EUR 2804.e

PART. VI

EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

SAXTON PLUTONIUM PROGRAM

Quarterly Progress Report
for the period ending December 31, 1965

by

N.R. NELSON
(Westinghouse Atomic Power Division)

1966

EURATOM/US Agreement for Cooperation
EURAEC Report No. 1534 prepared by the
Westinghouse Electric Corporation, Pittsburgh, Pa. - USA

AEC Contract No. AT (30-1)-3385

LEGAL NOTICE

This report is on sale at the addresses listed on cover page 4.

at the price of FF 4,—	FB 40,—	DM 3,20	Lit. 500,—	Fl. 3,—

When ordering, please quote the EUR number and the title, which are indicated on the cover of each report.

Printed by Guyot, s.a.
Brussels, August 1966

EUR 2804.e
PART. VI

EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

SAXTON PLUTONIUM PROGRAM

Quarterly Progress Report
for the period ending December 31, 1965

by

N.R. NELSON
(Westinghouse Atomic Power Division)

1966

EURATOM/US Agreement for Cooperation
EURAEC Report No. 1534 prepared by the
Westinghouse Electric Corporation, Pittsburgh, Pa. - USA

AEC Contract No. AT (30-1)-3385

SUMMARY

During the quarter, the plutonium fuel was installed in the Saxton Reactor. The scheduled test program was begun on December 6, 1965.

Near the end of December, power operation at 17 MWt was reached.

It is expected that the licensed power level based on not exceeding 16 kw/ft peak will be reached early in January. Current indications are that this will be about 22 MWt. After operation and burning-off peaks, pushed power to 28 MWt appears feasible.

During the next eighteen months, the Saxton partial plutonium core will be operated routinely as the source of power for the overall development program being carried out by the Saxton Nuclear Experimental Corporation (SNEC) in technical cooperation with Westinghouse. Core follow and analysis of operating conditions will be carried out during this routine operating period and during at least two shutdowns and startups.

Topical reports were completed, describing the fuel design and fabrication and the critical experiments.

TABLE OF CONTENTS

Page Number

LIST OF TABLES

LIST OF FIGURES

SAX-100 Project Administration

N. R. Nelson

All project work up to the stage of operating Saxton Core II up to a power level of 17 MWt has been completed including all scheduled topical reports. It is expected that the licensed power level based on not exceeding 16 kw/ft peak will be reached early in January. Current indications are that a power level of about 22 MWt can be maintained without exceeding the 16 kw/ft license limitation. After considerable operation and burning-off peaks, pushed power to 28 MWt appears feasible.

During the next eighteen months, the Saxton partial plutonium core will be operated routinely as the source of power for the overall development program being carried out by the Saxton Nuclear Experimental Corporation (SNEC) in technical cooperation with Westinghouse. Core follow and analysis of operating conditions will be carried out during this routine operating period and during at least two shutdowns and startups.

A relatively small amount of technical information will be generated during the next eighteen months. Consequently, the Commission, in order to reduce the expense required to issue bound quarterly reports for TID-4500 distribution, has approved a Westinghouse recommendation to issue these reports semi-annually through at least fiscal '67. Quarterly summary letters, however, will be used to meet Euratom report requirements; and monthly letters, for AEC administrative requirements. This information is included to alert the TID-4500 recipients that the next bound report will be issued in July 1966.

Manuscript received on March 7, 1966.

SAX-210 Nuclear Fuel Design, SAX-220 Fuel Design - Mechanical, Thermal & Hydraulic, SAX-230 Fuel Design - Materials, SAX-250 Planning and Analyses of Critical Experiments, SAX-310 Fuel Fabrication - Materials, SAX-320 Fuel Inspection and Assembly, SAX-330 New Fuel Shipping, SAX-340 Safeguards Analysis, SAX-350 Alpha Protection, SAX-400 Performance of Critical Experiments

The work required to date in all of the subtasks listed above has been completed. Minor investigatory work occasioned by fuel performance inpile may be necessary under Safeguards Analysis and under Alpha Protection if any unforeseen operating conditions should arise or if it should become desirable to alter currently planned operating conditions to make more meaningful the experimental and analytical results of the plutonium program. All four topical reports contemplated have been completed. Future reports will not include sections on these subtasks but will start with subtask SAX-510 Nuclear Analyses of Operating Performance. This subtask and SAX-520 Thermal Hydraulic Analyses are expected to be the only two technical areas of activity in the program for about the next eighteen months.

