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PART II

EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

SAXTON PLUTONIUM PROGRAM

Quarterly Progress Report for the period ending December 31, 1964

by

N.R. NELSON
(Westinghouse Atomic Power Division)

1966

EURATOM/US Agreement for Cooperation

EURAEC Report No. 1304 prepared by the
Westinghouse Electric Corporation, Pittsburgh, Pa. - USA

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

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One and two dimensional burn-up circulations were used to establish the desired Pu enrichment. The design of all the fuel rods has been completed incorporating whenever possible the suggestions of the fuel rod vendors. Detailed specifications for mixed pellets and powder have been written.

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SUMMARY

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One and two dimensional burn-up circulations were used to establish the desired Pu enrichment. The design of all the fuel rods has been completed incorporating whenever possible the suggestions of the fuel rod vendors. Detailed specifications for mixed pellets and powder have been written.

A preliminary measurement program for the critical experiments was formulated. The kinetic characteristics of single zone mixed-oxide (PuO_2-UO_2) critical assemblies were evaluated and a hazards study was made.

Draft of the Safeguard Report is in progress.

CONTENTS

LIST OF FIGURES

SAX-100 Project Administration

N. R. Nelson

Agreement has been reached with NUMEC and the fuel contract has been signed. The initial shipment of plutonium metal has arrived at NUMEC and work on preparation of PuO_2 has started. Additional plutonium has been ordered to allow increase in enrichment from 6.0 to 6.6 w/o PuO_2.

Hanford has converted plutonium metal to oxide, has calcined and screened the resulting material and has blended the PuO_2 for isotopic homogeneity with the Pu-240 content averaging 8.6%.

By using new ultrasonic crystals and improved testing techniques, Hanford has been able to discover minor defects in the areas of end plug welds of some of the fuel rods manufactured for EBWR. In the fuel rods so affected the end plugs are being cut out and new end plugs welded back in. It has been reported that the defects occurred only in the vicinity of those end plugs welded prior to the vibratory compaction process. Hanford is analyzing the problem and will not proceed with Saxton plutonium fuel rod manufacture until the energy and frequency inputs to the vibratory compaction process have been adjusted for satisfactory operation. In addition, all finished Hanford plutonium fuel rods will be tested in weld plug areas with the new Hanford ultrasonic equipment. Also helium leak tests will be run on all finished rods.

Manuscript received on December 10, 1965.

Delivery of the Zircaloy-4 fuel cladding tubes is behind schedule at Harvey Aluminum. The initial run of tubes had marginal chemical analyses in iron and chromium contents. To make certain the tubes would have adequate resistance to corrosion, a 14-day corrosion test was specified instead of the 3-day test normally used and the allowable maximum weight gain was reduced from 38 to 28 mgs/dm^2. Two 14-day tests were run at Harvey; the weight gain resulting from the first test was slightly over the limit set while the weight gain from the second test was acceptable. Upon review, details of test procedures at Harvey Aluminum were questioned and a third 14-day corrosion test was run as a referee test at Westinghouse. Results of this test showed a weight gain of about 24 mg/dm^2. Consequently the material was accepted. Harvey Aluminum is proceeding on the manufacture of backup tubing from a billet with chemical analysis superior to that of the billet used for the first run of tubes. About 200 tubes from this backup lot have been shipped to Hanford.

Earlier and prior to final acceptance, 20 tubes of the first run had been shipped, ten to Hanford and ten to NUMEC for use in pre-production development work including end plug welding.

On December 16th and 17th, Saxton Plutonium Project meetings were held at AEC Headquarters with AEC and Euratom personnel. After a review of project status, discussions were held on the feasibility of a Euratom request to include in the Saxton second core, thirty PuO_2-UO_2

vipac fuel rods to be made in Europe by Euratom to Westinghouse specifications.

Negotiations with the AEC are still underway to determine a method for calculating and verifying the extra costs to Westinghouse of supplying PuO_2-UO_2 fuel instead of UO_2 fuel in nine assemblies of the second Saxton core.

SAX-210 Nuclear Fuel Design

F. L. Langford, W. L. Orr,
R. H. Chastain, H. I. Sternberg

A. Introduction and Scope of Work

1. Introduction

The objective of the nuclear design task is to develop the nuclear specifications for the partial loading of the mixed-oxide (PuO_2-UO_2) fuel assemblies to be used in the Saxton reactor during a two-year irradiation period. The basic requirement is to determine a plutonium loading that provides the desired lifetime within power limitations set by the plant, thermal and hydraulic design parameters.

2. Scope of Work

As described in the previous quarterly, one-dimensional and two-dimensional burnup calculations were used to establish within a narrow range the desired plutonium enrichment. However, a number of unresolved design parameters such as the maximum allowable length of the fuel column and the composition and quantity of the material to be used for the grid structure prevented setting a final enrichment specification. During this quarter, the remaining design questions were answered and the plutonium enrichment was established at 6.6 w/o

PuO_2. This specification represents an increase over that of the reference configuration previously described (6.0 w/o PuO_2 to 6.6 w/o PuO_2).

Kinetic calculations were also completed during the quarter and are reported.

B. Effect of Enrichment Change

The change in enrichment from 6.0 w/o PuO_2 to 6.6 w/o PuO_2 results in the following nuclear effects:

1. The initial reactivity is increased by 0.5% $\Delta k/k$ from 9.8% $\Delta k/k$ to 10.3% $\Delta k/k$. For a calculated total control rod bank worth of 16.9% $\Delta k/k$, the hot, full power shutdown margin is expected to be 6.6% $\Delta k/k$.

2. The available lifetime is increased by more than 1000 hours from 7300 to 8450 hours at 23.5 MWt. Reactivity as a function of lifetime as determined by a LUX calculation, a one-dimensional burnout code, is shown in Figure 210.1.

3. The maximum radial power peaking factor in the central plutonium region is increased from 2.25 to 2.36, an increase of 5% in local power. Figure 210.2 summarizes the core radial power distribution from a PDQ/1 two-dimensional diffusion calculation. The analysis was

carried out for a plutonium enrichment of 6.5 w/o PuO_2. The difference between 6.5 w/o PuO_2 and 6.6 w/o PuO_2 is small ($\approx$ 1% in local power). Figure 210.3 summarizes the individual rod power in the center fuel assembly. The listed peak power includes a correction for the discrepancy between analysis and experiment from Saxton Core I and for the small extrapolation in local rod power for the difference in enrichment (6.5 w/o PuO_2 to 6.6 w/o PuO_2).

The increase in lifetime obtained by the change in enrichment significantly improves the probability of meeting a design lifetime objective of 8250 MWD. However, to provide sufficient lifetime, it was necessary to specify a plutonium enrichment that results in an increase in the nuclear hot channel factor over that of a conventional Saxton uranium-fueled core. Consequently, it may be necessary to limit the reactor power level initially to avoid exceeding a linear power limitation of 16 KW/ft. The forthcoming critical experiments described under SAX-250 should resolve much of the current uncertainty in power peaking analysis. Figure 210.4 (a) shows the nuclear hot channel factor as a function of operating time at 23.5 MWt. An operating sequence that avoids exceeding the 16 KW/ft limit is shown in Figure 210.4 (b).

An alternate procedure of reducing the nuclear hot channel factor is to operate the reactor with rods 2 and 5 partially inserted. Figure 210.5 shows the resulting power distribution. This figure indicates that with this mode of rodded operation, it is possible to operate at 23.5 MWt at the start. However, it would be advisable to operate with chemical shim using a specified power sequence in order to reduce the local power peaks prior to the necessity of achieving a high power level.

C. Kinetic Calculations

1. Reactivity Effects

a. Doppler and Power Coefficients

Doppler coefficient calculations were carried out as a function of the effective fuel temperature where the effective fuel temperature is defined as that temperature which gives the correct experimental power coefficients of reactivity when employed in standard design calculations. The relationship between pellet temperature and effective fuel temperature is based on the work of W. T. Sha who correlated effective fuel temperature for Doppler broadening of U-238 resonances with experimental power coefficient measurements in the Yankee, Saxton, and BR-3 reactors[/2]. The temperature power relationships developed by Sha for the Saxton reactor are shown in Figure 210.6.

The Doppler coefficient was determined by completing a series of LEOPARD[3] calculations for values of T_{eff} ranging from 800°F to 2000°F in 200-degree increments. The resulting group constants were then used in AIM-5[4] radial diffusion calculations. Figure 210.7 summarizes the results for variations in T_{eff} alone and for the variation in temperatures shown in Figure 210.6. The difference between the two curves is due to the change in moderator content resulting from the small change in clad dimensions with temperature. Figure 210.8 shows the derived power coefficient based on the Doppler calculations and the temperature-power-relationships of Figure 210.6.

Calculations were also made to determine the fraction of the total Doppler effect due to temperature changes in each region separately. Approximately 70% of the reactivity change due to Doppler is the result of temperature changes in the central plutonium region while 30% is the result of temperature changes in the outer uranium region.

b. Moderator Coefficient

The moderator temperature coefficient was determined by a sequence of LEOPARD and AIM-5 calculations. Figure 210.9 summarizes the results for the partial plutonium core and includes a comparison with that determined previously for the conventional Saxton all-uranium loading.

c. Pressure and Void Coefficient

Table 210.1 compares the pressure and void coefficients for the core containing nine plutonium fuel assemblies with that of the conventional uranium loading. The analysis was carried out using LEOPARD and AIM-5.

d. Boron Worth

The LEOPARD - AIM-5 calculated boron worth as a function of boron concentration is shown in Figure 210.10.

2. Kinetic Characteristics

β_{eff} was evaluated throughout life from a TURBO*[5] calculation. A constant value of ≈ 0.0049 was found. β_{eff} was determined by weighting the delayed group yields of the various fissioning materials by the fraction of neutrons from each isotope. An importance factor, derived from LEOPARD calculations using different source spectra, was applied to account for

Table 210.1

PRESSURE AND VOID COEFFICIENTS

Pressure Coefficient $\frac{1}{k}\frac{\partial k}{\partial P}$ (10^6 psia) Moderator = 530° F

Pu Core	CONVENTIONAL CORE			
1000 ppm Boron	Clean 0 Boron	1000 ppm Boron	2000 ppm Boron	Fully Rodded 0 Boron
+3.5	+3.1	+2.1	+1.3	+5.6
		Extrapolated Value		

Void Coefficient $\frac{1}{k}\frac{\partial k}{\partial P}$ (%Δk/k/% void) Moderator = 530° F

Pu Core	CONVENTIONAL CORE			
1000 ppm Boron	Clean 0 Boron	1000 ppm Boron	2000 ppm Boron	Fully Rodded 0 Boron
-0.27	-0.26	-0.18	-0.10	-0.43
		Extrapolated Value		

the difference in importance of delayed and prompt neutrons. Table 210.2 summarizes the power and neutron source fraction in each of the two regions for each isotope at the beginning-of-life. The table also includes delayed neutron data and the region and core average β_{eff} and prompt neutron lifetimes.

Table 210.2

ISOTOPIC POWER AND NEUTRON FRACTIONS, DELAYED NEUTRON DATA, β_{eff} AND PROMPT LIFETIME

Beginning-of-Life

Region	Isotopic Power Fractions				Neutron Source Fractions			
	U-235	U-238	Pu-239	Pu-241	U-235	U-238	Pu-239	Pu-241
Core Average	0.4301	0.0509	0.5078	0.0112	0.4008	0.0514	0.5352	0.0125
Pu Region/1	0.1302	0.0503	0.7998	0.0177	0.1188	0.0490	0.8132	0.0190
U Region/2	0.9390	0.0520	0.0088	0.0001	0.9340	0.0561	0.0099	0.0001

Delayed Neutron Data

Delayed Neutron Group, i	λ_i, sec^{-1}		β_i			
	U-235	Pu-239	U-235	U-238	Pu-239	Pu-241/3
1	0.0124	0.0128	0.000215	0.000204	0.000074	0.000091
2	0.0305	0.0301	0.001424	0.002151	0.000626	0.000775
3	0.111	0.124	0.001274	0.002543	0.000443	0.000549
4	0.301	0.325	0.002568	0.006092	0.000685	0.000848
5	1.13	1.12	0.000748	0.003533	0.000181	0.000224
6	3.00	2.69	0.000273	0.001178	0.000092	0.000114
			0.0065	0.0157	0.0021	0.0026

β_{eff} and Prompt Neutron Lifetime

Region	β_{eff}	Lifetime, usec/4
Core Average	0.0049	11.7/5
Pu Region	0.0035/1	8.6
U Region	0.0075/2	15.7

1. Includes partially depleted uranium fuel followers.
2. Includes partially depleted uranium L-sections.
3. Relative abundance for Pu-239 used.
4. Calculation made with core containing 1000 ppm boron.
5. Weighting based on power fractions of U = 0.439 (includes L-sections and followers),Pu = 0.561.

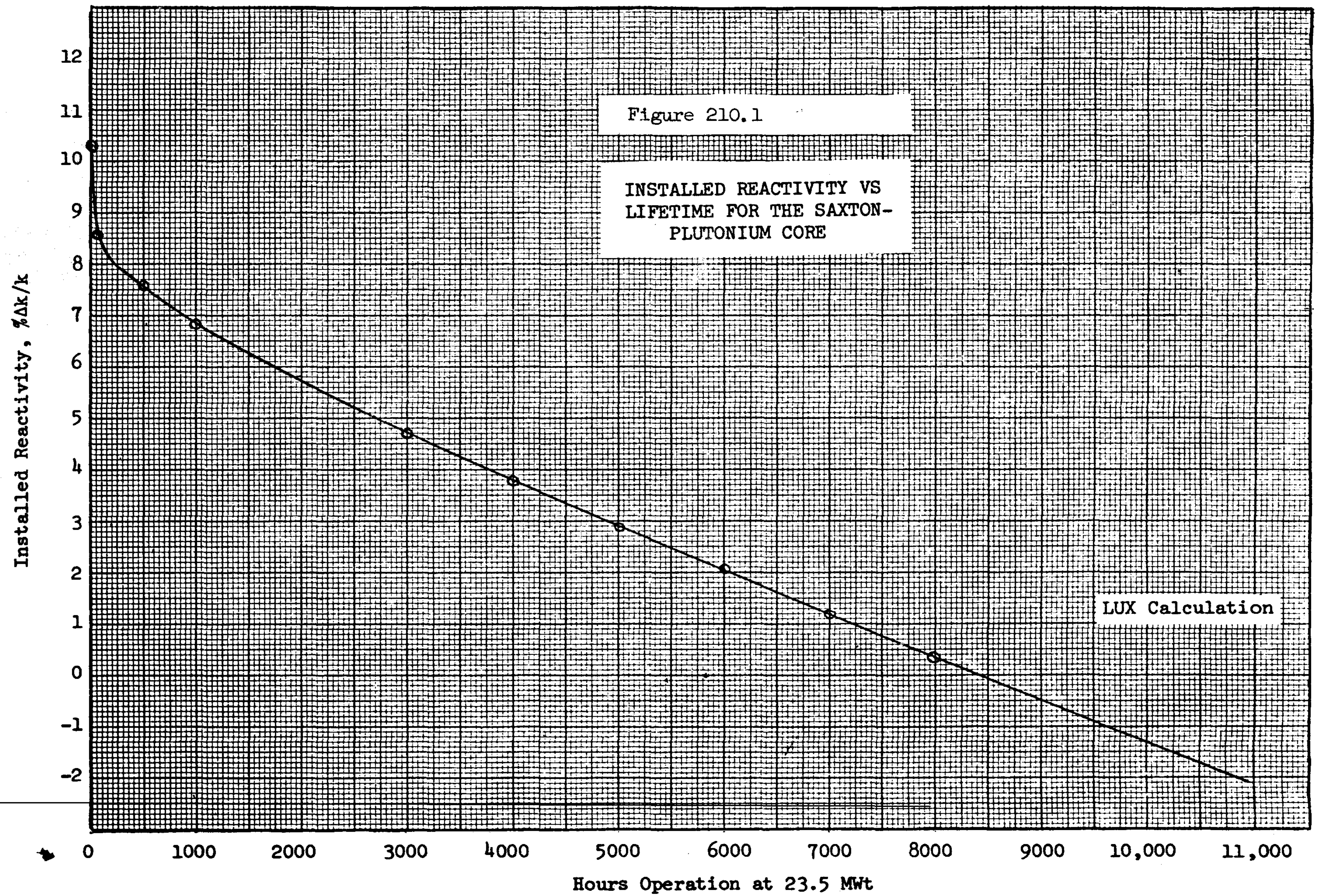
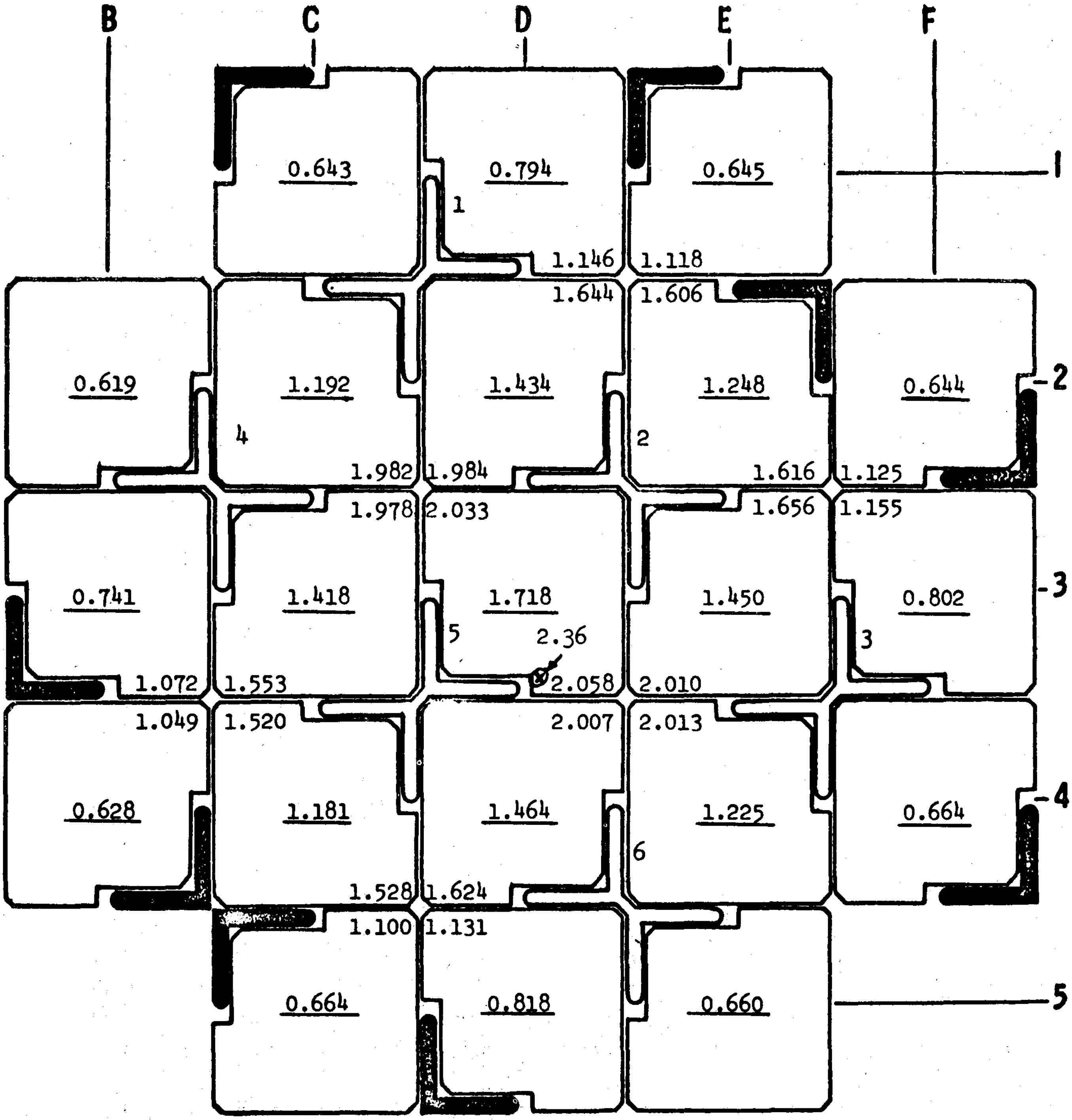


