE GEOMETRY: 19 x 19 square (figure B-9)

MODERATOR TEMP: 15.75°C.

EXCESS REACTIVITY: 0.0

MODERATOR HEIGHT: 81.79 Centimeters.

BORON: ZERO PPM.

RESULTS

POWER SCAN				
Direction	Planes	H _o (cm.)	H _c (cm.)	B _c ² (cm ⁻²)
North-South	{ Sum of 2 scans over six planes at 10,18,26,34, 52 and 60 cm. }	42.612	42.578	0.00544
East-West		42.237	42.203	0.00554
Axially	{ Average of 2 axial measurements }	94.559	94.379	0.00111
				0.01209 TOTAL

TABLE B-9 (Continued)
POWER SCAN DATA FOR BUCKLING
0.56" Pitch, 6.6 w/o PuO₂

RADIAL SCANS												
Rod No.	10 cm. Plane		18 cm. Plane		26 cm. Plane		34 cm. Plane		52 cm. Plane		60 cm. Plane	
	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)
8	4.6	14,941	4.5	19,850	4.6	24,251	4.6	25,953	4.6	23,368	4.6	20,339
10	4.7	14,506	4.7	19,838	4.8	23,487	4.8	25,368	4.8	22,717	4.8	19,831
29	5.0	11,132	5.1	15,435	5.0	18,332	5.0	19,752	5.1	17,624	5.1	15,150
27	5.1	12,799	5.2	17,287	5.2	20,565	5.2	21,969	5.2	20,196	5.3	17,478
25	5.4	14,132	5.4	19,294	5.4	23,324	5.4	25,041	5.3	22,329	5.5	19,523
23	5.4	14,601	5.4	20,244	5.5	24,407	5.5	25,726	5.5	23,408	5.5	20,070
22	5.6	14,784	5.6	20,016	5.6	24,352	5.7	26,714	5.7	23,889	5.8	20,696
20	5.8	13,957	5.8	19,002	5.8	22,835	5.8	24,409	5.9	22,556	—	—
20	6.4	14,040	6.3	19,220	6.3	22,660	6.4	24,168	6.4	22,567	6.5	19,382
18	6.6	13,063	6.5	17,484	6.5	20,825	6.6	23,033	6.8	20,724	6.7	17,731
16	6.8	10,963	6.8	15,232	6.7	17,397	6.8	19,630	6.8	17,882	6.8	14,990
8	7.0	14,730	7.2	20,699	7.2	24,905	7.1	26,334	7.2	23,858	7.2	20,412
1	7.4	11,274	7.5	15,355	7.4	18,422	7.4	19,703	7.5	18,012	7.5	15,175
3	7.6	12,638	7.6	17,186	7.7	20,832	7.7	22,613	7.8	20,582	7.9	17,411
5	7.9	14,033	7.9	19,518	7.9	23,328	7.9	24,967	8.0	23,160	8.0	19,274
7	8.3	14,881	8.3	20,453	8.3	24,115	8.3	26,120	8.6	23,387	8.1	19,150
8	8.5	14,971	8.5	20,410	8.6	24,876	8.5	25,901	8.8	24,284	8.7	20,302
15	8.8	10,876	8.8	15,245	8.9	18,425	8.9	19,496	8.9	17,763	8.8	14,855
13	9.1	12,677	9.1	17,622	9.0	20,455	9.1	22,424	9.4	20,806	—	—
13	9.2	12,639	9.2	17,509	9.3	20,610	9.4	22,726	9.3	20,228	9.4	17,472
11	9.7	14,434	9.7	19,670	9.7	23,476	9.8	25,216	9.7	22,330	9.8	19,294
9	10.0	14,744	10.2	20,537	10.1	23,906	10.1	26,023	10.2	23,052	10.2	20,146
8	10.4	15,234	10.5	20,719	10.5	24,896	10.6	26,736	10.7	24,315	10.7	20,435
17	10.9	12,203	11.0	16,852	10.9	19,648	10.9	21,074	11.1	19,308	11.1	16,597
19	11.3	13,459	11.2	18,552	11.4	22,458	11.6	24,136	10.8	20,864	11.3	18,490
21	11.3	14,674	11.6	20,603	11.4	24,262	11.7	25,913	11.6	23,496	11.7	19,930
10	12.9	14,655	12.9	20,308	12.9	23,890	13.2	26,102	13.1	23,480	13.1	19,885
8	13.2	15,017	13.4	20,737	13.2	24,507	13.3	26,447	13.5	23,855	13.4	20,423
6	13.1	15,086	13.8	20,701	13.7	23,938	13.8	26,715	13.9	23,340	13.9	20,106
14	14.2	12,057	14.3	16,811	14.2	19,763	14.2	21,631	14.1	19,608	14.3	16,540
24	14.7	14,523	14.1	19,215	14.6	23,922	14.8	26,335	14.7	23,425	14.9	20,355
26	14.9	13,638	14.9	18,639	14.9	22,306	15.2	24,272	15.0	21,688	15.3	18,524
28	15.4	12,198	15.7	17,043	15.8	20,344	15.5	21,069	15.8	19,594	15.6	16,556
12	15.9	13,436	16.0	18,576	15.9	22,263	15.9	23,974	16.0	21,811	16.3	18,971
Second Count												
8	9.3	7,699	9.4	10,203	9.4	12,456	9.4	13,296	9.3	11,862	9.2	9,938
29	9.3	5,505	9.5	7,746	9.4	9,003	9.5	9,921	9.3	8,852	9.5	7,639
27	9.4	6,272	9.8	8,786	9.3	10,152	9.8	11,698	9.8	10,268	9.9	8,787
25	9.9	7,164	9.8	9,834	9.8	11,798	9.9	12,832	10.0	11,524	9.8	9,835
23	9.9	7,164	10.0	10,189	10.1	12,374	10.1	13,085	10.2	12,444	10.0	10,205
22	10.4	7,623	10.4	10,668	10.3	12,266	10.4	13,268	10.3	11,792	10.4	10,383
20	10.3	6,971	10.5	9,563	10.4	11,090	10.3	12,011	10.8	11,758	10.7	9,672
18	10.6	6,189	10.7	8,895	11.0	10,645	10.8	11,470	10.8	10,366	11.0	8,904
16	10.8	5,378	11.0	7,814	11.0	8,956	10.9	9,781	11.0	8,967	11.3	7,577
1	11.3	5,665	11.1	7,680	11.3	9,171	11.2	9,916	11.1	8,954	11.4	7,738
3	11.5	6,399	11.3	8,730	11.5	10,543	11.6	11,428	11.7	10,739	11.6	8,920
5	11.4	6,879	12.0	9,916	10.9	11,086	11.4	12,484	11.9	11,575	11.8	9,920
8	11.9	7,536	12.0	10,485	11.8	12,259	12.0	13,387	12.1	12,152	12.0	10,133
11	12.2	7,358	12.0	9,846	12.2	12,095	12.2	12,800	12.1	11,206	12.1	9,768
4	12.1	6,750	12.3	9,469	12.2	10,966	12.2	11,681	12.8	11,225	12.0	8,914
2	12.6	6,124	12.7	8,411	12.6	10,025	12.5	10,677	12.6	9,355	12.8	8,389
21	12.8	7,502	13.1	10,294	12.1	11,358	12.8	12,998	13.1	11,920	12.6	9,869
10	13.0	7,328	12.7	9,685	—	—	13.1	13,008	13.1	11,752	13.3	10,041
26	13.0	6,659	13.2	9,228	13.4	11,113	13.4	12,133	13.4	10,661	13.4	9,176
12	13.6	6,625	13.5	9,304	13.5	10,945	13.9	12,077	13.9	11,123	13.7	9,452
8	14.0	7,785	13.9	10,101	13.6	12,069	13.9	13,316	14.0	11,878	13.8	10,072
24	14.1	7,163	14.3	10,212	14.3	11,901	13.8	12,737	14.4	11,747	14.0	9,972

TABLE B-9 (continued)

Rod No.	Second Count											
	10 cm. Plane		18 cm. Plane		26 cm. Plane		34 cm. Plane		52 cm. Plane		60 cm. Plane	
	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)
28	14.3	6,130	14.5	8,459	14.6	10,014	14.5	10,472	14.7	9,809	14.5	8,135
14	14.6	5,970	14.4	8,201	14.6	9,868	14.8	10,737	14.7	9,792	14.8	8,099
6	14.7	7,318	15.1	10,658	13.8	11,084	15.3	13,013	15.8	12,238	15.2	10,115
19	15.4	6,773	15.5	9,461	15.5	11,015	15.8	12,187	15.4	11,031	15.3	9,288
17	15.4	5,870	15.7	8,454	16.0	9,804	15.3	10,346	15.7	9,585	15.8	8,114
9	16.1	7,396	16.1	10,142	15.9	11,741	16.2	13,307	16.5	12,105	16.1	9,991
15	16.2	5,371	16.5	7,794	16.4	9,207	16.5	9,691	16.4	8,719	17.0	7,806
13	16.6	6,305	16.6	8,725	17.0	10,725	16.7	11,309	17.0	10,172	17.0	8,920
7	17.3	7,475	16.9	10,178	17.2	12,153	17.3	13,165	17.5	11,831	17.4	10,086
8	17.6	7,427	17.4	10,001	17.6	12,277	17.9	13,532	17.8	11,949	17.7	10,164
Background	18.0	26	17.4	19	17.8	23	—	—	—	—	—	—

AXIAL SCANS

ROD 84		
Count Time (secs)	Plane Position (cm)	Total Counts (counts)
3.5	2	8,788
3.4	6	11,175
3.5	10	14,683
3.5	14	17,529
3.6	18	20,589
3.5	22	21,999
3.5	26	23,996
3.6	30	25,036
3.6	34	25,666
3.6	38	25,929
3.6	42	25,355
3.8	46	22,099
3.7	50	23,392
3.7	54	22,210
4.3	58	21,203
4.3	62	19,149
4.3	66	16,366
3.8	70	13,928
3.8	74	10,269
3.8	78	6,694
3.8	82	1,909
3.8	86	587
3.8	90	304
3.9	92	216
3.9	88	395
3.9	84	866
3.9	80	4,568
—	76	—
—	72	—
—	68	—
4.0	64	17,795
3.9	60	19,707
4.0	56	21,927
4.0	52	23,292
4.0	50	23,715
4.0	48	22,965
4.0	44	24,596
4.1	40	25,801
—	36	—
4.1	32	25,957
4.1	28	24,529
4.1	24	22,982
4.1	20	21,108

TABLE B-9 (continued)

<u>AXIAL SCANS</u>		
ROD 84		
<u>Count Time</u> <u>(secs)</u>	<u>Plane Position</u> <u>(cm)</u>	<u>Total Counts</u> <u>(counts)</u>
4.2	16	19,185
4.2	12	16,145
4.2	8	12,894
4.2	4	9,693

FIGURE B-9 0.56" PVO₂-UO₂ CONFIGURATION

TABLE B-10

DATE: June 30, 1965.

CONFIGURATION

FUEL: 5.74 W/O U-235 in UO₂.

PITCH: 0.52" Square.

CORE GEOMETRY: 449 FUEL RODS (CYLINDRICAL).

MODERATOR TEMP: 19.2°C.

EXCESS REACTIVITY: 0.0.

MODERATOR HEIGHT: 93.63 centimeters.

BORON: ZERO PPM.

RESULTS

POWER SCAN				
Direction	Planes	H _o (cm.)	H _c (cm.)	B _c ² (cm ⁻²)
Radially	(Average of 2 rows over six planes at 10,18,26,34, 52 and 60 cm.)	23.107	23.081	0.01086
Axially	(Average of 2 axial measurements)	104.48	104.48	0.00090
				0.01176 TOTAL

TABLE D-10 (continued)

POWER SCAN DATA FOR BUCKLING
0.52" Pitch (cylindrical), 5.74 w/o UO₂

RADIAL SCANS

Rod No.	10 cm. Plane		18 cm. Plane		26 cm. Plane		34 cm. Plane		52 cm. Plane		60 cm. Plane	
	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)	Count Time (secs)	Total Counts (counts)
11	4.8	12,940	4.8	18,893	4.9	23,271	4.9	26,120	4.9	27,304	5.0	25,591
24	6.0	10,280	6.0	14,789	6.0	18,260	6.1	20,468	6.1	20,756	6.1	19,951
1	6.3	8,477	6.2	11,865	6.3	15,048	6.3	16,691	6.3	16,837	6.4	15,976
22	6.5	8,913	6.5	12,581	6.5	15,597	6.5	17,544	6.6	18,538	6.6	17,475
2	6.7	9,006	6.7	12,717	6.7	15,680	6.7	17,523	6.7	17,661	6.9	17,069
23	6.8	9,127	6.9	13,386	6.8	16,189	6.9	18,476	7.0	19,177	7.0	17,735
3	7.1	9,527	7.0	13,469	7.1	17,129	7.1	18,748	7.0	19,139	7.1	18,128
27	7.1	12,405	7.2	17,992	7.2	22,537	7.2	25,180	7.3	26,028	7.4	24,779
4	7.3	10,300	7.4	14,676	7.4	18,039	7.4	20,275	7.4	20,829	7.5	19,757
11	7.6	13,380	7.6	18,701	7.6	23,157	7.7	26,494	7.7	26,865	7.7	25,389
26	7.7	12,112	7.7	17,324	7.8	21,392	7.7	23,880	7.9	24,750	7.8	23,236
5	7.9	11,099	8.0	15,769	8.0	19,750	8.0	22,368	8.1	22,696	8.1	21,364
25	8.1	11,403	8.2	15,936	8.2	20,087	8.2	22,317	8.2	23,005	8.3	22,285
6	8.8	11,621	8.8	16,682	8.7	20,156	8.8	22,905	8.9	24,144	8.9	22,839
29	9.0	13,246	9.0	18,901	8.9	23,081	9.0	26,005	9.1	26,848	9.3	25,783
7	9.1	12,212	9.3	17,500	9.3	21,541	9.4	24,476	9.4	24,999	9.4	23,739
28	9.4	13,285	9.5	18,582	9.4	23,287	9.5	25,751	9.5	26,514	9.6	25,070
11	9.6	13,242	9.8	18,689	9.8	23,618	9.8	26,377	9.8	26,842	10.0	25,700
8	9.9	12,285	9.9	17,924	9.9	21,887	10.1	24,949	10.1	25,682	10.3	24,789
30	10.2	12,786	10.3	18,464	10.2	22,502	10.3	25,243	10.3	26,315	10.3	24,789
9	10.5	13,066	10.6	18,709	10.6	23,194	10.4	25,714	10.6	26,528	10.5	25,050
10	10.6	13,081	10.7	18,748	10.7	23,243	—	—	10.8	26,881	10.8	25,768
12	11.0	13,297	11.0	18,935	11.1	23,046	11.0	25,826	11.0	26,728	11.1	25,083
13	11.2	13,108	11.4	18,888	11.3	23,137	11.3	25,624	11.3	26,864	11.4	25,399
14	11.5	12,550	11.5	18,246	11.6	22,245	11.5	24,900	11.5	25,625	11.6	24,181
19	11.7	9,478	11.9	13,560	11.8	16,632	11.9	18,863	11.9	19,323	12.0	18,609
11	12.2	13,450	12.1	19,062	12.0	23,170	12.1	26,025	12.3	27,260	12.2	25,586
21	12.4	8,275	12.5	11,945	12.6	15,149	12.4	16,672	12.6	17,318	12.6	16,212
18	12.7	10,422	12.5	14,811	12.8	18,395	12.9	20,513	12.8	21,073	13.0	20,142
20	12.8	8,586	13.1	12,466	13.1	15,277	13.3	17,351	13.0	17,957	13.2	16,534
15	13.3	12,439	13.3	17,517	13.4	22,037	13.4	24,396	13.4	24,927	13.4	23,421
32	13.8	11,356	13.8	16,274	13.7	19,949	13.9	22,957	13.8	23,264	13.8	21,560
17	13.9	11,090	14.0	15,728	14.1	19,526	14.1	21,958	14.2	22,725	14.4	21,643
16	14.2	11,558	14.3	16,555	14.2	20,393	14.5	22,952	14.4	23,679	14.4	22,300
34	14.6	9,120	14.7	13,104	14.7	16,365	14.9	18,413	14.9	18,870	14.9	17,488
33	15.1	10,333	15.1	14,930	15.0	18,213	15.0	20,490	15.3	21,363	15.4	20,171
35	15.4	9,112	15.5	12,800	15.7	16,126	15.5	17,677	15.5	18,201	15.7	17,246
31	16.0	12,336	16.0	17,599	16.1	21,616	16.1	24,159	16.2	25,042	16.3	23,669
11	16.4	13,092	16.6	18,924	16.5	23,512	16.5	25,993	16.6	26,868	16.7	25,590
Background	16.8	21	16.7	21	16.9	15	16.9	22	17.1	21	17.2	25

TABLE B-10 (continued)

AXIAL SCANS

ROD 11			ROD 24		
Count Time (secs)	Plane Position (cm)	Total Counts (counts)	Count Time (secs)	Plane Position (cm)	Total Counts (counts)
3.4	2	7,413	5.0	2	5,873
3.5	6	10,238	5.1	6	7,882
3.5	10	13,726	5.1	10	10,282
3.5	14	16,385	5.1	14	12,711
3.5	18	19,075	5.1	18	14,504
3.5	22	21,517	5.2	22	16,445
3.5	26	23,791	5.2	26	17,994
3.6	30	25,656	5.2	30	19,427
3.6	34	26,818	5.2	34	20,266
3.6	38	27,681	5.2	38	20,604
3.6	42	24,478	5.3	42	21,322
3.6	46	24,627	5.3	46	18,863
3.6	50	27,424	5.3	50	20,927
3.6	54	27,102	5.3	54	20,676
3.6	58	26,462	5.2	58	20,063
3.6	62	24,951	5.3	62	19,139
3.7	66	23,650	5.3	66	17,563
3.7	70	21,362	5.3	70	15,915
3.7	74	18,957	5.4	74	14,355
3.6	78	15,970	5.4	78	12,291
3.7	82	13,091	5.4	82	10,131
3.6	86	9,600	5.4	86	7,409
3.7	90	6,403	5.4	90	4,902
3.8	92	4,905	5.4	92	3,672
3.7	88	8,075	5.5	88	6,259
3.8	84	11,836	5.5	84	9,079
3.8	80	14,839	5.5	80	11,075
3.8	76	17,554	5.5	76	13,402
3.8	72	19,982	5.5	72	15,338
3.8	68	22,500	5.6	68	16,942
3.8	64	24,100	5.6	64	18,562
3.8	60	25,591	5.6	60	19,853
3.8	56	26,382	5.6	56	20,736
3.8	52	27,635	5.6	52	21,168
3.8	50	26,454	5.7	50	20,799
3.9	48	25,857	5.8	48	19,722
3.9	44	27,295	5.8	44	20,779
3.9	40	27,224	5.8	40	21,074
3.9	36	26,871	5.8	36	20,440
4.0	32	26,073	5.8	32	19,732
3.9	28	24,569	5.8	28	18,567
3.9	24	22,367	5.8	24	17,156
3.9	20	20,378	5.8	20	15,614
4.0	16	17,753	5.9	16	13,806
4.0	12	14,952	5.9	12	11,174
4.0	8	11,688	5.9	8	9,066
4.0	4	8,546	5.9	4	6,418

FIGURE B-10 0.52" UO_2 LATTICE

ATTACHMENT C

Relative Power Distribution Results

Power shapes perpendicular to the following perturbations were shown in the main body of this report:

- (a) Control Rods.
- (b) A Water Slot.
- (c) An Aluminum Plate.

