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GENERAL ELECTRIC

HANFORD ATOMIC PRODUCTS OPERATION - RICHLAND, WASHINGTON

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TITLE

THE APPLICATION OF AN OPERATIONAL
REACTIVITY ACCOUNTING SYSTEM BASED
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THE APPLICATION OF AN OPERATIONAL
REACTIVITY ACCOUNTING SYSTEM BASED ON ONE-GROUP DIFFUSION THEORY

INTRODUCTION

HW-70780, "An Operational Reactivity Accounting System Based on One-Group Diffusion Theory" describes a reactivity accounting system which is an improvement over the present "flux-squared weighting" system.

Several changes and additions have been made which will simplify and increase the accuracy of the system described in the parent document. The changes occur primarily in the application of the system and are compatible with diffusion theory and the parent document.

Each change will be described briefly and to illustrate their application an example reactivity balance, using the reactivity accounting system, will be performed.

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DISCUSSION OF CHANGES

1. Material Bucklings

The cold, green, three-dimensional, material bucklings of uranium fuel are listed in Table 28*.

When the enriched uranium has a shorter charge length than the natural uranium, the relative "radial" material bucklings change. Since the material buckling of natural uranium should remain constant, the material buckling of the enrichment must change.

The material buckling of a 34-piece enriched uranium charge in an older reactor whose normal charge is 32 natural uranium slugs is plotted in Figure 1-S as a function of enrichment density and charge displacement.

2. Geometric Considerations

No change

3. Xenon and Iodine

No change

4. Samarium

No change

5. Neptunium Holdup

No change

6. Cold Long-Term Gains

The reactivity effect of increasing exposure of uranium fuel is shown by Figures 24 and 25 for natural and enriched uranium respectively. These curves may be described by

$$R_{ltg} = aE + bE^2 + cE^3 + dE^4 = g(E)$$

However, there exists in a region after a discharge, fuel at different exposures, E for the fuel recently charged and $E_0 + E$ for the remainder, where E is the exposure made since the fuel was charged and E_0 is the average exposure, at startup, of the fuel not discharged.

$$\text{So } R_{ltg} = f(aE + bE^2 + cE^3 + dE^4) + (1-f) [a(E_0 + E) + b(E_0 + E)^2 + c(E_0 + E)^3 + d(E_0 + E)^4]$$

$$\text{or } R_{ltg} = fg(E) + (1-f) g(E_0 + E)$$

At startup $E = 0$

$$\text{So } R_{ltg} = (1-f) g(E_0)$$

$$E_0 = \frac{\text{avg. exposure of the zone at startup}}{1-F}$$

where $f = \% f^2$ of the discharge in the region and F is the $\%$ factor of the region discharge
 *Any table or figure referred to in the parent document is noted by a plain number, those in this supplementary document are noted by -S, e.g., Figure 1-S.

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7. Moderator Coefficient

It is assumed that the moderator coefficient is dependent only upon the Pu²³⁹ concentration in the fuel. The relationship between C_T and Pu²³⁹ gms/ton is presented graphically in Figure 26.

The gms of Pu²³⁹ which are "held up" because of Neptunium may be determined by

$$\begin{aligned} \text{Np "hold up"} &= R_N (0.0747) \text{ K Nat} \\ &R_N (0.1006) \text{ K Enr} \\ &R_N (0.0772) \text{ Old Nat} \\ &R_N (0.1053) \text{ Old Enr} \end{aligned}$$

at equilibrium

$$\begin{aligned} \text{Np "hold up"} &= 0.00733 \text{ W} \quad \text{K Nat} \\ &0.00655 \text{ W} \quad \text{E Enr} \\ &0.01274 \text{ W} \quad \text{Old Nat} \\ &0.01200 \text{ W} \quad \text{Old Enr} \end{aligned}$$

By subtracting the gms of Pu²³⁹ held up from the gms of Pu²³⁹ obtained from Figure 20, C_T may be found from Figure 26.

$$C_T(\text{Region}) = C_T(\text{Enr}) f_{\text{Enr}} + C_T + C_T(\text{Nat})(1-f_{\text{Enr}})$$

8. Non-Uranium Columns

The effect of nonuranium columns can be treated in the following manner. Find the average nominal reactivity of the nonuranium (including spline tubes and short charges) in the region of interest. From Figure 2-S find the lattice material buckling (B^2_{nu}) which corresponds to the average nominal reactivity.

