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THE REACTIVITY EVALUATION OF PITA-IP22
DEMONSTRATION LOAD, SUPP. III

I. INTRODUCTION AND PURPOSE

PITA-IP22, SUPP II¹ has pointed out that distinct processing advantages may be realized by simplifying the E-N core by minimizing the number of different kinds of charges and the number of target slugs per charge. In an effort to experimentally verify the theoretical effects of converting to a simplified loading, a 102-tube test section, consisting of three 5.0 inch Li-Al target elements per tube was recently charged in H Reactor, under authority of the PITA supplement.

The purpose of this document is to evaluate the basic reactivity of the 102-tube test section, and to determine, from an operational physics viewpoint, whether full scale operation with the simplified core loading would be feasible.

II. SUMMARY AND CONCLUSION

The basic conclusion of this preliminary analysis is that it is reasonable, from a reactivity viewpoint, to charge the entire central zone of H Reactor with the new loading configuration as specified in PITA-IP22, SUPP. II¹. Calculations indicate a total pile reactivity change of ± 3 mk for the full scale loading, with a positive change the more probable. Such a reactivity increase can initially be taken care of by splines; ultimately, slight loading changes may be necessary to compensate for any such reactivity gain.

III. DISCUSSION

Evaluation of the basic lattice buckling of the test core required that first the reactivity (buckling) of the standard (fourth) core be ascertained; accordingly, one complete machine pass was used to find this buckling. After this value was established, the basic multiplication of the "demonstration load" was determined keeping in mind the fact that the fifth E-N load is simply the fourth E-N load plus the 102-tube test section. All reactivity calculations were performed with the aid of VITABUCK, a one-group diffusion theory computer code.

Two slightly different methods were employed in this evaluation, to provide cross checks on the reactivity. In both cases the reactor was divided into five concentric cylindrical regions: Region One - the 102-tube test block; Region Two - the remainder of the central zone; Region Three - the enrichment ring; Region Four - the fringe; and Region Five - the first lattice. Both methods mentioned above utilized and attempted to match reactivity data from startups on the fourth and fifth E-N blocks.

A. General Approach to the Problem

Basically, the problem evolved to an examination of observed operating characteristics of the reactor with and without the special 102-tube block in place.

From the observed full pile reactivity (both cold and hot-operating), the required test zone buckling was calculated by standard flux matching techniques.

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In the determination of the basic cold reactivity for the standard (fourth loading) E-N block (without the test core), observed data from several startups was considered; the data from all cases except one (the startup of August 16, 1963) was rejected due to abnormally wet startup conditions. The August 16 startup was used in the analysis outlined below.

The reactor loading at startup suggested geometrical breakdown into five regions of characteristic materials:

<u>Region</u>	<u>Radius, cm</u>	<u>Contents</u>
1,2	118.4, 401.2	1154 E-N "Striped" columns, 16 B-metal, 1 "Boll", 5 air channels, 8 graphite stringers, 10 PCCF columns (the central 102 channels constitute Region 1, the test core).
3	449.7	304 42-piece enriched-plus-mixer columns, 2 graphite stringers
4	497.0	332 43-piece enriched, no mixers
5	520	168 Boll, 3 B-metal, 1 air channel

In the actual calculation, Region Five was treated as a reflector augmentation, and was assigned a buckling identical to that of Region Four; this artifice results in a calculated flux distribution which closely resembles the observed. The region boundary corresponds to the point where the observed flux distribution of the active portion of the reactor would extrapolate to zero.

Average power factors and residual exposures were assigned to the regions, based upon standard production computing data.

<u>Region</u>	<u>Average Factor</u>	<u>$\bar{k}$</u>
1, 2	1.082	93.9 MWD/Tube
3	0.985	58.9
4	0.592	~58.9

B. Calculation of Effective Material Bucklings

Corrected material bucklings for the designated regions were calculated by the techniques outlined in References 2 and 3. The individual "delta bucklings" are summarized below:

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1. Effect of Nonuranium Columns

<u>Region</u>	<u>Nonuranium Material</u>	<u>Column Nominal Reactivity²</u>	<u>EBNom</u>	<u>δB^2</u>
1,2	10 PCCF	-44.9 c-mk	-449 c-mk	
	1 Boll	-164.4	-164.4	
	5 Air Channels	-11.6	-58.0	
	8 Graphite Stringers	-16.9	-135.2	
	16 B-Metal	-21.7	-347.2	
	Average	-28.9		-255 μb
3	2 Air Channels	-11.6	-23.2	
	Average	-11.6		-61 μb
4	None			

