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ENRICHED FUEL ELEMENT COLUMN CHARGE LENGTH OPTIMIZATION

INTRODUCTION

The selection of an optimum length of enriched fuel column charge is one facet in the efficient use of facilities and raw materials. An evaluation has been made of the economic incentive of changing the enriched fuel column charge length from present operating practices.

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SUMMARY AND CONCLUSIONS

The results of the study on the best charge length of enriched fuel to be used in the reactors indicate that with the present quality of fuel elements there is no economic incentive to change the charge lengths from those currently being used. The expected returns for operating D and C reactors at optimum conditions with different length enriched fuel charges are given in Figures 1 and 2, respectively. Detailed results from calculations concerning the other reactors would also exhibit similar trends.

The results are based on several assumptions as listed in the discussion, chief of which is that there is no interaction between the neutron flux of the columns of enriched uranium fuel and of natural uranium fuel. The effect of the assumptions is to make the results appear more unfavorable than they actually may be.

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○ $T_1 = 8^\circ\text{C}$
□ $T_1 = 17^\circ\text{C}$

Figure 1 - Expected Return Vs. Enriched Column Length - D Reactor

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○ $T_1 = 8^\circ\text{C}$
□ $T_1 = 17^\circ\text{C}$

Figure 2 - Expected Return Vs. Enriched Column Length - C Reactor

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going to a longer column charge. If more were known about the relationships modified or excluded by the simplifying assumptions, recalculation might show that the optimum lengths of charges are greater than those currently being used.

It would be of value to gain additional knowledge of the interaction of the neutron flux between the columns of enriched fuel and adjacent columns of natural fuel. Such knowledge should promote improved flux distribution control, permitting better fuel element environment; additional gains would result by operating with longer fuel column charge lengths if the newly acquired knowledge indicated that such lengths are more desirable.

DISCUSSION

The uranium fuel loading for the reactors at Hanford is comprised normally of columns of elements containing natural uranium and columns of elements containing uranium enriched in the isotope uranium - 235 to a concentration of 0.946 per cent. These latter fuel elements are distributed to fulfill three requirements, namely, radial flattening, fringe poison compensation and central zone "spike" enrichment.

The amount and placement of enriched fuel used for these three purposes varies from reactor to reactor depending upon items such as total reactor control criteria, number and location of control rods, and the presence and distribution of poison.

The choice of the lengths of enriched uranium column charges is dependent upon numerous variables. These variables include incremental metal costs, charge-discharge losses, metal performance index, coolant flow and temperature, power distribution, etc. For this study it was assumed that the choice of length was independent of total control considerations, reactor stability, local perturbation of axial flux, and interaction of the neutron flux between the enriched and the natural uranium charges.

Calculations

The primary tool used to make calculations for this study was an IBM 709 digital computer program⁽¹⁾ which is based on the optimization formula developed by members of Process Technology⁽²⁾. Included in a subroutine was a computation for varying the conversion ratio with column length.

The current configurations of enriched fuel loadings were selected as the basis upon which to make alterations. The lengths and quantity of enriched fuel column charges in the central zone were kept constant for this study to avoid changing the amount of peaking in that region. In the outer fringes of certain reactors, such as F and H, the enriched fuel column charges supporting the fringe poison loading are full length and need not be changed. The remaining portion of enriched fuel loading, known as radial enrichment, was considered for possible modification.

The lengths of radial enrichment charges were incrementally increased from 34 to 43 pieces for D Reactor and from 35 to 43 pieces for C Reactor to determine the relative effect on the net return plus fixed costs expected from operating the reactors at optimum conditions for these cases of fuel loading. The number of columns of radial enrichment was decreased to compensate for the added reactivity obtained through the use of lengthened column charges.

Certain input parameters to the program have a large effect on the results yet are difficult to estimate. For example, changes in power distribution have a marked

influence on the reactor metal performance and hence production efficiency. Another variable to which the results are sensitive is tube metal performance index (tube CR) and its estimated change from current operating conditions. At a constant power, average fuel element exposure, and outlet temperature, the rupture loss is proportional to the tube CR value.

Results

The returns which might be expected from operating at optimum conditions while loaded successively with increased lengths of enriched fuel column charges are given in Table I for D Reactor and Table II for C Reactor.