Figure 210.1
INSTALLED REACTIVITY VS LIFETIME FOR THE SAXTON-PLUTONIUM CORE
LUX Calculation
Installed Reactivity, %Δk/k
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
11,000
Hours Operation at 23.5 MWt

PDQ Power Distribution

Configuration: 9 PuO_2-UO_2 Assemblies (6.5 w/o PuO_2) in Center Positions
No rods, 1000 ppm Boron, Depleted Followers and L-Sections
λ = 1.08848



The underlined value in each assembly is the average power in that assembly relative to the average power in the core. The relative power is also shown for individual fuel rods near the uncontrolled corners of assemblies (where hot spots usually occur). The peak power includes a correction for the discrepancy between analysis and experiment for Saxton Core I and for an increase in boron content to 2400 ppm.

Figure 210.2. **Saxton-Plutonium Core Power Distribution**

Conditions: 9 PuO_2-UO_2 Assemblies (6.5 w/o PuO_2) in Center
No Rods, 1000 ppm Boron
Depleted Followers and L-Sections
$\lambda = 1.08848$

2.03	1.85	1.88	2.14		2.14	1.91	1.90	2.10
1.84	1.66	1.66	1.76	1.89	1.76	1.67	1.68	1.90
1.87	1.66	1.63	1.64	1.66	1.64	1.63	1.67	1.92
2.15	1.77	1.64	1.62	1.62	1.63	1.65	1.77	2.14
	1.94	1.66	1.63	1.62	1.63	1.66	1.90	
	1.94	1.673	1.63	1.63	1.63	1.65	1.77	2.15
	1.93	1.71	1.68	1.67	1.65	1.64	1.68	1.89
	2.00	1.94	1.95	1.95	1.78	1.67	1.68	1.87
					2.16	1.89	1.96	2.06

Maximum Rod Power = 2.36

(This value includes a correction for the discrepancy between analysis and experiment for Saxton Core I and for an increase in boron content to 2400 ppm).

Figure 210.3. **Center Assembly Power Distribution**

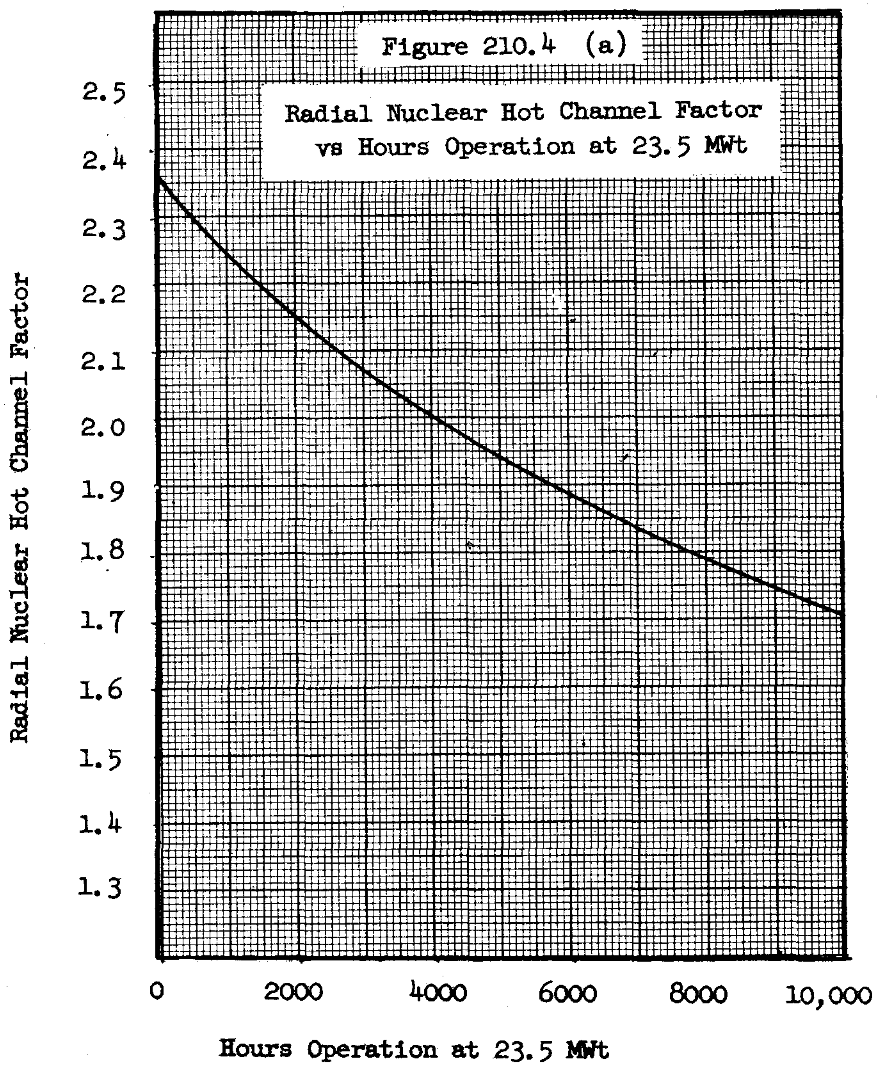


Figure 210.4 (a)

Radial Nuclear Hot Channel Factor vs Hours Operation at 23.5 MWt

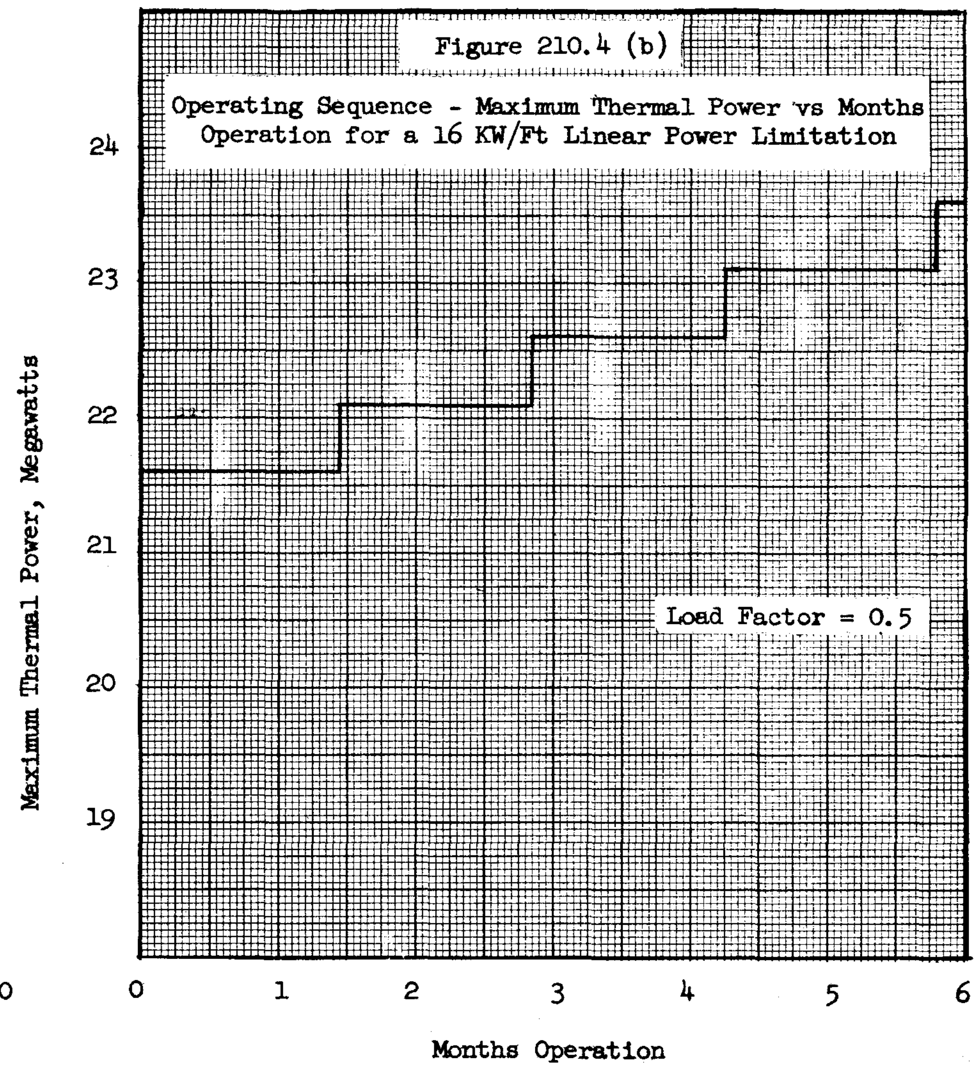
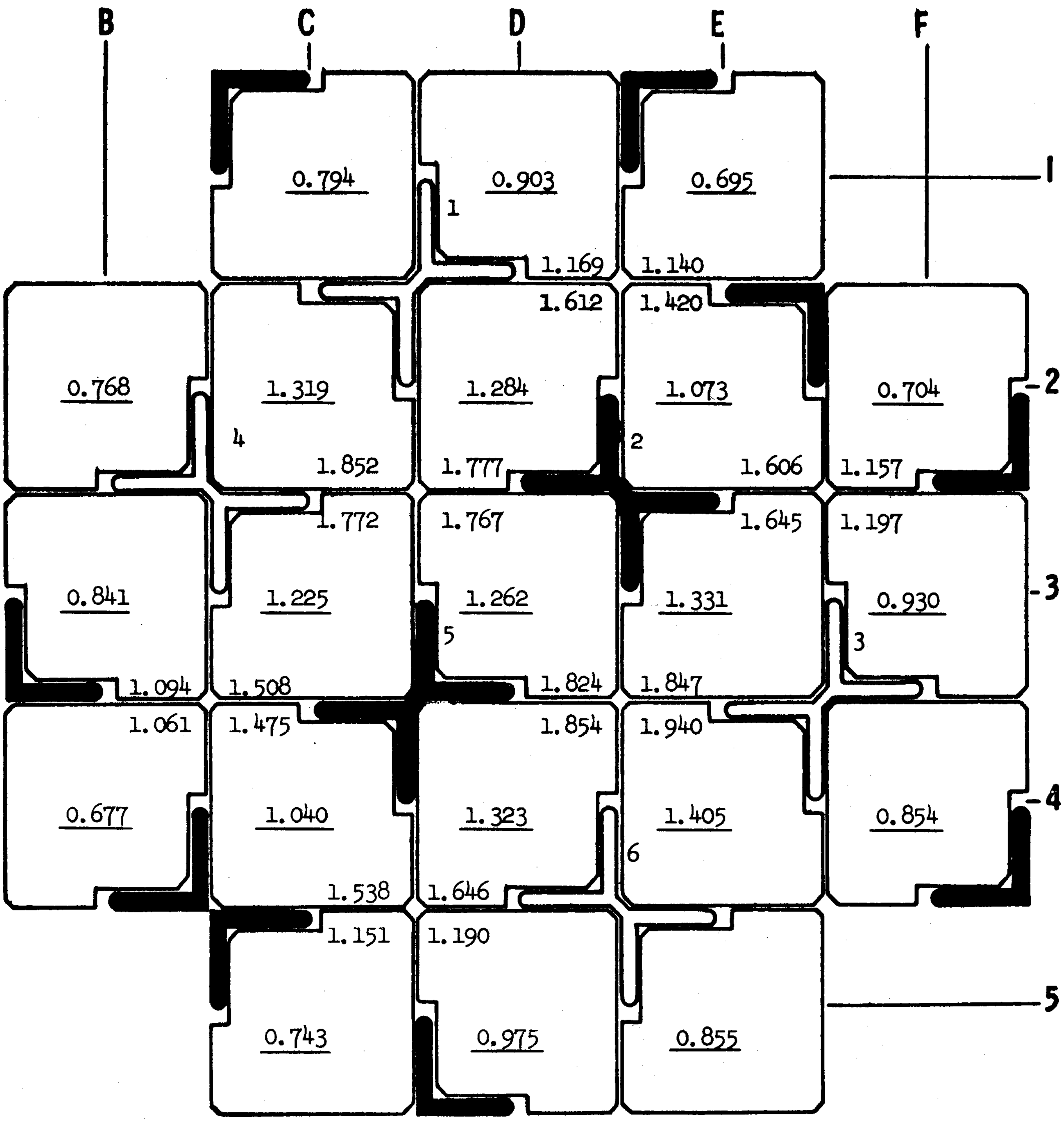


Figure 210.4 (b)

Operating Sequence - Maximum Thermal Power vs Months Operation for a 16 KW/Ft Linear Power Limitation

Extrapolated PDQ Power Distribution

Configuration: Nine (9) PuO_2-UO_2 Assemblies (6.5 w/o PuO_2 extrapolated from calculations at 5.0 w/o PuO_2), Rods 2 & 5 in, 1000 ppm Boron



The underlined value in each assembly is the average power in that assembly relative to the average power in the core. The relative power is also shown for individual fuel rods near the uncontrolled corners of assemblies (where hot spots usually occur). To correct for the discrepancy between analysis and experiment for Saxton Core I, the peak value should be multiplied by 1.063.

Figure 210.5 Saxton - Plutonium Core Power Distribution with Rods 2 and 5 Inserted.