SAX-510 Nuclear Analyses of Operating Performance

F. L. Langford, W. L. Orr, A. J. Impink, R. H. Chastain, H. I. Sternberg, G. F. Eletti,* P. Deramaix,** L. Bindler***

A. Introduction and Summary

1. Introduction

A basic objective of this task is to compare the expected performance of the plutonium fuel in the Saxton reactor with experimental results and to evaluate the differences

*On assignment from CNEN, Rome, Italy. **On assignment from Belgo-Nucleaire, Brussells, Belgium and CEN, Mol, Belgium*** working on the Saxton Plutonium Program in the scope of the EURATOM/AEC/Westinghouse contract.

between analysis and experiment that are found. A second objective is to provide supporting analysis during the irradiation period. The supporting analysis will include the evaluation of reactivity and power distribution changes with time corresponding to the operating history of the core.

2. Summary

During the quarter, the plutonium fuel was installed in the Saxton reactor according to the fuel loading pattern shown in Figure 510.1. The scheduled test program was begun on December 6, 1965. Near the end of December, power operation at 17 MWt was reached. The following analytical and experimental work was accomplished during the quarter.

a. The analysis required in preparation for the zero-power tests was completed. Anticipated boron concentration requirements and control rod worths were determined.

b. The analysis required in preparation for following the operating history of Saxton Core II was completed. An analysis sequence consisting of the LEOPARD[/1]/BUBBLE[/2]/PDQ-3*[/3] computer codes was adopted. With this sequence it will be possible to duplicate analytically the experimental history of the reactor as determined through the in-core instrumentation system.

