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CONVERSION RATIO CONSIDERATION
IN THE E-N FRINGE LOADING

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CONVERSION RATIO CONSIDERATION IN THE E-N FRINGE LOADING

by

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January 9, 1961

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CONVERSION RATIO CONSIDERATION IN THE E-N FRINGE LOADING

W. S. Nechodom
Process & Reactor Development

INTRODUCTION AND PURPOSE

This document summarizes the requested study of theoretical factors influencing the expected conversion ratio of the fringe enrichment portion of an E-N loading. Exact calculation of the quantity is very complicated and will not be attempted here; however, it is possible, with simple geometric approximations, to derive relative conversion ratios, based on a method discussed in a previous report(1). This present report summarizes the results of a study incorporating actual operating data from the present poisoned top and unpoisoned bottom fringe loadings at H Reactor.

SUMMARY

There is calculated decrease in buckled-zone (E-metal blanket) conversion ratio of 13% in the E-N loading as compared to normal fringe loadings; this loss is due to the effective reduction in pile size due to the presence of the blanket of BOLL material in the outermost lattice unit and the accompanying increase in enrichment demands. On a full pile basis, this loss represents about 5%. However, on the assumption that an atom of tritium is equivalent in value to an atom of plutonium, the BOLL material in the outermost layer augments over-all pile conversion by about 4% in the green reactor, and probably more in the ripe reactor(2), in addition to compensating the 5% loss in the E-metal blanket. An Appendix is included as a possible help in interpreting conversion ratio observations in fringe E-columns(3).

DISCUSSION

Source of Data

The present H Reactor loading includes a solid layer of BOLL material at the top of the reactor, followed by 5-tube layer of enrichment. Since this arrangement characterizes the anticipated fringe loading for the full-pile E-N load, it appears logical to draw some conclusions from it.

The thermal flux distribution (based on relative tube power) for the fringe is tabulated in Table I and presented in Figure 1; the two cases presented are for the normal fringe loading (Curve A) and for the E-N fringe loading (Curve B). The extrapolation distance for each load was determined analytically based on the flux points; of particular interest is the difference in pile augmentation between the two cases. Evidently, the E-N loaded reactor will have an effective radius of approximately 45 cm less than the effective radius with the "normal" fringe loading (i.e., a combination of normal uranium and enrichment); these observations are illustrated in Figure 1.

Calculational Techniques

The calculational techniques employed were straightforward. The fringe flux distribution for the H Reactor E-N load was plotted from operating data and then fitted with an equation of the form $A+Bx+Cx^2$, from which the extrapolation distance was determined. The flux distribution for the normal fringe (normal uranium plus enrichment) was similarly treated. The difference in extrapolation distances was then subtracted from the effective radius of the reactor front face; the resulting radius was considered to be the effective radius for a full-pile E-N loading. The result indicates that the pile

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DISCUSSION (Cont'd.)

Calculational Techniques (Cont'd.)

is effectively bounded by the BOLL material, which is to be expected; i.e., effectively all thermal neutrons passing into the BOLL layer are captured.

Once the E-N effective radius was determined, the effective fringe buckling was calculated from the relationship:

$$(1) \quad \frac{Y_1(b_2 r_1)}{J_1(b_2 r_1)} = \frac{Y_0(b_2 r_2)}{J_0(b_2 r_2)}$$

by the method of repeated trials. In equation (1)

J_i , Y_i are i^{th} order Bessel functions of the i^{th} first and second kinds, respectively, r_1 and r_2 are radius of flattening and radius of pile, respectively, and b_2^2 is the effective fringe buckling necessary to support a flat zone of radius r_1 .

Since current H Pile flattening efficiency is characterized by a 396 cm flat zone, and the extrapolated width of the E-N fringe zone is 140 cm, r_1 and r_2 are 396 cm and 536 cm, respectively. The quantity b_2^2 (or B_2^2) was found to be 142 μb (1 " μb " = 10^{-6} cm^{-2}).

Conversion Ratio Estimates - Enriched and Normal Uranium

The initial conversion ratio for enriched material in H Reactor is .680 $\frac{\text{atoms Pu produced}}{\text{atom U-235 consumed}}$ in a reactor with a cosine flux distribution*. The conversion ratio for any leakage is given approximately by:

$$(2)* \quad C_0 = 0.445 + 0.239 e^{-B^2 \tau}$$

where

τ is the Fermi age.