Calculate the material buckling of the region by

$$B_M^2 = f_{\text{Enr}} (B_{\text{Enr}}^2) + f_{\text{Nat}} (B_{\text{Nat}}^2) + f_{\text{Nu}} (B_{\text{Nu}}^2)$$

To determine the reactivity effect of the nonuranium columns, first calculate the material buckling of the region (B_M^2) without the nonuranium columns.

$$B_M^2 = f_{\text{Enr}} (B_{\text{Enr}}^2) + (1-f_{\text{Enr}}) (B_{\text{Nu}}^2)_{\text{calc}}$$

$$B_M^2 - B_M^2 = B_{\text{Nu}}^2$$

B_{Nu}^2 is the local change in buckling due to the nonuranium columns. This can be converted into reactivity from Figures 3-S or 4-S.

9. Horizontal Control Rods

The method outlined in the parent document was changed for two reasons. The first is that several methods of evaluating the reactivity effects of rods are being

developed, each being more accurate than the method outlined. Secondly, the method proposed in the parent document is felt to be no more accurate than the present method. The rods will still be considered to act only in the central region of the reactor. Figures 3-S and 4-S show the conversion of full pile reactivity to local buckling.

10. Metal Heating Effect

No change.

11. Fringe Poison and Compensating Enrichment

An "after the fact" type of analysis will be done to evaluate the fringe poison and compensating enrichment. Since diffusion theory breaks down near a strong absorber such as Li-Al, the method assumes that the presence of fringe poison reduces the effective pile size. The flux is plotted through the fringe and compensating enrichment and extrapolated to zero. The point at which the flux goes to zero is the effective pile boundary.

The change in buckling for a reactor with and without fringe poison is its reactivity worth. At reactors which have partial fringe poison loadings, the reactivity effect is multiplied by the percent of reactor perimeter which has fringe poison.

The compensating enrichment is evaluated by buckling calculations with and without the enrichment. The change in full pile buckling is the reactivity effect of the compensating enrichment.

12. Mixers

The effect of mixers is a function of mixer position and axial flux distribution. These values are calculated in HW-70370, "Physics Effects of Water Mixing Pieces."

REACTIVITY BALANCE

The example case will be done for F Reactor on 1-10-62.

A. Following is a list of information which is available from production computing.

	<u>Σ Factor</u>	<u>#Nat</u>	<u>#Enr</u>	<u>Nat. Prod.</u>	<u>Enr. Prod.</u>
Region 1	1169.12	953	31	53161	1431
2	154.00	47	85	2829	5202
3	619.86	684	143	36239	8082

B. Reactor Data

- Operating condition - equilibrium
- Power level - 1870 MW
- HCR's - 888 c-mks (eff.)
- He - 98%
- ECT - 1488
- Inactive Tubes

- 2 B-Metal central
- 8 GS, 4 air central
- 2 air E-ring
- 2 air fringe
- 19 short charges central

Splines

- 2 at 18'
- 3 at 26'
- 1 at 22'

PCCF's

- 13 SA and 5 H₂O

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C. Region Data

When setting up the regions the primary purpose is to obtain the best cylindrical approximation possible. The information received from production computing may not describe region situation properly. For example, enrichment which should be part of the enrichment ring may be considered by production computing to be in the fringe if the enrichment ring has been changed and the zone boundaries not adjusted. This is what happened in the example case. There are 85 compensating enriched columns in the fringe; however, production computing has 143 enriched columns listed; the extra 58 enriched columns should be considered as part of the enrichment ring. Thus for routine use of this system zone boundaries must be maintained current.