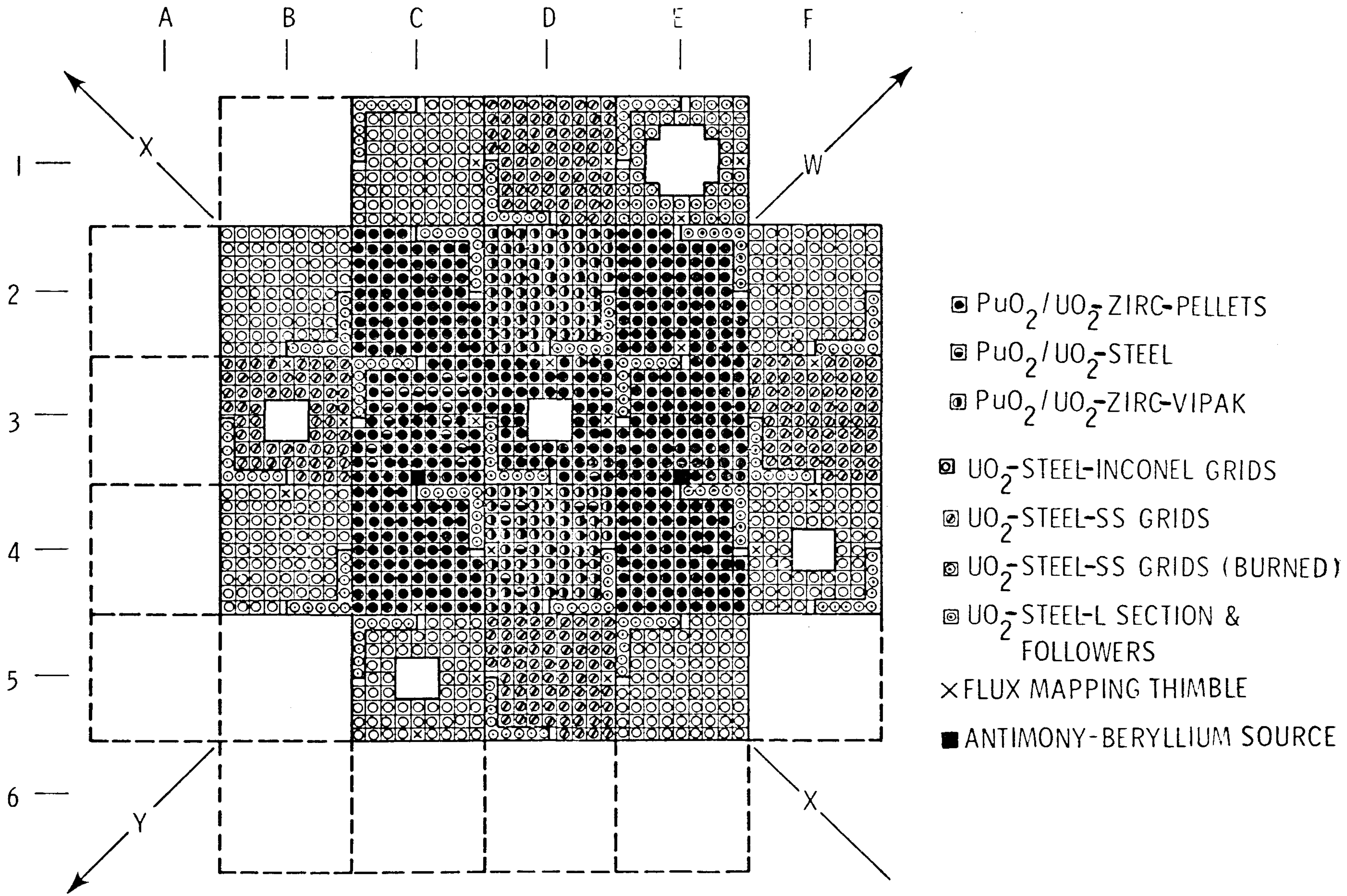

Figure 510.1: Saxton Core II Fuel Configuration

c. The experimental measurements program was begun. The required boron concentrations for the cold, zero-power and the hot, zero-power conditions were $\sim$ 170 ppm less than those predicted by the initial analysis. Power operation to 17 MWt was achieved. Data from these tests are being processed.

B. Experimental Program

1. Refueling Operations

During the loading of Saxton Core II, multiplication measurements were made as the Core I fuel elements were replaced with fresh fuel. The resulting $\frac{1}{m}$ plots show an interesting response as the two different fuel material types were installed in the core. When the central nine UO_2 fuel assemblies were replaced with PuO_2-UO_2 fuel, a significant variation in multiplication was observed. However, after all of the plutonium fuel assemblies had been installed, the substitution of fresh UO_2 fuel assemblies in peripheral locations produced only a slight change in multiplication. Representative $\frac{1}{m}$ plots for three detectors are shown in Figure 510.2. The location of the fuel element replaced at each step is also shown in this figure.