The relative power in those fuel rods not shown in the main body are given in Table C-1 of this attachment. The fuel rod numbers in the table correspond to those on the core map of Figure C-1.

Relative power shape data were measured in the same manner as the buckling data. The data processing differed in that the data points were dead-time corrected and normalized using the POWER SCAN⁵ code. After making a background correction, the data was introduced into the code. The code made a dead-time correction, averaged the corrected counts at each plane and then normalized the values to a selected input number.

TABLE C-1

Relative Power Points

Rod #	Unperturbed UO ₂	Through Control Rods UO ₂	Unperturbed PuO ₂ -UO ₂	Through an Alum. Plate PuO ₂ -UO ₂	Through a Water Slot PuO ₂ -UO ₂	Through Control Rods* PuO ₂ -UO ₂
1	1.0000	1.0000				
2	1.2523	1.1343				
3	1.3742	0.9964				
4	1.0689	1.0366	0.9360			
5	1.5153	1.4348				
6	1.1641	1.1267				
7	1.0000	1.0000				
8	2.0475	1.2200				
9	1.8408	1.5919				
10			1.2357	1.4552	1.7921	0.9507
11			1.2013	1.1570	1.6152	1.0399
12			1.1007	1.3973	1.1550	1.0003
13			0.9390	1.0816	0.9840	1.0413
14				0.9401	0.9256	
15				0.9703	1.2101	
16				1.1245	1.2484	1.0774
17				1.0002	1.1190	
18				1.1734	1.0232	1.0000
19				0.7168	1.1520	1.0768
20				1.0000		
21				0.9308	0.7367	
22				0.8700		
23				1.0283		
24						
25					2.0005	0.9283
26					1.1135	1.0816
27					1.4236	
28					1.0954	
29					1.0000	
30						
31						
32						0.8863
33						1.0788
34						1.0449
35						0.8492

- Notes: 1) All core configurations were 19x19 square except for the PuO₂-UO₂ control rod experiment which was a 21x21 square.
 2) All core pitchcs were 0.56" square.
 3) * No unperturbed 21x21 was measured.

FIGURE C-1 ROD LOCATIONS OF SCANNED RODS
IN PERTURBATION EXPERIMENTS.

ATTACHMENT D

Relative Fluxes

The relative flux values plotted in Figures 7 through 9, in the main body of this Appendix, are tabulated in Tables D-1 and D-2 of this attachment. The foil numbers in Table D-1 and Table D-2 have their positions shown in Figures D-1 and D-2, respectively.

The fast fluxes were measured with 0.300" diameter by 5 mil thick U-238 foils. The irradiated foils were counted immediately after shutdown with all gamma energies above 0.5 mev included in the count. One standard foil was counted frequently during the foil counting so a U-238 gamma decay curve could be plotted. The other foils were normalized to the decay curve to correct for wait and count times. Corrections were also made for background counts and differences in foil weight.

The resonance flux was determined by counting the U-238 foils three days following shutdown. Resonance capture in U-238 leads to buildup of ${}_{94}\text{Pu}^{239}$. During the formation of ${}_{94}\text{Pu}^{239}$ a 104 kev X-ray is emitted. It was this X-ray that was counted in measuring the resonance flux. One standard foil was counted frequently, as before, with other foils normalized to the standard foil decay curve. Background and weight corrections were also applied.

The gold foil fluxes were measured with 0.372 inch diameter by 5 mil thick bare gold foils. The irradiated foils were counted immediately following shutdown with all gamma energies above 50 kev included in the count. The DARED code was used to correct for background, foil weights and decay.

The dysprosium foil flux experiments were identical to the gold foil experiments.

TABLE D-1

UO₂ Relative Flux Results

<u>Foil #</u>	<u>Relative Fluxes</u>		
	<u>Fast</u>	<u>Resonance</u>	<u>Gold</u>
3			0.7232
4	0.6600	0.5943	0.6987
5	0.7097	0.6446	0.7426
6	0.7813	0.7058	0.8009
7	0.8464	0.8136	0.8657
8			0.9173
9	0.9347	0.8830	0.9655
10	0.9827	0.9100	0.9834
11	0.9991	0.9934	1.0000
12	1.0000	1.0000	0.9819
13	0.9976	0.9915	0.9736
14	0.9872	0.9621	0.9579
15	0.9750	0.9104	0.9150
16	0.9271	0.9258	0.8830
17	0.8666	0.8494	0.8065
18	0.8281	0.7846	0.7576
19	0.7642	0.7127	0.6979
20			0.7306
21	0.6636	0.5964	1.1084
22	0.6399	0.6220	1.6809
23	0.6134	0.7744	1.7840
24	0.5753	0.7190	1.6494
25	0.5040	0.6002	1.3914
26	0.3990	0.4946	1.1277
27	0.3206	0.3870	0.8864
28	0.2531	0.2840	0.6852
29	0.2077	0.2212	

Notes

1. 19x19 core with a square pitch = 0.56".
2. Accuracy = $\pm 1.3\%$ (one standard deviation) for fast and resonance fluxes.
3. Accuracy = $\pm 1.0\%$ (one standard deviation) for gold fluxes.

TABLE D-2
PuO₂-UO₂ Relative Flux Results

<u>Foil #</u>	<u>Relative Fluxes</u>			
	<u>Fast</u>	<u>Resonance</u>	<u>Gold</u>	<u>Dysprosium</u>
A			0.9538	
B			1.2274	2.7188
C			1.5672	3.5923
D			1.9130	4.3807
E			2.2216	5.0078
F			2.3661	5.3140
1	0.5684	0.8246	2.1641	4.7006
2	0.6235	0.7841	1.2851	2.4494
3	0.6420	0.7117	0.7491	0.8939
4	0.6653	0.6218	0.7071	0.7058
5	0.7127	0.7042	0.7719	0.7099
6	0.7591	0.7775	0.8360	0.7829
7	0.8111	0.8465	0.8595	0.8187
8	0.8675	0.9024	0.9201	0.8728
9	0.9007	0.9335	0.9693	0.9145
10	0.9349	0.9921	0.9869	0.9711
11	0.9550	0.9956	0.9914	1.0000
12	0.9519	0.9793	1.0000	0.9529
13	0.9566	1.0000	0.9724	0.9459
14	1.0000	0.9859	0.9509	0.9661
15	0.9134	0.9462	0.9295	0.9343
16	0.8860	0.9748	0.8701	0.8979
17	0.8415	0.9004	0.8221	0.8415
18	0.7894	0.8442	0.7684	0.7813
19	0.7379	0.7733	0.7230	0.7823
20	0.6882	0.6919	0.7510	0.9724
21	0.6627	0.6331		0.5872
22	0.6200	0.7469		
23	0.5989	0.8593		
24	0.5601	0.8169		
25	0.4913	0.6890		
26	0.4036	0.5629		

Notes

- 1) 19x19 core with a square pitch = 0.56", PuO₂-UO₂ pelletized with Zr-4 clad.
- 2) Accuracy = ± 1.3% (one standard deviation) for fast and resonance fluxes.
- 3) Accuracy = ± 1.0% (one standard deviation) for gold fluxes.

FIGURE D-1 FOIL LOCATIONS UO₂ 19x19

FIGURE D-2 FOIL LOCATIONS $\text{PuO}_2\text{-UO}_2$ 19x19

ATTACHMENT E

Circumferential Thermal Fluxes About Fuel Rods

The relative thermal circumferential fluxes about fuel rods, plotted in Figures 15 through 20, are tabulated in Table E-1 and E-2 of this attachment.

The fluxes were measured by one turn of dysprosium wire wrapped around different fuel rods. The locations of the dysprosium wrapped fuel rods are given in Figures E-1 and E-2. Figures E-1 and E-2 pertain to Tables E-1 and E-2, respectively.

The dysprosium was cut into pieces and gamma counted following shutdown. All gamma energies above 50 kev were counted. The DARED code was used to correct the data for background, wire weights and decay.

TABLE E-1
Circumferential Relative Fluxes (UO₂ Core)

Position	Circumferential Position	Relative Flux	Position	Circumferential Position	Relative Flux
Rod E (HT = 53.1")	1	1612	Rod C (HT = 37.5")	1	2692
	2	1546		2	2741
	3	1558		3	2471
	4	1579		4	2636
	5	1383		5	2891
	6	1442		6	3480
	7	1539		7	3691
	8			8	4109
	9	1521		9	3793
	10	1488		10	3639
Rod A (HT = 58.1")	1	1544	Rod C (HT = 58.1")	1	2432
	2	1548		2	
	3	1678		3	2513
	4	1728		4	2678
	5	1651		5	2916
	6	1466		6	3453
	7	1438		7	3806
	8	1347		8	4014
	9	1453		9	3355
	10	1469		10	2798

TABLE E-2

Circumferential Relative Fluxes ($\text{PuO}_2\text{-UO}_2$ Core)

<u>Position</u>	<u>Circumferential Position</u>	<u>Relative Flux</u>	<u>Position</u>	<u>Circumferential Position</u>	<u>Relative Flux</u>
Rod 62 (HT = 37.5")	1	2866	Rod 64 (HT = 58.1")	1	1252
	2	3757		2	1232
	3	4095		3	1135
	4	3666		4	1237
	5	3134		5	1152
	6	2623		6	1196
	7	2076		7	1216
	8	1945		8	1160
	9	1971		9	1214
	10	2188		10	1425
Rod 63 (HT = 37.5")	1	1715			
	2	1993			
	3	1909			
	4	2186			
	5	2200			
	6	2093			
	7	1837			
	8	1759			
	9	1578			
	10	1555

FIGURE E-1 DYSPROSIUM WRAPPED FUEL ROD LOCATIONS ($\text{PuO}_2\text{-UO}_2$)

FIGURE E-2 DYSPROSIUM WRAPPED FUEL ROD LOCATIONS (UO₂).

Appendix B

APPENDIX B

MULTI-REGION EXPERIMENTS.

by

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* On assignment from Belgo-Nucleaire, Brussels, Belgium working on the Saxton Plutonium Program in the scope of the EURATOM/AEC/Westinghouse Contract.

APPENDIX B

TABLE OF CONTENTS

	<u>Page No.</u>
LIST OF FIGURES	ii
LIST OF TABLES.	iv
ABSTRACT.	v
1.0 INTRODUCTION	1
2.0 POWER SHARING EXPERIMENTS.	4
3.0 REACTIVITY MEASUREMENTS.	11
4.0 FLUX MEASUREMENTS	16
5.0 TEMPERATURE COEFFICIENT.	22
REFERENCES	23
ATTACHMENT A - Power Scan Data	24
ATTACHMENT B - Reactivity-Period Relationships.	49
ATTACHMENT C - Flux Data	56

LIST OF FIGURES

<u>Figure No.</u>		<u>Page No.</u>
250.1	Factors for Relating Gamma Activity to Power for Two Fuel Types as a Function of Time After Shutdown	5
250.2	Core Diagram - Configuration 2.	10
250.3	Core Diagram for Quater-Core Reactivity Measurements. .	15
250.4	Multi-Region Clean Core Flux Measurements - 19x19 Core, 11x11 PuO ₂ -UO ₂ Center, UO ₂ Outer Region	17
250.5	Multi-Region Clean Core Flux Measurements - 19x19 Core, 11x11 UO ₂ Center, PuO ₂ -UO ₂ Outer Region	18
250.6	Multi-Region Borated Core Flux Measurements - 27x27 Core, 19x19 PuO ₂ -UO ₂ Center, UO ₂ Outer Region, 1453 ppm . . .	19
250.7	Multi-Region Borated Core Flux Measurements - 27x27 Core, 19x19 UO ₂ Center, PuO ₂ -UO ₂ Outer Region, 1252 ppm . . .	20
250.8	Insert Experiment Flux Measurements - 19x19 PuO ₂ -UO ₂ Core With 3x3 UO ₂ Insert	21
A-1	Configuration 1(a)	37
A-2	Configuration 1(b)	38
A-3	Configuration 3	39
A-4	Configuration 4	40
A-5	Configuration 5	41
A-6	Configuration 6	42
A-7	Configuration 7	43
A-8	Configuration 8	44
A-9	Configuration 9	45
A-10	Configuration 10.	46
A-11	Configuration 11.	47
A-12	Configuration 12.	48

LIST OF FIGURES (continued)

<u>Figure No.</u>		<u>Page No.</u>
B-1	Reactivity Versus Period for a 21x21 Multi-Region Configuration	50
B-2	Reactivity Versus Period for a 21x21 Inverted Multi-Region Configuration.	51
B-3	Reactivity versus Period Characteristics for a Number of Single Region and Multi-Region Critical Experiments.	52
B-4	$\delta\rho/\delta H$ versus Water Height for Single Region and Multi-Region Experiments.	53
B-5	Integral Moderator Worth, $\% \Delta k/k$, versus Water Height.	54
B-6	Installed Reactivity ($\% \Delta k/k$) Above Critical for Fully Flooded Multi-Region Cores.	55
C-1	Foil Locations in Multi-Region Clean Cores.	60
C-2	Foil Locations in Multi-Region Borated Cores.	61
C-3	Foil Locations for Insert Experiments	62

LIST OF TABLES

<u>Table No.</u>		<u>Page No.</u>
250.1	Measurement Program Summary	2
250.2	Summary of the Multi-Region Experiments	3
250.3	Power Scan Data for Configuration Two	9
250.4	Reactivity Data and Evaluation.	13
A-1	Power Scan Data for Configuration 1(a).	25
A-2	Power Scan Data for Configuration 1(b).	26
A-3	Power Scan Data for Configuration 3	27
A-4	Power Scan Data for Configuration 4	28
A-5	Power Scan Data for Configuration 5	29
A-6	Power Scan Data for Configuration 6	30
A-7	Power Scan Data for Configuration 7	31
A-8	Power Scan Data for Configuration 8	32
A-9	Power Scan Data for Configuration 9	33
A-10	Power Scan Data for Configuration 10.	34
A-11	Power Scan Data for Configuration 11.	35
A-12	Power Scan Data for Configuration 12.	36
C-1	Relative Fast, Resonance and Thermal Flux Measurements in 19x19 Multi-Region Cores	57
C-2	Relative Fast, Resonance and Thermal Flux Measurements in 27x27 Multi-Region Cores	58
C-3	Relative Thermal Flux in a 19x19 PuO ₂ -UO ₂ Core Containing a 3x3 UO ₂ Insert.	59

ABSTRACT

The data and results of the multi-region UO_2 and $\text{PuO}_2\text{-UO}_2$ critical experiments performed under the Saxton Plutonium Program are given in this Appendix. These results include experiments made to determine the relative power distribution, reactivity, relative flux shapes, and temperature coefficients in multi-region cores. Appendix A gives similar data for single region experiments.

1.0 INTRODUCTION

1.1 Purpose

A series of critical experiments was carried out at the Westinghouse Reactor Evaluation Center (WREC) as part of the Saxton Plutonium Program. Two different fuels were used, the conventional Saxton UO_2 fuel (5.74 w/o U-235) and a mixed oxide ($\text{PuO}_2\text{-UO}_2$) fuel containing 6.6 w/o PuO_2 .

1.2 Program Description

The measurements program is summarized in Table 250.1. The multi-region portion of these experiments was concerned primarily with power measurements. However, as shown in Table 250.1, reactivity information was also obtained for each configuration with flux and temperature coefficient measurements included in some of the configurations. The power measurements can be divided into two parts. First, experiments were made in unperturbed, multi-region cores, both clean and borated, to determine the power sharing between the two fueled regions. Second, experiments were made in both clean and borated multi-region cores in which a perturbation such as water slot or control rods was introduced in order to determine the effect on reactivity and local power. This second group of experiments also provides information as to power sharing. Table 250.2 summarizes the configurations for which power measurements were made. The table includes a summary of the flux data, measured with foils, in the power sharing configurations.

