HEDL-TME 76-31
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MASTER

HIGH-^{240}PU FUEL WORTH IN THE FAST TEST REACTOR ENGINEERING MOCKUP

HANFORD ENGINEERING DEVELOPMENT LABORATORY
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ABSTRACT

Reactivity effects associated with the replacement of low-^{240}Pu fuel with high-^{240}Pu fuel were calculated and compared to measurements made in the FTR Engineering Mockup. When the Pu and U isotopic compositions were changed in a way that increased the amounts of ^{240}Pu and ^{241}Pu and reduced the amounts of ^{239}Pu and ^{238}U while conserving total fissile mass and total fertile mass, the reactivity effect was positive. Calculation-to-experiment bias factors were obtained for this type of change and for the replacement of Fe_2O_3 with U_3O_8 in subassembly-size zones of the EMC. The k_e-k_c bias decreased when high-^{240}Pu fuel was introduced and increased when Fe_2O_3 was replaced with U_3O_8. When the two changes were combined, their effects on the k_e-k_c bias tended to cancel out.

This work is related to plans for the utilization of light water reactor discharge Pu in the FTR.

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1.0 INTRODUCTION

The initial fuel loading for the Fast Test Reactor (FTR) will contain plutonium (Pu) having approximately twelve percent ^{240}Pu. Current plans call for light water reactor (LWR) discharge Pu, containing twenty to twenty-five percent ^{240}Pu, to be used starting with the fifth FTR core. Plutonium used in the FTR Engineering Mockup Critical (EMC) assembly was approximately twelve percent ^{240}Pu. Toward the end of the EMC experimental program, it was decided that some experiments should be performed to investigate possible changes in the FTR neutronics parameters due to changes in the isotopic composition of the FTR fuel.

A series of experiments was planned in which regions of the EMC were to be reloaded with fuel having Pu with a higher (approximately twenty-six percent) ^{240}Pu content. It was assumed that, when the transition is made from low-^{240}Pu to high-^{240}Pu fuel in the FTR, the net reactivity of the fuel assemblies should remain unchanged. Therefore, one criterion in planning the high-^{240}Pu experiments in the EMC was that the reactivity change due to the high-^{240}Pu fueled regions should be essentially zero.

A preliminary experiment was planned and performed in the latter stages of the EMC program to determine how to reload parts of the inner and outer driver zones with high-^{240}Pu fuel without a significant change in reactivity. In this preliminary experiment the reactivity worth was measured for the substitution of Pu-U-Mo platelets containing high-^{240}Pu fuel for similar platelets containing low-^{240}Pu fuel in FTR subassembly-size zones in both the inner and outer cores of the EMC. These measurements were followed by measurements of the worth of substituting uranium oxide (U_3O_8) platelets for iron oxide (Fe_2O_3) platelets in the same EMC zones. From the results of these two sets of measurements it was possible to determine how much of the Fe_2O_3 in the original EMC composition would need to be replaced with U_3O_8 in order to have essentially zero reactivity change when the low-^{240}Pu fuel was replaced with high-^{240}Pu fuel. A final set of measurements was made to determine if the selected loading with high-^{240}Pu fuel and additional U_3O_8 did indeed result in zero reactivity change.

The results of this preliminary experiment were reported[1] by Argonne National Laboratory (ANL) and were used in specifying the loading for the high-^{240}Pu sector and central zone experiments in the EMC. These results also provide a set of data for testing the cross sections and codes now being used by the FFTF project for computing the reactivity effects due to changes in the isotopic composition of fuel as well as the relative worth of Fe_2O_3 and U_3O_8.

The purpose of the work described in this report was to calculate the reactivity worths, compare the calculated results with the experimental results, and assess the status of the computational tools for calculating the worths of these types of composition changes.

2.0 SUMMARY

An experiment was performed in the FTR-EMC at Argonne National Laboratory to determine fuel loadings to be used in a later series of high-^{240}Pu sector and central zone experiments. Experimental data were obtained on the worth of replacing the normal EMC fuel, having low-^{240}Pu content, with fuel having a high-^{240}Pu content. Also, the worth of U_3O_8 relative to Fe_2O_3 was measured.