In H Reactor, τ is about 348 cm^2 , and the longitudinal buckling is 15.2 μb for a 32 piece normal uranium (equivalent) loading. Thus the total fringe leakage is characterized by $B^2 = 142 + 15 = 157 \mu\text{b}$, and the fast leakage by $e^{-B^2 \tau} = 0.9469$. From equation (2); the initial conversion ratio is $0.445 + 0.239 (.9469) = 0.671 \text{ atoms/atom}$ for the fringe material, assuming the fringe is composed only of enrichment and BOLL.

Similarly, the initial conversion ratio for natural uranium is given by:

$$(3)* \quad C_{0N} = 0.592 + 0.242 e^{-B^2 \tau}$$

In the present bottom fringe loading (no fringe poison) the effective fringe buckling is 87 μb and the fast non-leakage probability is $e^{-B^2 \tau} = .9702$; this leads to natural and enrichment conversion ratios of 0.827 and 0.677, respectively, assuming one effective buckling applicable to both.

*Equations (2) and (3), and the initial conversion ratios were derived from FLEX IBM Code output, courtesy of W. L. Bunch.

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DISCUSSION (Cont'd.)

Pile Weighting

Table I shows relative flux distributions and other data based on existing pile observations⁽⁴⁾.

TABLE I

Flux Distributions from Operating Data

*l.u.	**Number of Tubes	E-N Load Relative Flux	$f_{i,1}$ E-N Load Rel. Power	Normal Load Rel. Flux	$f_{i,2}$ Normal Load Rel. Power
1	170	.18	---	.50	.50
2	163	.42	.49	.64	.64
3	155	.63	.73	.77	.77
4	148	.79	.92	.87	.91
5	140	.90	.95	.94	.99
6	.33	.97	1.02	.98	.98

* Distance into pile from reflectors measured in lattice units

** Number of tubes in blanket surrounding cone, at this distance into the pile

The fraction of pile power that is produced in the fringes is found from:

$$(4) \quad f = \frac{\sum_{l.u.1}^{l.u.6} f_i n_i}{\text{pile } f_i n_i}$$

Using the data in Table I, the relative powers are 37.18% for the E-N fringe and 39.96% for the present fringe. (It is assumed that the relative heat generations for 43- and 34-piece E-columns are 1.16 and 1.05, respectively.) Similar considerations indicate that 38.4% of the power in the present fringe loading is produced in the E metal. Thus, an effective fringe conversion factor for the "normal load" is

$$(.616)(.827) + (.384)(.677) = 0.769$$

Thus, there is a loss in conversion ratio in the fringe columns of $0.769 - 0.671 = .097$ or 12.6%; since the fringe in each case produces roughly 40% of the pile power, the loss projected to a full pile basis is 5%.

Correction for Tritium Production

To estimate the augmentation due to tritium production in the BOLL material, the initial conversion ratio for the E-N fringe will be converted to gms/MWD.

From the Accountability Reference⁽⁵⁾ the relationship between $\frac{\text{atoms Pu formed}}{\text{atoms U-235 destroyed}}$ and $\frac{\text{gms Pu}}{\text{MWD}}$ is obtained for the low exposure of 10 MWD/T; this factor is 1.129, or,

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DISCUSSION (Cont'd.)

stated another way, the initial conversion ratio in gms/MWD is 1.129 times the initial conversion factor in atoms Pu formed. Thus the adjacent fringe atoms U-235 destroyed

E-column is producing $(1.129)(.671) = .758$ gms/MWD; however, for the same MWD, the fringe BOLL column produces 1.407 gms/MWD(6). Thus, one fringe BOLL column is worth $\frac{1.407}{.758} = 1.86$ of its neighboring E-columns.

Now, considering that there are 170 columns in the BOLL blanket, and the average power factor for the adjacent E-column is 0.49, the BOLL material may be considered to produce $\frac{(170)(0.49)(1.86)}{598} = 0.255$ as much plutonium as the rest of the fringe E-metal combined, where the number 598 is $\sum_{i=1}^{1.4.6} f_{in_i}$. The fringe E-metal has a conversion factor of 0.671, and since the BOLL produces tritium and does not contain U-235, the effective fringe conversion is $1.256 (0.671) = 0.842$. Comparing this number to the "normal load" conversion,

$$\% \Delta C_o = \frac{0.842 - 0.769}{0.769}$$

or an over-all gain in fringe conversion of 9.49%.