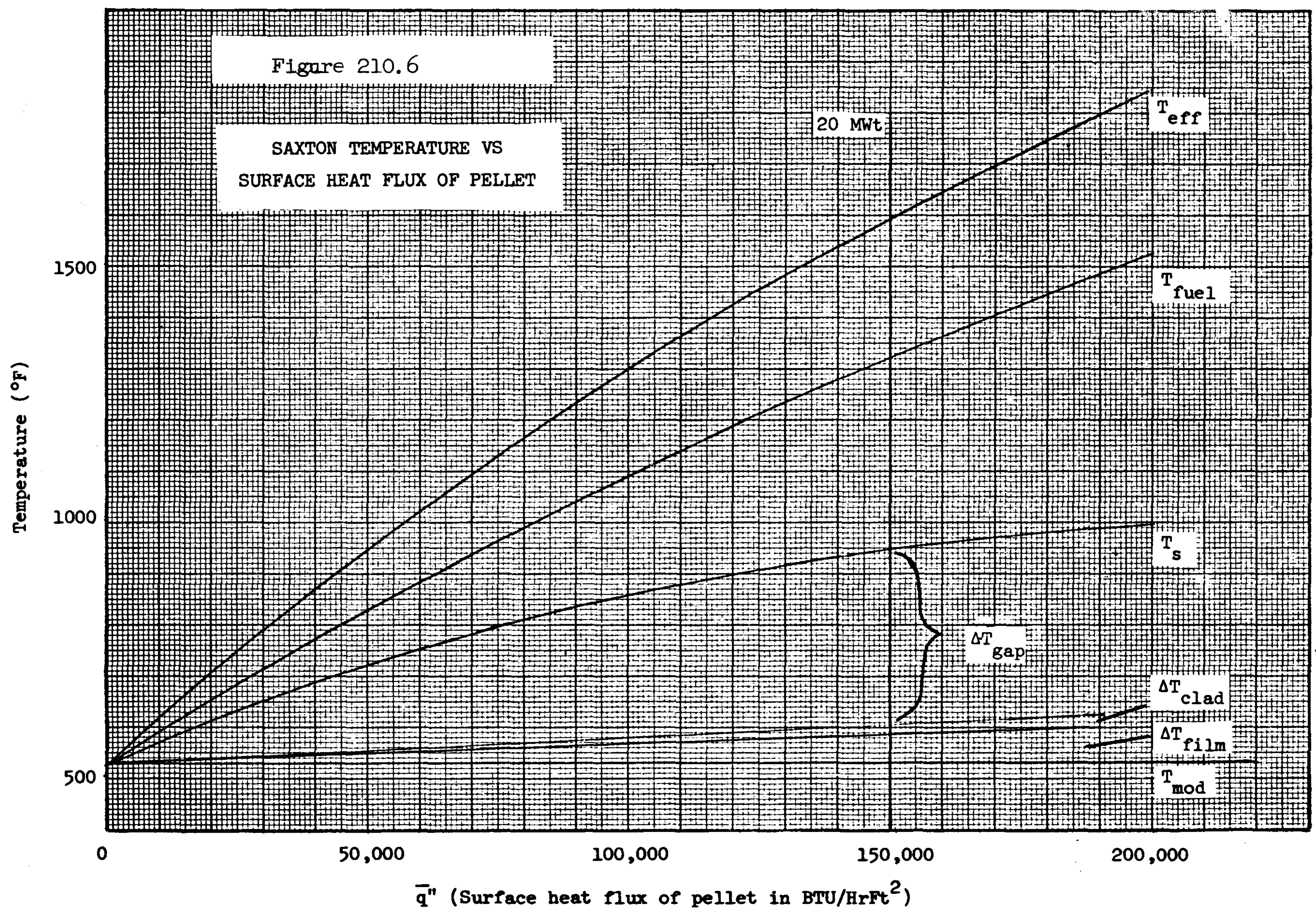


Figure 210.6
SAXTON TEMPERATURE VS
SURFACE HEAT FLUX OF PELLET
20 MWt
T_{eff}
T_{fuel}
T_s
ΔT_{gap}
ΔT_{clad}
ΔT_{film}
T_{mod}
1500
1000
500
Temperature (°F)
0
50,000
100,000
150,000
200,000
$\bar{q}''$ (Surface heat flux of pellet in BTU/HrFt^2)

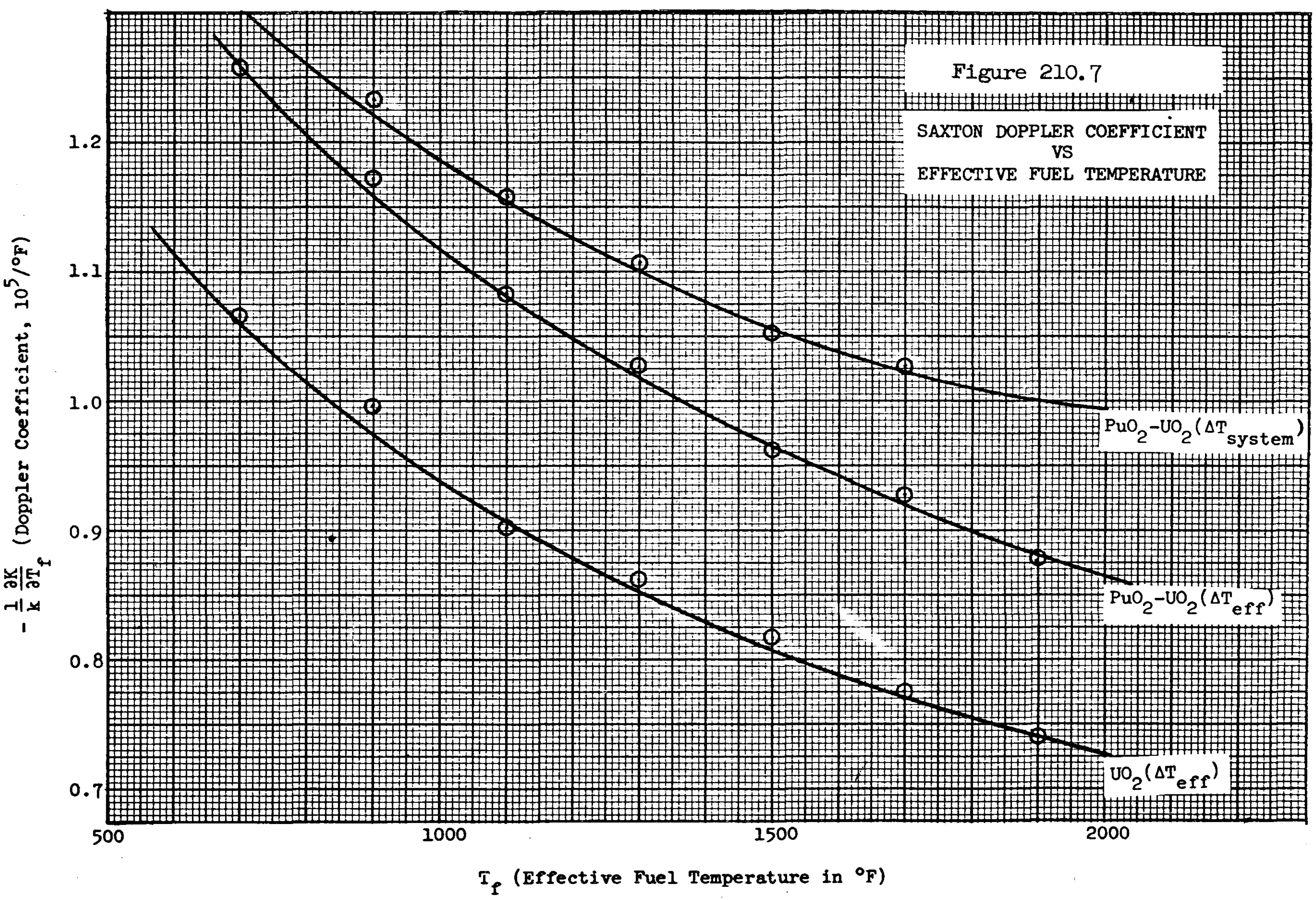


Figure 210.7

SAXTON DOPPLER COEFFICIENT
VS
EFFECTIVE FUEL TEMPERATURE

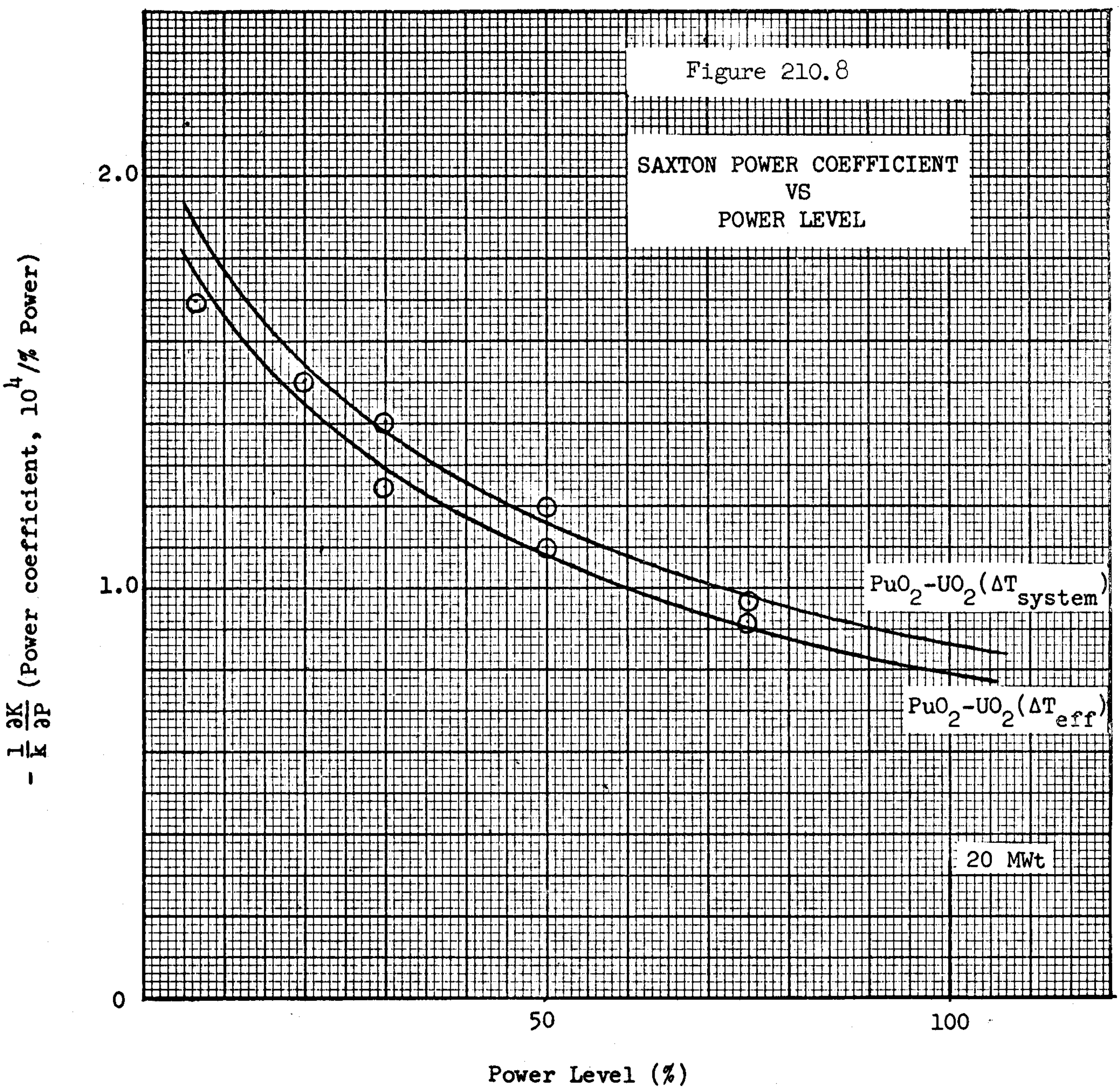


Figure 210.8
SAXTON POWER COEFFICIENT
VS
POWER LEVEL
$-\frac{1}{k}\frac{\partial K}{\partial P}$ (Power coefficient, 10^4/% Power)
2.0
1.0
0
50
100
Power Level (%)
$PuO_2-UO_2(\Delta T_{system})$
$PuO_2-UO_2(\Delta T_{eff})$
20 MWt

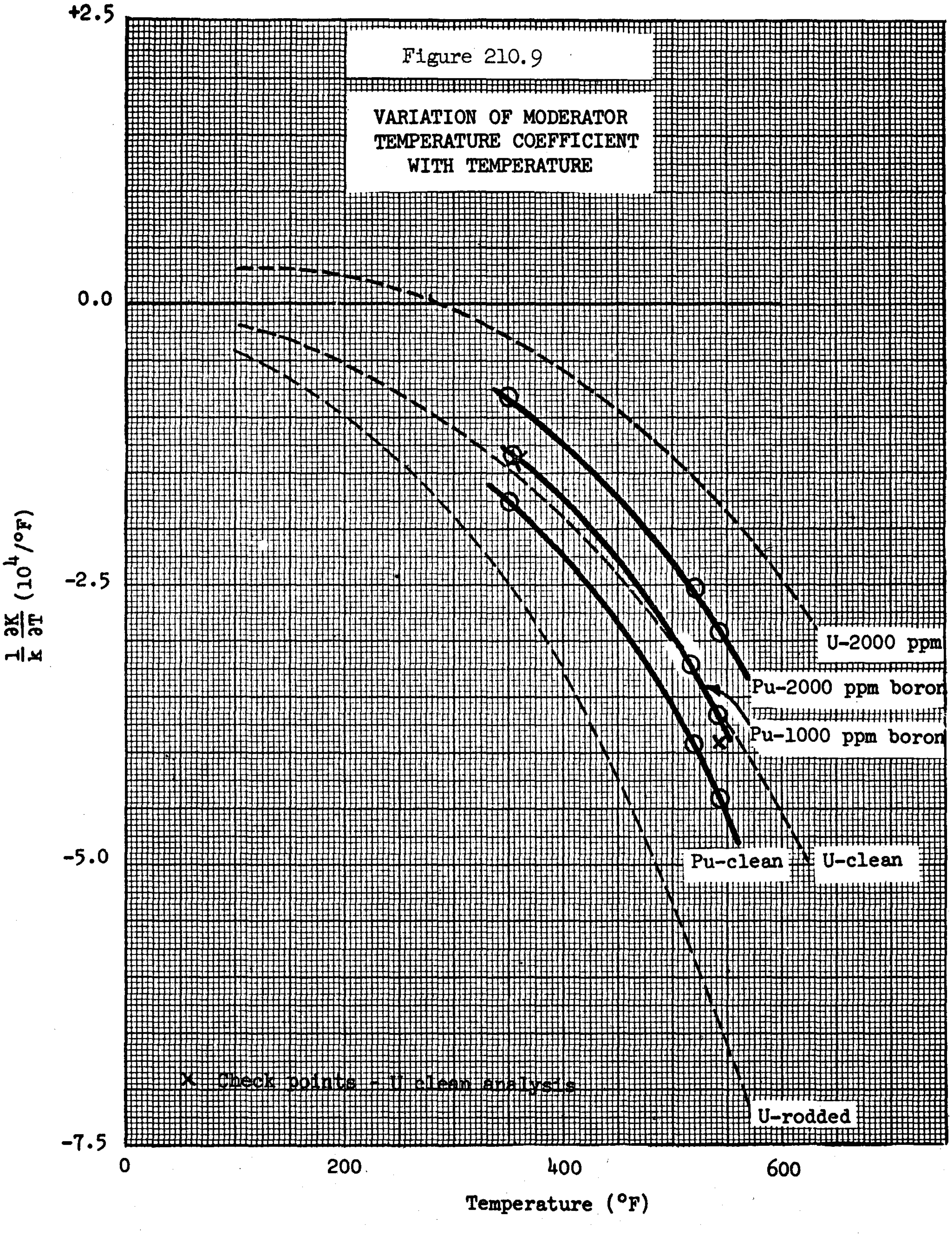


Figure 210.9
VARIATION OF MODERATOR TEMPERATURE COEFFICIENT WITH TEMPERATURE
+2.5
0.0
-2.5
-5.0
-7.5
$\frac{1}{k}\frac{\partial K}{\partial T}$ (10^4/°F)
0
200
400
600
Temperature (°F)
U-2000 ppm
Pu-2000 ppm boron
Pu-1000 ppm boron
Pu-clean
U-clean
U-rodded
X Check points - U clean analysis

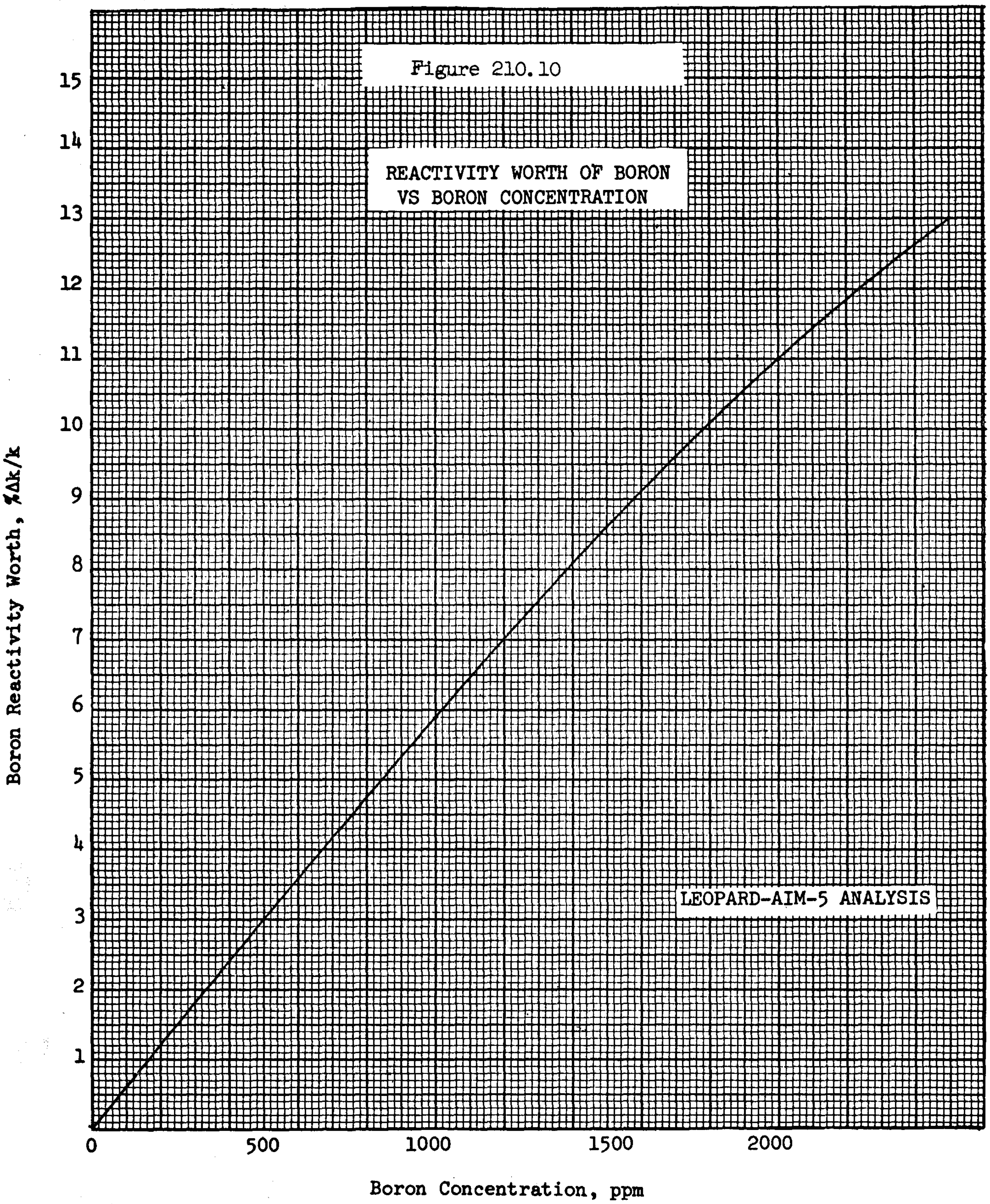


Figure 210.10
REACTIVITY WORTH OF BORON
VS BORON CONCENTRATION
LEOPARD-AIM-5 ANALYSIS
Boron Reactivity Worth, %Δk/k
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
500
1000
1500
2000
Boron Concentration, ppm

References

/1 W. R. Cadwell, et.al, "PDQ-3, A Program for the Solution of the Neutron Diffusion Equations in Two-Dimensions on the IBM-704", WAPD-TM-179 (May 1960)

/2 Private communication.