Also production computing lists only the active tubes in a region, so to define the actual region size the inactive tubes must also be considered.

Number of tubes per region

The number of tubes in Region 1 are:

$$953 \text{ Nat} + 31 \text{ Enriched} + 2 \text{ B-metal} + 8 \text{ Graphite Stringers} + 6^* \text{ Air Ch} \\ + 18 \text{ PCCF} = 1018 \text{ tubes}$$

$$\text{Region 2} - 47 \text{ Nat} + 85 \text{ Enriched} + 58^{**} \text{ Enriched} = 190 \text{ tubes}$$

$$\text{Region 3} - 684 + 85 + 27^{***} = 796 \text{ tubes}$$

Average factor per region

the natural uranium average tube factor (relative power) must be determined
The purpose here is to define the relative power of the region. To do this best, the data from production computing must be used exactly as it appears, converting enriched uranium tubes to natural tube power.

$$\text{Region 1} = 1169.12 / (953 + 31) = 1.19 \quad \text{should be } (1169.12) / (953 + 1.057 \times 31) = 1.185$$

$$\text{Region 2} = 154.00 / (47 + 85) = 1.17 \quad \text{should be } (154.00) / (47 + 85 (1.027)) = 1.125$$

$$\text{Region 3} = 619.86 / 827 = 0.75$$

Exposure

$$\text{Region 1} - \text{Nat} = 53161 / 953 = 55.78 \text{ MWD/T} \\ \text{Enr} = 1431 / 31 = 46.16 \text{ MWD/T}$$

$$\text{Region 2} - \text{Nat} = 2829 / 47 = 60.19 \text{ MWD/T} \\ \text{Enr} = 5202 / 85 = 61.20 \text{ MWD/T}$$

$$\text{Region 3} - \text{Nat} = \frac{36239 + 8082}{827} = 53.59 \text{ MWD/T}$$

$$\text{Weight of a column of 31 OIIN} + \text{mixer} = 31(7.41) + 5.3 = 235 \text{ lbs} \\ \text{Tubes/Ton} = 8.51 \text{ tubes/ton}$$

*Two of these air channels are in the enriched ring. The two air channels which are in fringe will be evaluated later.

**These 58 enriched columns were listed in the fringe.

***These 27 tubes contain 25 fringe poison + 2 Air Ch.

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Weight of a column of 330 OIIE + mixer = $5.31(33) + 5.3 = 180.5$ lbs
Tubes/Ton = 11.08 tubes/Ton

Region 1 Nat = $55.78 (8.51) = 475$ MWD/T
Enr = $46.16 (11.08) = 511$ MWD/T

Region 2 Nat = $60.19 (8.51) = 512$ MWD/T
Enr = $61.20 (11.01) = 678$ MWD/T

Region 3 Nat = $53.59 (8.51) = 456$ MWD/T

Fraction Enrichment

Region 1 = $31/1018 = 0.028$
Region 2 = $143/190 = 0.753$
Region 3 = 0

Power generation of an enriched column vs. a natural column the power generation per unit length of enriched uranium is 1.207 times that of natural uranium. Since a 34-piece enriched charge is shorter than a natural uranium charge, this value must be reduced. At F Reactor, the flux weighted relative heat generation per enriched tube is ~ 1.10 times that of a natural uranium tube. This value assumed a chopped cosine flux distribution. A more accurate number can be found from the actual flux distribution.