TABLE 250.1

MEASUREMENT PROGRAM SUMMARY

<u>Single-Region Experiments</u> <u>PuO₂-UO₂ Fuel</u>		<u>Multi-Region Experiments</u> ³ <u>PuO₂-UO₂ Inside, UO₂ Outside</u>	
<u>0.56-Inch Lattice</u> a. Cylindrical core-critical rods b. Buckling by fuel rod scans (19 x 19 core) ¹ c. Power map, foil traverses-U238, Au, Dy (19 x 19 core) d. Water slot in center-reactivity, power map ² e. Aluminum slab in center-reactivity, power map f. Five control rods in center-reactivity, power map (21 x 21 core) g. Moderator temperature coefficient h. Vipac vs pelletized fuel-reactivity, power map i. 3 x 3 UO ₂ insert-reactivity, power map, flux-Dy j. Fuel rod circumferential flux-Dy wire k. Pulsed neutron experiments-clean and borated l. Boron worth to 50 ppm (19 x 19 core) m. Boron worth to 337 ppm (21 x 21 core) n. Borated core buckling (21 x 21 core) o. Noise analysis (19 x 19 core)		<u>0.795-Inch Lattice</u> a. Cylindrical core-critical rods b. Buckling by fuel rod scans (12 x 12 core) c. Power map <u>0.52-Inch Lattice</u> a. Cylindrical core-critical rods b. Buckling by fuel rod scans (22 x 23 core) c. Pulse neutron experiments (23 x 23 core) <u>0.735-Inch Lattice</u> a. Cylindrical core-critical rods o. Buckling by fuel rod scans (13 x 13 core) <u>1.04-Inch Lattice</u> ⁴ a. Cylindrical core-critical rods b. Buckling by fuel rod scans (11 x 11 core)	
<u>UO₂ Fuel</u> <u>0.56-Inch Lattice</u> a. Cylindrical core-critical rods b. Buckling by fuel rod scans (19 x 19 core) c. Power map, foil traverses-U238, Au (19 x 19 core) d. Water slot in center-reactivity, power map e. Aluminum slab in center-reactivity, power map f. Five control rods in center-reactivity, power map (21 x 21 core) g. Moderator temperature coefficient h. 3 x 3 PuO ₂ -UO ₂ insert-reactivity, power map i. 7 x 7 PuO ₂ -UO ₂ insert-reactivity j. Fuel rod circumferential flux-Dy wire k. Pulsed neutron experiments 1. U-238 foils counted for fission activity and Np-239 decay 2. Power measurements by fuel rod scans 3. Carried out in 0.56-inch lattice 4. Not part of the Saxton Plutonium Program. Included to complete the summary of the buckling data available		<u>0.795-Inch Lattice</u> a. Cylindrical core-critical rods b. Buckling by fuel rod scans (13 x 14 core) c. Power map <u>0.52-Inch Lattice</u> ⁴ a. Cylindrical core-critical rods b. Buckling by fuel rod scans (cylindrical core)	
		<u>Clean</u> a. Fuel substitution in steps to the reference core (11 x 11 PuO ₂ -UO ₂ , 19 x 19 core)-reactivity b. Power map, foil traverses-U238, Dy c. Aluminum slab at boundary-reactivity, power map d. Water slot-reactivity, 3 positions (11 x 11 PuO ₂ -UO ₂ , 21 x 21 core) e. Five control rods-reactivity, 5 positions (11 x 11 PuO ₂ -UO ₂ , 21 x 21 core) f. Five control rods at fuel interface-power map g. Moderator temperature coefficient h. Pulse neutron experiments (11 x 11 PuO ₂ -UO ₂ in 19 x 19 and 21 x 21 cores) i. Noise analysis <u>Borated Core</u> a. Fuel and boron addition in steps to the reference core (19 x 19 PuO ₂ -UO ₂ , 27 x 27 overall, 1453 ppm boron) - reactivity b. Power map, foil traverses-U238, Dy c. Water slot experiment at fuel interface-reactivity, power map d. Aluminum slab experiment at fuel interface-reactivity, power map e. L-shaped UO ₂ inserts in PuO ₂ -UO ₂ region simulating Saxton design-Manganese wire activation at design flux wire locations and core power map (1425 ppm boron) f. 3 x 3 UO ₂ insert in PuO ₂ -UO ₂ region (1425 ppm boron) reactivity, power map	
		<u>UO₂ Inside, PuO₂-UO₂ Outside</u> <u>Clean</u> a. Fuel substitution in steps to inverted reference core (11 x 11 UO ₂ inside, 19 x 19 overall) b. Power map, foil traverses-U238, Dy c. Water slot-reactivity, 3 positions (11 x 11 UO ₂ , 21 x 21 core) d. Five control rods, 3 positions (11 x 11 UO ₂ , 21 x 21 core) e. Pulse neutron experiments (11 x 11 UO ₂ , 21 x 21 core) <u>Borated Core</u> a. Quarter-core step change in fuel position from 2-region core to inverted 2-region core-reactivity b. Full core change to inverted reference configuration (19 x 19 UO ₂ , 27 x 27 overall, 1252 ppm boron) c. Power map, foil traverses-U238, Dy	

TABLE 250.2
SUMMARY OF THE MULTI-REGION EXPERIMENTS
Power Sharing Experiments

Configuration	Region 1			Region 2		Core Size	Boron ppm	Date of Experiment	Foil* Data	Description
	Size	Fuel	Rods	Fuel	Rods					
-- 1(a) 1(b) --	11x11	PuO ₂ -UO ₂	121	UO ₂	240	19x19	0	4/29/65 6/03/65	U-238 Np-239 Dys	Reference Core - clean, two power taps were made in this configuration
2	19x19	PuO ₂ -UO ₂	361	UO ₂	368	27x27	1,453	5/14/65	U-238 Np-239 Dys	Reference Core - borated
3	19x19	PuO ₂ -UO ₂	352	UO ₂	368	27x27	1,425	5/21/65		3x3 UO ₂ insert in PuO ₂ -UO ₂ region
4	11x11	UO ₂	121	PuO ₂ -UO ₂	240	19x19	0	5/06/65	U-238 Np-239 Dys	Reference Inverted Core - clean
5	19x19	UO ₂	361	PuO ₂ -UO ₂	368	27x27	1,252	5/28/65	U-238 Np-239 Dys	Reference Inverted Core - borated
6	3x3	PuO ₂ -UO ₂	9	UO ₂	352	19x19	0	4/09/65		PuO ₂ -UO ₂ Insert Experiment
7	3x3	UO ₂	9	PuO ₂ -UO ₂	352	19x19	0	4/26/65	Dys	UO ₂ Insert Experiments - also used to compare power produced in Vipac and pelletized fuel
8	19x19	PuO ₂ -UO ₂ (UO ₂)	339 (18)	UO ₂	367	27x27	1,425	5/21/65	Mn Wire	L shaped UO ₂ insert in PuO ₂ -UO ₂ region - Mn wire activation in simulated Saxton des. core

Power Peaking Experiments

9	11x11	PuO ₂ -UO ₂	116	UO ₂	240	19x19	0	4/30/65		5 PuO ₂ -UO ₂ rods removed at fuel region interface - aluminum slab installed
10	11x11	PuO ₂ -UO ₂	116	UO ₂	320	21x21	0	5/04/65		5 PuO ₂ -UO ₂ rods removed at fuel region interface - 5 Ag-In-Cd rods installed
11	19x19	PuO ₂ -UO ₂	356	UO ₂	368	27x27	1,453	5/14/65		5 PuO ₂ -UO ₂ rods removed at fuel region interface - water slot formed
12	19x19	PuO ₂ -UO ₂	356	UO ₂	368	27x27	1,453	5/17/65		5 PuO ₂ -UO ₂ rods removed at fuel region interface - aluminum slab installed

*U-238 foils counted for fission activity and Np-239 decay

2.0 POWER SHARING EXPERIMENTS

2.1 Measurements

As described in the previous report¹, the relative power produced in a fuel rod was determined by measuring the gamma activity of the fission products. To correct for gamma decay, since the rods are not counted at the same time, a variable counting time is used. The counting interval is governed by the time required to reach a specified number of counts (usually 20,000) in an irradiated monitor rod. Thus, the counting is a function of the decay characteristics of the fuel in the monitor rod. The measured gamma activity of the rod is directly proportional to power if the fuel in the rod and in the monitor are the same.

For multi-region cores composed of plutonium and uranium fuels, the correct relative power within each region can be determined by measuring the gamma activity of the rods in that region while using a monitor rod of the same fuel type. However, since the gamma decay characteristics of the two fuels are different, this procedure does not provide the correct relationship between the power produced in rods of different fuel types. Consequently, experiments using two different methods were carried out to determine the ratio of gamma activity as a function of time after shutdown to the thermal power produced for each fuel. These experiments are reported separately. In the first method², thermally insulated rods were irradiated and the temperature rise of thermocouples attached to the fuel rod cladding was measured. Then after shutdown, the same fuel rods were gamma scanned and the ratio of gamma activity to thermal power was determined. In the second method³, foils made of the two different fuels were irradiated and subsequently gamma scanned. Later the La-140 activity in each foil was measured by gamma spectrometry. Using the yields for each type of fission the number of fissions occurring in each foil type was established. The resulting ratio of gamma activity after shutdown per fission event was corrected for the difference in energy release per fission. The end result of these experiments was the development of a time-dependent factor that is applied to the measured gamma activity in either fuel to determine the correct relative power. Figure 250.1 summarizes the results. The following equations show that multiplying the measured gamma activity in a plutonium fuel or dividing the

gamma activity in the uranium fuel by the time-dependent factor is the proper procedure for obtaining corrected relative power.

$$\frac{\gamma(\text{UO}_2)}{\text{Power}(\text{UO}_2)} / \frac{\gamma(\text{PuO}_2\text{-UO}_2)}{\text{Power}(\text{PuO}_2\text{-UO}_2)} = c(t)$$

$$\frac{\gamma(\text{UO}_2)}{\gamma(\text{PuO}_2\text{-UO}_2)} \cdot \frac{\text{Power}(\text{PuO}_2\text{-UO}_2)}{\text{Power}(\text{UO}_2)} = c(t)$$

For the same power production in rods of each fuel, $\gamma(\text{UO}_2) = c(t) \cdot \gamma(\text{PuO}_2\text{-UO}_2)$

2.2 Counting Procedure

During the multi-region experiments, the following counting procedure was usually followed:

1. Prior to irradiation, two fuel rods (one plutonium and one uranium) were installed in the core for use as monitor rods. An additional rod of each fuel type was selected from those included for the power scan and was designated as a standard for periodic counting. The locations chosen for the standards were usually at each side of the fuel region interface so that the standards were adjacent.
2. After irradiation, one of the monitor rods was placed in the monitor channel and all fuel rods (both plutonium and uranium) were gamma scanned at six longitudinal positions. Both standard rods were counted periodically throughout the rod count and time after shutdown at which the standard was counted was recorded.
3. After all rods were counted, the monitor was changed. Then, all fuel rods of the same fuel type as that of the monitor were gamma scanned. Again, both standards were counted periodically and the time after shutdown recorded.

Since the rods of each fuel type were scanned with the same type fuel monitor, the correct relative power within each region is correctly represented by the measured gamma activity. The repeated counting of the standard rods provides

an indication of the precision of the measurements and makes it possible to determine the relative power between the standard rods a number of times throughout the count using the time dependent factors of Figure 250.1. Since the derived relative power for the two rods should remain constant, a check on the measurements is available by the variation of this ratio with time.

2.3 Data Processing

After the fuel rods were gamma scanned, the following procedure was followed in processing the data.

1. Data from five of the six available longitudinal planes were used in the Power Scan Code ^{/4} to determine rod-averaged activity. Code calculations included:
 - a. The $\text{PuO}_2\text{-UO}_2$ rods including the $\text{PuO}_2\text{-UO}_2$ standard rod from data taken with the $\text{PuO}_2\text{-UO}_2$ monitor.
 - b. The UO_2 rods including the UO_2 standard rod from data taken with the UO_2 monitor.
 - c. The standard rods from data taken with alternate fuel monitors.
2. The relative power of the rods within each region (column 6 of Power Scan Data) was determined by normalizing the gamma activity in the rod to that of a reference in the same fuel type.
3. Ratios of gamma activity for the two standard rods counted in sequence at approximately the same time were determined. Correction factors read from Figure 250.1 at the appropriate time after shutdown were applied to the gamma activity ratios to determine the relative power between the standard rods.
4. The core power distribution was determined by normalizing to a selected rod position while preserving the correct power relationship of the standard rods.

2.4 Results

Table 250.3 contains a summary of the processed data available for configuration 2 of Table 250.2. Figure 250.2 is a core diagram illustrating the position of the power measurements made in this configuration. The foil and heat-rate factors that were used to determine the relative power production of the standard rods and the resulting core power distributions are also included in Table 250.3. Similar data for the other configurations of Table 250.2 are included in Attachment A.

TABLE 250.3
POWER SCAN DATA FOR CONFIGURATION 2

27x27 Core
19x19 PuO₂-UO₂ in Center Region
UO₂ Outer Region
1453 ppm Boron
Critical Water Height: 91.72 cm.
Temperature: 18.2°C
Date: 5/14/65

1 Type Fuel	2 Monitor Rod	3 Traverse Direction	4 Rod Position From Center	5 Rod Number	6 Reference Rod for Normalization	7 Count Normalized to Column 6	8 Corrected*	9 RELATIVE POWER	
								Foil Method	Thermal Method
PuO ₂ -UO ₂	PuO ₂ -UO ₂	Flat Side	1	87	87	1.000000	1.000000	1.000000	
			2	7		0.984621	0.984450	0.984450	
			3	90		0.989371	0.989254	0.989254	
			4	8		0.968199	0.967851	0.967851	
			5	92		0.947274	0.946697	0.946697	
			6	9		0.909628	0.903751	0.903751	
				81		0.899958			
			7	95		0.861805	0.860283	0.860293	
			8	67		0.803187	0.801034	0.801034	
			9	98		0.756164	0.753496	0.753496	
			10	68		0.760793		0.759428	
				85		0.760803			
				82		0.763577	0.762031	0.759428	
				83		0.757036			
				83		0.760014			
				83		0.771409			
				83		0.763350			
		Background				0.010822			
		Diagonal	1	87	87	1.000000	1.000000	1.000000	
			4	78		0.943039	0.942415	0.942415	
			6	75		0.807384	0.805276	0.805276	
			8	73		0.651819	0.648010	0.648009	
		Other Rods	10	72		0.569873	0.565197	0.560440	
				84		0.560521			
				99	87	0.726140	0.723147	0.723147	
				80		0.647977	0.644128	0.644128	
				79		0.829393	0.832302	0.830471	
						0.835211			
UO ₂	UO ₂	Flat Side	11	67	67	1.000000			
				79		0.999453	0.996515	1.000000	0.5718
				79		0.986607			0.5450
			12	68		0.973775	0.976896	0.5586	0.5324
		Diagonal	13	69		0.917294	0.919510	0.5258	0.5011
			14	70		1.002598	1.006181	0.5753	0.5483
			11	76		0.675065	0.671478	0.3830	0.3650
				80		0.667890			
		Other Rods	12	75		0.553872	0.550266	0.3146	0.2999
			13	74		0.487846	0.483183	0.2763	0.2633
			14	73		0.523307	0.519212	0.2969	0.2830
				71		0.936605	0.939130	0.5370	0.5118
		Background		72		0.828330	0.829121	0.4741	0.4519
		Power Sharing				0.012282			
		Background		79	79	1.000000			Time After Shutdown (min.)
				83		1.232789			40.21
				79		1.016768			41.33
				83		1.237639			51.50
				79		1.057401			52.88
				83		1.256195			73.53
				83		1.243071			75.21
				79		1.101516			102.38
				83	83	0.017623			
				79		1.000000			114.10
				79		0.884714			115.07
				79		0.873342			143.58
				83		0.964961			145.70
		Background				0.010872			

POWER RELATIONSHIP OF THE STANDARD RODS

Time After Shutdown	Activity Ratio U/Pu	Thermal Method		Foil Method	
		Factor	Relative Power	Factor	Relative Power
40 min. 21 sec.	0.80207	1.135	0.7063	1.088	0.7372
51 min. 50 sec.	0.81576	1.150	0.7094	1.102	0.7403
73 min. 53 sec.	0.84894	1.183	0.7176	1.130	0.7513
102 min. 38 sec.	0.88495	1.220	0.7254	1.160	0.7629
114 min. 10 sec.	0.87770	1.232	0.7124	1.168	0.7515
145 min. 42 sec.	0.90505	1.258	0.7194	1.192	0.7593

Average

0.7152

0.7504

*Corrected for background and renormalized.

Configuration 2
 27 x 27 Core
 19 x 19 PuO₂-UO₂ in Center Region
 UO₂ Outer Region
 1453 ppm Boron
 Date: 5/14/65

● PuO₂-UO₂
 ⊕ UO₂
 M Monitor
 S Standard

Figure 250.2 Core Diagram - Configuration 2

3.0 REACTIVITY MEASUREMENTS

3.1 Measurements

Reactivity measurements were made in a series of 0.56-inch pitch cores and included the effect of:

- 1) Peripheral substitution of rows of UO_2 in an all $\text{PuO}_2\text{-UO}_2$ 19 x 19 core.
- 2) Insertion of an aluminum plate at the fuel interface of a 19 x 19 core with an 11 x 11 $\text{PuO}_2\text{-UO}_2$ center surrounded by four peripheral rows of UO_2 .
- 3) Peripheral substitution of rows of $\text{PuO}_2\text{-UO}_2$ in an all UO_2 19 x 19 core.
- 4) Insertion of water slots and control rods in a 21 x 21 core containing an 11 x 11 UO_2 center surrounded by five peripheral rows of $\text{PuO}_2\text{-UO}_2$.
- 5) Insertion of water slots and control rods in a 21 x 21 core containing an 11 x 11 $\text{PuO}_2\text{-UO}_2$ center surrounded by five peripheral rows of UO_2 .
- 6) Variation of the boron concentration and fuel loading during an approach to a 27 x 27 core containing a 19 x 19 $\text{PuO}_2\text{-UO}_2$ center surrounded by four peripheral rows of UO_2 .
- 7) Inversion of a quarter of the borated core described in (6) by the substitution of UO_2 for $\text{PuO}_2\text{-UO}_2$ and $\text{PuO}_2\text{-UO}_2$ for UO_2 in steps.
- 8) Insertion of water slot and an aluminum plate in the core described in (6).

The actual measurements consisted of measuring a core period at a particular super-critical water height and a just-critical water height for each perturbation and fuel substitution.

3.2 Data Processing

Calculations were made to determine reactivities for a range of periods for the different cores in which reactivity measurements were made. The period-reactivity curves for the different cores are included in Attachment B, Figures B-1, B-2, and B-3. The periods measured in each experiment were converted to absolute reactivities using these curves. The resultant reactivities were used with their corresponding water height measurements to produce a $\delta p / \delta H$ point for each experiment. These $\delta p / \delta H$ values were plotted against H and a single curve for all the reactivity experiments was drawn, Figure B-4. The curve was integrated and the integrals at different water heights were plotted in a total worth curve, Figure B-5. From the total worth curve, reactivities at various water heights were subtracted from the fully inundated reactivity. The resultant installed reactivities were plotted versus critical height as shown in Figure B-6. Installed reactivity (reactivity available above just critical to fully inundated) was found for each experiment by using the just critical height for the experiment and Figure B-6. Reactivity worths were calculated by taking the installed reactivity difference between a reference core and the perturbed core. Core diagrams, data and results are included in Table 250.4 and Figure 250.3.