/3 R. F. Barry, "LEOPARD - A Spectrum Dependent Non-Spatial Depletion Code for the IBM-7094", WCAP-3741 (1963)

/4 H. P. Flatt and D. C. Haller, "AIM-5 - A Multi-Group, One-Dimensional Diffusion Equation Code", NAA-SR-4694 (March 1960).

/5 S. M. Hendley, R. A. Mangan, "TURBO* — A Two-Dimensional Few-Group Depletion Code for the IBM-7090", WCAP-6059 (1964)

SAX-220 Fuel Design - Mechanical, Thermal & Hydraulic

H. N. Andrews, N. J. Georges, E. A. Bassler,
E. A. McCabe, D. Fischer, E. Paxson, G. H. Eng, D. G. Frank

The design of the grids and enclosures for the Saxton Plutonium fuel assemblies is the same as for the second core uranium assemblies. The tooling for these components has been ordered.

The design of all the fuel rods has been completed incorporating whenever possible the suggestions of the fuel rod vendors.

The pelletized fuel rods to be made by NUMEC incorporate a new Westinghouse designed fuel pellet retaining spring which is of the Belleville type. The new spring has the following advantages over the old helical coil spring design:

1. It is not subject to the fuel rod component tolerances and therefore applies a more constant load for prevention of movement of fuel within the cladding during shipment and handling.
2. It does not apply a load to the end plug.
3. It is easier to insert during the manufacturing cycle.
4. It occupies negligible end gap volume.

The diametral gap of the stainless steel fuel rods has been increased by 0.0007 inches and the gap of the Zircaloy rods by 0.0006 inches. This change was made to accommodate the thermal expansion of the fuel at the beginning of life. In addition, the end gaps in the fuel rods to accommodate fisson gases have been finalized. Fuel rod data sheets for all PuO_2-UO_2 fuel were issued. (See Tables 220.1, 220.2, 220.3 and 220.4 at the end of this section.)

The design criteria used for stainless steel cladding are as follows:

1. The clad is free-standing at design pressure and temperature.
2. The pellet density is low enough so that no high rate of swelling occurs.
3. The pellet-to-clad cold diametral gap is established so that contact occurs only under the worst expected tolerance, power and burnup combination.
4. The end of life fission gas pressure is less than the coolant pressure.

The Zircaloy-4 cladding design criteria are similar to those for stainless steel except that the pellet-to-clad cold diametral gap is established without consideration of burnup. Fuel swelling is, therefore, accommodated by creep of the clad material.

The thermal and hydraulics calculations were made for the plutonium and uranium dioxide fuel regions of the core. These included calculations to determine the volumes of the fission gas plenums for both the stainless steel and Zircaloy-4 clad rods. A draft of the thermal and hydraulics portion of the Safeguards Report was written and submitted to the Safeguards Group. The following core parameters were used:

Total Core Power (initially)		22.1 MWt
Total Coolant Flow		2.94×10^6 lb/hr
Heat Transfer Flow		2.5×10^6 lb/hr

$$\left.\begin{array}{l}\text{Total } F_q \ - \ 3.61 \\ \text{Total } F_{\Delta H} \ - \ 2.81\end{array}\right\} \text{Central Plutonium Region}$$

$$\left.\begin{array}{l}\text{Total } F_q \ - \ 2.04 \\ \text{Total } F_{\Delta H} \ - \ 1.59\end{array}\right\} \text{Outer } UO_2 \text{ Region}$$

<u>Table 220.1</u>

<u>Fuel Rod Data Sheet</u>

A. REACTOR: Saxton Reactor Heat Output: 22.1 MWt (initially)

B. CORE AND/OR FUEL CHARGE NO.: Core II - PuO_2-UO_2 Fuel Charge 1 (Stainless Clad, Pelleted Fuel)

C. FUEL CHARGE:

1. Cycle No.		1
2. Maximum Power Density, kw/ft		16.0
3. Maximum Burnup, MWD/MTU		28,000

D. FUEL PELLET:

1. Material		UO_2 and PuO_2 (W) Spec. Nos. SAX-P001 and SAX-P003
2. Density, Theoretical		94 ± 2%
3. Outside Diameter 0.3558	inch,	± 0.0010
4. Length 0.366	inch,	± 0.030
*5. Dish Diameter 0.297	inch,	± 0.015
*6. Dish Depth 0.0135	inch,	± 0.0035

E. CLAD:

1. Material		10-15% cold worked type 304 stainless steel	(W) Spec. No. (10708-BN
2. Inside Diameter 0.3610	inch,	± 0.0005	
3. Outside Diameter 0.3910 Ref.,	inch,	± 0.0021	
4. Wall Thickness 0.0150	inch,	± 0.0008	
5. Inside Ovality	inch,	± 0.001	

F. FUEL ROD:

1. Cold Diametric Gap 0.0052	inch,	± 0.0015
2. Cold Fuel Column Length 36.6	inch,	± 0.183
3. Cold Void Volume, Minimum .1620 cubic inches		

*One end only.

Fuel Rod Data Sheet

A.	REACTOR: Saxton Reactor	Heat Output: 22.1 MWt (initially)
B.	CORE AND/OR FUEL CHARGE NO.:	Core II - PuO_2-UO_2 Charge 1 (Zircaloy Clad, Pelleted Fuel)
C.	FUEL CHARGE:	
	1. Cycle No.	1
	2. Maximum Power Density, kw/ft	16.0
	3. Maximum Burnup, MWD/MTU	28,000
D.	FUEL PELLET:	
	1. Material	UO_2 and PuO_2 (W) Spec. Nos. SAX-P001 and SAX-P003
	2. Density, Theoretical	94 $\pm$ 2%
	3. Outside Diameter 0.3374 inch,	$\pm$ 0.0010
	4. Length 0.366 inch,	$\pm$ 0.030
	*5. Dish Diameter 0.297 inch,	$\pm$ 0.015
	*6. Dish Depth 0.0135 inch,	$\pm$ 0.0035
E.	CLAD:	
	1. Material	Cold Worked Seamless Zircaloy-4 Min. 0.2% Y.S. at Room T - 65,000 psi (W) Spec. No. 18508AJ
	2. Inside Diameter 0.3445 inch,	$\pm$ 0.0015
	**3. Outside Diameter 0.391 Ref. inch,	$\pm$ 0.006
	**4. Wall Thickness 0.02325 inch,	$\pm$ 0.00225
	5. Inside Ovality inch,	$\pm$ 0.001
F.	FUEL ROD:	
	1. Cold Diametric Gap 0.0071 inch,	$\pm$ 0.0025
	2. Cold Fuel Column Length 36.6 inch,	$\pm$ 0.183
	3. Cold Void Volume, Minimum 0.1875 cubic inches	

*One end only.

**After Final Pickling.

Table 220.3

Fuel Rod Data Sheet

A.	REACTOR: Saxton Reactor	Heat Output: 22.1 MWt
B.	CORE AND/OR FUEL CHARGE NO.:	Core II - PuO_2-UO_2 Charge 1 (Stainless Clad, Vibratory Compacted Fuel)
C.	FUEL CHARGE:	
	1. Cycle No.	1
	2. Maximum Power Density, kw/ft	16.0
	3. Maximum Burnup, MWD/MTU	28,000
D.	FUEL:	
	1. Material	UO_2 and PuO_2 Vibratory Compacted (W) Spec. Nos. SAX-P002, SAX-P004
	2. Density, Theoretical	87 ± 1%
E.	CLAD:	
	1. Material	10-15% Cold Worked Type 304 Stainless Steel (W) Spec. No. 10708BN
	2. Inside Diameter 0.3610 inch,	± 0.0005
	3. Outside Diameter 0.3910 Ref. inch,	± 0.0021
	4. Wall Thickness 0.0150 inch,	± 0.0008
	5. Inside Ovality inch,	± 0.001
F.	FUEL ROD:	
	1. Cold Fuel Column Length 36.60 Ref. inch, ± 0.188	
	2. Cold Void Volume, Minimum .512* cubic inches	

*Includes Porosity in Fuel.

Table 220.4

Fuel Rod Data Sheet

A.	REACTOR: Saxton Reactor	Heat Output: 22.1 MWt
B.	CORE AND/OR FUEL CHARGE NO.:	Core II - PuO_2-UO_2 Charge 1 (Zircaloy Clad, Vibratory Compacted Fuel)
C.	FUEL CHARGE:	
	1. Cycle No.:	1
	2. Maximum Power Density, kw/ft	16.0
	3. Maximum Burnup, MWD/MTU	28,000
D.	FUEL PELLET:	
	1. Material	UO_2 and PuO_2 Vibratory Compacted (W) Spec. Nos. SAX-P002, SAX-P004
	2. Density, Theoretical	87 ± 1%
E.	CLAD:	
	1. Material	Cold Worked Seamless Zircaloy-4, Min. 0.2% Y.S. at Room T. = 65,000 psi (W) Spec. No. 18508AJ
	2. Inside Diameter 0.3445 inch,	± 0.0015
	*3. Outside Diameter 0.391 Ref. inch,	± 0.006
	*4. Wall Thickness 0.02325 inch,	± 0.00225
	5. Inside Ovality inch,	± 0.0015
F:	FUEL ROD:	
	1. Cold Fuel Column Length 36.60 Ref. inch, ± 0.188	
	2. Cold Void Volume, Minimum .461** cubic inches	

*After Final Pickling

**Includes Porosity in Fuel

SAX-230 Fuel Dèsign - Materials

R. J. Allio, A. Biancheria

The objective of this sub-task is to plan the materials portion of the program, establish the specifications and acceptance tests for all materials and processes used in fabricating the PuO_2-UO_2 bearing fuel rods and to provide materials data required by other groups for establishing design and safety criteria.

Several meetings were held with NUMEC personnel to discuss price adjustments and revisions to the fuel and fuel rod loading specifications for the pelletized fuel. All problems have now been resolved. Agreement with the Hanford National Laboratories on specification reviews for the vibrationally compacted fuel was reached during the previous quarterly report period.

The final specifications for both pelletized and vibrationally compacted fuel, each using both stainless steel and Zircaloy-4 cladding are included at the end of this section and are numbered, SAX-P001, SAX-P002, SAX-P003 and SAX-P004. The experience of the vendors with detailed steps of the fabrication processes, the limitations of their equipment and particular analytical techniques, and reliability of the fuel were considered in arriving at the final specifications. In case of the vibrationally compacted fuel, consideration was also given to the relatively large void volume resulting from the lower density.

NUMEC offered a price reduction if the weld design were changed to a fillet type end weld similar to that employed by Hanford. This change was made and preliminary welding specifications were reviewed with NUMEC. Initially, NUMEC was not prepared to guarantee the weld penetration requirements. Consequently, agreement was reached on the basis that the original Westinghouse design and specifications would be employed if pre-production trials indicated that penetration requirements could not be met on the fillet weld. In this event, the additional pre-production costs would be charged to the contract and the initial price reduction would not apply. NUMEC also took exception to the specified length to diameter ratio of 1.7 to 1.9 and requested this ratio be lowered to approximately 1.0. This change was accepted and revised pellet and pellet stack drawings were prepared by the Mechanical Engineering Section. Additional drawing modifications resulting from revised design calculations were made and forwarded to NUMEC. The modifications included a reduction in pellet diameter and gas plenum, and the inclusion of a Belleville type retainer spring in each fuel rod to prevent possible movement of pellets during handling and shipping of fuel rods. The Belleville type retainer also was added to the Saxton second core UO_2 fuel rods.

Final drawings for the vibrationally compacted fuel rods were reviewed, minor changes made, and the drawings released for fabrication.

In order to ensure adequate lifetime, the 6% PuO_2 specified in the preliminary specifications was changed to 6.6 w/o PuO_2 in the final specifications. Authority was obtained for release of the additional plutonium needed by NUMEC for the increased enrichment.

Flux depression factors for vibrationally compacted PuO_2-UO_2 fuel of 87% T.D. were calculated to refine the temperature profile estimates. Previous curves were calculated for pellets of 94% T.D.

Thermal-conductivity-temperature curves and heat rating curves for vibrationally compacted fuel were established during the previous quarterly report period from the available data and the known behavior of this type of fuel. The only remaining variable required for estimating fuel temperatures is the contact conductance between fuel and clad. A review of the literature revealed that no contact conductance measurements had been made on vibrationally compacted fuel and that no reliable calculational methods existed. Consequently, an estimate of this parameter was made from the sparse information available on irradiated vipac UO_2 fuel. The contact conductance was calculated from the equation:

$$h = \frac{Q}{T_s - T_i}$$

where h is the contact conductance in $BTU/hr/ft^2/{}^oF$, Q is the surface heat flux in $BTU/hr/ft^2$, and T_s and T_i are the fuel surface and clad I.D. temperatures respectively in ^oF. T_i was calculated from the known clad O.D. temperature, the thermal conductivity of the stainless steel cladding and the surface heat flux obtained from burnup data. T_s was calculated from the equation:

$$\int_{T_r}^{T_s} kdT = \frac{q}{4\pi} \phi = \frac{q}{4\pi} \frac{I_o (Ka) - I_o (Kr)}{0.5 \; Ka \; I_1 \; (Ka)}$$

where T_r is the fuel temperature at radius r, k is the thermal conductivity, q is the linear heat rating, ϕ is the flux depression factor, K is the inverse diffusion length, a is the radius of the rod, and I_o and I_1 are the modified Bessel functions of the zero and the first order respectively. T_r was determined from pore migration phenomena, q from burnup data, K from diffusion theory using GETR cross sections, and the $\int kdT$ from the previously established heat rating curves. The density of the fuel employed in the particular experiment evaluated was 86.7% T.D. Three cross sections of the capsule were examined. The 1850°C isotherm radius was used for all calculations. The results are summarized in Table 230.1.

While the variation in the results is rather large, these estimates are the best known basis for selecting a contact conductance. The values obtained are consistent with known pellet data. For design purposes, a conservative value of 1500 BTU/hr/ft^2/°F is recommended.

Analysis of the effects of hot spots resulting from use of mechanically mixed fuel is continuing. The preliminary analysis conducted during the previous quarterly report period indicated that such fuel is satisfactory for thermal reactor applications.

Table 230.1

Contact Conductance for Vibrationally Compacted Fuel

Q, BTU/hr/ft^2	T_s-T_i, $^\circ$F	h, BTU/hr/ft^2/$^\circ$F
4.87×10^5	241	2020
4.68	223	2100
4.42	385	1145
	Average:	1755 $\pm$ 23%

WESTINGHOUSE SPECIFICATION SAX-P001

PLUTONIUM DIOXIDE-URANIUM DIOXIDE PELLETS

1.0 This specification applies to solid cylindrical plutonium dioxide-uranium dioxide fuel pellets for nuclear power reactors.

2.0 No change shall be made in the quality of successive shipments of material furnished under this specification without first obtaining the approval of the purchaser.

MANUFACTURE

3.0 Manufacture

The pellets shall be manufactured by cold pressing and sintering. No materials shall be added to the PuO_2-UO_2 except small quantities of organic binders and/or an organic lubricant needed for pelletization.