The k_{eff} of each experimental configuration was computed using two-dimensional diffusion theory in X-Y geometry, and calculated material worths were obtained and compared with the experimental worths. The calculation-to-experiment (C/E) bias factor for the high-^{240}Pu fuel substitution was 1.18 at the center of the EMC core and 1.30 in the outer core zone. The C/E for the worth of U_3O_8 relative to Fe_2O_3 was found to be about 1.35 in both inner and outer core zones.

The k_e-k_c bias decreased when high-^{240}Pu fuel was introduced and increased when Fe_2O_3 was replaced with U_3O_8. When the high-^{240}Pu fuel and U_3O_8 substitutions were combined to give a new outer driver composition with essentially no reactivity change, the k_e-k_c bias was also essentially unchanged because the two effects on the bias cancelled out. In the inner driver the same trend was observed, however the cancellation was not as complete because of the larger differences in the C/Es for the two types of substitutions.

3.0 EXPERIMENT

The FTR-EMC[2] was assembled in the ZPR-9 critical facility at Argonne National Laboratory (ANL). The high-^{240}Pu fuel worth experiment,[1] described in this report, was performed in a configuration of the EMC simulating beginning-of-life conditions in the FTR. The primary purpose of the experiment was to determine drawer loadings for the inner and outer driver zones of the EMC such that a high-^{240}Pu fueled sector or central zone could be loaded without a significant reactivity change. These drawer loadings were determined in a three-step process. First, the Pu-U-Mo fuel platelets with low-^{240}Pu content (approximately 12%) were replaced with platelets having a high-^{240}Pu content (approximately 26%) and the reactivity increase due to this substitution was measured. Next, Fe_2O_3 platelets were replaced with U_3O_8 platelets and the reactivity decrease due to this substitution was measured. Finally, based on the measured reactivity changes, the number of U_3O_8 platelets was determined that would just balance the reactivity increase due to the high-^{240}Pu fuel substitution.

Figure 1 is a cross-sectional view of the EMC as viewed facing the front face of the stationary half. The reference configuration for the high-^{240}Pu worth experiments was designated BOL-REF-5S. This configuration had three peripheral shims (PS), three fully withdrawn safety rods (SR), three fully withdrawn control rods (CR-506, CR-514, and CR-522), and three control rods (CR-508, CR-516, and CR-524) which were fully inserted. At the lower right of the diagram in Fig. 1 is a sector of a simulated radial shield that was added to the EMC for use in other experiments. The BOL-REF-5S configuration contained approximately 538 kg of fissile plutonium (^{239}Pu + ^{241}Pu).

The high-^{240}Pu fuel substitutions were made in both the inner and outer core zones. In the inner core the substitutions were made in a four-matrix tube array at matrix positions 22-22*, 23-22, 22-23, and

* Matrix positions are identified by row number and column number in that order. See Fig. 1.