TABLE 250.4 - REACTIVITY DATA AND EVALUATION

Type of Experiment	Core Size	Region 1		Region 2	Critical Height (cm)	Period		Perturbation	$\Delta k/k$	Remarks	Experiment Date
		Size	Fuel	Fuel		sec	Height (cm)				
Fuel Substitution	19x19	19x19	UO ₂		81.73			None	0	21°C, Reference Case Buckling, Flux	4/09/65
	19x19	3x3	PuO ₂ -UO ₂	UO ₂	82.17			3x3 PuO ₂ -UO ₂ Inserted in Center	-0.028	21°C	
	19x19	19x19	UO ₂		81.95			Detectors Removed From Core Boundaries	0	18°C, New Reference	4/12/65
	19x19	7x7	PuO ₂ -UO ₂	UO ₂	84.22			Insertion of 7x7 PuO ₂ -UO ₂ in Center	-0.13	18°C	
	19x19	19x19	PuO ₂ -UO ₂		80.73			None	0	14.7°C Reference Case	4/26/65
	19x19	3x3	UO ₂	PuO ₂ -UO ₂	79.95			3x3 UO ₂ Insert in the Center	+0.053		
	19x19	19x19	PuO ₂ -UO ₂		80.78			None	0	15°C, Reference Case Buckling, Flux	4/28/65
	19x19	17x17	PuO ₂ -UO ₂	UO ₂	91.31			Substitution, 1 Outer Row of UO ₂	-0.55	15°C	
	19x19	15x15	PuO ₂ -UO ₂	UO ₂	92.76			Substitution, 2 Outer Rows of UO ₂	-0.62	15°C	
	19x19	15x15	PuO ₂ -UO ₂	UO ₂	92.02			Repeat Last Exp. - 4/28/65	0	14.8°C, New Reference	4/29/65
	19x19	13x13	PuO ₂ -UO ₂	UO ₂	90.87			Substitution, 3 Outer Rows of UO ₂	+0.06		
	19x19	11x11	PuO ₂ -UO ₂	UO ₂	88.40			Substitution, 4 Outer Rows of UO ₂	+0.16		
	19x19	19x19	UO ₂		81.73			None	0	16°C, New Reference	5/05/65
	19x19	17x17	UO ₂	PuO ₂ -UO ₂	71.90			Substitution, 1 Outer Row PuO ₂	+0.71	16°C	
	19x19	15x15	UO ₂	PuO ₂ -UO ₂	71.67			Substitution, 2 Outer Rows PuO ₂	+0.75	16°C	
	19x19	13x13	UO ₂	PuO ₂ -UO ₂	72.95			Substitution, 3 Outer Rows PuO ₂	+0.62	15°C	
	19x19	11x11	UO ₂	PuO ₂ -UO ₂	74.45			Substitution, 4 Outer Rows PuO ₂	+0.51	15°C	
	19x19	7x7	UO ₂	PuO ₂ -UO ₂	77.55			Substitution, 6 Outer Rows PuO ₂	+0.27	15.5°C	
	19x19	19x19	PuO ₂ -UO ₂		80.78			All PuO ₂	+0.05	15°C	
Borated Fuel Substitution In Quarter Core	27x27	19x19	PuO ₂ -UO ₂	UO ₂	86.56	43.0	87.97	Boron Content: 1425 ppm	0	Reference Core, T° = 18.0°C	5/25/65
	27x27	19x19	PuO ₂ -UO ₂	UO ₂	84.39	50.0	85.46	2 Rows of UO ₂ Removed From S-E Quadrant and Replaced by PuO ₂ -UO ₂	+0.13	T° = 18.0°C, Figure 250.3(a)	
	27x27	19x19	PuO ₂ -UO ₂	UO ₂	83.31	36.0	84.78	3 Rows of UO ₂ Replaced By PuO ₂ -UO ₂ in S-E Quadrant	+0.18	T° = 18.0°C, Figure 250.3(b)	
	27x27	19x19	PuO ₂ -UO ₂	UO ₂	81.78	32.0	83.04	S-E Quadrant is all PuO ₂ -UO ₂	+0.28	T° = 18.0°C, Figure 250.3(c)	
	27x27	19x19	PuO ₂ -UO ₂	UO ₂	84.09	69.0	84.94	16 PuO ₂ -UO ₂ Replaced by UO ₂ at the Center	+0.14	T° = 18.0°C, Figure 250.3(d)	
	27x27	19x19	PuO ₂ -UO ₂	UO ₂	88.64	62.0	90.18	49 PuO ₂ -UO ₂ Replaced by UO ₂ at the Center	+0.11	T° = 18.0°C, Figure 250.3(e)	
	27x27	19x19	PuO ₂ -UO ₂	UO ₂	93.44	30.0	98.67	100 PuO ₂ -UO ₂ Replaced by UO ₂ at the Center	-0.32	T° = 18.0°C, Figure 250.3(f)	

TABLE 250.4 (continued)

Type of Experiment	Core Size	Region 1		Region 2	Critical Height (cm)	Period		Perturbation	$\Delta k/k$	Remarks	Experiment Date
		Size	Fuel	Fuel		sec	Height (cm)				
Water Slot	21x21	11x11	PuO ₂ -UO ₂	UO ₂	51.38	52.0	51.90	None	0	Reference Core, T° = 15.5°C	5/04/65
	21x21	11x11	PuO ₂ -UO ₂	UO ₂	49.33	29.5	49.95	Water Slot in the Center	+0.46	T° = 15.5°C	
	21x21	11x11	PuO ₂ -UO ₂	UO ₂	50.11	43.0	50.65	Water Slot at PuO ₂ Interface	+0.27	T° = 15.5°C	
	21x21	11x11	PuO ₂ -UO ₂	UO ₂	50.35	30.0	50.95	Water Slot at UO ₂ Interface	+0.20	T° = 15.5°C	
Control Rods	21x21	11x11	PuO ₂ -UO ₂	UO ₂	51.38	52.0	51.9	None	0	Reference Core	5/04/65
	21x21	11x11	PuO ₂ -UO ₂	UO ₂	81.84	23.0	84.31	5 Control Rods in the Center	-3.65	T° = 15.5°C	
	21x21	11x11	PuO ₂ -UO ₂	UO ₂	73.88	28.6	75.39	5 Control Rods, 1 Row in From PuO ₂ -UO ₂ Interface	-3.10	T° = 15.5°C	
	21x21	11x11	PuO ₂ -UO ₂	UO ₂	71.86	37.0	73.09	5 Control Rods at PuO ₂ -UO ₂ Interface	-2.92	T° = 15.5°C	5/05/65
	21x21	11x11	PuO ₂ -UO ₂	UO ₂	68.49	36.0	69.69	5 Control Rods at UO ₂ Interface	-2.60	T° = 15.8°C	
	21x21	11x11	PuO ₂ -UO ₂	UO ₂	65.63	35.5	66.71	5 Control Rods, 1 Row Out From UO ₂ Interface	-2.25	T° = 15.8°C	
	21x21	11x11	PuO ₂ -UO ₂	UO ₂	62.90	52.5	63.63	5 Control Rods, 2 Rows Out From UO ₂ Interface	-1.92	T° = 15.8°C	
Water Slot Inverted Core	21x21	11x11	UO ₂	PuO ₂ -UO ₂	48.85	34.0	48.98	None	0	Reference Core, T° = 16.0°C	5/07/65
	21x21	11x11	UO ₂	PuO ₂ -UO ₂	47.62	41.4	48.05	Water Slot in the Center	+0.20	T° = 16.0°C	
	21x21	11x11	UO ₂	PuO ₂ -UO ₂	47.46	81.2	47.75	Water Slot at UO ₂ Interface	+0.28	T° = 16.0°C	
	21x21	11x11	UO ₂	PuO ₂ -UO ₂	47.49	49.4	47.87	Water Slot at PuO ₂ -UO ₂ Interface	+0.25	T° = 16.0°C	
Control Rods Inverted Core	21x21	11x11	UO ₂	PuO ₂ -UO ₂	48.85	34.0	48.98	None	0	Reference Core, T° = 16.0°C	5/07/65
	21x21	11x11	UO ₂	PuO ₂ -UO ₂	80.32	46.5	81.46	5 Control Rods in the Center	-4.35	T° = 16.0°C	
	21x21	11x11	UO ₂	PuO ₂ -UO ₂	62.0	36.7	62.84	5 Control Rods at UO ₂ Interface	-3.06	T° = 16.0°C	
	21x21	11x11	UO ₂	PuO ₂ -UO ₂	65.65	36.0	66.52	5 Control Rods at PuO ₂ -UO ₂ Interface	-2.55	T° = 16.0°C	
Boron Worth	27x27	19x19	PuO ₂ -UO ₂	UO ₂	65.46	74.0	65.97	Boron Content: 1166 ppm	0	Reference Core, T° = 18.4°C	5/12/65
	27x27	19x19	PuO ₂ -UO ₂	UO ₂	82.89	55.0	84.33	Boron Content: 1388 ppm	-1.49	T° = 18.5°C	5/13/65
	27x27	19x19	PuO ₂ -UO ₂	UO ₂	91.19	32.0	93.62	Boron Content: 1453 ppm	-1.95	T° = 18.5°C	5/13/65
Borated Perturbation	27x27	19x19	PuO ₂ -UO ₂	UO ₂	91.72	26.0	94.61	Boron Content: 1453 ppm	0	Reference Core, T° = 18.2°C	5/14/65
	27x27	19x19	PuO ₂ -UO ₂	UO ₂	98.19	87.0	102.36	Water Slot at PuO ₂ -UO ₂ Interface	-0.25	T° = 18.0°C	5/15/65
	27x27	19x19	PuO ₂ -UO ₂	UO ₂		140.0	104.76	Aluminum Slab at PuO ₂ -UO ₂ Interface	-0.42	T° = 17.8°C	5/17/65
Borated Insert	27x27	19x19	PuO ₂ -UO ₂	UO ₂	86.56	43.0	87.97	Boron Content: 1425 ppm	0	Reference Core, T° = 18.0°C	5/21/65
	27x27	19x19	PuO ₂ -UO ₂	UO ₂	87.85	27.0	89.77	3x3 UO ₂ Insert in Core Center	-0.07	T° = 18.5°C

Figure 250.3 - Quarter-Core Fuel Substitution Experiments

4.0 FLUX MEASUREMENTS

4.1 Measurements

As described in the previous report¹, the relative fast, resonance and thermal fluxes were measured by means of foils. The cores in which flux measurements were made are listed in Table 250.2.

The fast flux was measured by gamma counting irradiated U-238 foils. The gammas given off are a result of fission product decay. Since U-238 can only be fissioned by fast neutrons (above 1 Mev), the gamma emission is directly proportional to the greater than 1 Mev flux.

By counting the foils, three days later, the relative U-238 capture distribution was measured. This activity is due primarily to the resonance flux, however, it also contains a thermal flux component.

The 104 kev x-ray emitted during the formation of ${}_{94}\text{Pu}^{239}$ was counted.

Thermal flux shapes were determined using bare dysprosium foils. Gamma emission from dysprosium foils is due to activation by essentially thermal neutrons. Thus gamma counting leads to a measure of the thermal flux.

The relative flux shapes are shown in Figures 250.4 - 250.8. A tabulation of the relative flux values and the position of the foils in the core may be found in Attachment C.

Relative Fast and Resonance Flux

5.0 TEMPERATURE COEFFICIENT

The temperature coefficient of reactivity was calculated from the installed reactivity curve in Attachment B, Figure B-6, using the following data:

<u>Temperature</u>	<u>Height</u>	<u>$\Delta k/k$ (From Curve)</u>
65.4°C	99.63 cm.	0.11%
61.3°C	97.17 cm.	0.20%
16.2°C	89.44 cm.	0.54%

$$\alpha = \frac{-0.09\%}{4.1^{\circ}\text{C}} \times \frac{5}{9} = -12.2 \times 10^{-5}/^{\circ}\text{F at } 146.03^{\circ}\text{F}$$

$$\alpha = \frac{-0.34\%}{45.1^{\circ}\text{C}} \times \frac{5}{9} = -4.19 \times 10^{-5}/^{\circ}\text{F at } 101.75^{\circ}\text{F}$$

$$\alpha = \frac{-0.43\%}{49.2^{\circ}\text{C}} \times \frac{5}{9} = -4.86 \times 10^{-5}/^{\circ}\text{F at } 105.44^{\circ}\text{F}$$

REFERENCES

1. Sternberg, H. I., "Saxton Plutonium Critical Experiments, Single Region Experimental Data and Data Evaluation," Appendix A (1965).
2. Nath, R. J., and Leamer, R. D., "Measurements Relating Power Sharing Between Pu and U Fuel Rods," Appendix D (1965).
3. Hamilton, G. N., and Corbett, J. A., "Measurements of Gamma to Fission Ratios by Gamma Ray Spectrometry to Relate Uranium/Plutonium Multizone Power Distributions," Appendix C (1965).
4. Wood, P., "POWER SCAN - A Program for Correcting Dead Time and Normalizing Count Rates From Experimental Values to PDQ."

ATTACHMENT A

Power Scan Data

The power scan data for the power sharing experiments listed in Table 250.2 are listed in Table A-1 through A-12. Core diagrams showing the measurement locations are included in Figures A-1 through A-12.

TABLE A-1

POWER SCAN DATA OF CONFIGURATION 1(a)

19x19, 0.56-inch Pitch Core
 11x11 PuO_2 - UO_2 in the Center
 UO_2 Outer Region

Critical Water Height: 88.57 cm.
 Water Temperature: 14.9°F
 Date: 4/29/65

1	2	3	4	5	6	7	8		
Type Fuel	Monitor Rod	Traverse Direction	Rod Position From Center	Rod Number	Reference Rod for Normalization	Count Normalized to Column 6	RELATIVE POWER *		
							Foil Method	Thermal Method	
PuO ₂ -UO ₂	PuO ₂ -UO ₂ (67)**	Flat Side	1	69	69	1.0	1.0		
			2	71		0.994814	1.000977	1.000977	
				80		1.007140			
			3	91		0.982318		0.982318	
			4	83		0.973143		0.973143	
			5	85		0.957861	0.955504	0.955504	
				74		0.953147			
			6	88		0.965602	0.978816	0.978816	
				80		1.007140			
				70: standard		0.962577			
						0.985837			
						0.976487			
						0.975255			
		Diagonal	1	69		1.0	1.0		
			2	73		1.000782		1.000782	
			3	81		0.975149		0.975149	
			4	84		0.918709		0.918709	
			5	89		0.879472		0.879472	
			6	97		0.906933		0.906933	
		Other Rods		98		0.920679		0.920679	
			Flat Side	7	5: standard	(1) = 1.994366	1.328941	1.326067	0.7859
						1.328099			
						1.327819			
						1.339291			
				1.330901					
				1.333586					
				1.216974					
				1.320556					
				1.328508					
				1.324954					
				1.306971					
	8	3			1.348195		0.7990	0.7536	
	9	2			1.416438		0.8395	0.7918	
	10	1			1.994366	1.968904	1.1669	1.1006	
		6			1.943441				
Diagonal	7	12			1.154641	1.157476	0.6860	0.6470	
					1.160310				
	8	11		1.045863		0.6198	0.5846		
	9	10		1.071098		0.6348	0.5987		
	10	9		1.708466		1.0125	0.9550		
Other Rods		14		1.283336		0.7606	0.7174		
		13		1.190816		0.7057	0.6657		
		15		1.294417		0.7671	0.7236		

*The time after shutdown the gamma count was made was not recorded. To relate the power distribution in each region, the power factors obtained in configuration 1(b) were used. They are 0.8029 and 0.7573 for the foil and thermal methods respectively for UO_2/PuO_2 - UO_2 .

**Monitor Rod

TABLE A-2
POWER SCAN FOR CONFIGURATION 1(b)

19x19 Core, 0.56-inch Pitch
11x11 PuO₂-UO₂ in the Center
UO₂ Outer Region

Critical Water Height: 89.43 cm.
Temperature: 16.2°C
Date: 6/3/65

1 Type Fuel	2 Monitor Rod	3 Traverse Direction	4 Rod Position From Center	5 Rod Number	6 Reference Rod for Normalization	7 Count Normalized to Column 6	8 RELATIVE POWER		9
							Thermal Method	Foil Method	
PuO ₂ -UO ₂	PuO ₂ -UO ₂ (16)**	Flat Side	1	15	15	1.0			1.0
			2	12		0.992694			0.992694
			3	10		0.973521			0.973521
			4	7		0.965661			0.965661
			5	4		0.925034			0.925034
			6	1: standard		0.956994			0.959169
				17		0.946095			
				18		0.927532			
				1		0.961053			
				1		0.971293	0.959169		
				1		0.968163			
				1		0.973372			
				1		0.978036			
				14		0.949944			
		Diagonal	1	15		1.0			1.0
			2	13		0.988110			0.988110
			3	11		0.943276			0.943276
			4	9		0.912593			0.912593
			5	6		0.859423			0.859423
			6	3		0.894029			0.894029
		Other Rods		8		0.956977			0.956977
				5		0.903848			0.903848
				2		0.923924			0.923924
UO ₂	UO ₂ (29)**	Flat Side	7	32: standard	L	1.003190	0.7264		0.7701
				K		1.007318			
				J		1.000311	1.002958		
				L		1.000000			
				32		1.003974			
			8	28		1.047785	0.7589		0.8045
			9	23		1.093378	0.7919		0.8395
			10	10		1.524134	1.1039		1.1703
		Diagonal	7	D		0.872129	0.6316		0.6697
			8	31		0.790867	0.5728		0.6073
		Diagonal	7	D		0.872129	0.6316		0.6697
			8	31		0.790867	0.5728		0.6073
			9	27		0.808420	0.5855		0.6207
			10	22		1.297138	0.9395		0.9960
		Other Rods		24		1.053872	0.7634		0.8092
				33		0.988427	0.7159		0.7589
				20		1.463406	1.0599		1.1236
				25		0.978342	0.7086		0.7512
				21		1.301410	0.9426		0.9993
				26		0.860530	0.6232		
				32	1	0.844120	35.03 min.*		
UO ₂	PuO ₂ -UO ₂ (16)	Power Sharing		32	1	0.855680	43.97 min.*		
				32	1	0.866890	50.83 min.*		
				32	1	0.884020	59.70 min.*		
				32	1	0.901460	70.55 min.*		
				32	1	0.928960	90.87 min.*		

*Time after shutdown the gamma count was made
**Monitor rod

POWER RELATIONSHIP OF STANDARD RODS

Time After Shutdown	Activity Ratio Pu/U	Foil Method		Thermal Method	
		Factor	Relative Power	Factor	Relative Power
35.03 minutes	0.844121	1.128	0.7483	1.057	0.7986
43.97 minutes	0.855684	1.140	0.7506	1.070	0.7997
50.83 minutes	0.866886	1.150	0.7538	1.085	0.7990
59.70 minutes	0.884015	1.165	0.7588	1.103	0.8015
70.55 minutes	0.901456	1.180	0.7640	1.117	0.8070
90.87 minutes	0.928959	1.208	0.7690	1.145	0.8113

TABLE A-3

POWER SCAN FOR CONFIGURATION 3

27x27 core, 0.56-inch pitch
UO₂ in the outer region
19x19 PuO₂-UO₂ in the inner region

3x3 UO₂ inserted in PuO₂-UO₂ region
1425 ppm boron
Just critical water height: 87.50 cm.
Temperature: 18.5°C

1	2	3	4	5	6	7	8	9			
Type Fuel	Monitor Rod	Traverse Direction	Rod Position From Center	Rod Number	Reference Rod for Normalization	Count Normalized to Column 6	Corrected**	RELATIVE POWER			
								Foil Method	Thermal Method		
PuO ₂ -UO ₂	PuO ₂ -UO ₂	Background Flat Side	3	5: standard	5	0.018964	1.0	1.0			
						1.0					
						1.010728					
						1.007050					
						1.004459					
						0.986923					
						0.914784				0.916649	0.916649
						0.882062				0.883166	0.883166
						0.838578				0.838671	0.838671
						0.757821				0.756036	0.756036
		0.708445	0.705512	0.705512							
		Other Rods	10	1	1.010252	1.014336	1.014336				
				3	0.934895	0.937227	0.937227				
				4	0.985151	0.988652	0.988652				
UO ₂	UO ₂	Background Flat Side	1	I=24	I=24	0.009916	1.0	0.905034 0.850332			
						1.0					
						0.937807					
						0.837728					
						0.946793					
						0.945763					
						0.945322					
						0.949292					
						0.937175					
						0.608952				0.605035	0.547580 0.514480
		Other Rods	11	A=20	0.901778	0.900108	0.814633 0.765391				
				E=22	0.900159	0.901099					
				K=26	0.897004						
				M=28	0.905456						
UO ₂	PuO ₂ -UO ₂	Power Sharing	2	L=27	5	0.889955	0.882825	18 min 22 sec *			
						0.890429	0.883306	22 min 10 sec *			
						0.894455	0.887386	24 min 17 sec *			
						0.906622	0.899719	34 min 06 sec *			