4.0 Financial Responsibility

The manufacturer shall be financially responsible for all losses and contamination occurring in his pelletizing operation, including repurification, reconversion into a form acceptable to AEC and unrecoverable losses of uranium and plutonium, all related shipping charges, and any use charges, unless otherwise specified on the Purchase Order.

CHEMICAL PROPERTIES AND TESTS

5.0 Chemical Composition: The pellets shall conform to the following chemical composition:

5.1 Group I Requirements:

5.1.1 Elements

Element	ppm (Max)	Macroscopic Cross Section (2200 m/sec) Imparted by This Level of Impurity $cm^2/cm^3 \times 10^{-5}$
Al	300.0	1.5
B	1.5	63.7
Bi	2.0	0.0002
Ca	100.0	0.66
Cd	1.0	28.0
Co	6.0	2.3
Cr	500.0	18.3
Cu	50.0	1.75

For additional elements see next page.

Element	ppm (Max)	Macroscopic Cross-Section (2200 m/sec) Imparted by This Level of Impurity $cm^2/cm^3 \times 10^{-5}$
Fe	500.0	13.6
In	3.0	3.0
Mg	50.0	0.08
Mn	10.0	1.5
Mo	150.0	2.4
Ni	300.0	14.4
Pb	20.0	0.010
Si	500.0	1.4
Sn	5.0	0.015
Ti	40.0	3.1
V	1.0	0.059
W	50.0	3.0
Zn	20.0	0.21
C	100.0	0.016
F	10.0	0.0007
N	75.0	6.2
Cl	10.0	

5.1.2 The ratio of oxygen to metal in the plutonium-uranium pellet shall be between 1.97 and 2.02. Vendor shall submit details of their test procedure for approval.

5.1.3 The hydrogen content (exclusive of any amount contributed by water) shall not exceed 15 ppm. Vendor shall submit details of their test procedure for approval.

5.1.4 Plutonium-Uranium Ratio - The ratio of plutonium to uranium in any pellet sample shall be 0.071 ± 0.001.

5.1.5 The total rare earth composition (Gd, Sm, Eu and Dy) shall not exceed 0.6 ppm. For calculation of the total thermal neutron absorption cross-section, the macroscopic cross-section absorption imparted by 0.6 ppm of these rare earths is 91.44×10^{-5} cm^2/cm^3.

5.1.6 The total moisture content shall not exceed 30 ppm. Moisture desorption temperatures employed in test shall exceed 700°C. Details of test procedure shall be submitted by vendor for approval.

5.1.7. The total plutonium plus uranium content shall be 87.8% by weight minimum.

5.1.8 The total gas release exclusive of H_2O shall not exceed 0.05 cc/gm of PuO_2-UO_2 fuel at S.T.P. Gas release shall be measured by out-gassing for at least 30 min. at temperatures of at least 1000°C and a pressure of $1x10^{-6}$ mm Hg.

5.1.9 Isotopic. The isotopic composition of UO_2 and PuO_2 shall be the same as that of the material received.

5.1.10 The total thermal neutron absorption cross-section imparted by all impurities listed in Group I, Section 5.1 and, in Group II, Section 5.2, shall not exceed $100x10^{-5}$ cm^2/cm^3.

The impurity level of the rare earth elements shall be included in the calculation of the total macroscopic cross-section absorption when analyzed.

PHYSICAL PROPERTIES AND TESTS

6.0 Weight Per Unit Length: The pellets shall be inspected for weight per unit length with the limits calculated as follows:

Maximum grams per inch = K(Max Diameter)^2 (Max Density)
Minimum grams per inch = K(Min Diameter)^2 (Min Density)

Where diameter is in inches, specified on the drawing, density is in % T.D., specified on the drawing. Theoretical density shall be calculated by linear interpolation between the theoretical densities of UO_2 and PuO_2 (10.96 gm/cc and 11.46 gm/cc respectively).

$$K = \frac{\pi (2.54)^3 (T.D.)}{4}$$

Allowance shall be made for the average weight of fuel removed by the "dished" ends according to $(1/12)\pi h (3r^2 + h^2) 16.387 \times D$ where h is the average dish height in inches, r is average dish radius in inches and D is the nominal density in gms/cc.

6.1 The vendor shall submit for approval a sampling plan, procedural details, and standards for a test method such as autoradiography to demonstrate that the pelletized PuO_2-UO_2 fuel blend is sufficiently homogeneous.

6.2 (Mechanically mixed fuel only) All PuO_2 powder employed in preparing the initial PuO_2-UO_2 fuel blend shall pass through a 325 mesh U.S. Standard Sieve. All UO_2 powder employed in preparing the initial PuO_2-UO_2 fuel blend shall pass through a 200 mesh U. S. Standard Sieve.

DIMENSIONS

7.0 Dimensions: The dimensions and tolerances shall conform to those specified on the pellet drawing.

8.0 Squareness of Ends: The plane of each end shall not deviate from a plane perpendicular to the pellet axis, taken through the extreme edge of the pellet, by more than 0.010 inch across the diameter of the pellet.

9.0 Chips and Fissures: Chips and fissures shall be inspected per mutually agreeable visual standards. Standards shall meet the following requirements:

9.1 The chipped pellets shall not have lost more than 10 per cent of the area at either end of the pellets.

9.2 The sum of the circumferential length along the periphery of the pellet and the radial depth of each imperfection on the pellet cylindrical surface shall not exceed one-tenth inch. The maximum axial length of any one chip shall not exceed 1/8 inch. The sum of the circumferential lengths of all chips, and pock marks in any one plane perpendicular to the pellet cylindrical axis shall not exceed 1/8 inch except as specified in Section 9.1. In cases of doubt of acceptability, fissures and chips are acceptable provided they meet the weight per unit length specification and withstand shipping, handling, and tube loading without further chipping.

SAMPLING

10.0 Dimensional Samples

10.1 Pellets shall be inspected 100% visually for chips, fissures, etc.

10.2 A 95x97 attribute sampling plan will apply to the diameter and density. Based on a 30 kg batch size, containing approximately 6000 pellets, a random sample of 125 pellets will be drawn. With zero defective parts the lot will be accepted; with two defective parts the lot will be rejected; and with one defective part an additional random sample of 125 pellets will be drawn and it must contain zero defectives for lot to be accepted.

10.3 For dish and squareness of ends, a random sample of pellets equivalent to 1/8 the number of pellets drawn on the basis of 95x97 percent sampling plan will be drawn from the original sample. If there are no rejects the lot will be accepted and if there is one or more rejects, the lot will rejected.

11.0 Chemical Samples

11.1 Seller will randomly select three (3) pellets from each batch, approximately 30 kg per batch, and upon completion of the last batch will make a composite sample for rare earth, isotopic and thermal neutron cross section analysis.

11.2 One analysis is to be performed per batch to determine the chemical composition and impurities listed under Section 5.0 of this specification. The samples for these analyses shall consist of a minimum of six randomly selected pellets from each batch.

11.3 Gas release will be measured from chips of pellets selected at random from the composite sample of each batch.

11.4 Three analyses per batch are to be performed for Pu/U ratio. Pellets for these analyses are to be drawn from the beginning, middle and end of each pellet batch.

11.5 Autoradiography will be performed on one pellet from each batch.

TEST REPORTS

12.0 Test Reports:

12.1 Three (3) copies of certified analyses for total U, U-235, Pu, Pu isotopic concentrations and the impurities specified in Section 5, shall be submitted to the purchaser when each pellet batch is released for fabrication into fuel elements. The vendor shall submit the batch size for purchaser's approval.

12.2 The vendor shall provide three (3) copies of all inspection and test reports as soon as they are generated.

PACKING AND MARKING

13.0 Packing: The packaging shall conform to pertinent ICC and AEC regulations, regarding nuclear materials, and shall be approved by the purchaser.

14.0 Marking: Each container shall be individually and consecutively numbered and shall be plainly marked as follows: Purchase Order Number, (Plutonium Dioxide-Uranium Dioxide Pellets) W Spec. SAX P001, Gross, Tare and Net Weight; PuO_2-UO_2) Lot number from which the pellets were made; Name of Manufacturer; total gms U-235, total gms of Pu, Pu isotopic concentrations.

INSPECTION

15.0 Inspection:

15.1 Test and inspection shall be made at the place of manufacture in the presence of purchaser representative.

15.2 The manufacturer shall afford the purchaser's representatives, free of cost, all reasonable facilities to satisfy themselves that the material furnished is in accordance with this specification.

15.3 Material accepted by the purchaser's inspector at the place of manufacture which subsequently reveals imperfections not detected at the place of manufacture, or which subsequent tests or analysis show not to be in accordance with this specification, is subject to rejection.

COMPLIANCE WITH REGULATIONS

16.0 Compliance with Regulations: The manufacturer shall have appropriate licenses and clearances indicating that he is aware of and responsible for complying with all applicable regulations of Federal, State and local regulatory bodies with respect to receiving, accounting for, processing, storing and shipping of PuO_2-UO_2 powder and pellets.

WESTINGHOUSE SPECIFICATION SAX-P002

LOOSE POWDER FOR VIBRATIONALLY COMPACTED

PLUTONIUM DIOXIDE-URANIUM DIOXIDE FUEL

1.0 This specification applies to loose powder plutonium dioxide-uranium dioxide fuel to be used in manufacturing fuel elements by the vibrational compaction process.

2.0 No change shall be made in the quality of successive shipments of material furnished under this specification without first obtaining the approval of the purchaser.

3.0 The manufacturer shall be financially responsible for all losses and contamination occurring in his manufacturing operation, including repurification, reconversion into a form acceptable to AEC, and unrecoverable losses of uranium and plutonium, all related shipping charges, and any use charges, unless otherwise specified on the Purchase Order.

CHEMICAL PROPERTIES AND TESTS

4.0 CHEMICAL COMPOSITION: The powder shall conform to the following chemical composition:

4.1 Group I Requirements:

4.1.1 Elements

Element	ppm (Max)	Macroscopic Cross Section (2200 m/sec) Imparted by This Level of Impurity $cm^2/cm^3 \times 10^{-5}$
Al	500.0	2.5
B	1.5	63.7
Bi	2.0	0.0002
Ca	100.0	0.66
Cd	1.0	28.0
Co	6.0	2.0
Cr	500.0	18.3
Cu	50.0	1.75
Fe	1000.0	27.2
In	3.0	3.0
Mg	50.0	0.08
Mn	10.0	1.5

For additional elements see next page.

Element	ppm (Max)	Macroscopic Cross Section (2200 m/sec) Imparted by This Level of Impurity $cm^2/cm^3 \times 10^{-5}$
Mo	150.0	2.4
Ni	300.0	14.4
Pb	20.0	0.010
Si	500.0	1.4
Sn	5.0	0.015
V	1.0	0.059
Zn	20.0	0.21
C	150.0	0.024
F	10.0	0.0007
N	100.0	8.3
Cl	20.0	

4.1.2 The ratio of oxygen to uranium in the uranium-dioxide shall be 2.0 ± 0.02.

4.1.3 The ratio of oxygen to plutonium in the plutonium-dioxide shall be 2.0 ± 0.10.

4.1.4 The ratio of plutonium to uranium in any dry powder sample shall be 0.071 ± 0.002.

4.1.5 H_2 Content: - Employ a carbon tetrachloride Soxhlet extraction followed by infrared examination of the stretching frequency of the C-H bond and the Si-H bond to show that these groups are not present to greater than 20 ppm.

4.1.6 The total moisture content shall not exceed 100 ppm. Moisture desorption temperatures employed in test shall exceed 700°C.

4.1.7 The total plutonium plus uranium content of any powder sample as determined by routine analysis shall be 87.0% by weight minimum. A special analysis on a composite sample must prove that plutonium plus uranium content is actually 87.7% by weight minimum.

4.1.8 The total gas release exclusive of H_2O shall not exceed 0.06 cc/gm of PuO_2-UO_2 fuel at S.T.P. Fuel which passes through a 200 mesh U.S. Standard sieve must be out-gassed for at least 30 minutes at temperatures of at least 1000°C and a pressure of 1×10^{-6} mm Hg during test.

4.1.9 The isotopic composition of UO_2 and PuO_2 shall be the same as the material received.

4.1.10 The total thermal neutron (2200 m/sec) absorption cross-section imparted by all impurities listed in Group I, Section 4.1 and the rare earths shall not exceed a boron equivalent of five (5).

The total rare earth content will not be routinely determined. The effect of the absorption cross-section of these elements will be included in the EBC calculations. A sample of UO_2 powder will be sent to Westinghouse Analytical Laboratories for rare earth analysis.

PHYSICAL PROPERTIES

5.0 Particles, crystals, and inclusions of any material other than UO_2 or PuO_2 and porous particles of PuO_2 or UO_2 shall not exceed one percent by weight of the batch size.

5.1 Particle Size:

5.1.1 All PuO_2 powder employed in preparing the initial PuO_2-UO_2 fuel blend shall pass through a 325 mesh U. S. Standard sieve.

5.1.2 All UO_2 powder employed in preparing the initial PuO_2-UO_2 fuel blend shall pass through a 200 mesh U. S. Standard sieve.

5.1.3 All the densified PuO_2-UO_2 fuel employed in fabricating the fuel elements shall pass a 6 mesh U. S. Standard sieve.

5.2 The particle density of the PuO_2-UO_2 fuel blend shall be greater than 98.7% of theoretical density. Details of and a sampling plan for a vacuum-mercury displacement test shall be submitted by vendor for purchaser's approval. Theoretical density shall be calculated by linear interpolation between the theoretical densities of UO_2 and PuO_2 (10.96 gms/cc and 11.46 gms/cc respectively).

5.3 The vendor shall submit for purchaser's approval a sampling plan, procedural details, and standards for a test method such as autoradiography to demonstrate that the densified PuO_2-UO_2 fuel blend is sufficiently homogeneous.

CHEMICAL SAMPLES AND TESTS

6.0 Chemical Samples and Tests

6.1 The vendor shall submit for purchaser's approval sampling plans for and details of all tests they will employ to control the chemical composition and impurities listed under Section 4.

6.2 The vendor shall submit for approval a sampling plan and details of a test method to demonstrate that the fuel which has been processed, stored and shipped has the same U^{235} enrichment and Pu isotopic ratios as the received fuel.

TEST REPORTS

7.0 Test Reports

7.1 A complete test report will be submitted with finished fuel rods. Report will include three (3) copies of certified analyses for total U, U^{235}, Pu, Pu isotopic concentrations, and the impurities specified in Section 4 for each fuel batch. The vendor shall submit the batch size for the purchaser's approval.

7.2 On site purchaser's inspectors will review inspection and test reports prior to release of fuel batches for manufacture into fuel elements.

PACKING AND MARKING

8.0 Packing

The packaging shall conform to the pertinent ICC and AEC regulations regarding nuclear materials, and shall be approved by the purchaser.

9.0 Marking

Each container shall be individually and consecutively numbered and shall be plainly marked as follows: Purchase Order Number, (Plutonium Dioxide-Uranium Dioxide Loose Oxide Powder), W. Spec SAX- P002, Gross, Tare, and Net Weight; (PuO_2-UO_2) Lot Number from which the powder was made, Name of Manufacturer, Total gms U^{235}; Total gms Pu; Pu Isotopic Concentrations.

INSPECTION

10.0 Inspection

10.1 Test and inspection shall be made at the place of manufacture in the presence of purchaser's representative.

10.2 The manufacturer shall afford the purchaser's representatives, free of cost, all reasonable facilities to satisfy themselves that the material furnished is in accordance with this specification.

10.3 Material accepted by the purchaser's inspector at the place of manufacture which subsequently reveals imperfections not detected at the place of manufacture, or which subsequent tests or analysis show not to be in accordance with this specification, is subject to rejection.

COMPLIANCE WITH REGULATIONS

11.0 Compliance with Regulations

The manufacturer shall have appropriate licenses and clearances indicating that he is aware of and responsible for complying with all applicable regulations of Federal, State and local regulatory bodies with respect to receiving, accounting for, processing, storing and shipping of PuO_2-UO_2 powder.

WESTINGHOUSE SPECIFICATION SAX-P003

FUEL ROD INSPECTION AND LOADING REQUIREMENTS FOR PELLETIZED PuO_2-UO_2 FUEL

I. The purchaser shall supply all clad material, end plugs, springs, and Al_2O_3 spacers as specified on drawing.

II. The clad and end plugs shall be inspected by purchaser before shipment. Vendor shall inspect clad for cleanliness before loading.

III. Shipment to Vendor

A. Each rod shall be individually bagged and shipped to vendor for loading. Identification of materials and sizes, and inspection certification shall be included.

IV. Hardware itemized in Section I shall be inspected for shipping damages at Vendor's plant, in presence of purchaser's representative.

V. Identification - Each rod shall be individually identified according to Westinghouse specifications.

VI. Rods shall be filled as per Westinghouse specification.

A. Each rod shall be weighed before and after filling and those weights recorded on rod identification form.

B. Each rod shall be measured for length as per drawing and that length recorded on rod identification form.

C. Plutonium Loading

(1) The weight of plutonium in each rod shall be controlled to $\pm$ 1.5% of the specified weight. (Weights will be provided at later date.)

(2) The weight of plutonium in any random 100 rods shall be controlled to $\pm$ 0.15% of the specified weight. (Weight will be provided at later date.)