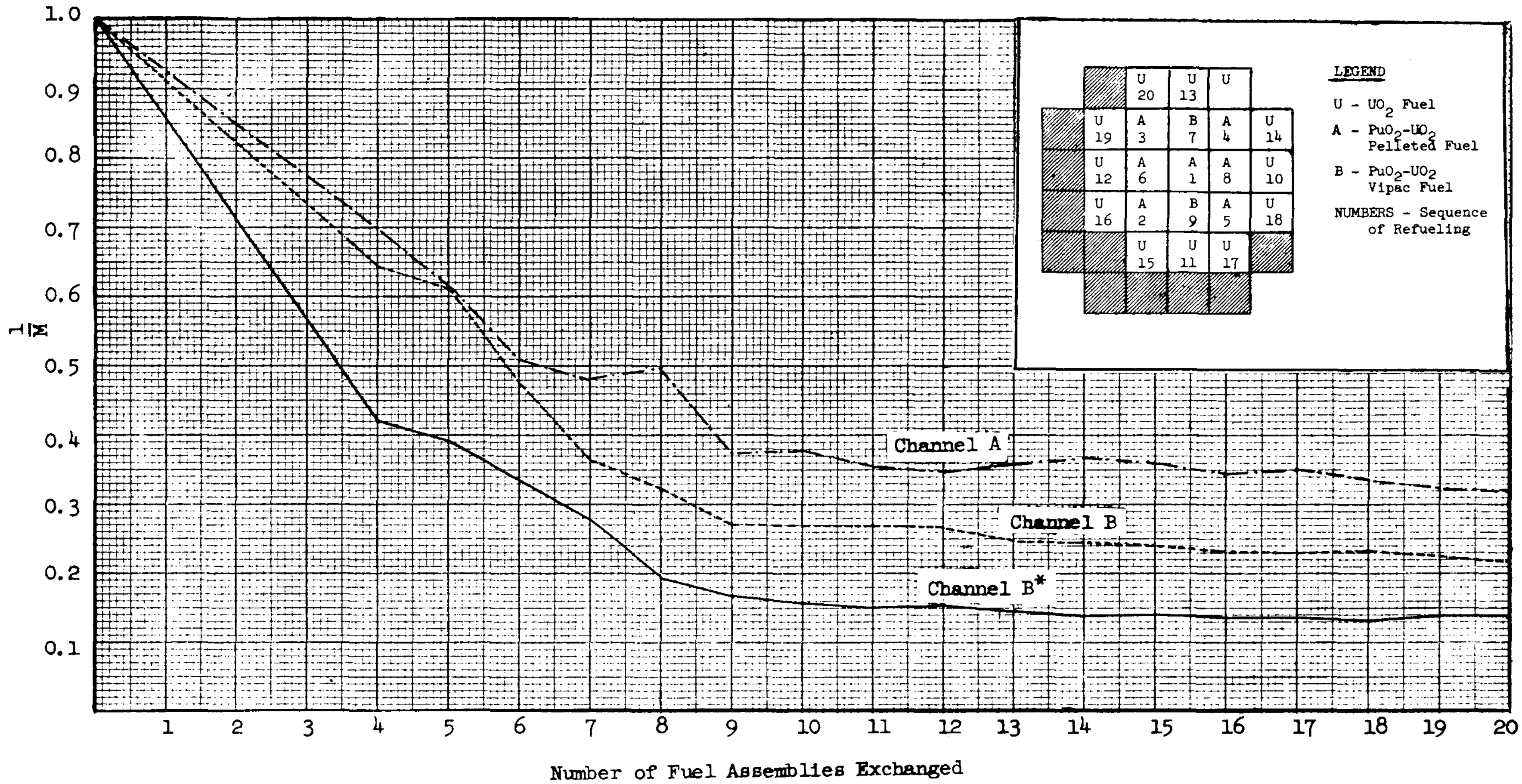

Figure 510.2: $\frac{1}{M}$ versus Number of Fuel Assemblies Exchanged

2. Zero Power Tests

Saxton Core II initial criticality was achieved on December 6, 1965 and the zero-power test program outlined in the previous quarterly[/4] was begun. The processing of data obtained during these initial tests is in progress.

The boron concentration requirements for two core conditions were:

Core Condition	Boron, ppm
Cold (140°F), zero-power, rods out	2718
Hot (530°F, 2000 psi), zero-power, rods out	2294

A complete summary of the experimental information obtained during this phase of the program will be included in the next report.

3. Operations at Power

At the close of the quarter, Saxton Core II operation had reached a power level of 17 MWt. The at-power portion of the experimental test program is now in progress.

C. Supporting Analysis

During the quarter, the supporting analysis has been concerned with the following three areas:

(1) Establishing the analytical procedure to be used in following the nuclear performance of Saxton Core II.

(2) Determining the boron concentration requirements and control rod worths expected during the experimental program.

(3) Calculating the kinetic characteristics of anticipated experimental configurations to aid in the interpretation of reactivity measurements.

1. Preparation for Operations Follow

To follow the operating history of Saxton Core II, a mechanized procedure was adopted that uses the LEOPARD-5/BUBBLE/PDQ-3* computer code sequence. LEOPARD-5 was selected because of the favorable comparison of analysis with critical experiments carried out at the Westinghouse Reactor Evaluation Center (WREC) using the design fuel.[/4] The BUBBLE code will be used because it provides a flexible method of analytically duplicating the experimental history of the reactor.

The basic purpose of the BUBBLE code is to generate macroscopic cross sections as a function of boron concentration and burnup and punch them out in a form that can be used in PDQ-3*. The code is essentially an interpolation and extrapolation procedure. A burnup-boron concentration matrix is defined for the various fuel regions in the core. Then a LEOPARD-5 lifetime calculation is carried out in accordance with the defined matrix. Macroscopic cross sections at arbitrary local burnup and boron concentrations are generated in BUBBLE for each composition by interpolation or extrapolation in the basic matrix. This procedure permits the frequent updating of the design core PDQ's based upon an evaluation of the in-core instrumentation data.

Xenon concentrations and microscopic resonance absorption cross sections are adjusted to account for the effect of differences in the local power level and the power level of the reference LEOPARD-5. "Alien" fuels, which are fuel regions that occur in quantities too small to dominate the neutron spectrum in which they occur are burned in accordance with the spectrum of the surrounding dominant fuel. The UO_2 fuel follower rods within the dominant PuO_2-UO_2 fueled region is an example of "alien" fuel.