POWER RELATIONSHIP OF THE STANDARD RODS

Time After Shutdown	Activity Ratio U/Pu	Foil Method		Thermal Method	
		Factor	Relative Power	Factor	Relative Power
18 min. 22 sec.	0.882825	1.030	0.857111	1.092	0.808447
22 min. 10 sec.	0.883306	1.032	0.855916	1.100	0.803005
29 min. 17 sec.	0.887386	1.046	0.848361	1.114	0.796576
34 min. 06 sec.	0.899719	1.056	0.852006	1.126	0.799039

Average

0.853348

0.801760

*Time after shutdown the gamma count was made
**Corrected for background and renormalized

TABLE A-4
POWER SCAN OF CONFIGURATION 4

19x19 core, 0.56-inch pitch
11x11 UO₂ in the center, PuO₂-UO₂ outer region
Just critical water height: 74.43 cm.
Temperature: 15.6°C
Date: 5/06/65

1 Type Fuel	2 Monitor Rod	3 Traverse Direction	4 Rod Position From Center	5 Rod Number	6 Reference Rod for Normalization	7 Count Normalized to Column 6	8 Corrected**	9 RELATIVE POWER	
								Foil Method	Thermal Method
UO ₂	76: UO ₂	Background Flat Side	1	69	69	0.014716	0		
			2	70		1.0	1.0	1.0	
			3	71		0.991678	0.991552	0.99155	
			4	78		0.982276	0.985132	0.984909	0.98491
			5	72		0.987989			
			6	74		0.944163	0.943328	0.94333	
				73		0.877597	0.875768	0.875768	
				67: standard		0.765073	0.778499	0.775190	0.77519
						0.787345			
						0.779698			
						0.781880			
		Diagonal	1	69		1.0	1.0	1.0	
			2	75		0.980957	0.980672	0.98067	
			3	79		0.952446	0.951735	0.95174	
			4	81		0.888781	0.887119	0.88712	
			5	83		0.782953	0.779711	0.77971	
			6	84		0.608538	0.602691	0.60269	
		Other Rods		77		0.931689	0.930668	0.93067	
				80		0.853827	0.851643	0.85164	
				82		0.725351	0.721248	0.72125	
PuO ₂ -UO ₂	97: PuO ₂ -UO ₂	Background Flat Side	7	11	11	0.016740	0	0	0
				96: standard		1.0	1.0	0.87984	0.83193
						1.013347	1.012622		
						1.011338			
						1.014384			
						1.024045			
			8	12		0.830437	0.817062	0.71888	0.67974
			9	13		0.816947	0.803516	0.70696	0.66847
			10	17		1.256038	1.244422	1.09489	1.03527
		Diagonal	7	90		0.715440	0.701589	0.61729	0.58367
			8	92		0.602636	0.588319	0.51763	0.48944
			9	93		0.619582	0.605335	0.53260	0.50360
		Other Rods	10	94		1.159064	1.147047	1.00922	0.95426
				18		0.984122	0.971382	0.85466	0.80812
				19		0.815868	0.802432	0.70601	0.66757
				20		0.787499	0.773946	0.68095	0.64387
				85		1.196011	1.184147	1.04186	0.98513
				86		0.893306	0.880191	0.77443	0.73226
				87		0.757367	0.743695	0.65433	0.61870
				88		0.710868	0.696998	0.61325	0.57985
				89		1.102305	1.090054	0.95907	0.90685
				91		0.648279	0.63415	0.55795	0.52757
UO ₂	97: PuO ₂ -UO ₂	Power Sharing		67	96		0.99015	35 min.	***
							1.00231	49 min.	52
							1.01354	55 min.	47
							1.03560	68 min.	08
UO ₂	76: PuO ₂ -UO ₂	Power Sharing		96	67		0.95261	70 min.	40
							0.94105	85 min.	35
							0.93063	93 min.	53

**Corrected from background and renormalized
***Time after shutdown the gamma count was made

POWER RELATIONSHIP OF THE STANDARD RODS

Time After Shutdown	Activity Ratio U/Pu	Thermal Method		Foil Method	
		Factor	Relative Power	Factor	Relative Power
35 min.	1.00995	1.128	1.1392	1.057	1.0675
49 min. 52 sec.	0.99769	1.150	1.1473	1.085	1.0825
55 min. 47 sec.	0.98664	1.158	1.1425	1.093	1.0784
68 min. 08 sec.	0.96562	1.177	1.1365	1.116	1.0776
70 min. 40 sec.	0.95261	1.180	1.1241	1.118	1.0650
85 min. 35 sec.	0.94105	1.200	1.1293	1.138	1.0709
93 min. 53 sec.	0.93063	1.210	1.1261	1.150	1.0702

Average

1.1350

1.0732

TABLE A-5

POWER SCAN FOR CONFIGURATION 5

27x27 core, 0.56-inch pitch
19x19 UO₂ in the center, PuO₂-UO₂ outer region
1252 ppm boron

Critical water height: 85.05 cm.
Temperature: 20°C
Date: 5/28/65

1 Type Fuel	2 Monitor Rod	3 Traverse Direction	4 Rod Position From Center	5 Rod Number	6 Reference Rod for Normalization	7 Count Normalized to Column 6	8 RELATIVE POWER	
							Foil Method	Thermal Method
UO ₂	UO ₂	Flat Side	1	0	1	1.0000	1.0	1.0
			2	F		0.947884	0.947884	
			3	E		0.925046	0.925046	
			4	B		0.904733	0.904733	
			5	A		0.888631	0.888631	
			6	98		0.840597	0.840597	
			7	97		0.815733	0.815733	
			8	96		0.763982	0.763982	
			9	95		0.697033	0.697033	
			10	94		0.648776	0.611045	
		Diagonal		I: standard		0.598489		
						0.592206	0.611045	
						0.622699		
				4		0.587571		
				P		0.603372		
			1	0	1	1.0000	1.00	
			4	93		0.881436	0.881436	
			6	89		0.764661	0.764661	
			8	86		0.605302	0.605302	
			10	83		0.383271	0.383271	
PuO ₂ -UO ₂	PuO ₂ -UO ₂	Flat Side		88		0.508842	0.508842	
				90		0.850660	0.850660	
				91		0.565209	0.565209	
				92		0.784210	0.784210	
			11	79	80	1.030090	0.655780	0.687242
				80: standard		1.013603	1.019973	
				80		1.0		
				72		1.024974		
				81		1.018029		
			12	78		0.818071	0.525969	0.551203
		Diagonal	13	77		0.742092	0.477119	0.500010
			14	76		0.925472	0.595910	0.624499
				82		0.928236		
			11	71		0.597965	0.589332	0.378904
				73		0.580600		
			12	69		0.450371	0.289561	0.303453
			13	68		0.394540	0.253665	0.265835
			14	67		0.533733	0.343157	0.359621
		Other Rods		72		1.024974	0.658995	0.690611
				74		0.704801	0.453143	0.474884
				75		0.786030	0.505369	0.529614
UO ₂	PuO ₂ -UO ₂	Standard	10	I	80	1.08265	84 min. after shutdown	
			10	I	80	1.094672	102 min. 14 after shutdown	
PuO ₂ -UO ₂	UO ₂	Standard	11	80	I	0.972921	56 min. 5 after shutdown	
			11	80	I	0.968401	69 min. 42 after shutdown	
			11	80	I	0.949293	82 min. after shutdown	

POWER RELATIONSHIP OF THE STANDARD RODS

Time After Shutdown	Activity Ratio U/Pu	Foil Method		Thermal Method	
		Factor	Relative Power	Factor	Relative Power
56 min. 5 sec.	0.972921	1.110	1.0799	1.155	1.1237
69 min. 48 sec.	0.968401	1.125	1.0894	1.180	1.1427
82 min.	0.949293	1.140	1.0822	1.195	1.1344
84 min.	0.923659	1.142	1.0548	1.200	1.1084
102 min.	0.913515	1.160	1.0597	1.220	1.1145

Average

1.0732

1.1247

TABLE A-6

POWER SCAN FOR CONFIGURATION 6

19x19 UO₂ core, 0.56-inch lattice
3x3 PuO₂-UO₂ insert

Just critical water height: 82.17 cm.
Water Temperature: 21.2°C

Date: 4/ 9/65

1 Type Fuel	2 Monitor Rod	3 Traverse Direction	4 Rod Position From Center	5 Rod Number	6 Reference Rod for Normalization	7 Count Normalized to Column 6	8 RELATIVE POWER	
							Foil Method	Thermal Method
UO ₂	UO ₂	Flat Side	3	30	28	1.571529	1.198540	
				23: standard		1.613138		
						1.637971		
						1.634106		
						1.641274		
						1.620177		
			4	31		1.653264	1.228751	
				22		1.667788		
			6	32		1.549643	1.143958	
				21		1.542231		
			8	33		1.347290	1.0	
				20		1.355494		
		Diagonal	3	25	1	1.653257	1.223372	
			4	26		1.605104	1.187740	
			6	27		1.298409	0.960793	
			8	28		1.0	0.739977	
		Other Rods		24		1.586740	1.179178	
				29		1.600326		
PuO ₂ -UO ₂	PuO ₂ -UO ₂	Flat Side	1	15		1.0	1.318159	1.388394
			2	12		1.074686	1.40361	1.478399
				18		1.044923		
				14: standard		1.078933		
		Diagonal		16		1.060764		
			1	15		1.0	1.318159	1.388394
			2	13		1.109150	1.477186	1.555894
				19		1.132327		
PuO ₂ -UO ₂	UO ₂	Power Sharing		17	23	1.120452		
				14		1.0683	58 minutes*	
						1.0539	63 minutes*	
						1.0500	67 minutes*	
						1.0484	71 minutes*	
						1.0363	77 minutes*	
						0.9825	121 minutes*	

Power Relationship of the Standard Rods

Time After Shutdown	Activity Ratio Pu/U	Foil Method		Thermal Method	
		Factor	Relative Power	Factor	Relative Power
58 minutes	1.0683	1.100	1.1750	1.164	1.2435
63 minutes	1.0539	1.108	1.1677	1.170	1.2331
67 minutes	1.0500	1.115	1.1707	1.178	1.2369
71 minutes	1.0484	1.117	1.1711	1.182	1.2392
77 minutes	1.0363	1.130	1.17102	1.190	1.2332
121 minutes	0.9825	1.177	1.1564	1.237	1.2154
Average			1.1711		1.2335

*Time after shutdown the gamma count was made

TABLE A-7

POWER SCAN OF CONFIGURATION 7

19x19 $\text{PuO}_2\text{-UO}_2$ core, 0.56-inch pitch
3x3 UO_2 insert

Just critical water height: 79.96 cm.

Temperature: 14.7°C

Date: 4/26/65

1	2	3	4	5	6	7	8	9												
Type Fuel	Monitor Rod	Traverse Direction	Rod Position From Center	Rod Number	Reference Rod for Normalization	Count Normalized to Column 6	Corrected**	RELATIVE POWER Foil Method	Thermal Method											
PuO ₂ -UO ₂ (Pellets)	PuO ₂ -UO ₂ (Pelletized)	Background Flat Side	3	10	13	0.013883	0	1.351733	1.351733											
				15		1.349633				1.342597										
				32		1.342107														
				35		1.326664														
			4	11		1.351985														
				16		1.203366				1.208223	1.215031	1.215031								
				5		12: standard				1.213081										
										1.121974	1.134145	1.139669	1.139669							
						1.130464														
						1.144000														
			7			1.134401														
						1.136566														
						1.133172														
						1.126722														
			9			1.150055														
						1.132068														
						1.132866														
						1.133307														
			7	13		1.0				0.996854	1.0	1.0								
				18		0.993709														
		9		14		0.968195				0.969416	0.972087	0.972087								
				19		0.970637														
		Diagonal	3	20		1.217613				1.225063	1.232162	1.232162								
				34		1.232513														
			4	21		1.111692				1.116827	1.116827									
				5		22				1.034869	1.032744	1.036512	1.036512							
			7	23		1.030620														
				24		0.792720				0.792329	0.792329									
			9	30		0.721054				0.719422	0.719422									
				31		1.299094				1.304758	1.313238	1.313238								
			Other Rods			31				1.310422										
		PuO ₂ -UO ₂ (Vipac)	PuO ₂ -UO ₂ (Pelletized)	Flat Side		4				43 } = { 11	1	1.225206	1.221262	1.228296	1.228296					
										44 } = { 16		1.217319								
				Diagonal		4				41 } = { 21		1.151345				1.157167	1.157167			
										40 } = { 30		1.342401				1.339731	1.348817	1.348817		
				Other Rods		4				42 } = { 31		1.337061								
				UO ₂		UO ₂				Background Flat Side		1				5	0.012300	0		
																2	1.117146	1.107892	1.1522	1.0805
UO ₂	UO ₂			Diagonal	1	5	1.053645	1.043572	1.0852	1.0584										
						8	1.051852	1.053003												
		6	1.053513																	
		5	1.117146			1.107839	1.1522	1.0805												
		2	1.0			1.009550	1.0	1.0400	0.9752											
		3	1.009365																	
		9	1.012595																	
		7	1.007571																	
			1.024158																	
			1.003611																	
UO ₂	PuO ₂ -UO ₂	Background Power Sharing	1	12: standard	0.012251	0														
					1.100873	1.098373	1.099593	175 minutes *												
					1.093025															
					1.104770															
					1.094824															

TABLE A-8
POWER SCAN FOR CONFIGURATION 8

27x27 core, 0.56-inch pitch
19x19 PuO₂-UO₂ in the center, UO₂ outer region
L shaped UO₂ inserted in PuO₂-UO₂ region
Mn wire activation in simulated Saxton design core

1425 ppm boron
Just critical water height: 90.56 cm.
Temperature of water: 18.5°C
Date: 5/21/65

1	2	3	4	5	6	7	8			
Type Fuel	Monitor Rod	Traverse Direction	Rod Position From Center	Rod Number	Reference Rod for Normalization	Count Normalized to Column 6	RELATIVE POWER			
							Foil Method	Thermal Method		
PuO ₂ -UO ₂	PuO ₂ -UO ₂	Flat Side West		21	20	0.950617	1.0			
				20: standard		0.999654	1.051948			
				On Diagonal		}	1.003125	1.0		
							1.001569			
							0.995653			
		1.008125					1.060495			
		0.724727					0.762375			
		17				0.949113	0.998418			
		13				0.903728	0.950675			
		9				0.767276	0.807134			
		6				0.610809	0.642539			
		4				0.524434	0.551677			
		Flat Side North		10		0.997157	1.048957			
				7		0.785482	0.826286			
				5		0.725266	0.762942			
				Flat Side South		24	0.805936	0.847803		
						Flat Side East	22	0.814230	0.856528	
		Other Rods					8	0.684204	0.719747	
							11	0.670721	0.705564	
							12	0.752856	0.791965	
				14			0.925934	0.974034		
				15		0.718287	0.755601			
		16		0.795003		0.836302				
UO ₂	UO ₂	L Shape, West		79: standard	79	0.990635	1.0	0.809770	0.768252	
						1.009365				
						80		0.978024	0.791974	0.751369
						81		0.982967	0.795977	0.755166
						82		0.963098	0.779988	0.739902
		L Shape, East				78	0.932540	0.755143	0.716426	
						Flat Side Outer, N	72	0.700365	0.567135	0.538057
							71	0.729367	0.590620	0.560338
							70	0.470387	0.380905	0.361376
						Diagonal Outer	69	0.398930	0.323042	0.306479
		68					0.341652	0.276660	0.262475	
		67					0.373171	0.302183	0.286689	
		Other Rods					73	0.519873	0.420978	0.399393
							74	0.644353	0.521778	0.495025
75	0.707079				0.572571	0.543215				
76	0.732333				0.593021	0.562616				
UO ₂	PuO ₂ -UO ₂ *			Power Sharing	79	20	0.82558	52 min. 59 sec.	***	
		0.83756					63 min.	***		
		0.87926					90 min.	***		
		0.89809					102 min. 20 sec.	***		
		1.10622					107 min. 15 sec.	***		
PuO ₂ -UO ₂	UO ₂ **	Power Sharing		20	79	1.07823	125 min. 50 sec.	***		

POWER RELATIONSHIP OF THE STANDARD RODS

Time After Shutdown	Activity Ratio U/Pu	Thermal Method		Foil Method	
		Factor	Relative Power	Factor	Relative Power
52 min. 59 sec.	0.82558	1.152	0.71665	1.090	0.75741
63 min.	0.83756	1.170	0.71586	1.110	0.75456
90 min.	0.87926	1.208	0.72786	1.145	0.76791
102 min. 20 sec.	0.89809	1.220	0.73614	1.160	0.77422
107 min. 15 sec.	0.90398	1.226	0.73734	1.164	0.77661
125 min. 50 sec.	0.92744	1.240	0.74793	1.177	0.78797
Average			0.73030		0.76978

***Time after shutdown the gamma count was made

TABLE A-9
POWER SCAN FOR CONFIGURATION 9

19x19 Core, 0.56-inch Pitch
11x11 PuO₂-UO₂ in the Center, UO₂ Outer Region
5 PuO₂-UO₂ Rods Removed at the Fuel Interface and an Aluminum Plate Installed

Just Critical Water Height: 90.44 cm.
Temperature ≈ 15°C
Date: 4/30/65

1 Scanned Fuel Rods	2 Monitor Rod Used	3 Traverse Direction	4 Rod Position From Boundary	5 Rod Number	6 Reference Rod For Normalization	7 Count Normalized to Column 6	8 Corrected and Renormalized	9 RELATIVE POWER*	
								Thermal Method	Foil Method
C PuO ₂ -UO ₂	PuO ₂ -UO ₂	Background			76	0.019629	0		
		Flat Side └ Aluminum Plate	5	77		1.073408	1.074878	1.074878	
			10	80		1.108622	1.110797	1.110797	
			11	79		1.095076	1.096979	1.096979	
			12	82		1.095225	1.097132	1.097132	
			13	84		1.137707	1.140464	1.140464	
			14	96		1.350848	1.357873	1.357873	
		Around Plate		89		1.336976	1.343711	1.343711	
				88		1.283665	1.289345	1.289345	
				99		1.068320	1.069688	1.069688	
				98		1.199364	1.203631	1.203631	
				86		0.976775	0.976310	0.976310	
				94		1.026016	1.026537	1.026537	
				93		0.996654	0.996587	0.996587	
		Other Rods		76: standard		1.008951	1.0	1.0	1.0
						0.996227			
						0.994822			
O UO ₂	UO ₂	Background			20	0.021059	0		
		Flat Side └ Plate	16	22		1.478603	1.488899	1.053814	1.117268
			17	23		1.269177	1.274968	0.902398	0.956735
			18	24		1.234335	1.239376	0.877207	0.930027
			19	25		1.709668	1.724934	1.220876	1.294389
			4	21		1.146919	1.150079	0.814005	0.863019
		Around Plate		26		1.450089	1.459771	1.033198	1.095411
				27		1.361720	1.369501	0.969307	1.027672
				29		1.173091	1.176814	0.832927	0.883080
		Other Rods		28		1.198785	1.203061	0.851504	0.902776
				30		1.167738	1.171346	0.829056	0.878977
				31		1.077866	1.079541	0.764079	0.810086
				32		1.038725	1.039558	0.735779	0.780083
				33		0.998066	0.998024	0.706382	0.748916
				20: standard		1.008999	1.0	1.0	0.707781
						1.011659			
						0.994798			
						0.995387			
						0.999307			
						0.989850			

*The time after shutdown the gamma count was made was not recorded. Therefore, in order to determine the relative power in the two regions of the core, the power relationship between rods 77 (PuO₂-UO₂) and 21 (UO₂) from the non-perturbed case of Configuration 1 was used.