2. Material Bucklings Including Nonuranium Columns

$$B_{m1,2}^2 = X$$

$$B_{m3}^2 = \frac{(277)(302) + (-61)(2)}{304} = 274.8 \mu b$$

$$B_{m4}^2 = B_{m5}^2 = 277.0 \mu b$$

3. Axial Leakage

$$\delta B_{A1,2} = \delta B_{A13} = \delta B_{A14} = \delta B_{A15} = -15.2 \mu b$$

4. Cold Long-Term Gains

$$\delta B_{Ltg1,2} = -485 \text{ c-mk} = -7.85 \mu b$$

$$\delta B_{Ltg3} = B_{Ltg4} = -187 \text{ c-mk} = -3.03 \mu b$$

5. Mixer Reactivity⁴

$$\delta B_{m3}^2 = -2.30 \mu b$$

6. Xenon

The power (flattening) correction factors for use in xenon computations are calculated using methods described in Reference 2. In general, the corrected power for a given region may be expressed as

$$\gamma^* = (\text{Constant}) W_{\text{actual}}$$

where the constant is composed of three factors, $\bar{f}_1$, $\bar{d}f$, $\bar{m}f$.

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Thus, $W_i^* = (W_{\text{actual}})(\overline{mf})(\overline{df})(f_i)$

$$W_{1,2}^* = (1615)(1.082)(0.72)(0.789) = 993 \text{ MW}$$

$$W_3^* = (1615)(0.985)(0.8)(0.789) = 1004 \text{ MW}$$

$$W_4^* = (1615)(0.592)(1.0)(0.789) = 754 \text{ MW}$$

Xenon and iodine reactivities were obtained from the tables, using the above corrected power levels.

Accordingly, after a 27.7 hour outage,

$$\delta B_{Xe_{1,2}} = -37.80 \text{ } \mu\text{b}, \delta B_{Xe_3} = -38.18 \text{ } \mu\text{b}, \text{ and } \delta B_{Xe_4} = -29.69 \text{ } \mu\text{b}$$

7. Samarium

$$\delta R_S = \delta R_S^E + \overline{pf} (\delta R_P^E - \delta R_P^O) e^{-\lambda_P t} - [\delta R_S^E - \delta R_Q^O + \overline{pf} (\delta R_P^E - \delta R_P^O)] e^{-\sigma_S \phi t}$$

Substitution into the above equation yields ($\delta R_S = \delta B_S^2$)

$$\delta B_{S_{1,2}}^2 = -10.2 \text{ } \mu\text{b}, \delta B_{S_3}^2 = -10.1 \text{ } \mu\text{b} \text{ and } \delta B_{S_4}^2 = -9.62 \text{ } \mu\text{b}$$

8. Neptunium

$$\delta R_N = \delta R_N^E + (\delta R_N^O - \delta R_N^E) e^{-\lambda_N t}$$

Substitution into the above equation yields

$$\delta B_{N_{1,2}}^2 = -2.32 \text{ } \mu\text{b}, \delta B_{N_3}^2 = -2.11 \text{ } \mu\text{b}, \text{ and } \delta B_{N_4}^2 = -1.27 \text{ } \mu\text{b}$$

9. Control Rods

All HCR's were out during this startup; therefore, $\delta B_{CR}^2 = 0$.

10. Sum of Bucklings

$$B_1^2 = B_{M1}^2 + \delta B_{A1}^2 + \delta B_{Ltg1}^2 + \delta B_{S1}^2 + \delta B_{Xe1}^2 + \delta B_{N1}^2 + \delta B_{M1}^2$$

$$B_{1,2}^2 = X - 15.2 - 7.85 - 10.2 - 37.80 - 2.32 = X - 73.37 \text{ } \mu\text{b}$$

$$B_3^2 = 274.9 - 15.2 - 3.03 - 10.1 - 38.18 - 2.11 - 2.30 = 203.42 \text{ } \mu\text{b}$$

$$B_4^2 = 277.0 - 15.2 - 3.03 - 9.62 - 29.60 - 1.27 = 217.72 \text{ } \mu\text{b}$$

$$B_5^2 = 217.72 \text{ } \mu\text{b}$$

C. Calculation of Core Effective Material Buckling Based on Startup Reactivity

The summarized input data was then prepared for the VITABUCK computer code; the indicated material buckling ($B_{1,2}$) was calculated by the code to fit observed total reactivity, assuming all bucklings except $B_{1,2}$ known. The resulting E-N core buckling, corrected for nonuranium columns, was found to be 79.77 μ b.