Region Radius

Region 1 $R_1 = \sqrt{\frac{1018}{2004}} 519.8 = 370.5$ cm

Region 2 $R_2 = \sqrt{\frac{1018 + 190}{2004}} 519.8 = 403.6$ cm

calculated Region 3 $R_3 = 519.8$ cm *2004 257*

avg Region 4 $R_4 = 582.8$ cm

D. Calculation of Bucklings

1. Material Buckling

The displacement of the 34-slug enriched uranium columns is only about 2 cm at F Reactor. The material buckling of these enriched columns as determined from Figure 1-S are:

Region 1 $B_{(Enr)}^2 = 246.3 \mu b$

Region 2 $B_{(Enr)}^2 = 257.5 \mu b$

Region 1 $B_M^2 = 246.3 (0.028) + 60.1 (0.972) = 65.3 \mu b$

Region 2 $B_M^2 = 257.5 \mu b (0.753) + 60.1 (0.247) = 208.7 \mu b$

Region 3 $B_M^2 = 60.1 \mu b$

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2. Xenon

$$\text{Region 1} \quad \overline{mf} = 0.972 + 0.028 (0.789)(1.10)^{1.057} = 0.996$$

$$W_1^* = 1870 (1.19)(0.72)(0.996) = 1596$$

$$B_{x_1}^2 = 2696 \text{ c-mk (local)} = 43.6 \mu b$$

$$\text{Region 2} \quad \overline{mf} = 0.247 + 0.753 (0.789)(1.10)^{1.057} = 0.901$$

$$W_2^* = 1870 (1.17)^{1.13} (0.80)(0.901) = 1577$$

$$B_{x_2}^2 = 2690 \text{ c-mk (local)} = 43.5 \mu b$$

$$\text{Region 3} \quad \overline{mf} = 1$$

$$W_3^* = 1870 (0.75) = 1403$$

$$B_{x_3}^2 = 2643 \text{ c-mk (local)} = 42.8 \mu b$$

3. Neptunium Holdup

$$\text{Region 1} \quad R_{NP_1} = 0.972 (0.165)(2225)^{2.225} + 0.028 (0.114)(2225)^{2.225} \times 1.057$$

$$= 364 \text{ c-mk (local)} = 5.9 \mu b$$

$$\text{Region 2} \quad R_{NP_2} = 0.247 (0.165)(2188)^{2.225} + 0.753 (0.114)(2188)^{2.225} \times 1.057$$

$$= 277 \text{ c-mk (local)} = 4.5 \mu b$$

$$\text{Region 3} \quad R_{NP_3} = 0.165 (1403) = 231 \text{ c-mk (local)}$$

$$= 3.7 \mu b$$

4. Samarium

$$\text{Region 1} \quad R_S = 0.972 (548) + 0.028 (550) = 548 \text{ c-mk (local)}$$

$$= 8.9 \mu b$$

$$\text{Region 2} \quad R_S = 0.247 (548) + 0.753 (550) = 550 \text{ c-mk (local)}$$

$$= 8.9 \mu b$$

$$\text{Region 3} \quad R_S = 548 \text{ c-mk (local)} = 8.9 \mu b$$

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5. Cold Long Term Gains

Region 1 $R_{LTG} = 0.972 (475) + 0.028 (-185)$

$= 457 \text{ c-mk (local)} = 7.4 \mu b$

Region 2 $R_{LTG} = 0.247 (480) + 0.753 (-310)$

$= -115 \text{ c-mk (local)} = 1.9 \mu b$

Region 3 $R_{LTG} = 471 \text{ c-mk (local)} = 7.6 \mu b$

6. Metal Heating

Region 1 $C_{m1} = 0.972 (0.3) + 0.028 (1.10)(0.3) = 0.301$

$R_{m1} = 2225 (0.301) = 670 \text{ c-mk (local)}$

$= 10.8 \mu b$

Region 2 $C_{m2} = 0.247 (0.3) + 0.753 (1.10)(0.3) = 0.323$

$R_{m2} = 2188 (0.323) = 707 \text{ c-mk (local)}$

$= 11.4 \mu b$

Region 3 $C_{m3} = 0.3$

$R_{m3} = 1403 (0.3) = 421 \text{ c-mk (local)}$

$= 6.8 \mu b$

7. Nonuranium Columns

<u>Material</u>	<u>R_{NOM}/Column</u>	<u>R_{NOM}</u>	<u>%R_{NOM}</u>	<u>R_{eff}</u>
2 B-metal	at -22.3	= 44.6	3.87%	23.1 c-mk
6 Air	at -12.2	= 73.2	6.35%	38.0 c-mk
8 Graphite S.	at -17.5	= 140.0	12.14%	72.6 c-mk
19 Short charge	at - 6.7	= 128.0	11.10%	66.4 c-mk
6 Splines	at -20	= 120.0	10.40%	62.2 c-mk
18 PCCF		647.5	56.14%	335.7 c-mk
59		1153.3		

