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VALIDITY OF HOMOGENEOUS METHOD-
OVERBORED VS. PRESENT LATTICE CONVERSION RATIOS

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VALIDITY OF HOMOGENEOUS METHOD -
OVERBORED VS. PRESENT LATTICE CONVERSION RATIOS

W. D. Gilbert
Special Studies
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INTRODUCTION AND PURPOSE

As per your request, a study was made to establish the validity of using homogeneous-lattice machine program calculations of the relative conversion ratio of the overbored lattice as compared to the present case. A full discussion of this variable is inordinately complex and must await extensive machine computations and detailed studies; consequently, such a discussion is not attempted here. However, it is possible to draw both qualitative and quantitative conclusions from hand calculations utilizing simplified geometries; it is the purpose of this document to summarize such a study. Numbers included herein are not intended to represent absolute quantities, since the required calculations lie outside the scope of this study. Nevertheless, it is felt that a comparison of the overbored to the existing lattice based on the values presented here is a good "first order" approximation.

SUMMARY AND CONCLUSIONS

1. Based on two-region buckling calculations and the associated fringe leakage, it appears that the machine program* homogeneous technique would over-calculate the overbore case conversion ratio by ~1.1%; however, the over-calculation is little over one-half that for the present lattice (i.e., the program would over-calculate current production by ~1.7%). Therefore, the net improvement, overbored over present case, as calculated by the program should be slightly conservative. In each case, the over-calculation is due to inability of the program to consider differential leakage effects of flattened versus unflattened flux distributions. (This comparison assumes that current flattening efficiency will be maintained.)
2. Conversion ratios for cosine distributions as calculated by the uniform enrichment technique should be fairly accurate when projected to a "spike" enrichment concept. Flux dimpling and peaking due to the varying blackness across the core (due to interspacing enrichment and normal uranium) is assumed to be a second order effect, and the pile very likely homogenizes itself much as the machine calculation program assumes.
3. Due to the significant decrease in conversion ratio with increasing flattening efficiency, there is economic incentive to operate a reactor with the natural (chopped cosine) flux distribution if the only limit to operation is bulk outlet temperature.

DISCUSSION

Two cases of overbored operation in the C Reactor were considered--a "flattened" flux distribution (corresponding to ~85% flattening efficiency or 1650 ECT) and a natural "chopped cosine" distribution. For an approximation to the effect on

* FLEX, IDIOT, etc.

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overall pile conversion ratio due to fringe leakage, the fringe was treated as a slab of material of buckling sufficient to support a particular flat zone (radius 400 cm). The resulting uniform fringe leakage will not exactly equal that for a two-region fringe (i.e., an enrichment ring followed by a blanket of normal uranium), but the difference is undoubtedly small, and does not significantly affect the conclusions. The conversion ratio for the pile was then calculated as an average of a central zone conversion plus a fringe zone conversion.

The initial conversion factor for a production reactor in atoms Pu formed,
is given by: (1) atoms U-235 destroyed

$$C_0 = \frac{\sigma_a(28)}{R \sigma_a(25)} + \eta(25) \epsilon P_f P_r (1-p) \quad (1)$$

where

$\sigma_a(28)$ = thermal absorption cross section of U-238
 $\sigma_a(25)$ = thermal absorption cross section of U-235
 R = % U-235 in fuel
 $\eta, \epsilon, P_f, P_r(1-p)$ = fast and resonance contribution to plutonium production.
 B^2 = buckling
 τ = Fermi age

(Strictly speaking, this equation yields the number of atoms of Uranium-239 formed per U-235 atom destroyed; the difference between this and the plutonium production rate is negligible for present purposes.) It can be seen that the conversion factor can be broken down into two parts:

$$C_0 = f_1 (\text{thermal absorption}) + f_2 (\text{fast and resonance absorption}) \quad (2)$$

Furthermore, it is seen that the thermal portion is a function of fuel makeup only; other lattice characteristics and system geometry effects are tied up in the fast absorption portion.

The quantities P_f and P_r are the fast and resonance non leakage probabilities, respectively. They may be combined without incurring any serious error by considering their product as the probability of a fast neutron reaching thermal velocity, which is the familiar $e^{-B^2 \tau}$, τ being the age-to-thermal of fission neutrons. Furthermore, for a given lattice temperature, $\eta(25)$, ϵ , and p are constant, thus we may write simply

$$\begin{aligned} C_0 &= (\text{Const.})_1 + (\text{Const.})_2 e^{-B^2 \tau} \\ &= A_1 + A_2 e^{-B^2 \tau} \end{aligned} \quad (3)$$

(1) The Physical Theory of Neutron Chain Reactors, A. M. Weinberg and E. P. Wigner, p. 178.

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The purpose of this notation is to allow use of already calculated conversion factors; these were computed by the FLEX IBM-709 program, courtesy of R. J. Shields. He has calculated the factor C_0 for natural and enriched fuel in both the present and overbored lattices, assuming a cosine flux distribution in a one-region reactor; from the FLEX program output, the following relationships are determined:

	C_0 , 500 mil Overbored Lattice	C_0 , Present Lattice
Natural	$0.587 + 0.402 e^{-B^2\tau}$	$0.590 + .245 e^{-B^2\tau}$
Enriched	$0.441 + 0.395 e^{-B^2\tau}$	$0.443 + .241 e^{-B^2\tau}$

It is evident that the fast- and resonance-production contribution is relatively higher in the overbored case; this is to be expected due to the higher fast-to-thermal flux ratio in the under-moderated lattice. (The small variations in the thermal conversion are due to different assumed neutron temperatures for the two cases.)