Power ratio of UO₂ to PuO₂ by the thermal method = 0.7573
Power ratio of UO₂ to PuO₂ by the foil method = 0.8029

TABLE A-10
POWER SCAN FOR CONFIGURATION 10

21x21 Core, 0.56-inch Pitch
11x11 PuO₂-UO₂ in the Center, UO₂ Outer Region
5 PuO₂-UO₂ Removed at the Interface and Replaced with 5 Ag-In-Cd Control Rods (

0 ppm Boron, Date: 5/4/65
Temperature: 15.5°C
Just critical water height: 71.86 cm.

1 Type Fuel	2 Monitor Rod	3 Traverse Direction	4 Rod Position From Boundary	5 Rod Number	6 Reference Rod for Normalization	7 Count Normalized to Column 6	8 RELATIVE POWER	
							Thermal Method	Foil Method
PuO ₂ -UO ₂	PuO ₂ -UO ₂	Flat Side ⌞ Control Rods	6	83: standard	83	1.007536 } 0.992464 }	1.0	
			11	82		0.935372	0.935372	
			12	81		0.869712	0.869712	
			13	78		0.851918	0.851918	
			14	75		0.777314	0.777314	
		Around Control Rods	15	68		0.626287	0.626287	
				85		0.626417	0.626417	
				87		0.661893	0.661893	
				95		0.732330	0.732330	
				92		0.719699	0.719699	
				79		0.781479	0.781479	
				8		0.825518	0.825518	
				7		0.775476	0.775476	
		Other Rods		90		0.947194	0.947194	
UO ₂	UO ₂	Flat Side ⌞ Control Rods	17	E	F	0.648722	0.500850	0.530871
			18	D		0.745984	0.575942	0.610463
			19	C		0.757118	0.584538	0.619575
			20	B		0.800645	0.618144	0.655194
			21	A		1.156905	0.893197	0.946734
		Around Control Rods		G		0.671523	0.518454	0.549529
				I		0.677998	0.523453	0.554828
				K		0.733149	0.566033	0.599960
				F		1.009138 } 0.975759 }	1.0	0.772057
						1.015103		
				N		0.785435		
				32		0.998039		
				O		0.896282		
		Other Rods		33		0.753800	0.581977	0.616859
				Q		0.783054	0.604562	0.640799
				J		0.753621	0.581838	0.616713
				M		0.726840	0.561162	0.594797
				H		0.799171	0.617006	0.653988
PuO ₂ -UO ₂	UO ₂	Power Sharing		L		0.762215	0.588473	0.623746
				83	F	1.141529	36 minutes***	
						1.129970	48 minutes	
UO ₂	PuO ₂ -UO ₂	Power Sharing				1.118748	65 minutes	
				F	83	0.923064 0.949653	82 minutes 98 minutes	

Power Relationship Between Standard Rods

Time After Shutdown	Activity Ratio U/Pu	Thermal Method		Foil Method	
		Factor	Relative Power	Factor	Relative Power
36 minutes	0.876018	1.130	0.775237	1.058	0.827994
48 minutes	0.884979	1.147	0.771559	1.083	0.817155
65 minutes	0.893856	1.173	0.762025	1.110	0.805275
82 minutes	0.923064	1.198	0.770504	1.128	0.818319
98 minutes	0.949653	1.216	0.780964	1.154	0.822922

Average

0.772057

0.818333

***Time after shutdown the gamma count was made

TABLE A-11
POWER SCAN FOR CONFIGURATION 11

27x27 core, 0.56-inch pitch
19x19 PuO₂-UO₂ in the center, UO₂ outer region
5 PuO₂-UO₂ removed at the interface forming a water slot

1453 ppm boron, Date: 5/14/65
Temperature: 18.0°C
Just critical water height: 98.19 cm.

1 Type Fuel	2 Monitor Rod	3 Traverse Direction	4 Rod Position From Boundary	5 Rod Number	6 Reference Rod for Normalization	7 Count Normalized to Column 6	8 RELATIVE POWER	
							Thermal Method	Foil Method
PuO ₂ -UO ₂	PuO ₂ -UO ₂	Flat Side ⌞ to Waterslot	5	77: standard	77	1.003732 0.999012 0.998123 0.999133	1.0	1.0
			10	79		1.240404		1.240404
			14	80		1.304562		1.304562
			16	82		1.298761		1.298761
			18	83		1.225721		1.225721
			19	84		1.166383		1.166383
			20	85		1.131366		1.131366
			21	86		1.112095		1.112095
			22	87		1.371288		1.371288
		Around Waterslot		88		1.337463		1.337463
				89		1.250793		1.250793
				91		1.051634		1.051634
				69		1.140988		1.140988
				71		0.947828		0.947828
		Other Rods		76		1.018795		1.018795
UO ₂	UO ₂	Flat Side ⌞ to Waterslot	1	97	94	1.028109	0.73835	0.78106
			2	96		0.920592	0.66113	0.69938
			3	95		0.980846	0.70440	0.74516
			4	94: standard		0.999665 1.000335	0.71816	0.75971
		Around Waterslot	24	88		1.470039	1.05572	1.11680
			25	85		1.083743	0.77830	0.82333
			26	84		0.929808	0.66775	0.70638
			27	83		1.003141	0.72042	0.76210
				86		1.284277	0.92232	0.97568
				87		1.437531	1.03238	1.09211
				90		1.300846	0.93422	0.98827
		Other Rods		91		1.072137	0.76997	0.81451
				92		0.667006	0.47902	0.50673
				93		1.013668	0.72798	0.77009
				94	77	0.802030 0.819910 0.850380	31 min. 8 sec. 49 min. 72 min. 33 sec.	* * *
UO ₂ -UO ₂	UO ₂	Power Sharing		77	94	1.178953 1.137552	75 min. 45 sec. 94 min.	* *

Power Relationship Between the Standard Rods

Time After Shutdown	Activity Ratio U/Pu	Thermal Method		Foil Method	
		Factor	Relative Power	Factor	Relative Power
31 min. 8 sec.	0.80203	1.120	0.716098	1.050	0.76384
49 min.	0.81991	1.150	0.71297	1.083	0.75707
72 min. 33 sec.	0.85038	1.180	0.72066	1.120	0.75927
75 min. 45 sec.	0.84821	1.187	0.71458	1.125	0.75396
94 min.	0.87908	1.210	0.72651	1.150	0.76442
Average			0.71816		0.75971

*Time after shutdown the gamma count was made.

TABLE A-12

POWER SCAN FOR CONFIGURATION 12

27x27 core, 0.56-inch pitch

19x19 PuO₂-UO₂ in the center, UO₂ outer region5 PuO₂-UO₂ rods removed at the interface of the two regions and aluminum slab installed

Date: 5/17/65, 1453 ppm boron

Temperature: 17.8°C, Period: +140 sec.

Irradiation water height: 104.76 cm.

1 Type Fuel	2 Monitor Rod	3 Traverse Direction	4 Rod Position From Boundary	5 Rod Number	6 Reference Rod for Normalization	7 Count Normalized to Column 6	8 RELATIVE POWER	
							Thermal Method	Foil Method
PuO ₂ -UO ₂	PuO ₂ -UO ₂	Flat Side ⌞ Aluminum Plate	5	98	92: standard	1.005171	1.005171	
			10	95		1.244939	1.244939	
			14	90		1.306534	1.306534	
			16	85		1.301192	1.301192	
			18	84		1.232920	1.232920	
			19	83		1.180572	1.180572	
			20	82		1.125071	1.125071	
			21	81		1.105157	1.105157	
			22	75		1.204888	1.204888	
		Around Aluminum		78		1.227333	1.227333	
				79		1.154910	1.154910	
				80		1.020394	1.020394	
				7		1.096056	1.096056	
				8		0.955778	0.955778	
			Other Rods		92: standard	0.996941	1.0	1.0
						1.002668		
						1.000390		
						0.724316		
UO ₂	UO ₂	Flat Side ⌞ Aluminum Plate	24	74	79	1.274056	0.92584	0.97514
			25	70		1.027039	0.74634	0.78608
			26	69		0.919434	0.66814	0.70372
			27	67		1.014954	0.73756	0.77683
		Around Aluminum		71		1.177208	0.85547	0.90101
				73		1.240718	0.90162	0.94962
				75		1.223665	0.88923	0.93657
				76		1.168447	0.84910	0.89431
				77		1.023938	0.74409	0.78370
		Other Rods	79: standard			0.999894	1.0	0.72669
						1.000106		
						0.661340		
						0.84351		
UO ₂	PuO ₂ -UO ₂	Power Sharing		79	92	0.85602	62 min.	***
						0.86915	73 min.	
						1.13575	82 min.	
PuO ₂ -UO ₂	UO ₂	Power Sharing		92	79	1.13020	87 min.	
						1.12881	96 min.	
							103 min.	

Power Relationship Between the Standard Rods

Time After Shutdown	Activity Ratio U/Pu	Thermal Method		Foil Method	
		Factor	Relative Power	Factor	Relative Power
62 minutes	0.84351	1.170	0.72095	1.110	0.75992
73 minutes	0.85602	1.182	0.72421	1.120	0.76430
82 minutes	0.86915	1.197	0.72611	1.135	0.76577
87 minutes	0.88048	1.202	0.73251	1.140	0.77235
96 minutes	0.88050	1.212	0.73020	1.155	0.76623
103 minutes	0.88590	1.220	0.72615	1.160	0.76371

Average

0.72669

0.76538

***Time after shutdown the gamma count was made

Configuration 1(a)

19x19 Core
 11x11 PuO₂-UO₂ Center Region
 UO₂ Outer Region
 Date: 4/29/65

Figure A-1

O UO₂
 ● PuO₂-UO₂
 S Standard
 M Monitor

Configuration 1 (b)

19x19 Core
 11x11 PuO₂-UO₂ Center Region
 UO₂ Outer Region
 Date: 6/3/65

Figure A-2

○ UO₂
 ● PuO₂-UO₂
 S Standard
 M Monitor

Configuration 3

Core 27x27
3x3 UO₂ Insert
19x19 PuO₂-UO₂ Inner Region

UO₂ Outer Region
1425 ppm Boron
Date: 5/21/65

Figure A-3

○ UO₂
● PuO₂-UO₂
S Standard
M Monitor

Configuration 4

19x19 Core
 11x11 UO₂ Center Region
 PuO₂-UO₂ Outer Region
 Date: 5/6/65

Figure A-4

○ UO₂
 ● PuO₂-UO₂
 S Standard
 M Monitor

Configuration 5
 27x27 Core
 19x19 UO₂ Center Region
 PuO₂-UO₂ Outer Region
 1252 ppm Boron
 Date: 5/28/65

○ UO₂
 ● PuO₂-UO₂
 S Standard
 M Monitor

Figure A-5

Configuration 6

19x19 UO₂
 3x3 PuO₂-UO₂ Insert
 Date: 4/9/65

Figure A-6

○ UO₂
 ● PuO₂-UO₂
 S Standard
 M Monitor

Configuration 7

19x19 PuO₂-UO₂
3x3 UO₂ Insert

Date: 4/26/65

Figure A-7

- UO₂
- Pelletized PuO₂-UO₂
- Vipac PuO₂-UO₂
- S Standard
- M Monitor

CONFIGURATION 8

27x27 Core
 19x19 $\text{PuO}_2\text{-UO}_2$ Inner Region
 L-Shaped UO_2 Inserts
 UO_2 Outer Region

Figure A-8

Configuration 9
 19x19 Core
 11x11 $\text{PuO}_2\text{-UO}_2$ Center Region
 UO_2 Outer Region
 Aluminum Slab at Region Boundary
 Date: 4/30/65

Figure A-9

○ UO_2
 ● $\text{PuO}_2\text{-UO}_2$
 S Standard
 M Monitor

Configuration 10

Core 21x21

11x11 PuO₂-UO₂ Center Region

UO₂ Outer Region

Date: 5/4/65

Figure A-10

○ UO₂
 ● PuO₂-UO₂
 □ Ag-In-Cd Rods
 S Standard
 M Monitor

Configuration 11

27x27 Core
19x19 PuO₂-UO₂ Center Region
UO₂ Outer Region

1453 ppm Boron
Water Slot at Region Boundary
Date: 5/14/65

Figure A-11

○ UO₂
● PuO₂-UO₂
S Standard
M Monitor

Configuration 12
 27x27 Core
 19x19 PuO₂-UO₂ Center Region
 UO₂ Outer Region
 Aluminum Slab at Region Boundary

Date: 5/17/65

Figure A-12

○ UO₂
 ● PuO₂-UO₂
 S Standard
 M Monitor

ATTACHMENT B

Reactivity-Period Relationships

Figures B-1, B-2, and B-3 contain the reactivity-period relationships for the multi-region experiments. The evaluation of the reactivity measurements has been carried out using Figures B-4, B-5, and B-6.

Figure B-5

Integral Moderator Worth, $\% \Delta k/k$, Versus Water Height

Water Height, cm.

Integral Moderator Worth, $\% \Delta k/k$

Figure B-6

Installed Reactivity ($\beta\Delta k/k$) Above Critical
for Fully Flooded Multi-Region Cores

Installed Reactivity Above Critical, $\beta\Delta k/k$

Critical Water Height, cm

ATTACHMENT C

Flux Data

The relative flux values included in Figures 250.3 - 250.8, in the main body of this report, are tabulated in Tables C-1, C-2, and C-3. The measurement positions are shown in Figures C-1, C-2, and C-3.

The fast fluxes were measured with 0.300" diameter by 5 mil thick U-238 foils. The irradiated foils were counted immediately after shutdown with all gamma energies above 0.5 Mev included in the count. One standard foil was counted frequently during the foil counting so a U-238 gamma decay curve could be plotted. The other foils were normalized to the decay curve to correct for wait and count times. Corrections were also made for background counts and differences in foil weight.

The resonance flux* was determined by counting the U-238 foils three days following shutdown. Resonance capture in U-238 leads to a buildup of $_{94}\text{Pu}^{239}$. During the formation of $_{94}\text{Pu}^{239}$ a 104 kev X-ray is emitted. The 104 kev X-ray was counted to determine the resonance flux. One standard foil was counted frequently, as before, with the other foils normalized to the standard foil decay curve. Background and weight corrections were also applied.

The thermal fluxes were measured with 0.372 inch diameter by 5 mil thick bare dysprosium foils. The irradiated foils were counted immediately following shutdown with all gamma energies above 50 kev included in the count. The DARED code was used to correct for background, foil weights and decay.

*The measured flux also contains a thermal component due to thermal capture in U-238

TABLE C-1

RELATIVE FAST RESONANCE AND THERMAL FLUX MEASUREMENTS IN
 19x19 MULTI-REGION CORES
 11x11 PuO_2 - UO_2 INNER REGION, UO_2 OUTER REGION
 4/29/65

<u>Foil #</u>	<u>Relative Fast Flux</u>	<u>Relative Resonance Flux</u>	<u>Relative Thermal Flux</u>
1	0.555	0.800	5.268
2	0.616	0.847	4.712
3	0.638	0.768	2.814
4	0.689	0.703	1.456
5	0.734	0.715	1.196
6	0.795	0.825	1.178
7	0.859	0.867	1.072
8	0.911	0.908	0.925
9	0.946	0.946	0.918
10	0.982	0.962	0.949
11	0.993	0.976	0.969
12	1.000	1.000	1.000

11x11 UO_2 INNER REGION, PuO_2 - UO_2 OUTER REGION
 5/5/65

<u>Foil #</u>	<u>Relative Fast Flux</u>	<u>Relative Resonance Flux</u>	<u>Relative Thermal Flux</u>
1		0.774	3.275
2	0.625	0.841	2.764
3	0.639	0.731	1.401
4	0.659	0.683	0.547
5	0.706	0.698	0.458
6	0.706	0.785	0.496
7	0.769	0.815	0.688
8	0.835	0.901	0.840
9	0.890	0.935	0.917
10	0.960	0.983	0.965
11	0.987	0.961	0.987
12	1.000	1.000	1.000

TABLE C-2

RELATIVE FAST RESONANCE AND THERMAL FLUX MEASUREMENTS IN

27x27 MULTI-REGION CORES

19x19 PuO_2 - UO_2 INNER REGION, UO_2 OUTER REGION

5/20/65

<u>Foil #</u>	<u>Relative Fast Flux</u>	<u>Relative Resonance Flux</u>	<u>Relative Dysprosium Flux</u>
1	0.255	0.384	1.691
2	0.312	0.455	1.777
3	0.368	0.432	1.346
4	0.439	0.465	0.871
5	0.508	0.521	0.845
6	0.576	0.596	0.880
7	0.658	0.679	0.857
8	0.709	0.707	0.738
9	0.769	0.755	0.777
10	0.834	0.816	0.830
11	0.869	0.862	0.889
12	0.894	0.904	0.933
13	0.928	0.905	0.922
14	0.966	0.944	0.963
15	0.981	0.953	0.986
16	1.000	1.000	1.000

19x19 UO_2 INNER REGION, PuO_2 - UO_2 OUTER REGION

5/27/65

<u>Foil #</u>	<u>Relative Fast Flux</u>	<u>Relative Resonance Flux</u>	<u>Relative Dysprosium Flux</u>
1	0.299	0.464	1.206
2	0.372	0.560	1.177
3	0.437	0.526	0.668
4	0.506	0.533	0.355
5	0.566	0.578	0.333
6	0.645	0.643	0.400
7	0.708	0.727	0.543
8	0.753	0.779	0.687
9	0.816	0.852	0.765
10	0.852	0.867	0.820
11	0.894	0.891	0.868
12	0.929	0.917	0.903
13	1.002	0.981	0.953
14	1.000	1.000	0.971
15	1.003	1.011	0.976
16	1.000	1.000	1.000

TABLE C-3

RELATIVE THERMAL FLUX IN A 19x19
PuO₂-UO₂ CORE CONTAINING A 3x3 UO₂ INSERT
4/27/65

<u>Foil #</u>	<u>Relative Dysprosium Flux</u>
1	4.026
2	3.503
3	1.899
4	0.683
5	0.527
6	0.531
7	0.601
8	0.630
9	0.627
10	0.710
11	0.865
12	0.968
13	1.000
14	0.878
15	0.691
16	0.649
17	0.620
18	0.579
19	0.537
20	0.522
21	0.682
22	1.663
23	3.529
24	4.051

Figure C-1. Foil Locations in Multi-Region Clean Cores.