$R_{NOM}(\text{Avg}) = 19.5 \mu b$ $B_{NU}^2 = -148 \mu b$

$B_M^2 = \frac{31(246.3) + 59(-148) + 928(60.1)}{1018} = 53.7 \mu b$

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7. Nonuranium Columns (Cont'd.)

$$B_M^2 = 65.3 \mu b$$

$$B_{NU}^2 = B_M^2 - B_M^2 = 53.7 - 65.3 = -11.6 \mu b$$

From Figure 3-8 the reactivity effect of the nonuranium columns is 598 c-mks. The reactivity effect of the different types is $\%R_{NOM}(598)$. The reactivity effect of the two air channels in the fringe is 2 c-mk.

8. Horizontal Control Rods

The effective reactivity of the HCR's is 888 c-mk. The local buckling effect is found to be -17.3 μb from Figure 3-8.

9. Water Mixers

F Reactor had water mixers at this time which were positioned in the seventh slug from the rear of the charge for both natural and enriched columns. The reactivity effect* of these mixers are:

$$NAT = -129 \text{ c-mk} = -2.1 \mu b$$

$$ENR = -294 \text{ c-mk} = -4.8 \mu b$$

$$\text{Region 1} \quad B_{MIX}^2 = 0.972 (-2.1) + 0.028 (-4.8) = -2.2 \mu b$$

$$\text{Region 2} \quad B_{MIX}^2 = 0.247 (-2.1) + 0.753 (-4.8) = -4.1 \mu b$$

$$\text{Region 3} \quad B_{MIX}^2 = -2.1 \mu b$$

10. Moderator Effect

$$\text{Region 1} \quad NAT (475 \text{ MWD/T}) = 405 \text{ gms Pu/T}$$

From Fig. 20

$$ENR (511 \text{ MWD/T}) = 370 \text{ gms Pu/T}$$

$$Np \text{ holdup (NAT)} = 2225 (0.01274) = 28 \text{ gms/T}$$

$$Np \text{ holdup (ENR)} = 2225 (0.0120) = 27 \text{ gms/T}$$

$$\therefore NAT = 405 - 28 = 377 \text{ gms Pu/T}$$

$$ENR = 370 - 27 = 343 \text{ gms Pu/T}$$

$$C_T(NAT) = 6.2 \quad C_T(ENR) = 5.9$$

From Fig. 26

$$C_T(\text{Region 1}) = 0.972 (6.2) + 0.028 (5.0)$$

$$= 6.19 \text{ c-mk/}^\circ\text{C}$$

*HW-70370, "Physics Effects of Water Mixing Pieces," D. G. Montague, 7-14-61, pg 11

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Region 2 $\text{NAT} (612 \text{ MWD/T}) = 432 \text{ gms/T}$
 $\text{ENR} (678 \text{ MWD/T}) = 473 \text{ gms/T}$
 $\text{Np holdup (NAT)} = 0.01274 (2188) = 28 \text{ gms/T}$
 $\text{Np holdup (ENR)} = 0.0120 (2188) = 26 \text{ gms/T}$
 $\therefore \text{NAT} = 432 - 28 = 404 \text{ gms/T}$
 $\text{ENR} = 473 - 26 = 447 \text{ gms/T}$
 $C_T(\text{NAT}) = 6.43 \quad C_T(\text{ENR}) = 6.8$
 $C_T(\text{Region 2}) = 0.247 (6.43) + 0.753 (6.8)$
 $= 6.71 \text{ c-mk/}^\circ\text{C}$