D. **Samples from each lot shall be retained for reference. Sample identification shall include, Lot Number, Fuel Rod Numbers, Purchase Order Number, Name of Manufacturer, Name of Purchaser, Gross,Tare and Net Weight, Total gms U-235, Total gms Pu, and Pu Isotopic Concentrations.**

VII. Completed Rod Inspection and Procedures

A. Weld

(1) Weld and inspect - as per (W) Process Spec. 292712 (stainless steel clad) or CAP 292717-1 (Zircaloy clad).

a. The welds shall be made vertically using a modified Hanford method.
b. Vendor will prick punch end plug in accordance with the drawings.
c. X-ray of welds is not required.
d. Ten preproduction samples (short length tubing) of welded Zircaloy rods and ten of stainless rods shall be submitted to the purchaser to qualify the welding procedure and to establish weld parameters.
e. During production runs, the vendor will make one dummy rod for test purposes in each production lot. The dummy rod shall be inserted at random in any position in the weld box indexing head, except that it shall not be the first or last rod welded. The lot size shall not exceed 33 rods including the dummy.

(i) The dummy rods shall be cross-sectioned in two planes perpendicular to each other and perpendicular to the circumferential plane of each end plug weld. The first cross-section cut shall be made at a point in the weld periphery located between the points where the weld overlap begins and ends.

(ii) Photomicrographs are required on the polished cross-sections. Sections are to be etched to show the weld puddle clearly at the four 90° intervals.

(iii) If either of the dummy rod welds are rejected, repeat (i) and (ii) for welds from the production rods welded immediately prior to and immediately following the dummy rod. If both of these rods are found acceptable, the entire lot is acceptable. If either one is not acceptable, the entire lot will be rejected.

(2) Weld diameter check - as per Drawings No. 540F555 and 882D154.

(3) Each weld shall be dye penetrant tested as per specification 80165-3. Penetrant required is ZL-22 or ZL-1.

(4) Vendor shall submit for purchaser's approval details of inspection procedures for Item VII-A-2.

(5) The gap between the spacer and end plug shall be controlled as follows:

(a) Distance from top of tube to top of spacer shall be gauged by a go-no go gauge.
(b) Distance from top of end plug to top of tube shall be gauged by an insertion fixture.

(6) The end of the completed rod with variable number of spacers shall be X-rayed in the horizontal position after holding the rod in vertical position with the variable spacer end at the top to determine that the proper number of spacers have been added.

(7) Seller shall submit a procedure for helium check for purchaser's approval. Procedure must include the following:

(a) Equipment shall be capable of detecting leak rate of 10^{-6} cc He per second at 45 psi pressure differential.
(b) Rods shall be leak tested within 24 hours of completion or stored in helium atmosphere.
(c) If condition b is not met, rods must be pressurized in helium at a minimum of 150 psig for a minimum of 15 minutes and tested within 24 hours.
(d) Procedure applies for both zircaloy and stainless steel rods.

B. Contamination

(1) Each assembled fuel rod shall be wipe tested and the wipe shall be counted in a gas proportional counter with 50% geometry and less than three counts per minute background; and if the counts obtained per minute of time do not exceed ten, then the rods shall be considered free of alpha contamination. If the counts exceed ten, then the rod shall be recleaned and recounted.

(2) Welds must be checked with an Eberline scintillation counter or equivalent. Readings of greater than 50 counts/minute per probe area on any assembled fuel rod is cause for rejection.

C. Corrosion Test (Zirc rods only) - as per PS-293058 and PS-293055.

VIII. Packing and shipping per AEC requirements and Westinghouse specification.

IX. Inspection

A. Test and inspection shall be made at the place of manufacture in the presence of purchaser's representative.

B. The manufacturer shall afford the purchaser's representative, free of cost, all reasonable facilities to satisfy themselves that the material furnished is in accordance with this specification.

C. Material accepted by the purchaser's inspector at the place of manufacture which subsequently reveals imperfections not detected at the place of manufacture, or which subsequent tests or analysis show not to be in accordance with this specification, is subject to rejection.

X. Purchaser shall inspect at point of arrival.

A. 100% check for damage as per VI-B and VII-B.

XI. Compliance with Regulations

The manufacturer shall have appropriate licenses and clearances indicating that he is aware of and responsible for complying with all applicable regulations of Federal, State and local regulatory bodies with respect to receiving, accounting for, processing, storing, and shipping of PuO_2-UO_2 powder and pellets.

WESTINGHOUSE SPECIFICATION SAX-P004

FUEL ROD INSPECTION AND LOADING REQUIREMENTS FOR VIBRATIONAL COMPACTION PROCESS

I. The purchaser shall supply all clad material, end plugs, springs, and Al_2O_3 spacers as specified on drawings.

II. The clad and end plugs shall be inspected by purchaser before shipment. Vendor shall inspect clad for cleanliness before loading.

III. Shipment to Vendor

A. Each rod shall be individually bagged and shipped to vendor for loading. Identification of materials and sizes, and inspection certification shall be included.

IV. Hardware itemized in Section I shall be inspected for shipping damages at Vendor's plant, in presence of purchaser's representatives.

V. Identification - Each rod shall be individually identified according to Westinghouse specifications.

VI. Rods shall be filled as per Westinghouse specification.

A. Each rod shall be weighed before and after filling and those weights recorded on rod identification form.

B. Each rod shall be measured for length as per drawing and that length recorded on rod identification form.

C. The average density of the fuel in the rod shall be 87.0 $\pm$ 1.0% T.D.

D. Plutonium Loading

(1) The weight of plutonium in each rod shall be controlled to $\pm$ 2.0% of the specified weights. (Weights will be provided at a later date.)

(2) The weight of plutonium in any 100 rods shall be controlled to $\pm$ 0.2% of the specified weight. (Weights will be provided at a later date.)

E. Samples from each lot shall be retained for reference. Sample identification shall include, Lot Number, Fuel Rod Numbers, Purchase Order Number, Name of Manufacturer, Name of Purchaser, Gross, Tare and Net Weight, Total gms U-235, Total gms Pu, and Pu Isotopic Concentrations.

VII. Completed Rod Inspection

A. Weld

(1) Weld and inspect - as per Westinghouse Process Specification 292712 (stainless steel clad) or CAP-292717-1 (Zircaloy clad) with following exceptions or revisions:

(a) Hanford welding procedures apply
(b) X-ray and dye penetrant test of welds is eliminated. X-ray of tube end is to be performed to verify installation of springs and alumina wafers.
(c) Helium leak test by drawing a vacuum (10^{-4} mm Hg pressure) around welded tubes and use most sensitive scale on CEC He leak detector to determine rejects.

(2) Weld diameter check - as per Drawings No. 540F555 and 882D154.

(3) Vendor shall submit for purchaser's approval details of inspection procedures for Item VII-A-2.

B. Contamination

(1) Each assembled rod must be free of alpha contamination as determined by a smear test.

(2) Welds must be checked with an Eberline scintillation counter or equivalent. Readings of greater than 50 counts/minute per probe area on any assembled fuel rod is cause for rejection.

C. Corrosion Test (Zircaloy rods only)-as per Westinghouse spec. 293058 and PS-293055 with following exceptions or revisions:

(a) Autoclave for 18 hrs at 1000 psi at approximately 400°C ± 5°C.
(b) Pickling 1-2 mils (1.5 mil average) off of tube wall is permitted.

VIII. To verify plutonium concentration and homogeneity along the length of the fuel rods, at least one fuel rod made with powder from each PuO_2-UO_2 blend must pass a gamma scan test. Vendor shall supply details of test procedure for purchaser's approval.

IX. Packing and shipping as per AEC requirements and Westinghouse specifications.

X. Inspection

A. Test and inspection shall be made at the place of manufacture in the presence of purchaser's representative.

B. The manufacturer shall afford the purchaser's representative, free of cost, all reasonable facilities to satisfy themselves that the material furnished is in accordance with this specification.

C. Material accepted by the purchaser's inspector at the place of manufacture which subsequently reveals imperfections not detected at the place of manufacture, or which subsequent tests or analysis show not to be in accordance with this specification, is subject to rejection.

XI. Purchaser shall inspect at point of arrival.

A. 100% check for damage as per VI-B and VII-B.

B. Check rods as per VIII on a sampling basis.

XII. Compliance with Regulations

The manufacturer shall have appropriate licenses and clearances indicating that he is aware of and responsible for complying with all applicable regulations of Federal, State and local regulatory bodies with respect to receiving, accounting for, processing, storing, and shipping of PuO_2-UO_2 powder and pellets.

SAX-250 Planning and Analysis of Critical Experiments

F. L. Langford, W. L. Orr,
R. H. Chastain, H. I. Sternberg

A. Introduction and Scope of Work

1. Introduction

The objective of this task is to plan, design, and analyze the critical experiments to be conducted to verify the nuclear characteristics of the unirradiated fuel before it is installed in the Saxton reactor.

A program of critical experiments of approximately 2-1/2 months duration will be carried out at the Westinghouse Reactor Evaluation Center (WREC). The same fuel rods to be used in the irradiation test will be available for these experiments. The experiments will include measurements in critical assemblies of mixed-oxide fuels (PuO_2-UO_2), conventional Saxton fuel (UO_2), and in critical configurations composed of both fuels in separate regions.

2. Scope of Work

During the quarter, a preliminary measurements program was formulated. In addition, analytical work was carried out in the following three areas:

a. The kinetic characteristics of single-zone, mixed-oxide (PuO_2-UO_2) criticals were evaluated and a hazards study was carried out.

b. The number of fuel rods required for criticality for a multi-zone assembly composed of PuO_2-UO_2 and UO_2 fuel rods was determined.

c. The effect of the change in plutonium enrichment from 6.0 w/o PuO_2 to 6.6 w/o PuO_2 on the number of fuel rods required for criticality for single-zone, mixed-oxide (PuO_2-UO_2) cores was investigated as a function of lattice pitch.

B. Preliminary Measurements Program

1. Time Available

The time available for the critical experiments program is determined by a starting date set by the availability of the PuO_2-UO_2 fuel and an end date fixed by the time required to fabricate the fuel assemblies to meet the subsequent Saxton irradiation schedule. In the formulation of the measurements program, the philosophy has been to identify the measurements that provide information useful in the conduct of the irradiation test and to assign an order of priority for their accomplishment. The program described in the following paragraphs is preliminary in nature, as it may not be possible to complete all the desired measurements in the anticipated 2-1/2 months available.

2. Important Parameters

In addition to the basic purpose of investigating the characteristics of the unirradiated plutonium fuel before it is installed in the Saxton reactor, it is desirable to determine if a change in the reference Saxton core configuration or subsequent mode of operation is necessary in order to meet the overall program objectives. Three areas of importance are a) Initial Reactivity, b) Power Peaking Effects and c) Reactivity and Kinetic Response.

a. Reactivity

As discussed in the last quarterly,[1] there is a large uncertainty as to the initial reactivity of the reference Saxton design as indicated by a comparison of analysis and experiment for 6 critical and/or approach to critical experiments conducted at Hanford. For these more lightly loaded experiments (1.5 w/o PuO_2 compared to 6.6 w/o PuO_2 for Saxton) an average discrepancy of +2.6% $\Delta k/k$ was found. An allowance for this discrepancy has been included in the reactivity and lifetime predictions for the system. However, the absence of any mixed oxide experiments near the proposed loading means a large reactivity uncertainty will prevail until the proposed experiments are conducted.

b. Power Peaking Effects

The specification of the enrichment for the plutonium fuel rods requires a compromise between irradiation, power limitations, and lifetime objectives. The decision to install the plutonium fuel assemblies in the center of the core was based on the desire to maximize the irradiation exposure of the mixed oxide fuel. However, a plutonium enrichment that provides sufficient lifetime when installed in the center of the reactor results in an increase in the radial nuclear hot channel factor over that of the conventional Saxton loading. The peak power occurs in the central plutonium region at the beginning-of-life. Since the plutonium region has a larger absorption cross section than the outer uranium region, the thermal flux undergoes a marked change at region boundaries and peaks to a greater extent in water slots near the plutonium. The plutonium fission cross section is also larger than the uranium. Consequently, local power peaking tends to occur in plutonium rods at region boundaries and water slots.

Measurements are needed to determine if the analysis adequately predicts power peaking effects and to indicate the most desirable method of correcting unanticipated adverse power effects should they exist.

c. Reactivity and Kinetic Response

There are a number of important differences in the reactivity and kinetic response in assemblies containing plutonium alone, uranium alone, and combinations of the two fuels. Some examples of these differences for the fuel and lattices to be used at the WREC are the following:

(1) The cores containing plutonium have been calculated to have a more negative temperature and void coefficient.

(2) Identical boron concentrations and control rods are worth less in plutonium cores.

(3) β_{eff} is less in the plutonium cores.

In order to understand the experimental information obtained, it is desirable to evaluate these and other differences separately and to determine how they interact when combined.

3. Lattice and Core Description

Measurements in three lattices for six different core configurations are proposed. The core configurations are identified in Table 250.1. The type of measurements to be made in each configuration is also included in this table. A description of the measurements that make up each type is included in a following paragraph.

4. Measurement Sequence

The sequence of measurements summarized in Table 250.1 is designed to provide essential reactivity information in three different lattices as early as possible at the start of the program. More detailed measurements are then made in various core configurations in a lattice that has the same H/Pu ratio as the Saxton design at temperature. Changing the relative position of the PuO_2-UO_2 fuel and UO_2 fuel (configurations 4 and 6) aids in the evaluation of the data and also provides the information that would be needed if it were necessary to make a major change in the reference core design. Measurements are also made in a configuration containing UO_2 alone since this core can be formed in a normal loading step in developing the inside-out core, configuration 6. In so far as possible the same measurements are made in the four configurations carried out with the Saxton H/Pu ratio. This procedure should make it possible to evaluate

Table 250.1

CONFIGURATION SUMMARY

Configuration	Regions No.	Regions Inner	Regions Outer	Lattice	Type Measurements	REMARKS
1	1	PuO_2-UO_2	-	1	A	Loose lattice
2	1	PuO_2-UO_2	-	2	A	Tight lattice
3	1	PuO_2-UO_2	-	3	B	Type 3 lattice = Saxton H/Pu ratio at temperature.
4	2	PuO_2-UO_2	UO_2	3	C	Core formed by removing part of the rods of (3) and adding UO_2 rods.
5	1	UO_2	-	3	B	
6	2	UO_2	PuO_2-UO_2	3	C	Core formed by removing part of the rods of (5) and adding PuO_2 - UO_2 rods.

the relative importance and method of combining the various parameters to be investigated.

5. Measurement Description

The desired measurements are classified according to the following three types:

a. Type A Measurements

Type A measurements represent the minimum requirements for any configuration and include the following:

(1) Number of fuel rods required for criticality at full moderator height.

(2) Critical buckling and reflector savings.

(3) Relative radial and longitudinal power traverses.

(4) β/l measurements.

b. Type B Measurements

Type B measurements represent the detailed measurements required for single-zone cores at the Saxton lattice pitch. These measurements include Type A measurements as well as the following:

(1) Power calibration of the core to develop a fuel power normalization factor for use with two-region cores.

(2) Water slot experiments consisting of

(a) Power measurements in fuel rods with no water slots.

(b) Removal of fuel rods and the measurement of power of designated adjacent rods.

(c) Substitution of fuel rods of a different fuel type (for example UO_2 for PuO_2 rods) and the measurement of power in the replaced rods and adjacent rods.

(3) Moderator temperature coefficient

(4) Radial poison and fuel worth

(5) Flux traverses

(6) Boron worth in coolant.

c. Type C Measurements

Type C measurements represent the detailed measurements for two-region cores. These measurements consist of the Type A measurements with the following additions:

(1) Water slot experiments similar to that in (2) above except the water slot is located at the interface between the two fueled regions.

(2) Moderator temperature coefficient

(3) Radial poison and fuel worth

(4) Flux traverses

(5) Boron worth in coolant for core configuration (4).

C. Kinetics Evaluation and Hazards Study

1. Introduction

During the quarter, the kinetic characteristics of single-zone mixed-oxide (PuO_2-UO_2) critical assemblies were evaluated and a hazards study was made. The study was carried out in two steps. In the first round of calculations the expected fuel and moderator temperatures to be reached in a transient were assumed and reactivity coefficients were determined for these assumed temperatures. The reactivity coefficients and the calculated values for β_{eff}, neutron lifetime, and heat transfer coefficients were then used in a transient analysis code, WIT-5, for various ramp and step reactivity insertion values. (The WIT-5 code is basically a one-region neutron kinetics program that includes the effect of delayed neutrons and thermal feedback[2]). The code computes the fuel, clad, and moderator temperatures reached during the transient. The second round of calculations consisted of using the calculated temperatures in a second iteration. In this instance, however, a realistic assumption as to the amount of reactivity that could be added was made.

2. First Round Calculations

The Doppler coefficients for three mixed-oxide PuO_2-UO_2 critical lattices, 0.6-inch, 0.58 inch, and 0.55 inch, were calculated using the LEOPARD[3] code. The code was run for variations in fuel pellet and effective resonance temperature between 500° F and 1500° F with a constant moderator and clad temperature of 212° F. The resulting values of k_{eff} were used to calculate the following Doppler coefficients:

	0.6" Lattice 131 H/Pu	0.58" Lattice 118 H/Pu	0.55" Lattice 100 H/Pu
α Doppler (0 ppm Boron, Fuel at 1000° F)	$-1.25 \times 10^{-5}/°F$	$-1.34 \times 10^{-5}/°F$	$-1.48 \times 10^{-5}/°F$

The moderator temperature coefficient for the three lattices was calculated using the LEOPARD code by varying the moderator temperature from 68° F to 212° F while other temperatures were held constant. Figure 250.1 summarizes the results for the 0.6 inch lattice. The moderator coefficient at 135° F ($-1.96 \times 10^{-4}/°F$) was used in the first round transient study of the 0.6 inch lattice.