Figure C-2. Foil Locations in Multi-Region Borated Cores.

Figure C-3. Foil Locations for Insert Experiments.

Appendix C

APPENDIX C

MEASUREMENTS OF GAMMA-TO-FISSION RATIOS
BY GAMMA RAY SPECTROMETRY TO RELATE
URANIUM/PLUTONIUM MULTIZONE POWER DISTRIBUTIONS

by

G. N. Hamilton
J. A. Corbett

APPENDIX C

TABLE OF CONTENTS

	<u>Page No.</u>
LIST OF FIGURES	ii
ABSTRACT	v
1. INTRODUCTION	1
2. EXPERIMENTAL TECHNIQUE.	3
3. DATA EVALUATION	5
4. DISCUSSION	6
4.1 Results.	6
4.2 Comparison to Other Experimental Data and Techniques	11
4.3 Comparison to Analysis	14
5. CONCLUSIONS	16
REFERENCES	17

LIST OF FIGURES

<u>FIGURE</u>		<u>PAGE</u>
1	Fission Product Spectra (>0.5 Mev) $\approx$ 18.7 Days after Irradiation	4
2	Gamma Activity per Relative Thermal Power Unit in 5.7% UO_2 to 6.6% PuO_2/UO_2 versus Elapsed Time from Shutdown	7
3	Spectrometric Analysis of Fuel Used in the Calorimetric Experiments Compared to Foil Analysis	8
4	Fuel Composition and Spectrum Independence of Spectrometric Techniques	10
5	Gamma Activity per Relative Thermal Power Unit in 5.7% UO_2 to 6.6% PuO_2/UO_2 versus Elapsed Time from Shutdown	12
6	$P(t, 0.5 \text{ Mev})$ Measured by Spectrometric Techniques Compared to Prior Measurements	13
7	Comparison of Calculated and Measured Power Distribution for a Two-Region Assembly	15

ABSTRACT

Measurements of gamma-to-fission ratios between 6.6% PuO_2/UO_2 and 5.7% UO_2 are described with application to normalized power distribution measurements in multizoned systems. Experimental techniques consisted of measurements of fission product gamma decay schemes for both fuel types and the measurement of lanthanum-140 concentrations by gamma ray spectrometry from which relative fission ratios were established. Results agree favorably with values obtained by other experimental techniques and conventional methods of analysis.

1. INTRODUCTION

One of the most accurate and versatile methods to experimentally determine power distributions is that of fuel rod activation in the particular core of interest. By establishing the fission product gamma activity (corrected for decay) as a function of position on preselected fuel rods, both transverse and axial power distributions can be established. Further, in clean cores; i.e., no control rods or other lumped foreign materials, the geometric buckling can be determined by this technique.

To establish the fission product decay correction, two methods are sometimes applied: (1) Counting a specific position on an irradiated rod as a function of time and establishing a time dependent, relative normalization factor; or (2) counting a preset number of counts at a specific position on a monitor fuel rod and allowing the counting time to vary. The variable counting time is then used to establish the counting interval at the various positions on the data rods. Further checks of the variable counting interval are performed by re-counting various data rods during data acquisition for comparison purposes. The latter technique has been used very successfully in past experimental programs at the Westinghouse Reactor Evaluation Center (WREC). in both single zoned and multizoned systems containing various U-235 enrichments.

The above technique, although valid for a system containing the same fissile material, is not valid when a particular system contains more than one type of fissile material. For example, the decay characteristics of plutonium fission products are different from those of uranium fission products. Using the technique above, the decay corrections would be meaningless unless applied to data taken from fuel of the same type.

Further, since the fission product yields are slightly different, it is assumed that the gamma activity would be of a different spectrum when comparing fission product activities of one fuel type to another. Assuming the fission product decay corrections are correctly applied, the relationship of gamma activity per fission would have to be further established to adequately relate power production in one zone to the other. The most desirable form of a normalization factor would be the ratio of gamma activity per fission between the two fissile materials of interest. This normalization factor can be measured fairly accurately since the total number of fissions need not be measured but, instead, some quantity proportional to total fissions, e.g., fission rate, fission product analysis, fuel clad heat-up rate, etc. The procedure described in this report utilized fission product analysis for an isotope for which the fission product yield is fairly accurately known. Further, the experiment required a minimum of equipment and reactor operating time which in the opinion of the authors enhanced the accuracy of the desired power normalization factor.

2. EXPERIMENTAL PROCEDURE

Aluminum alloy foils, containing fissile metal of the same enrichment as the desired fuel (6.6% PuO_2/UO_2 and 5.74% enriched UO_2) were irradiated in the peak thermal flux in the reflector of the CES research reactor located at the WREC facilities at Waltz Mill, Pennsylvania. As soon as practicable after shutdown, the foils were retrieved and continuously gamma counted for approximately nine hours. The discriminator setting was such that the counter accepted all gamma rays above 0.5 Mev (the same energy range that is used in the fuel rod scanning instrumentation). After a lapsed time (greater than two weeks) the foils were again counted specifically for the gamma peak at 1.6 Mev corresponding to the gamma decay scheme of lanthanum-140. Since the fission yields of barium-140 (precursor of lanthanum-140 which has zero independent yield) are well known for both plutonium and uranium,¹ it was fairly easy to establish a number proportional to the total number of fissions that had occurred in both types of foils. From the data acquired following this technique, the power normalization, or power sharing factor can be generated. Figure 1 shows typical gamma decay spectra for 6.6% Pu/U and 5.7% U-235 measured approximately 18.7 days from irradiation.

3. DATA EVALUATION

The gamma intensity as a function of time was established for both foil types and the ratio of gamma activity from U-235 foils to the gamma activity of the plutonium foils was calculated as a function of time. From these data and the analysis of lanthanum-140 in each foil type, the following relationship was determined:

$$\frac{(\gamma\text{-activity/relative thermal power unit})_{\text{U}}(t)}{(\gamma\text{-activity/relative thermal power unit})_{\text{Pu}}(t)} = \frac{A_{\text{U}}(t)}{A_{\text{Pu}}(t)} \cdot \frac{\text{La}^{140}_{\text{Pu}} y^{\text{Ba}}_{\text{Pu}}}{\text{La}^{140}_{\text{U}} y^{\text{Ba}}_{\text{U}}} \cdot \frac{(E/f)_{\text{Pu}}}{(E/f)_{\text{U}}}$$

where,

$A(t)$ = the time dependent gamma activity (>.5 Mev) of the subscripted foil type.

La^{140} = the intensity of the lanthanum line from gamma spectrometric analysis of the subscripted foil type.

y^{Ba} = the fission yield of Ba^{140} of the subscripted foil type.

E/f = Mev per fission of the subscripted foil type.^{/2}

Fission yields (y^{Ba}) and energy release per fission (E/f) were corrected for the presence of U-238 in the uranium foils and for the natural uranium present in the plutonium-bearing foils using data from LEOPARD, a spectrum dependent, nonspatial, neutron diffusion code.^{/3}

The data evaluation required the knowledge of fission product yields. The reference cited in this report gave little indication as to the accuracy of these yields and, hence, the values used were considered as being absolute. Counting statistics were optimized in all cases where possible. Energy yields were considered as being absolute and were not corrected for the presence of U-238 common to both foil types.

4. DISCUSSION

4.1 Results:

To adequately determine the power sharing coefficient, two separate experiments were performed, one using bare foils, the other using cadmium (0.020-inch thick) covered foils. This was done to evaluate the effects of small spectrum shifts on the power sharing factor which might be encountered at zone interfaces. As seen in Fig. 2, the results are in good agreement--the accuracy of the experiment as a whole being $\pm 2.5\%$. It should be noted that data were not taken until approximately one hour after scram time. Due to rather long count time associated with the determination of La-140, a rather healthy irradiation was applied to the foils which resulted in pulse pile-up during the initial gamma counting. The cadmium covered foils, which gave rather good decay data, had the bare minimum of irradiation time to give good statistics in the lanthanum evaluation. Figure 2 shows a plot of gamma activity per power unit in the uranium-bearing foils to gamma activity per power unit in the plutonium-bearing foils for the two cases.

Counting geometries were modified in such a manner that spectrometric analysis of actual fuel rods could be performed. In both counting systems, only a one centimeter section of fuel was exposed to the counter detector which was sufficient to give favorable results. Figure 3 shows a plot of gamma-to-fission ratio vs. time for both the foil irradiations and fuel irradiations for comparison purposes. The scatter in the data is attributable to the excessive long time between irradiation and spectrometric analysis (approximately one month) which yielded numbers accurate to only $\pm 4\%$.

Figure 2

SPECTROMETRIC ANALYSIS OF FUEL USED IN THE CALORIMETRIC EXPERIMENTS COMPARED TO FOIL ANALYSIS.

Figure 3

Once it was established that the spectrometric technique could be used in conjunction with actual fuel rods, an experiment was performed to evaluate the effects of spectrum shifts at fuel interfaces and fuel density variations on the power sharing factor. The experiment was performed using the PuO_2/UO_2 fuel of two types; coprecipitated PuO_2/UO_2 and vibratory compacted PuO_2/UO_2 both clad in Zircaloy-4. The data were treated in the same manner as if two types of fuel were used. Figure 4 shows a plot of the gamma activity per power unit vs. time from shutdown for the two comparisons. Results were within $\pm 2.5\%$ which indicates that neither spectrum shifts nor fuel density affects the measurements.

FUEL COMPOSITION & SPECTRUM INDEPENDENCE OF SPECTROMETRIC ANALYSIS TECHNIQUE.

Figure 4

4.2 Comparison to Other Experimental Data and Techniques

At the same time the spectrometric technique was being used, experiments were being performed to measure the gamma-to-fission ratio by calorimetric techniques.^{/4} The fuel rods used in these experiments were the same as those used for the first fuel spectrometric analysis evaluations. Figure 5 shows a comparison of the two techniques. It is noted that the two techniques yield results that are comparable within the accuracy of the two experiments, but are consistently different. It is felt that the major part of the difference is in the calorimetric technique since spectrometric analysis of these fuel rods was performed with fairly good results (Fig. 3).

As one final check, a measurement of $P(t, .5 \text{ Mev})$ (gamma-to-fission ratio between U-235 and U-238) was performed. Foil material consisted of depleted uranium metal and 14% (>93% U-235) uranium aluminum alloy. Comparison was made to results obtained at Savannah River Laboratories (SRL) of $P(t, 1.2 \text{ Mev})$.^{/5} SRL data were normalized to $P(t, .5 \text{ Mev})$ from data previously measured at WREC;^{/6} namely,

$$\frac{P(t, 1.2 \text{ Mev})}{P(t, .5 \text{ Mev})} = 1.14 \pm .02$$

Figure 6 shows a comparison of the spectrometric measurements and the WREC-adjusted SRL values. It is felt that the agreement is better than indicated, since WREC evaluation of the averaged normalizing factor is consistently lower than the individual measurements quoted for a similar foil irradiation geometry. This, in the opinion of the authors, would increase the ratio first quoted by WREC for this foil irradiation geometry, and would, therefore, lower the adjusted SRL values shown in Fig. 6, increasing the agreement. No attempt has been made at this time to measure $P(t, 1.2 \text{ Mev})$ by spectrometric techniques.

Figure 5

GAMMA ACTIVITY PER RELATIVE THERMAL POWER UNIT IN 5.7 % UO_2 TO 6.6 % $\text{PuO}_2 / \text{UO}_2$ VERSUS ELAPSED TIME FROM SHUTDOWN.

Figure 6

4.3 Comparison to Analysis

Standard two-dimensional analysis (PDQ) was performed for a two region core consisting of a 19 x 19 array of 5.7% UO_2 with a 11 x 11 6.6% PuO_2/UO_2 inner region. Figure 7 shows a comparison of analytical power distribution and the measured power distribution. 7

The data taken in the UO_2 zone were normalized to the PuO_2/UO_2 region by both spectrometric and calorimetric power sharing factors. It is interesting to note the excellent agreement between experiment and analysis that was obtained with the spectrometric derived power sharing factors. It is felt, however, that the final and valid check of these factors will be in thermal and hydraulic measurements to be performed on the same fuel in a power reactor environment.

Figure 7

COMPARISON OF CALCULATED & MEASURED POWER DISTRIBUTIONS FOR A TWO-REGION ASSEMBLY.

5. CONCLUSIONS

In the opinion of the authors, gamma ray spectrometry has proven to be a valuable technique in the measurement of parameters leading to fission ratios or power normalization factors. It was shown that this technique could be applied to actual fuel rods, irradiated in a typical reactor environment, and yield numbers which would need no spectrum shift considerations.

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Appendix D

APPENDIX D

MEASUREMENTS RELATING POWER
SHARING BETWEEN Pu AND U FUEL RODS

by

R. J. Nath
R. D. Leamer

APPENDIX D

TABLE OF CONTENTS

	<u>Page No.</u>
LIST OF FIGURES	ii
ABSTRACT.	iii
1. INTRODUCTION	1
2. EXPERIMENTS PERFORMED AND EXPERIMENTAL TECHNIQUES	3
2.1 Thermal Measurements of 1.6 w/o and 3.7 w/o Enriched UO_2 Fuel Rods	3
2.2 Thermal Measurements of 5.7 w/o UO_2 Fuel Rod and Pelletized Mixed Oxide Fuel Rod.	4
2.3 Thermal Measurements of 5.7 w/o UO_2 Fuel Rod and Vibratory Compacted Mixed Oxide Fuel Rod	10
3. SUMMARY	13

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
2.1	Heat Rate Data from Experiment Using 1.6 and 3.7 w/o UO_2 Fuel Rods	5
2.2	Comparison of Axial Distributions Obtained from γ -activity and Heating Rate Measurements	6
2.3	Average Ratio of γ -activity to Heating Rate for Six Axial Positions on the 1.6 w/o and the 3.7 w/o UO_2 Fuel Rods	7
2.4	PuO_2 - UO_2 Factors for the Pelletized Fuel Rods as a Function of Time	8
2.5	Plot of Thermocouple Output as a Function of Time for the 5.7 w/o UO_2 and the Vipac PuO_2 - UO_2 Saxton Fuel Rods	11
2.6	PuO_2 - UO_2 Gamma Conversion Factors as a Function of Elapsed Time after Reactor Scram	12

ABSTRACT

This report describes a method for direct measurement of fuel rod fission power through the use of heating rates. These measurements, when used in conjunction with subsequent measurements of fission product gamma decay, provide useful data for the interpretation of power sharing in low power critical experiments. A direct relationship is provided to relate conventional measurements of gamma activity for fuels having different fissile elements to the power sharing of the fuels. The particular experiments performed related power sharing in a multizoned core having both plutonium and uranium fuels. Results from measurements at the Westinghouse Reactor Evaluation Center show that a time dependent correction is necessary because of differences in the fission product decay characteristics of the fuels. This correction reaches a maximum value of 30% approximately 4 hours after shutdown.

1. INTRODUCTION

Measurements have been made in order to evaluate the use of conventional gamma scanning techniques for the determination of relative power production in critical experiments having both UO_2 and PuO_2 - UO_2 fuel rods. Due to differences in fission product yields, energy per fission, and fission product decay characteristics of the Pu and U fuels, a method for converting relative gamma decay measurements to relative power production was required. Thermally insulated fuel rods were irradiated in the CES core which is located at the Westinghouse Reactor Evaluation Center (WREC), and the temperature rise measured by thermocouples attached to the cladding. After shutdown, these same rods were gamma scanned. The two sets of measurements provided a time dependent multiplier for use in converting gamma decay ratios to thermal power ratios.

In order to establish the validity of the technique, measurements were first performed with UO_2 fuel rods of two different enrichments (1.6 and 3.7 w/o U-235). It was found that, indeed, the ratio of thermal power determined from heating rates was the same to within two percent as the power production ratio determined from gamma scanning following shutdown. Furthermore, the axial power distribution along the fuel rods as determined by the two measurements agreed to within approximately 3% which demonstrated that axial thermal conduction along the fuel rod did not invalidate the technique.

Subsequent measurements were performed using UO_2 fuel rods enriched to 5.7 w/o U-235 and PuO_2 -natural UO_2 mixed oxide fuel rods

having 6.6 w/o PuO_2 and a Pu composition of 90.43 a/o Pu-239, 8.60 a/o Pu-240, 0.92 a/o Pu-241 and 0.05 a/o Pu-242. It was found that a significant correction to the gamma decay measurements was required in order to obtain thermal power ratios. This correction amounted to approximately 6% immediately after shutdown and 30% four hours after shutdown.

All measurements and results reported were performed as part of the Saxton Plutonium Experimental Program. The results are intended for direct use in converting conventional gamma scanning measurements to relative power sharing for critical experiments having multizoned cores of 5.7 w/o UO_2 and 6.6 w/o PuO_2 -natural UO_2 mixed oxide fuel rods.

2. EXPERIMENTS PERFORMED AND EXPERIMENTAL TECHNIQUES

Prior to the thermal measurements of heating rates, twelve copper-constantan thermocouples were made. After calibration, the thermocouples were fixed at six axial positions on the two particular fuel rods of interest. The fuel rods were then packed in styrofoam in an aluminum thimble and placed in symmetric positions in the CES core. The reactor was so operated that a step change in power was simulated. Heating rates were determined for the two test rods by measuring each thermocouple temperature as quickly as possible for various times before, during, and after control rod motion. After sufficient data were collected and the reactor shut down, the test fuel rods were withdrawn and the gamma activity of their fission products above 0.5 Mev measured periodically. Three separate measurements were performed using various uranium and plutonium fuel rods.