Region 3 $\text{NAT} (456 \text{ MWD/T}) = 391 \text{ gms/T}$
 $\text{Np holdup} = 1403 (0.01274) = 18 \text{ gms/T}$
 $\text{NAT} = 391 - 18 = 373 \text{ gms/T}$
 $C_T(\text{Region 3}) = 6.16 \text{ c-mk/}^\circ\text{C}$

It is now necessary to find the "temperature" of the moderator. The buckling in Region 1 should be about zero in a reactor operating at equilibrium. So let the buckling effect of the moderator be such a value that the sum of all the buckling effects in Region 1 equals zero.

$$B_1^2 = 65.3 - 15.2 - 43.6 - 5.9 - 8.9 + 7.4 - 10.8 - 11.6 - 2.2 - 17.3$$

$$+ \delta B_T^2 = -42.8 + \delta B_T^2$$

$$\therefore B_{T_1}^2 = C_{T_1} T_1 = -42.8 \mu b = 2645 \text{ c-mk (local)}$$

and $T_1 = \frac{2645}{C_{T_1}} = \frac{2645}{6.19} = 427^\circ\text{C}$

From the parent document the most likely relationship to describe T is $T = W(a+b\%He + c\%He^2)$. It takes several evaluations of the reactor under different conditions to find the values of the constants. Since this is the first evaluation of F Reactor, for this evaluation we must assume that $(a+b\%He + c\%He^2)$ is the same for each region. If this is true then $T = KW$ where $K = (a+b\%He + c\%He^2)$ and is the same in each region.

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$$K = T/W = \frac{427^\circ\text{C}}{2225 \text{ MW}} = 0.192^\circ\text{C/MW}$$

so $T_2 = 0.192^\circ\text{C/MW}(2189) = 420^\circ\text{C}$

$$T_3 = 0.192(1403) = 269^\circ\text{C}$$

and

$$B_{T_1}^2 = C_{T_1} T_1 = 2645 \text{ c-mk (local)} = 42.8 \mu\text{b}$$

$$B_{T_2}^2 = C_{T_2} T_2 = 6.71 (420) = 2818 \text{ c-mk (local)} \\ = 45.6 \mu\text{b}$$

$$B_{T_3}^2 = C_{T_3} T_3 = 6.16 (269^\circ\text{C}) = 1657 \text{ c-mk (local)} \\ = 26.8 \mu\text{b}$$

11. Region Bucklings

$$B_1^2 = 65.3 - 15.2 - 43.6 - 5.9 - 8.9 + 7.4 \\ - 10.8 - 11.6 - 17.3 + 42.8 - 2.2 = 0$$

$$B_2^2 = 208.7 - 15.2 - 43.5 - 4.5 - 8.9 - 1.9 \\ - 11.4 + 45.6 - 4.1 = 164.8 \mu\text{b}$$

$$B_3^2 = 60.1 - 15.2 - 42.8 - 3.7 - 8.9 + 7.6 \\ = 6.8 + 26.8 - 2.1 = 15.0 \mu\text{b}$$

After the region bucklings have been calculated the reactor must be checked to see if it is critical with these bucklings. This may be done using parametric buckling curves, or using a computer code such as "Zilch" or "vita-buck".

In the case of F Reactor a uniform change of $0.8 \mu\text{b}$ is required to bring the reactor to critical. This means that the moderator effect must be increased by $0.8 \mu\text{b}$ in each region.

Region 1 $B_{T_1}^2 = 42.8 + 0.8 = 43.6 \mu\text{b}$

Region 2 $B_{T_2}^2 = 45.6 + 0.8 = 46.4 \mu\text{b}$

Region 3 $B_{T_3}^2 = 26.8 + 0.8 = 27.6 \mu\text{b}$

12. Fringe Poison Evaluation

The flux is plotted in the fringe of the reactor. The flux is extrapolated to zero 2 cm outside the physical boundary of the reactor on the far side and 11 cm inside the boundary at the top. There are 16 fringe poison tubes in the top of the reactor. The 10 fringe poison tubes on the far side are charged in every other lattice.