The non-leakage factor $e^{-B^2\tau}$ was evaluated utilizing FLEX calculations for τ , the Fermi age, and flux-matching calculational techniques to determine the buckling B^2 . In the unflattened case, of course, the buckling of the entire reactor is given by

$$B_g^2 = \left(\frac{2.405}{R'} \right)^2 + \left(\frac{\pi}{L'} \right)^2 = 31.5 \times 10^{-6} \text{ cm}^{-2} \text{ (31.5 "micro-bucks")}$$

where R' is the augmented radius of an equivalent cylindrical pile (600 cm at C Reactor),
and L' is the augmented length (805cm).

The flattened case buckling is determined by solving the critical equation

$$\frac{Y_1(b_2 r_1)}{J_1(b_2 r_1)} = \frac{Y_0(b_2 r_2)}{J_0(b_2 r_2)} \quad (4)$$

where J_1 , Y_1 are Bessel Functions of the first and second kinds, respectively, r_1 and r_2 are respectively radius of the flat zone and pile, and $b_2 = \sqrt{B_2^2}$.

The equation was solved for $r_1 = 400$ cm and $r_2 = 600$ cm, which is equivalent to ~1650 ECT; the calculated value for the required buckling B_2^2 is 72.9 μb in the radial plane, plus 15.3 μb in the longitudinal (unflattened) plane. This quantity is related to the lattice multiplication constant approximately as the equation

$$B^2 \sim \frac{k_{\infty} - 1}{M^2} \quad (5)$$

FLEX output includes all necessary factors for evaluating B^2 ; available case studies include the present and 500-mil-overbored lattice. Utilizing this data and equation (3) for natural and enriched elements at a "discharge" pile exposure of 600 MWD/ton (the pile contains fuel from 0 to 600 MWD/ton rather evenly distributed); the enrichment requirements for the two degrees of flattening were calculated.

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The fringe zone buckling in both cases is simply $88.2 \mu b$ (72.9 radial + 15.3 longitudinal); lattice "buckling" values follow: (2)

	<u>Overbored (500 mils)</u>	<u>Present Case</u>
Natural	5.57 μb	31.5 μb
Enriched	171 μb	182 μb

The fractional portion, f_E , of a region that must be charged enrichment is determined from

$$B_r^2 = f_E (B_E) + (1-f_E) B_N \quad (6)$$

where

$$B_r^2 = \text{required regional buckling}$$

$$B_E = \text{enriched lattice buckling}$$

$$B_N = \text{normal uranium lattice buckling}$$

$$f_E = \frac{\text{No. E tubes required}}{\text{Total No. Tubes in Region}}$$

Results for the present cases are tabulated below:

	<u>Overbored Lattice f_E</u>	<u>Present Lattice f_E</u>
Flattened Flux, central region*	.168	.009
Flattened Flux, fringe region	.499	.379
Cosine Flux, central region*	.266	.112
Cosine Flux, fringe region	.190	0

*Central region includes 12 mk excess reactivity for rods and flattening

The conversion factor for a given region is then found by weighting the natural and enriched factors, $(C_o)_N$ and $(C_o)_E$ by their pile weighting (i.e., the flat zone, or central region, produces 60.8% of the reactor power), as follows:

$$(C_o)_{\text{Pile}} = .608 [f_E (C_o)_E + (1-f_E)(C_o)_N] \text{ flat zone} \quad (7)$$

$$+ [.392] [f_E (C_o)_E + (1-f_E)(C_o)_N] \text{ fringe zone}$$

The technique was applied for only two cases, or degrees of flattening; it is equally applicable for any flattening efficiency, but time and space limitations do not allow discussion in the present document.

The initial conversion ratios calculated for the two cases in the present and overbored lattices, together with other pertinent data, follow:

Flux Distribution	<u>Present Lattice</u>		<u>500 Mils Overbore Case</u>	
	Cosine	Flattened	Cosine	Flattened
ECT	<1000	~1650	<1000	~1650
No. E-Cols. Required	124	348	466	633
Initial Conversion ratio	.823	.809	.949	.939

(2) Personal communication from W. L. Bunch; FLEX Program Output

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It is noteworthy that flattening a reactor for improved flux distribution is accomplished at the expense of conversion ratio, due to the increased fringe leakage. Again, the given values should be utilized for indicating differences rather than absolute values.

A further note may be appropriate here. The flux matching technique predicts (3) 332 enriched tubes for 1650 ECI in a 3-region calculation for the existing C-pile lattice; there are currently 360 tubes of enrichment at C Reactor with a flattening efficiency of 1700 ECI. Consequently, it is felt that this part of the calculational technique employed herein is sufficiently accurate, and that considering the fringe as one uniform region rather than an enrichment blanket plus a natural uranium zone introduces no serious error.

CE Bowers

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

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(3) An unpublished analogue study by C. P. Farkas and W. L. Stiede

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