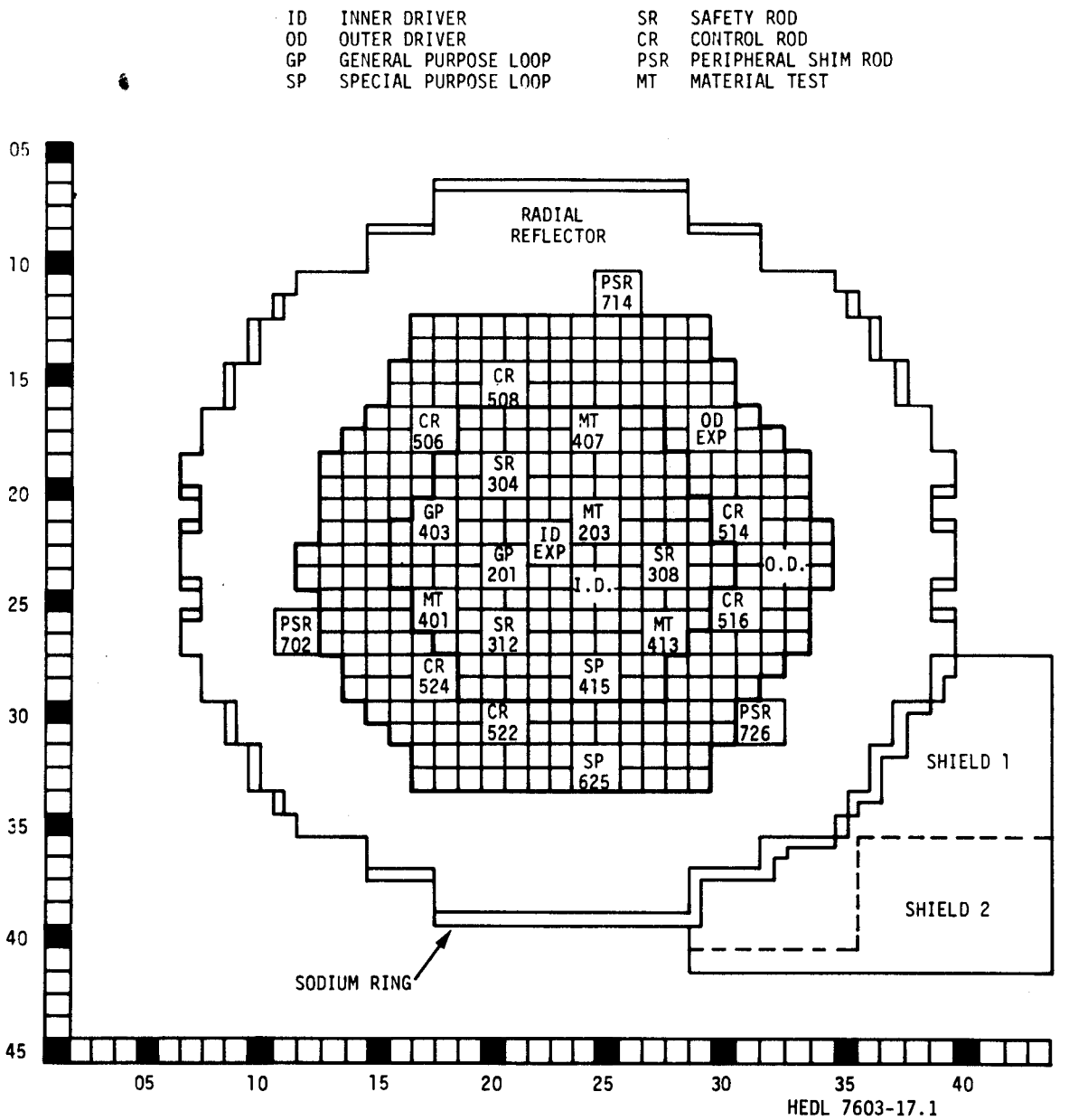

FIGURE 1. Diagram of BOL-REF-5S (762349-5).

23-23, identified as "ID EXP" in Fig. 1. In the outer core the substitutions were made at 17-29, 17-30, 18-29, and 18-30, designated "OD EXP" in Fig. 1. Four EMC matrix tubes are approximately equal in cross sectional area to an FTR subassembly.

The inner driver and outer driver zones of the EMC were each made up of approximately equal numbers of type A and type B tubes (see Figs. 2 and 3). The type A tubes were located in the odd-numbered matrix columns (see Fig. 1) and the type B tubes were in the even-numbered columns. The two arrays, ID EXP and OD EXP, were composed of two type A and two type B tubes. The reactivity of loading R, defined in Table I, was used as the reference. For loading R, ID EXP and OD EXP contained the standard inner driver and outer driver platelet loadings shown in Figures 2 and 3. For loadings I_1 and O_1 the standard loadings were replaced with those shown in Figs. 4 and 5 in which the standard Pu-U-Mo platelets were replaced with others having high-^{240}Pu fuel. By comparing the measured reactivities of the I_1 and O_1 loadings with the reference, the worths of the high-^{240}Pu platelets relative to the low-^{240}Pu platelets were obtained.

For loadings I_2 and O_2 the compositions shown in Figs. 6 and 7 were used in ID EXP and OD EXP, respectively. The worth of twelve columns* of U_3O_8 relative to Fe_2O_3 at core center was determined from the difference in reactivities between loadings I_1 and I_2. Similarly, the worth of the substitution of twelve columns of U_3O_8 for Fe_2O_3 in the outer core was determined from the reactivities of O_1 and O_2. The EMC inner driver composition had twelve columns of Fe_2O_3 plates in a four-matrix tube array (see Fig. 2). The outer driver had sixteen (Fig. 3). The number of these to be replaced with U_3O_8 was determined by dividing the total worth of the fuel substitution by the worth of replacing one Fe_2O_3 column with U_3O_8. The platelet loading patterns that were selected for the inner and outer driver "null compositions" are shown in Figs. 8 and 9, respectively. Reactivity measurements were made with each null composition as indicated by I_N and O_N in Table I.