TABLE I

Expected Return Vs. Enriched Column Length - D Reactor

No. Pieces Per Column	$T_i = 8^\circ\text{C}^*$		$T_i = 17^\circ\text{C}$	
	$Z(\$)^{**}$	$\Delta Z(\$)$	$Z(\$)$	$\Delta Z(\$)$
34	38,199	0	36,713	0
36	38,120	- 79	36,670	- 77
38	38,017	- 182	36,575	- 172
40	38,877	- 322	36,448	- 299
43	37,700	- 499	36,253	- 494
46	37,400	- 799	36,047	- 700

* T_i = coolant inlet temperature

**Z = net return plus fixed costs per day

TABLE II

Expected Return Vs. Enriched Column Length - C Reactor

No. Pieces Per Column	$T_i = 8^\circ\text{C}^*$		$T_i = 17^\circ\text{C}$	
	$Z(\$)^{**}$	$\Delta Z(\$)$	$Z(\$)$	$\Delta Z(\$)$
35	40,004	0	37,616	0
37	39,813	- 191	37,469	- 147
39	39,647	- 357	37,290	- 326
41	39,402	- 602	37,066	- 550
43	39,125	- 879	36,804	- 812

* T_i = coolant inlet temperature

**Z = net return plus fixed costs per day.

These reactors were investigated as representative of small and moderate per cent enrichment, respectively. The results indicate that, under the assumptions stated above, there is no economic incentive to use longer lengths of enriched fuel column charges. Similar results would be expected from all other reactors.

The results are based on the assumption that the axial neutron flux has a chopped cosine distribution and that this distribution does not change as the column charges are lengthened. That is, the chopped cosine flux distribution assumed to be existing

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for a full length column was used as the basic distribution. The neutron flux distribution for the shorter lengths were assumed to be the same as the center portions of the flux distribution associated with a full length column charge. In actuality, the neutron flux distribution of a shorter column charge has a higher maximum to average ratio than the distribution of a longer column charge.

Another factor which was assumed to have no effect for this study was the interaction of the neutron flux between charges of enriched uranium fuel and charges of natural uranium fuel. The true situation involves interaction between the flux arising from each type of fuel charge. The neutron flux of the natural uranium fuel charge is increased while the neutron flux of the same length of enriched fuel charge is decreased from what they would be if each charge were surrounded only by its respective type of fuel. The effect of a shorter length of enriched fuel charge on the flux distribution of an adjacent full length natural fuel charge is to increase it at the center and decrease it at the ends of the charge. The extent of the effect on the flux distribution diminishes as the distance from the enriched fuel column charges increases.

The net effect on the results of the study by the two assumptions listed above is to make the results of using longer enriched uranium fuel column charges appear to be worse than is the true situation. It would be beneficial to evaluate these aspects of the problem since the results of such evaluation may indicate that the optimum length of enriched uranium fuel charge is longer than those used in current practices.

Let us consider what changes might be made in light of the results of the study. There would be no economic loss due to changing to full length enriched fuel column charges if it were possible to modify the axial neutron flux distribution while increasing the enriched fuel column charge length from the present lengths to full length and thereby obtain a factor of improvement of approximately two in the tube metal performance index. If larger factors of improvement were attained, gains would result. An example of how a factor of two improvement might be accomplished for a constant length fuel column would be by depeaking a chopped cosine distribution by 13 per cent, or by moving the point of maximum flux upstream five pieces, or by some intermediate combination of these procedures⁽³⁾. The term depeaking, as it is used here, is defined as reducing the ratio of the maximum to average fuel element power factor by a given percentage. Figure 3 shows a chopped cosine curve, a curve depeaked 13 per cent, and a curve skewed upstream about six pieces and slightly peaked. Either of the latter two distributions would result in improving the tube metal performance index by a factor of two mentioned in this example.

It would be quite beneficial to learn more concerning the interaction of the neutron flux between columns of natural uranium fuel and adjacent columns of enriched uranium fuel. The knowledge of this interaction together with knowledge of methods of modifying the axial neutron flux might show that either one or a combination of the following improvements would be possible: 1) improved fuel element environment through optimization of axial neutron flux distribution and 2) increased net return by increasing the enriched fuel column charge length.

Figure 3 - Sample Flux Distributions

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