The extrapolated radial boundary at the top of the reactor is 508.8 cm. The radial boundary on the far side is 521.8 cm.

The uniform change in reactor buckling caused by reducing the effective pile size to 508.8 cm is 12.03 μ b and to 521.8 cm is 9.47 μ b. So the reactivity effect of the fringe poison is

$$R_{FP}(\text{Top}) = \left(\frac{16}{174.6} \right) (12.03)(61.8) = 68 \text{ c-mks}$$

$$R_{FP}(\text{Far Side}) = \left(\frac{19}{174.6} \right) (9.47)(61.8) = 64 \text{ c-mks}$$

$$R_{FP}(\text{Total}) = 68 + 64 = 132 \text{ c-mk}$$

To see if the fringe poison is compensated correctly the compensating enrichment must be evaluated. To do this a ring of enrichment corresponding to the compensating enrichment will be inserted at the boundary of the reduced pile.

For example, to evaluate the compensating enrichment in the top of F Reactor we approximate the reactor as follows:

Region 1	Central Zone	$r_1 = 370.5 \text{ cm}$
Region 2	Enriched Ring	$r_2 = 403.6 \text{ cm}$
Region 3	Fringe Natural Uranium	$r_3 = 429.4 \text{ cm}$
Region 4	Compensating Enrichment	$r_4 = 508.8 \text{ cm}$

The difference in full pile buckling between a case with the compensating enrichment in Region 4 and one where Region 4 has natural uranium is the reactivity effect of the compensating enrichment. But this value must be reduced by the percentage of reactor perimeter which is loaded in this manner.

$$\text{So } R_{CE}(\text{Top}) = \left(\frac{16}{174.6} \right) (10.93)(61.8) = 62 \text{ c-mk}$$

$$R_{CE}(\text{Far Side}) = \left(\frac{19}{174.6} \right) (6.46)(61.8) = 43 \text{ c-mk}$$

$$R_{CE}(\text{Total}) = 62 + 43 = 105 \text{ c-mk}$$

It appears that the fringe poison is undercompensated by 27 c-mk which must be compensated somewhere else in the reactor.

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E. Reactivity Effects

The full pile reactivity effect of various power or fission product effects may be calculated. If their bucklings are subtracted from the region bucklings, the uniform change in buckling over the reactor, to bring it back to critical is their reactivity effect in units of microbucks.

For example, the following is a calculation of the combined reactivity effect of Xenon, Samarium, Neptunium "holdup," cold long-term gains, moderator effect, and metal heating effect.

R Power: Xe, Sm, Np, Ltg, Moderator, Metal Heating

Region Bucklings

Region 1	0.8 μ b
Region 2	165.6 μ b
Region 3	15.8 μ b

$$B^2(\text{Power}) = B^2(\text{Region}) - B_X^2 - B_S^2 - B_N^2 - B_{\text{LTG}}^2 - B_T^2 - B_M^2$$

$$\begin{aligned}\text{Region 1 } B_1^2(\text{Power}) &= 0.8 + 43.6 + 8.9 + 5.9 - 7.4 - 43.6 \\ &+ 10.8 = 26.2 \mu\text{b}\end{aligned}$$

$$\begin{aligned}\text{Region 2 } B_2^2(\text{Power}) &= 165.6 + 43.5 + 8.9 + 4.5 + 1.9 - 46.4 \\ &+ 11.4 = 189 \mu\text{b}\end{aligned}$$

$$\begin{aligned}\text{Region 3 } B_3^2(\text{Power}) &= 15.8 \mu\text{b} + 42.8 + 8.9 + 3.7 - 7.6 \\ &- 27.6 + 6.8 = 42.8 \mu\text{b}\end{aligned}$$

The uniform change in buckling across the reactor is -20.9 μ b giving

$$R \text{ Power} = -1290 \text{ c-mk.}$$

This value may be obtained either by using the parametric curves or by using a computer code.