* A column of material is a 36" stack of plates in the direction perpendicular to the plane shown in Figs. 1 through 9.

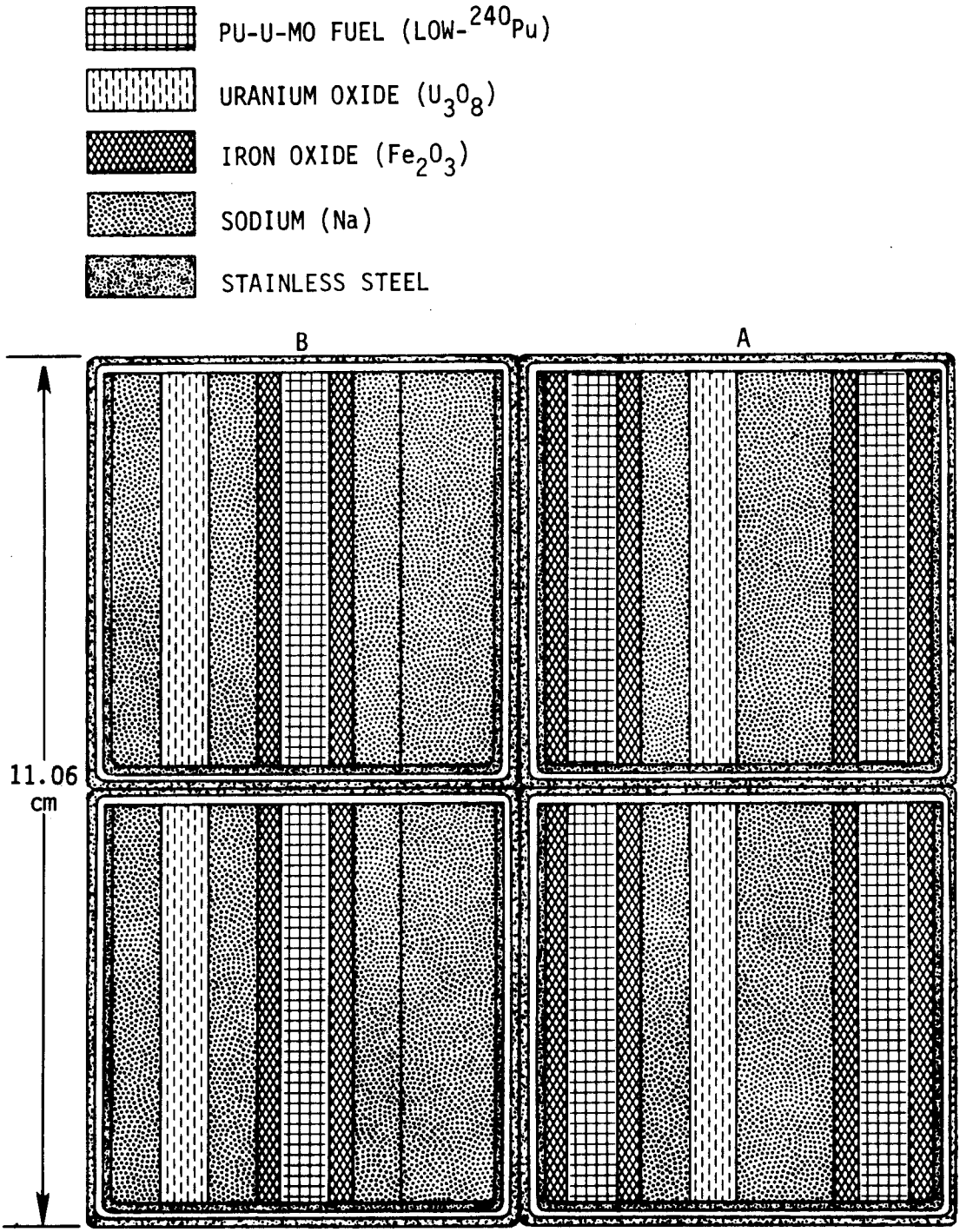

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FIGURE 2. Platelet Loading Pattern of ID EXP with Inner Driver Composition (762349-1).