During the quarter, the LEOPARD-5 calculations required in the boron-burnup matrix were completed. The data were stored on tape and a complete check out of the sequence was made. The system is now ready for use in following the operating history of the reactor throughout its lifetime.

2. Calculated Boron Requirements and Rod Worth

In preparation for the Saxton Core II experimental program, zero-power, pre-startup, criticality calculations were carried out using the LEOPARD-5/BUBBLE/PDQ-3* computer code sequence previously described. To correct for the small differences between the analysis and the critical experiments conducted at the WREC, a reactivity correction was included. The correction was included by dividing the LEOPARD-5 $\nu\Sigma_f$'s by 1.0058 for the UO_2 fuel and 1.0096 for the PuO_2-UO_2 fuel (Table 510.4, Reference 4).*

For each major fuel region in the core, a series of LEOPARD-5 calculations was run for four different boron concentrations. The BUBBLE code was then used to punch out PDQ-3* input constants at the desired boron concentrations. Number densities used in BUBBLE for alien fuel areas such as followers and sub-assemblies were combined in the code with microscopic cross sections from the nearest major fuel area to produce macroscopic constants. Water slot constants were determined in BUBBLE from a LEOPARD-5 calculation matrix of water and steel at various steel volume fractions and boron concentrations.

*The comparison of analysis with experiment for the PuO_2-UO_2 cores was carried out using a version of the code containing no built-in reactivity bias. The production version of the code contains a bias of 1.003. Consequently, the bias included should have been 1.0126 for PuO_2-UO_2. Therefore, to correct for the bias error, .003 was subtracted from the calculated k_{eff}.

The 87 x 87 PDQ-3 matrix used in these calculations was basically the same as that used in the determination of flux wire factors for Saxton Core I and for the Core II design calculations. The mesh was changed slightly to form a more convenient pattern in each fuel assembly. Separate hot and cold mesh spacings were adopted. The axial buckling was varied with boron concentration.

The results of the zero-power calculations are summarized in Table 5.10.1 and Table 510.2. From these calculations the following boron requirements were expected. Measured values are included for comparison.

	Calculated	Measured
Cold, zero-power	2895	2718
Hot, zero-power	2460	2290

The comparison of measured and calculated boron concentration requirements show the analysis overpredicts the required values by about 170 ppm. This discrepancy in boron concentration is larger than that which could reasonably be expected in view of the previous good agreement between the analysis and the WREC experiments. Consequently, a calculation was made using the LEOPARD-5/BUBBLE/PDQ-3* sequence for the hot, zero-power, just-critical condition for Saxton Core I (1804 ppm boron). Using this sequence the calculated reactivity was 1.2% $\Delta k/k$

TABLE 510.1

Summary of Saxton Core II Zero Power Reactivity Calculations

Cold,[1] Zero Power

Control Rods Inserted	PPM Boron	Calculated k_{eff}[2]
0	2300	1.0392
0	2950	0.9966
2,5	2950	0.9267
2,5	1800	1.0042
1,3,4,6	1800	1.0182
1,2,3,4,5,6	1800	0.9238
1,2,3,4,5,6	2300	0.8917

Hot,[3] Zero Power

Control Rods Inserted	PPM Boron	Calculated k_{eff}[2]
0	2300	1.0081
0	2650	0.9906
0	1225	1.0701
2,5	2650	0.9144
2,5	1225	0.9904
2,5	1800	0.9597
1,2,3,4,5,6	1225	0.8968

1. 100 F, 350 psi
2. 0.006 was subtracted from the calculated value for the reactivity bias and inconel grids
3. 533 F, 2000 psi

TABLE 510.2

Calculated Boron and Control Rod Worth for Saxton Core II

Cold,[1] Zero Power

Initial Rods	Insert Rods	Remove Rods	Initial Boron, ppm	Final Boron, ppm	Reactivity Change,[2] % ΔK/K
0	-	-	2300	2950	4.13 (157.3 ppm/1% Δρ)
0	2,5	-	2950	2950	7.25
0	All	-	2300	2300	15.33
All	-	2&5	1800	1800	9.64
All	-	1,3,4,6	1800	1800	8.33
All	-	-	1800	2300	3.45 (145 ppm/1% Δρ)

Hot,[3] Zero Power

Initial Rods	Insert Rods	Remove Rods	Initial Boron, ppm	Final Boron, ppm	Reactivity Change,[2] % ΔK/K)
0	-	-	1225	2300	5.86 (183.5 ppm/1% Δ)
0	-	-	2300	2650	1.81 (193.4 ppm/1% Δ)
0	2,5	-	2650	2650	7.90
0	2,5	-	1225	1225	7.58
0	All	-	1225	1225	17.56

1. 100 F, 350 psi
2. reactivity change = $\% \ln \frac{k_1}{k_2}$
3. 533 F, 2000 psi

higher than that indicated by the experiment. Previously, the calculated k_{eff} for these conditions was in excellent agreement with the experiment using the analysis sequence that was used throughout the nuclear design of Saxton Core II, LEOPARD-II/PDQ-3. A calculated k_{eff} of 0.9997 was found for the just-critical experimental condition.