Next, the case with Region 1 charged with the "test core" load was similarly analyzed; this time, the buckling for Region 2 was set at 79.77 μ b, as indicated by the first pass. Two reactor startups were thus investigated; the data from the October 8, 1963 startup was selected, since the reactor was relatively dry at that time. A corrected value of 84.68 μ b was accordingly established for the 102-tube test block buckling.

The "test core" buckling was next estimated in a slightly different manner; this method differs from the foregoing procedure in that material bucklings were compensated only by axial leakage and exposure effects (long-term gains, samarium, etc.). The basic core loading of 79.8 μ b was used.

Bucklings from -50 to +150 μ b were assigned to the test section, and the computer program was then asked to give full pile delta bucklings which would bring the pile to a critical condition. These values were converted to the desired reactivity unit (c-mk), and then were plotted in Figure 1 as cold clean reactivities. On the October 8, 1963 startup, a cold clean reactivity of 3072 c-mk was observed. From Figure 1, this reactivity corresponds to a test section buckling of 77.5 μ b. After making a nonuranium column correction, the 102-tube test block buckling was seen to be 81.37 μ b. Thus, the "test core" buckling (i.e., cold reactivity) is assumed to be slightly greater than the standard (fourth core) loading.

D. Hot Reactivity Change Between the Fourth and Fifth Loads

An equally or more important reactivity consideration is the available hot operating reactivity. A straightforward attack along these lines utilizes the well-known criticality condition⁵.

$$\int_{R_1} (B_1^2 - B^2) \phi^2 dV + \int_{R_2} (B_2^2 - B^2) \phi^2 dV = 0$$

In our case, R_1 is the region from the axis of the reactor cylinder to the to the boundary of zones one and two, and R_2 is the remainder of the central zone. Since it is known that $\phi^2 = Kf^2$, where K is a constant and f is the so-called tube factor, a factor-squared plot may be used. Upon special request, production computing computed the value $\sum_{i=1}^6 f_i^2$ in selected top-to-

bottom and side-to-side locations for the 4th and 5th E-N blocks; this provided, in effect, a radial flux distribution through the buckled zone.

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Then, the above equation may be reduced to a more applicable form:

$$\int_0^{6LU} B^2 f^2 dr + \int_{6LU}^{19LU} B_C^2 f^2 dr = \int_0^{19LU} B^2 f^2 dr$$

Where B_T and B_C are the bucklings of the test section and the remainder of the flat zone, respectively. The buckling of the 4th E-N central zone is represented by B . This equation was solved by numerical integration methods (Trapezoid Rule) in four directions, i.e., center-to-top, near, far, and bottom. After averaging the coefficients of the corresponding four equations, the following result was obtained:

$$B_T^2 + 2.4675 B_C^2 = 3.5955 B^2$$

$$\text{since } B_C^2 \approx B^2,$$

$$B_T^2 = 1.128 B^2$$

The indicated "hot operating" reactivity of the test section is thus 12.8 per cent greater than the present load, that is, $\Delta\rho = (3072 \text{ c-mk})(0.128) = 393 \text{ c-mk}$. After corrections for loading changes between the 4th and 5th block are imposed, the full pile effect is estimated at $\sim +2 \text{ mk}$ total reactivity, if the "test core" is expanded to full central zone size.

E. Summary of Results

E-N Type	$B_m^2, \mu b$	$\Delta\rho, \text{ c-mk}$
(18 - 4.2 inch N)/5 tubes	79.77	
(6 - 5.0 inch N)/2 tubes	81.37	+99
	84.68	+303
		+183*

*Hot reactivity; corrected for loading changes.

Thomas H. Essig
 Thomas H. Essig
 Technical Graduate
 Pile Physics Unit
 Operational Physics Subsection
 Research and Engineering

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Figure 1

Observed Cold Clean Reactivity, in c-mk

*Includes nonuranium columns

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