Values of β_{eff} were determined from the neutron production and delayed neutron characteristics of each of the fissionable isotopes. These values with the calculated prompt neutron lifetimes are shown on the following page.

	0.60" Lattice	0.58" Lattice	0.55" Lattice
β_{eff}	0.00302	0.00306	0.00314
ℓ, microseconds	11.32	10.15	8.50

The first round hazards study using the WIT-5 code was made to determine if the fuel and clad temperatures would reach melting or if the moderator would reach boiling during a transient. The analysis was based on a slightly larger core radius than needed for criticality for the 0.6 inch lattice. The reference configuration is critical at a core radius of 6.02 inches and a core height of 28.75 inches where the total fuel height is 36.6 inches. Thus, the addition of moderator to cover the core represents a positive reactivity insertion.

Calculations were made for ramp insertions of 6.45 ¢/sec and 20 ¢/sec and for a step insertion of $2.00 for different volumes of water ranging from that contained within the core ($\approx$ 1.3 ft^3) to approximately 40% of the total contained within the core tank (144 ft^3). Because of the treatment of the heat sink in the code, the effect of a large moderator volume is to simulate the results one might expect from forced moderator circulation. In reality this condition could not occur since even convection is restricted by core support plates. The 6.45 ¢/sec ramp is the maximum rate of reactivity change that can be obtained by adding moderator above the 28.75 inch level at the expected fill rate.

The results for representative cases are summarized in Table 250.2. These cases show that the energy involved in the transient is proportional to the reactivity inserted and the assumed water volume. In all the calculations the fuel and clad reached temperatures that were far below melting. However, in most cases a clad temperature of 212°F was reached which would have produced local boiling of the moderator. Since the void coefficient is negative, the transient would have been terminated sooner than indicated.

3. Second Round Calculations

The information obtained in the first-round transient calculations were used as a basis for a more realistic second-round analysis. The temperature distributions determined in WIT-5 were used in the LEOPARD code to generate improved reactivity coefficients. In the second-round transient calculation, the Doppler coefficient was varied as a function of the fuel temperature as shown in Figure 250-2. The moderator coefficient at a core average temperature of 100°F was used. In addition, revised heat transfer coefficients between fuel and clad and between clad and coolant were determined.

Table 250.2

SUMMARY OF REPRESENTATIVE FIRST-ROUND TRANSIENT CALCULATIONS

	Case I		Case II	Case III	Case IV
	Initial Power Peak	Final Power Peak			
Moderator Volume (cu ft)	1.33	1.33	144*	1.33	1.33
Reactivity Insertion	6.5 ¢/sec	6.5 ¢/sec	6.5 ¢/sec	20 ¢/sec	$2 ($333/sec)
Length Reactivity Insertion (sec)	56	56	56	155	0.006
Duration of Analysis (sec)	350	350	350	355	150
Power Peak (Mw)	1.56	0.08	6	9	746
Time to Peak (sec)	15.5	55.6	55	5.5	0.083
Time to Subcritical (sec)	18.3	58.1	72	51	0.20
Total Energy Release (Mw-sec)	8	8	541	18	16
Peak Fuel Temperature °F	123	136	616	237	536
Time Fuel Temperature (sec) peak	17.3	230	56	51	0.10
Maximum Clad Temperature °F	118	136	480	237	380
Time Clad Temperature 212°F (sec)	-	-	20	45	0.13
Time of Maximum Clad Temperature (sec)	17.8	230	56	51	0.44
Bulk Moderator Temperature (Max) °F	-	136	125	212	200
Time of Maximum Moderator Temp. (sec)	-	240	300	51	85

* Corresponds to ≈ 40% of the total within the tank.

A 6.45 ¢/sec ramp was inserted initially. Decreasing values of the ramp were then inserted to account for the decreasing reactivity worth of the moderator as the water level rose above the 28.75 inch starting level. Reactivity changes with water height in the core were determined by two-group hand calculations using LEOPARD group constants. The water was permitted to rise 5.9 inches above the full height of the fuel where the reactivity no longer changed with additional water. The reactivity worth of the water reflector added above the fuel was calculated using AIM-5[4]. After the water height reached 5.9 inches above the fuel, it was assumed that the dump valve was activated and moderator removed in reactivity steps in accordance with the known dump rate. This assumption does not influence the transient.

The following input parameters were used in the analysis:

Water Volume*	2.15 ft^3
Heat transfer coefficient, fuel-to-clad	100 BTU/ft^2-hr-°F
Heat transfer coefficient, clad-to-water	280 BTU/ft^2-hr-°F
Specific heat of fuel	0.064 BTU/lb-°F
Specific heat of clad	0.073 BTU/lb-°F
Fuel Weight	303 pounds
Clad Weight	57.5 pounds

*Slightly more than that within the core.

The results of the second round WIT-5 transient calculations are summarized in Figure 250.3. From this figure it can be seen that the Doppler coefficient is the most important factor in terminating the transient. As the fuel temperature begins to rise near 15 seconds, the rate of reactivity removal due to Doppler exceeds the 6.45 ¢/sec reactivity addition rate due to the rising moderator. Thus the k_{eff} curve peaks and begins to descend as the fuel temperature increases. At approximately the 23 second mark the system becomes subcritical with the Doppler effect compensating for ≈63% of the total reactivity added.

D. Fuel Rods Required for Criticality

1. Single-Zone Criticals

The LEOPARD code was used with AIM-5 to determine the number of fuel rods required for criticality in a single-zone assembly composed of mixed-oxide (PuO_2-UO_2) fuel. The analysis was carried out as a function of lattice pitch for two enrichments, 6.0 w/o PuO_2 and 6.6 w/o PuO_2. The calculations include an equivalent infinite water reflector radially and at the top and bottom of the core. The results are summarized in Figure 250.4. The values at 6.0 w/o PuO_2 are revised from those included in the last quarterly because of a change in the reflector savings. The calculations include an allowance in k_{eff} of 2.5% for the discrepancy between analysis and experiment in the comparison of the Hanford experiments.

2. Two-Zone Criticals

The number of fuel rods needed for criticality for a two-zone critical composed of PuO_2-UO_2 (6.0 w/o PuO_2) and UO_2 fuel rods was determined for the 0.6 inch lattice using LEOPARD and AIM-5. A k_{eff} allowance of 2.5% was included. The PuO_2-UO_2 area was 8/21 of the total area with the PuO_2-UO_2 in the center of a cylindrical configuration. A total of 113 PuO_2-UO_2 rods and 184 UO_2 rods was required which results in a core radius of 5.84 inches.

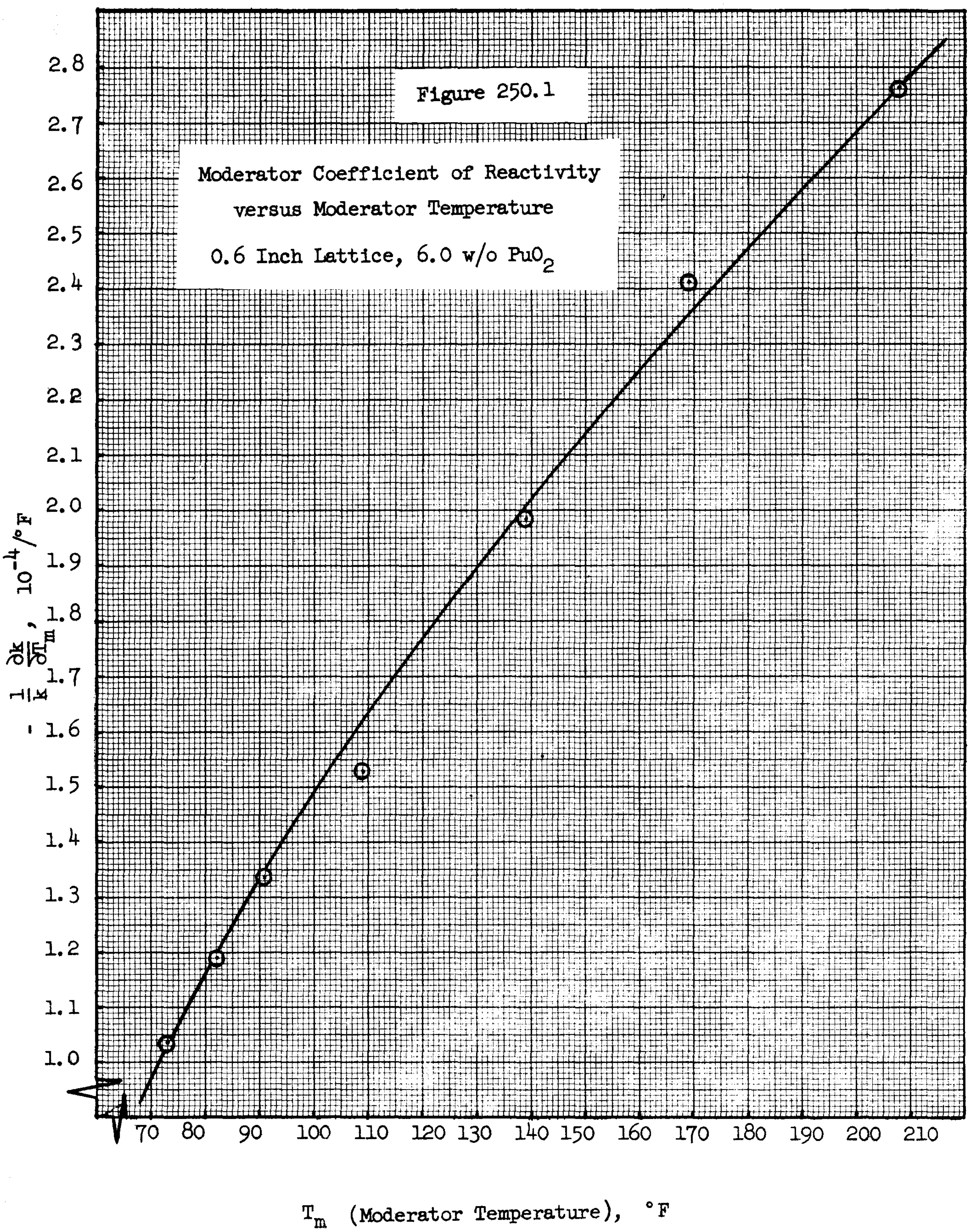


Figure 250.1

Moderator Coefficient of Reactivity versus Moderator Temperature

0.6 Inch Lattice, 6.0 w/o PuO_2

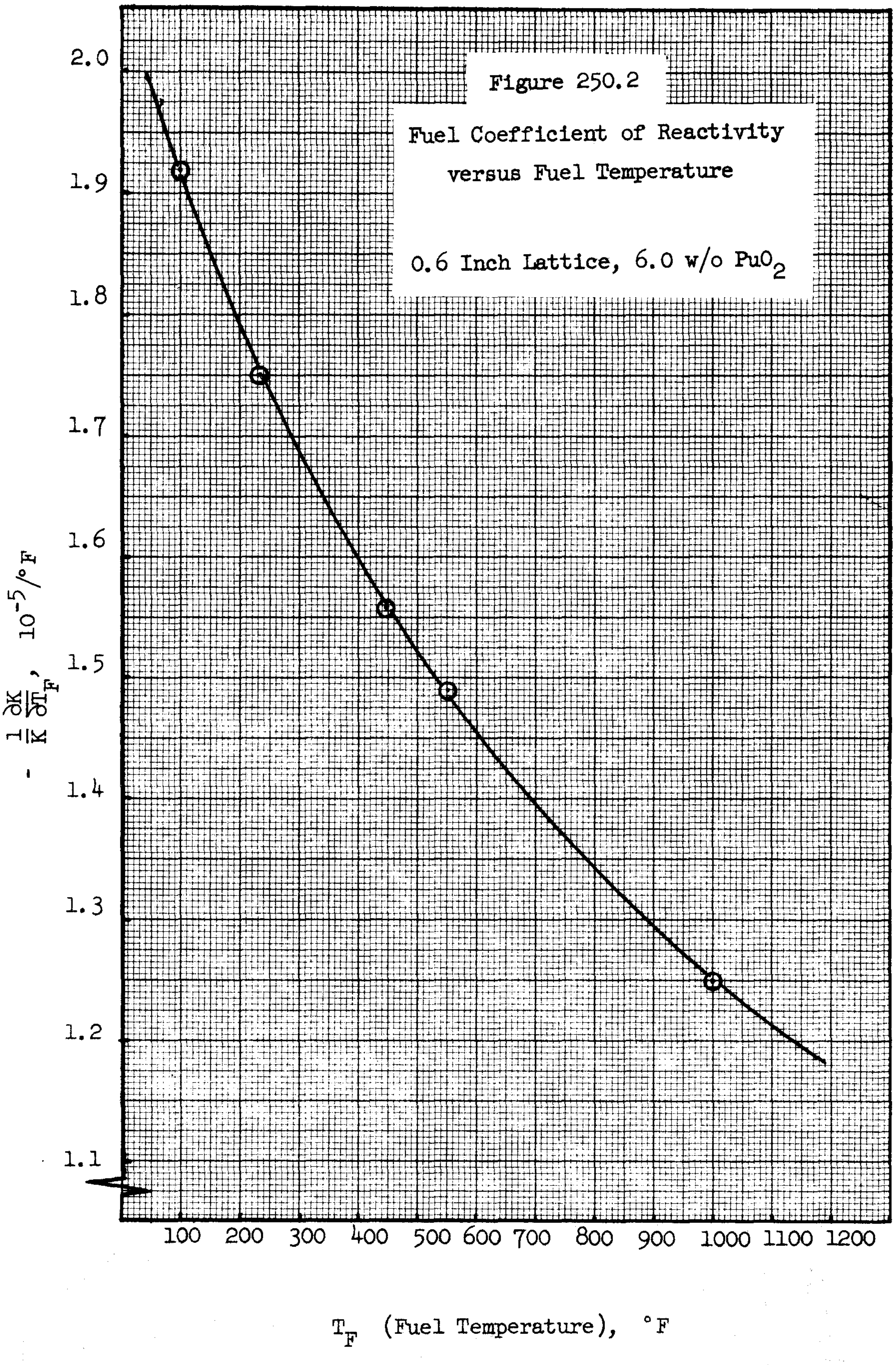


Figure 250.2
Fuel Coefficient of Reactivity
versus Fuel Temperature
0.6 Inch Lattice, 6.0 w/o PuO_2
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
$-\frac{1}{K}\frac{\partial K}{\partial T_F}$, $10^{-5}/°F$
100 200 300 400 500 600 700 800 900 1000 1100 1200
T_F (Fuel Temperature), °F

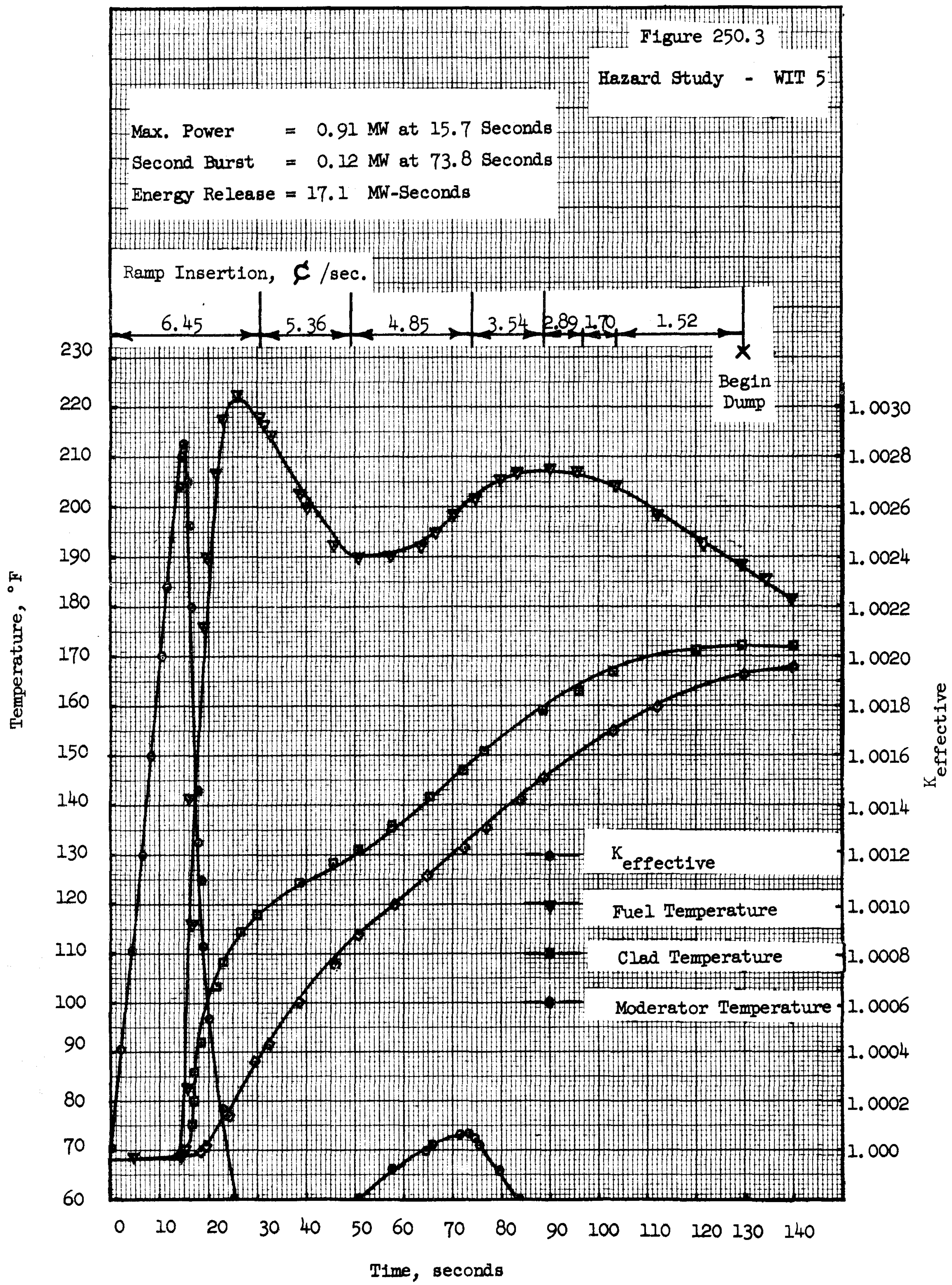


Figure 250.3
Hazard Study - WIT 5
Max. Power = 0.91 MW at 15.7 Seconds
Second Burst = 0.12 MW at 73.8 Seconds
Energy Release = 17.1 MW-Seconds
Ramp Insertion, ¢ /sec.
6.45
5.36
4.85
3.54
2.89
1.70
1.52
Begin Dump
Temperature, °F
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
1.0030
1.0028
1.0026
1.0024
1.0022
1.0020
1.0018
1.0016
1.0014
1.0012
1.0010
1.0008
1.0006
1.0004
1.0002
1.000
$K_{effective}$
$K_{effective}$
Fuel Temperature
Clad Temperature
Moderator Temperature
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Time, seconds