The reason has not been determined for an increased reactivity discrepancy in the analysis of Saxton Core I for the new sequence as compared to the old. However, it should be pointed out that in both of the PDQ-3 calculations (X-Y geometry) the longitudinal grid structure is neglected. Consequently, in the Core I calculation that agrees well with the experiment, any discrepancy in the basic method of analysis was apparently compensated for by neglecting the longitudinal grid structure. When the new sequence was adopted, the reactivity base point for Saxton Core I was changed, thereby introducing a reactivity error in the subsequent calculations. Using the new sequence, if the reactivity error for the Saxton Core I calculation is subtracted from the Saxton Core II calculations made in preparation for the zero-power tests, the calculated boron concentration requirements would compare favorably with the experimental requirement, for example:

Core Condition	Corrected Calculated Boron, ppm	Measured Boron, ppm
Cold (140°F), zero-power, no rods	2700	2718
Hot (530°F, 2000 psia), zero-power, no rods	2230	2290

Additional work will be carried out in the next quarter to determine the reasons for the reactivity discrepancy that was found.

3. Kinetics

During the WREC critical experiments program, a number of multi-region experiments were carried out in which PuO_2-UO_2 fuel and UO_2 fuels were installed in separate regions. The performance of these experiments and the subsequent comparison with analysis illustrated the importance of a kinetics evaluation of each configuration in order to interpret reactivity results. In preparation for the zero-power tests, the kinetic characteristics were investigated for the following configurations:

(1) Cold - zero-power, no rods, 2950 ppm boron

(2) Hot - zero-power, no rods, 2650 ppm boron

(3) Hot - zero-power, rods 2 and 5 in, 1225 ppm boron

(4) Cold - zero-power, rods 2 and 5 in, 1800 ppm boron

The method that was used is the same as that used in the critical experiments program. In brief, the following procedure was followed:

(1) Group constants for each fuel region were determined using a prompt and delayed spectrum in LEOPARD-5.

(2) A cylindrical AIM-5[5] calculation was carried out using the prompt group constants. A buckling search was used to adjust the transverse buckling until a calculated k_{eff} of 1.0 was obtained. (The boron concentration which reduced k_{eff} to approximately 1.0 was selected on the basis of PDQ-3 results reported in Table 510.1. Consequently, only small variations in buckling were required.)

(3) A second AIM-5 calculation was made using the transverse buckling determined in (2). In this calculation both prompt and delayed constants were used with the neutron source fraction in the delayed group equal to β for the particular fuel region. No transfers occur from prompt to delayed groups; instead, both groups transfer directly to the thermal group. The resulting calculated $k_{eff} = 1 + \beta_{eff}$.

(4) A core average β was determined from the AIM-5 source distribution by weighting the source fraction for each

fissionable isotope by the β for that isotope and integrating over the core.

(5) An importance factor was determined from $\beta_{eff} = I\,\bar{\beta}$. These quantities were then used in the Inhour code to determine the reactivity - period relationship.

To simulate control rods, the absorption cross section in the rod region was increased until the reactivity change was equivalent to rod worth calculations in PDQ-3.

The results using this procedure for the four configurations of interest are summarized in Table 510.3.