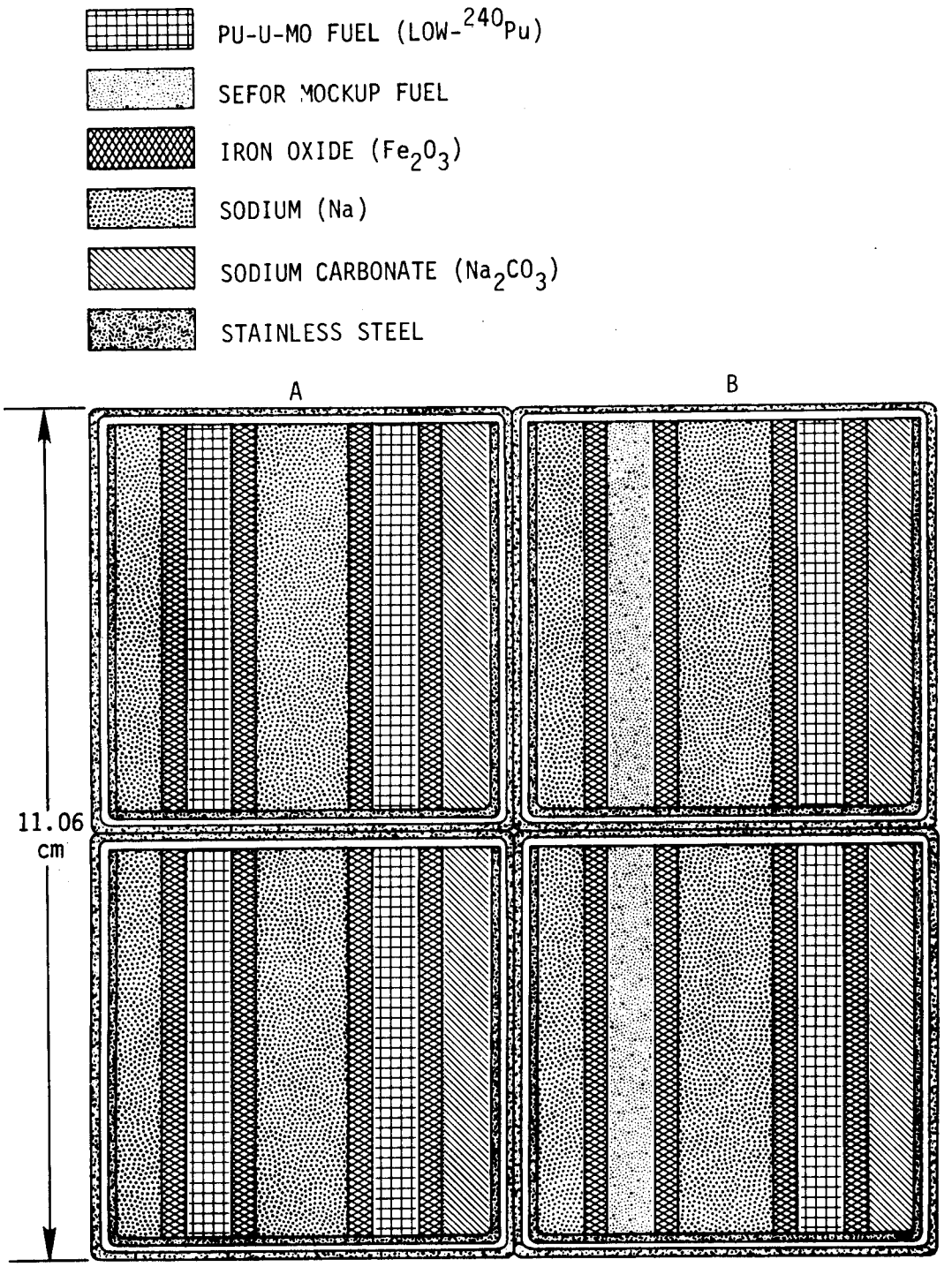

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FIGURE 3. Platelet Loading Pattern of OD EXP with Outer Driver Composition (762349-8).