2.1 Thermal Measurements of 1.6 w/o and 3.7 w/o Enriched UO_2 Fuel Rods

The first heating rate measurement performed compared the γ -activity to heating rate ratio of two different enrichment uranium fuel rods. The two fuel rods used contained 1.6 w/o and 3.7 w/o enriched UO_2 fuel. Since no correction factor is necessary to compare the relative power sharing of different enrichment uranium fuel rods, this measurement was performed as a check on the feasibility of the heating rate experimental technique. If the measured heating rates are proportional to fission power, the ratios of γ -activity to heating rate for the 1.6 w/o and 3.7 w/o UO_2 fuel rods will be identical since the γ -activation of their fission products is directly proportional to fission power level.

Figure 2.1 shows the output of two typical thermocouples. Note that the beginning of the heating curve showed a linear rise, and this portion could be used to determine heating rate. Figure 2.2 illustrates

Figure 2.1 Heat Rate Data From Experiment Using 1.6 and 3.7 w/o UO_2 Fuel Rods

Figure 2.2 Comparison of Axial Distributions Obtained from γ -activity and Heating Rate Measurements

typical axial distributions obtained from the gamma activities and the corresponding measured heating rates. In this example, the activation was that of 3.7 w/o enriched UO_2 fuel rod. Figure 2.3 gives the γ -activity to heating rate ratios obtained for both the 1.6 w/o and 3.7 w/o enriched UO_2 fuel rods. Figures 2.3 and 2.2 show that the resultant ratios obtained are the same within the experimental errors associated with the data and that the axial thermal conduction along the fuel rod did not invalidate the technique. Therefore, the heating rates are proportional to the fuel rod power as was anticipated.

2.2 Thermal Measurements of 5.7 w/o UO_2 Fuel Rod and Pelletized Mixed Oxide Fuel Rod

After completion of the measurements of two different enrichment uranium fuel rods as described in section 2.1, a similar measurement was performed comparing a 5.7 w/o UO_2 fuel rod with that of a pelletized mixed oxide 6.6 w/o PuO_2 - UO_2 fuel rod. The experimental procedure was essentially the same as that described in section 2.1 with a slight modification of the axial positions of the thermocouples. During this measurement, two of the six thermocouples were placed at an identical axial position to determine the reproducibility of the thermocouple data. The shapes of the heating rate curves and gamma activity curves were similar to those shown on figures 2.1 and 2.2 but differed in magnitude. The resulting data were reduced and a curve of the ratio

$$\left[\frac{\gamma\text{-activity}(\text{UO}_2)}{\text{Thermal Power}(\text{UO}_2)} \bigg/ \frac{\gamma\text{-activity}(\text{PuO}_2\text{-UO}_2)}{\text{Thermal Power}(\text{PuO}_2\text{-UO}_2)} \right] *$$

was constructed as a function of time after reactor scram and is shown in Figure 2.4. Figure 2.4 is the result of the reduced data after

*This ratio is referred to as the PuO_2 - UO_2 factor.

Figure 2.3 Average Ratio of γ -activity to Heating Rate for Six Axial Positions on the 1.6 w/o and the 3.7 w/o UO_2 Fuel Rods

Figure 2.4 PuO₂-UO₂ Factors for the Pelletized Fuel Rods as a Function of Time

correcting the heating rates to account for differences in the masses of the UO_2 and PuO_2 fuels. Note that the value of the PuO_2 - UO_2 factor is dependent upon the time after irradiation the fuel rods were counted. This is caused by the difference in the decay characteristic of the fission product activity in the two types of fuel.

A brief explanation of the meaning of Figure 2.4 follows. The PuO_2 - UO_2 factor is that number which is used to multiply the activation of the mixed oxide fuel rod to obtain the relative power sharing of that fuel rod based on the UO_2 fuel rods. This assumes that the mixed oxide fuel rods were counted at the same time as the UO_2 fuel rods. Dimensionally the correction is as shown in equation 2.1.

$$\left[\frac{\gamma\text{-act}(\text{UO}_2)_1}{\text{Ther. Pow.}(\text{UO}_2)_0} \right] \times [\gamma\text{-act}(\text{PuO}_2\text{-UO}_2)_1] = \gamma\text{-act}(\text{UO}_2)_2 \left[\frac{\text{Ther. Pow.}(\text{PuO}_2\text{-UO}_2)_0}{\text{Ther. Pow.}(\text{UO}_2)_0} \right] \quad (2.1)$$

In equation 2.1 the subscript 0 refers to scram time and the subscript 1 refers to any time after scram. Figure 2.5 is directly applicable after all of the activations have been corrected to a single reference time. Note that the PuO_2 - UO_2 factor corrects for differences due to both fission product yields and energy per fission.

The thermal power in equation 2.1 is related to the heating rate as shown in equation 2.2

$$\text{Thermal Power} = \rho = \text{Mc}_p (\Delta T / \Delta t) \quad (2.2)$$

Figure 2.5 Plot of Thermocouple Output as a Function of Time for the 5.7 w/o UO_2 and the Vipac $\text{PuO}_2\text{-UO}_2$ Saxton Fuel Rods

where $\Delta T/\Delta t$ is the measured heating rate. Therefore, in order to relate the heating rates to power, one must correct for the differences in the heat capacity of the fuels. These corrections were made by weighing the fuel rods of interest and assuming that the specific heats are identical.

2.4 Thermal Measurements of 5.7 w/o UO_2 Fuel Rod and Vibratory Compacted Mixed Oxide Fuel Rod

Because the Saxton plutonium critical experiments were performed using both the pelletized and the vibratory compacted mixed oxide fuel rods, thermal measurements were also performed on a vipac fuel rod. This measurement also served to determine the effect that variation of the gap between the fuel and clad had on the heating rate measurements. The pelletized fuel rod had a 0.0071" gap and the vipac rod had no gap. In an effort to improve the heating rate data during this measurement, the experimental technique was changed. Instead of six thermocouples on each rod, only one was used. Thus more data points were obtained on the linear portion of the heating rate curve, due to faster readout.

The data obtained during this measurement are shown on Figure 2.5. Note that the heating rate curvature does not become significant until about 5 minutes after heating starts. The ratio of the heating rates obtained from this measurement was compared to those obtained for the pelletized plutonium fuel rods and differed by $\approx 2\%$. This difference can probably be attributed to the uncertainty of the axial position of the thermocouples.

The PuO_2 - UO_2 factors obtained from the measurement using the vibratory compacted plutonium fuel rod were compared to those obtained from the pelletized plutonium fuel rod measurements and are shown on Figure 2.6. The PuO_2 - UO_2 factors are the same for both the pelletized and vipac plutonium fuel rods within the experimental error associated with the results.

Figure 2.6 $\text{PuO}_2\text{-UO}_2$ GAMMA CONVERSION FACTORS AS A FUNCTION OF ELAPSED TIME AFTER REACTOR SCRAM

3. SUMMARY

A technique has been developed to measure power sharing in multi-region cores of different fissile nuclides. The technique relates gamma output of fission products to heat produced in fission, and so does not require knowledge of fission product yields or energy yield per fission. The method can be used in a low-power critical assembly and gives results accurate to several percent.

Appendix E

APPENDIX E

— VOID EFFECTS

by

D. F. Hanlen

VOID EFFECTS

A series of voiding effect experiments was performed. The core grid plates were fabricated with holes interstitial to the fuel rod positioning holes. Thin-wall aluminum void tubes were inserted in several configurations and their effects on core operating characteristics were measured.

Table I presents the data derived from the several critical assembly operations and includes reference to appropriate core diagrams.

Table II indicates the physical dimensions of core inserts and perturbations including fuel, void tubes, and core plates.

Figure 1 illustrates the physical configuration of the critical assembly.

Figures 2 through 17 are schematic cross sections of core loadings for the experiments conducted. The left hand column of Table I identifies each figure with the core parameters used in the experiment illustrated by that figure.

Figure	Fuel	Fuel Configuration	Fuel Loading	Fuel Pitch	Void Configuration	Void Loading	Void Pitch	Moderator Height	Period (sec)	Reactivity (ρ)	Temperature ($^{\circ}\text{C}$)	Mod. Reference Difference	$\frac{\delta\rho}{\delta h} - \frac{\rho}{h}$ - cm
2	PuO_2	23x23	529	0.52	-	-	-	74.33	∞	0	19.5	Ref	
								74.40	24	27.3		1.07	25.5
								75.03	44	19.2		0.7	27.4
								74.66	140	8.2		0.33	24.9
3	PuO_2	23x23	529	0.52	8x8	64	.52	96.48	66	14.3	19.5	1.43	10.0
								95.05	∞	0		Ref	
4	PuO_2	25x23	575	0.52	8x8	64	.52	73.09	∞	0	18.9	Ref	
								73.89	32	23.2		0.80	29.0
5	PuO_2	25x23	575	0.52	12x12	144	.52	92.26	∞	0	18.9	Ref	
								93.77	37	21.4		1.51	14.2
6	PuO_2	25x23	575	0.52	*	72	.792	73.76	∞	0	19.8	Ref	
								74.24	71.4	13.8		0.48	28.8
7	PuO_2	25x24	600	0.52	*	276	.792	93.36	∞	0	19.0	Ref	
								95.66	21	29.5		2.30	12.8
8	PuO_2	25x24	600	0.52	*	153	.792	77.24	∞	0	18.9	Ref	
								77.84	54	16.8		0.60	28.0
9	PuO_2	25x24	600	0.52	*	91	.792	68.96	∞	0	18.9	Ref	
								69.52	43	19.5		0.56	34.8
10	PuO_2	25x24	600	0.52	*	-	-	57.22	∞	0	18.9	Ref	
								57.51	62	15.3		0.29	52.8
11	PuO_2	23x23	529	0.52	*	-	-	73.98	∞	0	19.6	Ref	
								74.93	28	25.3		0.95	23.5
12	PuO_2	23x23	529	0.52	4x4	16	.52	78.16	-	0	19.5	Ref	
								78.20		0.6		0.04	15
								78.75	64	13.2		0.59	22.4

* See appropriate figure

TABLE I

Figure	Fuel	Fuel Configuration	Fuel Loading	Fuel Pitch	Void Configuration	Void Loading	Void Pitch	Moderator Height	Period (sec)	Reactivity (ρ)	Temperature ($^{\circ}\text{C}$)	Mod. Reference Difference	$\frac{\delta\rho}{\delta h} - \frac{\delta\rho}{\delta h}$
13	PuO_2	23x23	529	0.52	4x4	16	0.52	77.88	-	0	19.6	Ref	
								77.99		2.3		0.11	21
								78.60		15.8		0.72	22
								77.66	decreasing	4.4		-0.22	20
14	PuO_2	23x23	529	0.52	4x4	16	0.52	77.20	∞	0	19.9	Ref	
								76.98	decreasing	5.1		-0.22	23
								77.85	increasing	14.3		0.65	22
15	PuO_2	23x23	529	0.52	4x4	16	0.52	76.27	∞	0	19.8	Ref	
								76.70	82	10.9		0.43	25.4
								76.07	decreasing	-4.5		-0.20	22.5
16	PuO_2	23x23	529	0.52	4x4	16	0.792	75.84	∞	0	19.6	Ref	
	UO_2		Pu** 312 U					76.85	≈ 31	23.7	19.6	1.01	23.5
17	PuO_2		529	0.52	8x8	64	0.792	84.81	+	0.4	19.8	Ref	
			Pu 312 UO_2	0.52	8x8	64	0.792	86.22	30	24.2	19.8	1.41	17.2

TABLE I (continued)

**

 $C_B = 929 \text{ ppm}$

TABLE II

	Void Tube	Fuel Rod Clad (Zircaloy)	Center Plate	Fuel (PuO ₂ -UO ₂)
Length (cm)	145	-	66.1	93
Width (cm)	-	-	66.1	-
Diameter, OD (cm)	0.4725	0.993	-	0.857
Material Thickness (cm)	0.0127 (wall)	0.0584 (wall)	0.635	-
Wt/cc	0.386	-	0.546	94% theoretical

Figure 1 VERTICAL CROSS-SECTION OF CORE FOR
PLUTONIUM (or UO_2) FUEL

Figure 2

23 x 23 = 529 Fuel Rods

Clean Core

Figure 3

• - 23 x 23 = 529 Fuel Rods

+ - 8 x 8 = 64 Voids

Figure 4

• - 25 x 23 = 575 Fuel Rods
 + - 8 x 8 = 64 Voids

Figure 5

• - 25 x 23 = 575 Fuel Rods

+ - 12 x 12 = 144 Voids

Figure 6

• - 25 x 23 = 575 Fuel Rods

+ ----- = 72 Voids

Figure 7

• - 25 x 24 - 600 Fuel Rods

+ ----- 276 Voids

Figure 8

• - 25 x 24 - 600 Fuel Rods

+ _____ 153 Voids

Figure 9

• - 25 x 24 - 600 Fuel Rods

+ _____ 91 Voids

Figure 10

• - 25 x 24 - 600 Fuel Rods
Clean Core (No Voids)

Figure 11

• - 23 x 23 = 529 Fuel Rods

Offset, Clean Core (No Voids)

Figure 12

- - 23 x 23 - 529 Fuel Rods
 - + - 4 x 4 Voids, 16 Total - in Center
- Core Offset

Figure 13

- - 23 x 23 - 529 Fuel Rods
- + - 4 x 4 Void, 16 Total - West Center 3/4 Cell.
Core Offset

Figure 14

- - 23 x 23 - 529 Fuel Rods
- + - 4 x 4 Voids, 16 Total - West Center 6/4 Cell
Core Offset

Figure 15

- - 23 x 23 - 529 Fuel Rods
- + - 4 x 4 Voids, 16 Total, West Center 9/4 Cell
Core Offset

Figure 16

- - 23^2 = 529 Pu Fuel Rods
- - $29^2 - 23^2$ = 312 UO_2 Fuel Rods
- + - 4×4 = 16 Voids

Figure 17

- - 23^2 = 529 Pu Fuel Rods
- - $29^2 - 23^2$ = 312 UO_2 Fuel Rods
- + - 8×8 = 64 Voids

Appendix F

APPENDIX F

NOISE ANALYSIS EXPERIMENTS

by

V. Rajagapol

NOISE ANALYSIS

Satisfactory noise measurements were obtained in only one configuration, a 27 x 27 core with an inner 19 x 19 region of $\text{PuO}_2\text{-UO}_2$.

In this experiment, the fluctuations in the signal from an ion chamber located in the reflector at the mid-plane of the core were recorded on magnetic tape with the reactor power kept approximately constant at 10 watts. The removal of the steady component of the signal while amplifying the fluctuations was done by an analog computer (Electronic Associates TR-10.) The power spectrum ($\phi_{ii}(f)$) of the ion chamber fluctuations was determined in an analog spectrum analyzer (Boonshaft and Fuchs Model 711C).

The power spectrum is related to neutron kinetics and instrumentation response through the following equation:

$$\phi_{ii}(f)^{1/2} = \frac{A}{(1 + 2\pi f \frac{\ell}{\beta}) (1 + 2\pi f \tau_i)}$$

where f is frequency cycles per second

ℓ is prompt neutron lifetime

β is delayed neutron fraction

and τ_i is instrumentation time constant

The instrumentation frequency response was measured using a neutron source. The system response is flat to about 300 cps and then falls off at a slope of 20 db/decade. The frequency response of the measuring system is sufficiently high to permit determination of β/ℓ without correction to the data.

The measured power spectrum is shown in Figure 1. From the estimated break frequency of 46 cps, the β/λ is calculated to be 292. Noise measurements were made with a miniature fission detector in different fuel rod locations in a multi-region core containing both $\text{PuO}_2\text{-UO}_2$ and UO_2 fuels and in a single-region core containing $\text{PuO}_2\text{-UO}_2$. The instrumentation was similar to that for ion chamber measurements. It was hoped that with an in-core detector it would be possible to determine if there was a variation in spatial kinetic characteristics of coupled cores. However, the inherent noise in the fission chamber was considerably higher than the reactor fluctuations seen by the detector. Analysis of the data showed that the power spectrum in all cases followed the response of the measuring system to a white noise source. Therefore, it was not possible to determine whether a spatial variation in noise characteristics exists.

FIG. 1- POWER SPECTRUM OF ION CHAMBER FLUCTUATIONS

Appendix G

APPENDIX G

PULSED NEUTRON EXPERIMENTS

by

G. N. Hamilton

PULSED NEUTRON EXPERIMENTS

Pulsed neutron experiments were performed in a square array of 5.7% enriched UO_2 fuel rods having a W/U of 4.13:1. Unsuccessful attempts were made to use pulsed neutron experiments with single region plutonium fuels and two-region cores of plutonium and uranium fuels. The data were discarded as being not representative because the coupling between the reflector and cores make it nearly impossible to measure the fundamental neutron decay mode.

During the course of the UO_2 experiments, the reactor was maintained in a subcritical condition by moderator level adjustments such that shutdown reactivities ranged between \$0.04 and \$2.29. Due to high background count rates, no attempt was made to determine α at just critical. Instead, the value of α at just critical was obtained by plotting subcritical neutron decay constants as a function (inverse square) of moderator level and extrapolating to the measured just critical level. Figure 1 shows a plot of these data and shows that:

$$\alpha_c = \frac{\beta_{\text{eff}}}{l_{\text{eff}}} = 240 \text{ sec}^{-1}$$

As a check, shutdown reactivities were calculated from the relationship:

$$\$ = \frac{\alpha - \alpha_c}{\alpha_c}$$

and compared to values measured by differential moderator worth techniques.

Table I gives the results of the neutron decay constants and shows the comparisons of the two methods of shutdown determination. Figure 2 shows a plot of the reactor core and shows the relative location of the pulsed neutron detector.

TABLE 1

Moderator Height (cm)	H^{-2} (cm^{-2})	α^* (sec^{-1})	Shutdown (\$)		error (%)
			by α measurement	by $\delta\rho/\delta k$ measurement	
81.70	.0001153	240 (extrap)	critical	-	-
81.37	.0001161	248	0.04	0.051	22%
80.85	.0001174	261	0.09	0.13	31%
79.97	.0001197	286	0.193	0.28	29%
78.05	.000125	341	0.42	0.60	30%
72.99	.000140	503	1.10	1.58	30%
65.84	.000168	789	2.29	3.28	30%

$$*\lambda_z = 11.42 \text{ cm.}$$

Experimental techniques and data reduction methods are described in References 1, 2, and 3.

The fundamental prompt neutron decay mode was obtained using an RIDL Model 34-12, 400 channel analyzer. These data were put into the OMNIFIT computer code to least squares fit the data to obtain each alpha. These alphas were in turn put into the OMNIFIT code to obtain the data shown in Table 1 and Figure 1.

FIGURE 1

FIGURE 2
 CORE LOADING
 361 - 5.7% UO₂ Rods
 W/U = 4.13:1

REFERENCES

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3. Kuchle, "Pulsed Neutron Measurements on a Heavy Water Reactor at Zero Energy," IAEA Proceedings, Vol. II, 1964, 575-586.