The reactivity evaluation of spike or radial enrichment is described on page 21 of the parent document. It may be noted that Figures 3-S or 4-S may also be used to evaluate spike enrichment.

All other items on the reactivity balance sheet, Figure 5-S, should be self-explanatory.

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F. Comments

There are several points in the reactivity accounting system which still can be refined.

1. The evaluation of the moderator coefficient assumes that it is dependent only upon the concentration of Pu239. This may not be a good approximation for the enrichment because of a different neutron flux spectrum and because the fuel is "blacker."

The moderator effect evaluated in the example is probably too large. The reason being that its accuracy is no greater than the combined accuracy of the other variables and the reactivity value used for the HCR's is probably 100 to 200 c-mks too large.

The assumption in the example that the moderator "temperature" is directly proportional to the radial flux distribution is not correct. The temperature to power ratio will be greater in the fringe because of thermal leakage. One may get some idea of the magnitude of this difference by comparing the axial graphite temperature distribution with the axial neutron flux distribution.

2. Some of the geometric considerations can probably be improved. For instance, the active portion of the reactor should have the same volume in cylindrical approximation as it does physically. The change in effective reactor size should take place in the augmentation distance when the reactor is approximated by a cylinder. This keeps the power density the same.

This is a second order effect and at this time no attempt will be made to change it.

3. In some situations it may be more realistic to consider the HCR's and non-uranium columns to act not only in the flat zone but also the enriched ring. This situation would occur if splines or PCCF tubes were located near the enriched ring and several short rods were in the reactor.
4. The accuracy of the cold long-term gains could be increased during nonequilibrium and shutdown by examining the discharge of natural and enriched uranium separately. For instance, the central zone discharge may entirely consist of spike enrichment if the reactor was on the block discharge concept. This effect has been checked through and the error is small.
5. The fission product effects are based on an axial cosine flux distribution. Some improvement could be made in this area if the true axial flux distribution were considered.

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Operational Physics Sub-Section
Research and Engineering Section
IRRADIATION PROCESSING DEPARTMENT

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Displacement of Enriched Charge (cm)

Figure 1-8

Figure 2-3

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Figure 3-5

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Figure 4-5

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Figure 5-8

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REACTIVITY BALANCE
(in mk)

F Reactor

Date 1-10-62

By: _____

A. REGION DATA

Region	1	2	3
Number Tubes	1018	190	796
Fraction ENR	0.028	0.753	0
Exposure Natural	475	512	456
Exposure ENR	511	678	-
Average Factor	1.19	1.17	0.75

B. REACTIVITY BALANCE μb

Region	1	2	3
B_M^2	65.3	208.7	60.1
B_X^2	-43.6	-43.5	-42.8
B_S^2	-8.9	-8.9	-8.9
B_N^2	-5.9	-4.5	-3.7
B_{LTG}^2	7.4	-1.9	7.6
B_T^2	43.6	46.4	27.6
B_m^2	-10.8	-11.4	6.8

Cold Clean 29.08

Δ Cold Clean

Control

Rods 8.88
PCCF 3.36
Splines 0.62
Total 12.86

Specials

M¹sc. 0.66
Li-Al 1.32
SR 0.23
PA 0
D&B 1.11
T.F. 0
Total 3.32

ΔR Xe, Moderator, Metal Heating 8.31

ΔR Power: Xe, Sm, Np, LTG, Moderator, Metal Heating 12.90

ΔR E-N Spike 7.65 Radial 8.14 Compensating 1.05

C. REACTOR DATA

1. ECT 1488
2. He % 98
3. Avg. Max. Tube Power 1253

4. Avg. Max. Tube Outlet Temp. 106.0
5. Max. Graphite Temp. 617
6. Orificing Efficiency 0.81

DATE

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8 / 31 / 94

END