TABLE 510.3

Kinetic Characteristics for Saxton Core II

for Four Different Core Conditions

Core Condition	$\bar{\beta}$	I	β_{eff}
Cold, 68°F, 14.7 psi, 2950 ppm, unrodded core	0.004131	0.88665	0.003662
Cold, 100°F, 350 psi, 1800 ppm, rods in 2 and 5	0.004499	0.91687	0.004125
Hot, 533°F, zero power, 2000 psi, 2650 ppm, unrodded core	0.004544	0.90094	0.004094
Hot, 533°F, zero power, 1225 ppm, 2000 psi, rods 2 and 5 in	0.004784	0.93477	0.004472

REFERENCES

1. R. F. Barry, "LEOPARD - A Spectrum Dependent Non-Spatial Depletion Code for the IBM-7094," WCAP-3741 (1963).

2. G. F. Eletti, "BUBBLE - A Linking Code to Automate LEOPARD-PDQ System," WCAP-2877 (1965).

3. W. R. Cadwell, et. al., "PDQ-3, A Program for the Solution of the Neutron Diffusion Equation in Two-Dimensions on the IBM-7094," WAPD-TM-179 (1960).

4. N. R. Nelson, "Saxton Plutonium Program Quarterly Progress Report for the Period Ending September 30, 1965," WCAP-3385-5 (1965).

5. H. P. Flatt and D. C. Haller, "AIM-5 - A Multi-Group, One-Dimensional Diffusion Equation Code," NAA-SR-4694 (1960).

Remaining Subtasks

A. A. Bishop, et. al.

SAX-520 Thermal-Hydraulic Analyses of Operations

A. A. Bishop

This work, which will consist of a minimum effort thermal and hydraulic follow program during startup and operation is primarily for the purpose of providing flow and heat transfer consultation.

SAX-610 Post Irradiation Storage & Shipments - H. E. Walchli

SAX-620 Post Irradiation Examination - Transfer Building - D. T. Galm

SAX-630 Post Irradiation Examination - Hot Cells - D. T. Galm

SAX-640 Post Irradiation Radiochemical Examination - D. T. Galm

SAX-650 Waste Disposal - D. T. Galm

SAX-660 Materials Evaluation - R. J. Allio

SAX-670 Fuel Reprocessing - H. E. Walchli

The major technical work in the SAX-600 post irradiation series of shop orders will commence in early 1968. A small amount of work tentatively is planned to examine some 3 x 3 subassembly removable rods in 1967 and to update planning for the major post irradiation program.

NOTICE TO THE READER

All Euratom reports are announced, as and when they are issued, in the monthly periodical **EURATOM INFORMATION,** edited by the Centre for Information and Documentation (CID). For subscription (1 year : US$ 15, £ 5.7) or free specimen copies please write to :

Handelsblatt GmbH
"Euratom Information"
Postfach 1102
D-4 Düsseldorf (Germany)

or

Office de vente des publications
des Communautés européennes
2, Place de Metz
Luxembourg

To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

SALES OFFICES

All Euratom reports are on sale at the offices listed below, at the prices given on the back of the front cover (when ordering, specify clearly the EUR number and the title of the report, which are shown on the front cover).

PRESSES ACADEMIQUES EUROPEENNES
98, Chaussée de Charleroi, Bruxelles 6

Banque de la Société Générale - Bruxelles
compte N° 964.558,

Banque Belgo Congolaise - Bruxelles
compte N° 2444.141,

Compte chèque postal - Bruxelles - N° 167.37,

Belgian American Bank and Trust Company - New York
compte No. 22.186,

Lloyds Bank (Europe) Ltd. - 10 Moorgate, London E.C.2,

Postscheckkonto - Köln - Nr. 160.861.

OFFICE CENTRAL DE VENTE DES PUBLICATIONS DES COMMUNAUTES EUROPEENNES
2, place de Metz, Luxembourg (Compte chèque postal N° 191-90)

BELGIQUE — BELGIË
MONITEUR BELGE
40-42, rue de Louvain - Bruxelles
BELGISCH STAATSBLAD
Leuvenseweg 40-42 - Brussel

DEUTSCHLAND
BUNDESANZEIGER
Postfach - Köln 1

FRANCE
SERVICE DE VENTE EN FRANCE DES PUBLICATIONS DES COMMUNAUTES EUROPEENNES
26, rue Desaix - Paris 15e

ITALIA
LIBRERIA DELLO STATO
Piazza G. Verdi, 10 - Roma

LUXEMBOURG
OFFICE CENTRAL DE VENTE DES PUBLICATIONS DES COMMUNAUTES EUROPEENNES
9, rue Goethe - Luxembourg

NEDERLAND
STAATSDRUKKERIJ
Christoffel Plantijnstraat - Den Haag

UNITED KINGDOM
H. M. STATIONERY OFFICE
P. O. Box 569 - London S.E.1

EURATOM — C.I.D.
51-53, rue Belliard
Bruxelles (Belgique)