Projecting this to full pile conversion, the over-all gain is approximately $.40 (9.49) = 3.80\%$

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APPENDIX

QUALITATIVE REASONING FOR VARIATION IN RADIAL BUCKLING DUE TO FRINGE LEAKAGE

Measured conversion ratios⁽⁷⁾ for fringe E metal have been considerably lower than expected, based on current accountability references. The following is presented as a possible explanation.

Only qualitative conclusions should be drawn from the concept at present; however, it is currently being investigated on a much more detailed basis than is presented here, and firm quantitative results will be forthcoming. They will be published if warranted.

The buckling of a reactor at critical is given by:

$$(5) \quad B^2 = - \frac{\nabla^2 \phi}{\phi}$$

where

B^2 is the pile buckling
 ϕ is the flux
 ∇^2 is the Laplacian operator.

In a reactor whose composition is uniform from reflector to reflector, the buckling is not a function of position, and the uniform materials buckling is everywhere equal to the geometric buckling. The solution to equation (5) is then either $\phi = \cos Bx$ or $\phi = J_0(Br)$. A perfectly uniform loading is rather hard to come by in actual practice, however, due to flattening requirements, non-uniform fission product and temperature effects, control rods, etc., and consequently, the buckling varies across the reactor. However, since every point in a critical reactor is critical itself (or very close to critical), the buckling at any point is still $-\frac{\nabla^2 \phi}{\phi}$. Thus, if one could accurately describe the flux distribution, one could accurately derive the buckling.

Consider the flux distribution given in Figure 1, derived from operating data. It looks like a portion of a sine or cosine function, but a moment's reflection will prove otherwise. The buckling across the region cannot be constant, since it is a garbled mixture of lithium, E-metal, xenon, and displaced cross-sections. Theoretically, the flux distribution could be described by an infinite conglomeration of sines and cosines, a characteristic set for each individual point. One can also, if daring enough, describe the flux distribution by a polynomial:

$$(6) \quad \phi = A + B + C^2 + D^3 + \dots$$

Then the buckling is given by:

$$(7) \quad B^2 = \frac{-2C + 6D + 12E^2}{A + B + C^2 + D^3 + E^4 + \dots}$$

to any desired accuracy, depending upon the number of terms carried in equation (6).

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In the present case, the E-N fringe flux distribution was fitted to a polynomial in x^2 :

$$\phi = 0.139 + 0.327x - 0.0237x^2.$$

The buckling then is (approximately) $\frac{.0474}{\phi}$, and is plotted in Figure 2. A sharp

increase in buckling is noted as the BOLL layer is approached from the center, which may appear improper at first glance. If one considers the extremely sharp bending that the flux undergoes near the BOLL, (which is by definition the buckling), however, the idea of the buckling varying with radius appears reasonable.

Now consider the E-column residing adjacent to the BOLL; it "sees" a buckling (in this example) of 250 ub, while the fringe as a whole sees an effective buckling of only 140 ub. Calculating its conversion ratio, we find:

$$C_0 = 0.445 + 0.239 e^{-(250 \times 10^{-6})(348)} = 0.662$$

In contrast, the E-column adjacent to the flat zone "sees" a conversion factor $C_0 = 0.673$. The conversion factors for the various lattices are plotted in Figure 3.

A further note on the validity of this method may be appropriate. The fringe buckling for several different reactors has been evaluated in this manner, and in each case the flux-squared-weighted buckling agreed very closely with conventional one-group diffusion theory results. (The effective pile size dictated by the zero point of the analytical flux distribution was used in these calculations.) Furthermore, the method was applied to both near and far sides at KE Reactor [assuming $\phi = A+Bx+Cx^2+Dx^3$] and the difference in buckling plotted as a function of position. Since the near and far enrichment rings are very nearly identical, the buckling difference at the zeroth lattice unit should equal the local strength of the HCR's flux squared weighted if the traverse is made in a region where all rods are penetrating the zeroth lattice unit. When this weighting is considered in the present case, the observed strength of 50 μ b compares quite well to the pile strength of 54 μ b calculated by more refined methods.

Admittedly, this presentation does not tell the full story; one must utilize more terms in the flux distribution and multigroup theory to fully analyze a given reactor. However, since tube powers rather nicely describe the thermal flux, and since a great deal of reactor work is done adequately with one-group theory, the general technique should have considerable application. The application to conversion ratios included herein is not strictly valid, since the fast flux distribution is not identical with the thermal flux distribution; however, comparisons should be qualitatively acceptable

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Relative Flux, Arbitrary Units

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FIGURE II
Conversion Factor Variations;
Order Approximation

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