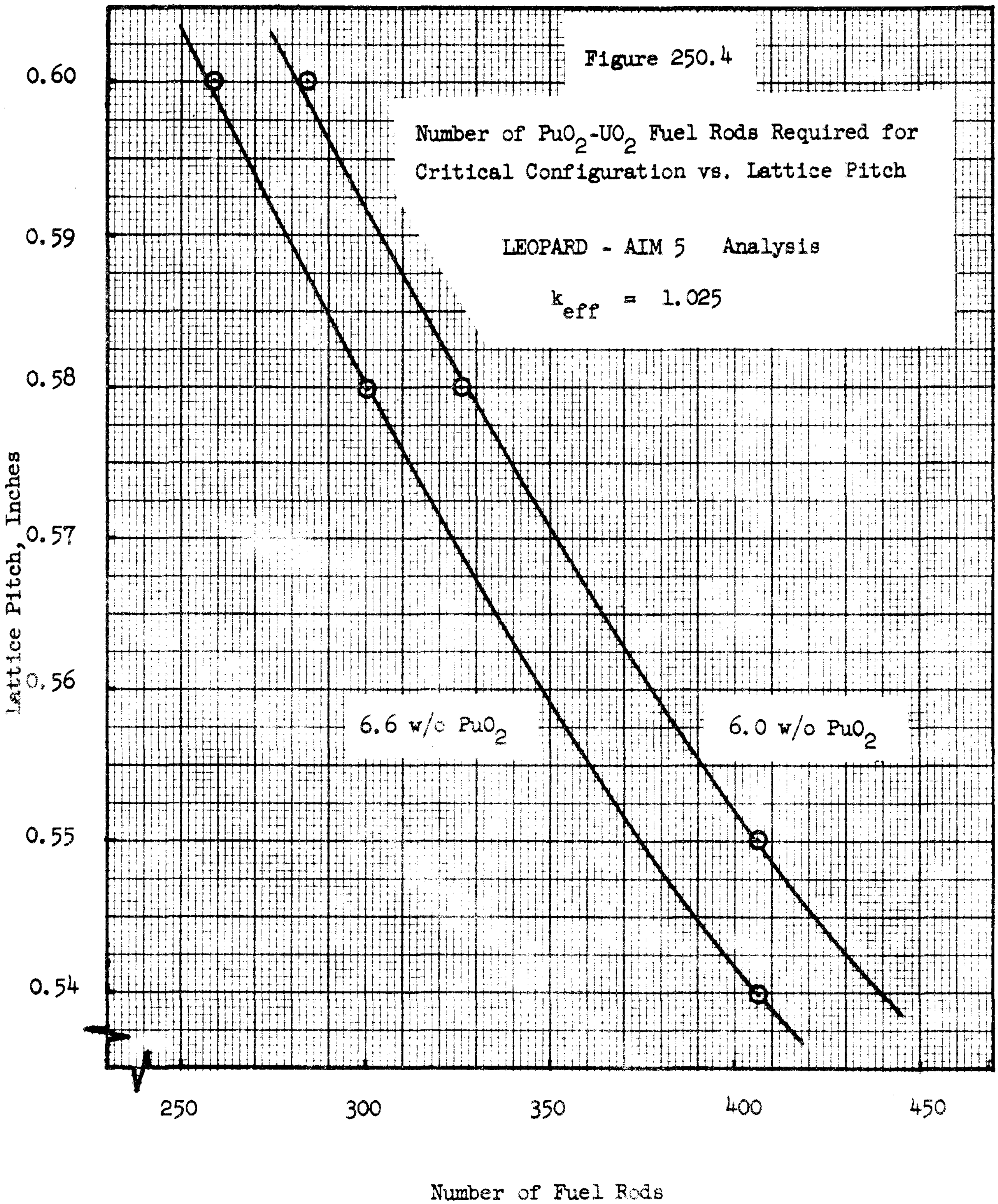


Figure 250.4
Number of PuO_2-UO_2 Fuel Rods Required for Critical Configuration vs. Lattice Pitch
LEOPARD - AIM 5 Analysis
k_{eff} = 1.025
6.6 w/o PuO_2
6.0 w/o PuO_2
Lattice Pitch, Inches
0.60
0.59
0.58
0.57
0.56
0.55
0.54
250
300
350
400
450
Number of Fuel Rods

References

/1 N. R. Nelson, "Saxton Plutonium Program, Quarterly Progress Report for the Period Ending September 30, 1964", WCAP-3385-1 (1964)

/2 G. H. Minton, C. P. Saalbach, "Numerical Solutions of the Reactor Kinetic Equations", Transactions of the American Nuclear Society, Volume 2, No. 2, November 1959, p. 65.

/3 R. F. Barry, "LEOPARD - A Spectrum Dependent Non-Spatial Depletion Code for the IBM-7094", WCAP-3741 (1963).

/4 H. P. Flatt and D. C. Baller, "AIM-5 - A Multi-Group, One-Dimensional Diffusion Equation Code", NAA-SR-4694 (March 1960).

SAX-F-310 Fuel Fabrication - Materials

R. J. Allio, A. Biancheria, M. D. Houston

The objective of this sub-task is to procure the required number of PuO_2-UO_2 bearing fuel rods for the program and to assure that all materials and fabrication processes meet Westinghouse specifications.

A purchase order for 150 Zircaloy-4 clad and 10 stainless steel clad vibrationally compacted fuel rods was approved and released to the Hanford National Laboratories for fabrication. Hanford has prepared eight kilograms of PuO_2 powder by oxidizing the plutonium buttons in a steam atmosphere. The resulting oxide has been calcined, screened and blended for isotopic homogeneity. To date, forty kilograms of arc-fused UO_2 have been heat treated in preparation for blending with the PuO_2. Both materials were certified for processing. The analytical results were reviewed on site by Westinghouse personnel, A. Biancheria and M. D. Houston, prior to release of the fuel for mechanical blending.

One-half of the total UO_2 - 6.6 w/o PuO_2 fuel has been processed through mechanical blending, canning, pneumatic impaction and decanning. Sampling plans for autoradiography was established for each pneumatically impacted (Nupac) fuel can. Establishment of the fuel rod welding parameters is in progress. Several samples were welded and are being inspected by X-ray, ultrasonic and photomicrographic techniques. A. Biancheria and M. D. Houston were present to observe most of these processes.

A purchase order for 510 Zircaloy-4 clad and 20 stainless steel clad fuel rods was approved and released to NUMEC for fabrication. NUMEC has received the first shipment of plutonium metal buttons and ten samples of Zircaloy-4 tubing. All the UO_2 has been received. Plutonium metal cleaning and dissolution have been initiated. Pre-production welding runs and inspection have been completed and have shown that 100% penetration can be achieved with the modified Hanford weld.

NUMEC has indicated that the first 500 pelletized Zircaloy clad fuel rods necessary for critical experiments will be shipped prior to the end of February 1965. Hanford vipac fuel is expected by late January or early February.

SAX-F-320 Fuel Inspection and Assembly

R. W. Brown, R. H. Rahiser,
A. Biancheria, D. B. Scott

The objective of this sub-task is to assist vendors of material and of fuel rods in inspecting their products to meet specifications, to conduct receiving inspections upon receipt of the fuel rods by Westinghouse and to fabricate and inspect fuel assemblies.

During this quarter, specifications for fuel pellets and fuel rods were reviewed, finalized, and submitted to vendors for final quotations and placement of purchase orders. In addition to the placement of these purchase orders, the following first piece items were either inspected or received for review by Quality Control:

1. Zircaloy-4 tubing manufactured by Harvey Aluminum - Samples of Lot #1 taken prior to final annealing were tested for corrosion at Harvey Aluminum and were rejected for failure to meet corrosion weight gain specifications. A retest was run on the final annealed product both at Harvey and at Westinghouse. The results of the final 14-day 750°F steam corrosion tests showed acceptable weight gains. Dimensional inspection and nondestructive inspection was performed at Harvey Aluminum, and approximately 100 pieces of tubing were accepted and shipped to Hanford. Material from Lot #2 was found to have low tensile strength and was rejected at Harvey Aluminum. Provided tensile tests at

elevated temperatures are satisfactory, Lot #2 may be useable. Lot #3 was dimensionally inspected, nondestructively tested and fourteen-day corrosion tests are due out the week of January 4, 1965.

Lot #4 was made from a Zircaloy-4 billet which met the chemical specifications and passed the 3-day corrosion tests. About 200 pieces of tubing from this lot have been accepted and shipped to Hanford.

2. Three lots of spacers have been received from Coor's Porcelain, have been accepted by Quality Control and have been placed in storage awaiting issuance for manufacturing.

3. Zircaloy-4 bar stock has been checked nondestructively and dimensionally and has been forwarded to Vallorbs Jewel for machining of end plugs. Revised end plug drawings have been sent to Hanford covering identification and marking of the end plugs to be used in vipac fuel rods.

4. The cans and grids to be used in the fuel enclosures will be of the same design as being used for the Saxton second core uranium fuel. Both sets of enclosures will be manufactured at the Westinghouse Atomic Power Division plant at Cheswick. The necessary materials have been ordered. Tooling used on previous Saxton orders has been received at Cheswick and additional necessary

tooling is being designed and ordered. All component parts and tooling are on schedule. The retort necessary for the brazing of the grids has been ordered and will be delivered soon. Redesign of the dies necessary to make the new style grid straps is proceeding on schedule.

5. The new Westinghouse design Belleville type retainer to be used to hold down pellets within the fuel rods is out for quotes and design drawings have been finalized. No problems are anticipated in obtaining these retainers in time to meet the production schedule.

SAX-330 <u>New Fuel Shipping</u>

H. E. Walchli

A decision on procurement of special shipping containers for the Saxton PuO_2 fuel has been delayed pending completion of criticality evaluations to meet the requirements set forth in the recently proposed revised Federal Regulation 10 CFR 71. If analysis indicates that more than one assembly can be included in a container and meet the licensing requirement it appears feasible to modify existing large containers for power reactor fuel to accept the Saxton fuel. Completion of the criticality evaluation and container design requirements is expected in the next period.

SAX-340 Safeguards Analysis

R. C. Nichols

Preparation of the draft of the Safeguards Report was continued throughout the period. As the detailed writing progressed on various sections, the outline as presented in the last quarterly progress report was revised and expanded. The final report will follow this outline very closely.

I. Introduction

   A. Objective and Scope

   B. Program Description

II. Mechanical Design

   A. Fuel Assembly Configurations

   B. Fuel Assembly Design

   C. Fuel Rod Design

III. Core Thermal and Hydraulic Design

   A. General

   B. Coolant Flow

   C. Variation in Primary System Temperature and Pressure

   D. Engineering Hot Channel Factors

   E. Departure from Nucleate Boiling

   F. Hydraulic and Thermal Design Parameters

   G. Central Temperature of Hot Pellet

VII. Safety Considerations

A. Justification of the Use of Vipac PuO_2 Fuel

B. Operation with Defective Fuel

VIII. Conclusions

All sections of the report were completed in draft form except the Boron Release and Steam Break Accident analyses which will be completed early in the next quarter. A preliminary information meeting was held with the Saxton Safety Committee on November 23 to discuss the overall Plutonium Project status and objectives. The Committee expressed concern in the following areas and requested additional information at a subsequent meeting.

a. Effect of the PuO_2 on the Doppler coefficient

b. Effect of the PuO_2 on the accident analysis results and methods

c. Melting temperature of the mixed oxide fuel

d. Possible pre-program irradiation of a removable 3 x 3 subassembly

e. Adequacy of presently installed Saxton safety and control systems and their operating parameters

f. Assurance that adequate alpha monitoring equipment will be installed at Saxton

g. Incremental changes in maximum hypothetical accident due to possible metal-water reaction and hydrogen recombination energies.

Information on and answers to the above items are being developed for the next Safety Committee meeting expected early in January 1965.

SAX-350 Alpha Protection

J. W. Power

The following alpha monitoring system requirements have been established for environmental monitoring.

To provide a complete radiation detection capability at Saxton, an alpha monitoring system will be added to the environmental monitoring procedures presently being used. The alpha monitoring system will be capable of detecting and indicating alpha contamination levels throughout the plant.

The system will be capable of detecting surface contamination and air particulate contamination. Surface contamination will be monitored using two separate systems. One system consists of portable (battery powered, hand-held) survey meters that have a detection sensitivity range of 2 to 2000 alphas per square centimeter per minute. The second system that will have a more sensitive detection limit for surface contamination is a portable smear sample kit. The kits are to be supplemented with the necessary laboratory analysis instrumentation to detect alpha activity levels of 0.2 alphas per square centimeter per inch.

Air particulate contamination will also be monitored using two separate systems. The alpha contamination of the vapor container will be continuously monitored by an on-line air sampling system. This system takes a continuous air sample from the container through a closed, sealed system, passes it through a scintillation detector, filter paper assembly and then returns it to the vapor container. Particles greater than 1 micron in diameter are collected by the filter paper. The paper is then viewed by a photomultiplier-scintillation crystal combination and monitored for alpha activity. The system contains sufficient delay time between collection and monitoring to permit the decay of the masking Radon-Thoron activities. The overall sensitivity of this system is 1×10^{-12} $\mu c/cc$ for Pu-239.

Portable air sampling collectors and associated laboratory analysis instrumentation are also included in the alpha monitoring system to provide a flexible air monitoring system that can be used to monitor specific areas of the containment or areas not covered by the continuous air sampling system. This portable air monitoring system will have a detection sensitivity 2×10^{-12} $\mu c/cc$ for Pu-239. These portable detectors will be used in conjunction with the routine health physics survey program at Saxton.

In addition to the above, alpha monitoring of plant coolants is now being investigated for inclusion into the alpha monitoring system.

Requests for quotations on the above described equipment have been issued.

SAX-400 Performance of Critical Experiments
D. F. Hanlen, R. D. Leamer

A. Introduction

1. Objective

The objective of this task is to perform the critical experiments required to verify the nuclear characteristics of the unirradiated fuel before it is installed in the Saxton reactor. Certain aspects of planning and analysis are intrinsic.

2. Experiment Sequence

Separate single-zone criticals with both plutonium and uranium bearing fuel rods and two-zone criticals consisting of distinct plutonium and uranium regions have been scheduled for performance.

3. Scope of Work

In preparation for the experimental work, an application for an operating license amendment was submitted to the Atomic Energy Commission. In response to the application, a group of questions was generated by the Commission. These questions were answered in the license application. At a meeting in Bethesda on December 17, most questions seemed to be resolved. DRL(AEC) hopes to issue the operating license by February 1, 1964.

Remaining Subtasks

F. Langford, et. al.

SAX-510 Nuclear Analyses of Operation - F. Langford

SAX-520 Thermal-Hydraulic Analyses of Operations - E. A. McCabe

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 - B. D. Lamont

SAX-650 Waste Disposal - D. T. Galm

SAX-660 Materials Evaluation - R. J. Allio

SAX-670 Fuel Reprocessing - H. E. Walchli

Technical work in the preceding areas will commence later in the program. A PERT-type summary schedule of the project was included at the end of the first Quarterly Report, WCAP-3385-1, issued in October 1964.

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

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