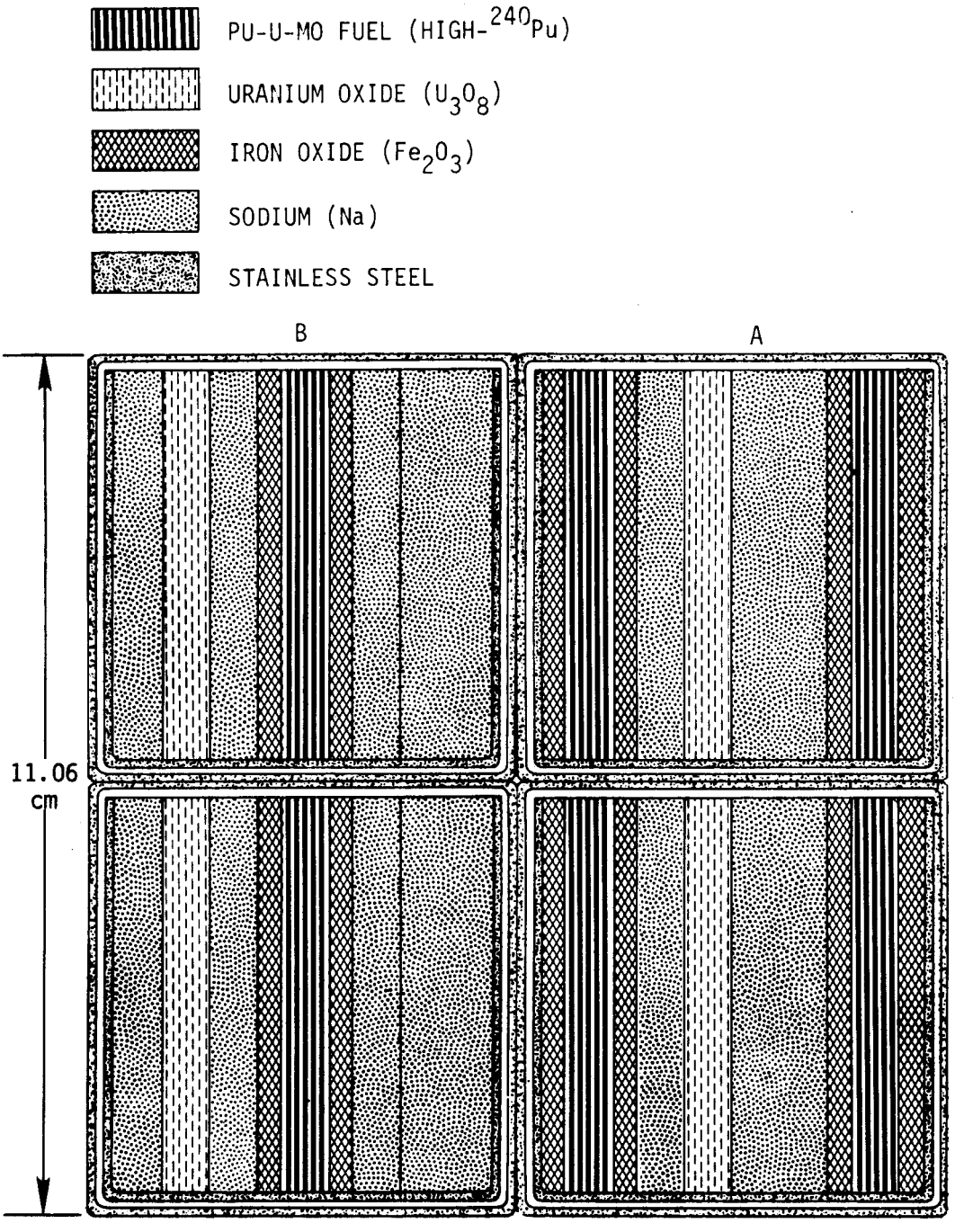

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FIGURE 4. Platelet Loading Pattern of ID EXP with High-^{240}Pu ID Composition 1 (762349-9).

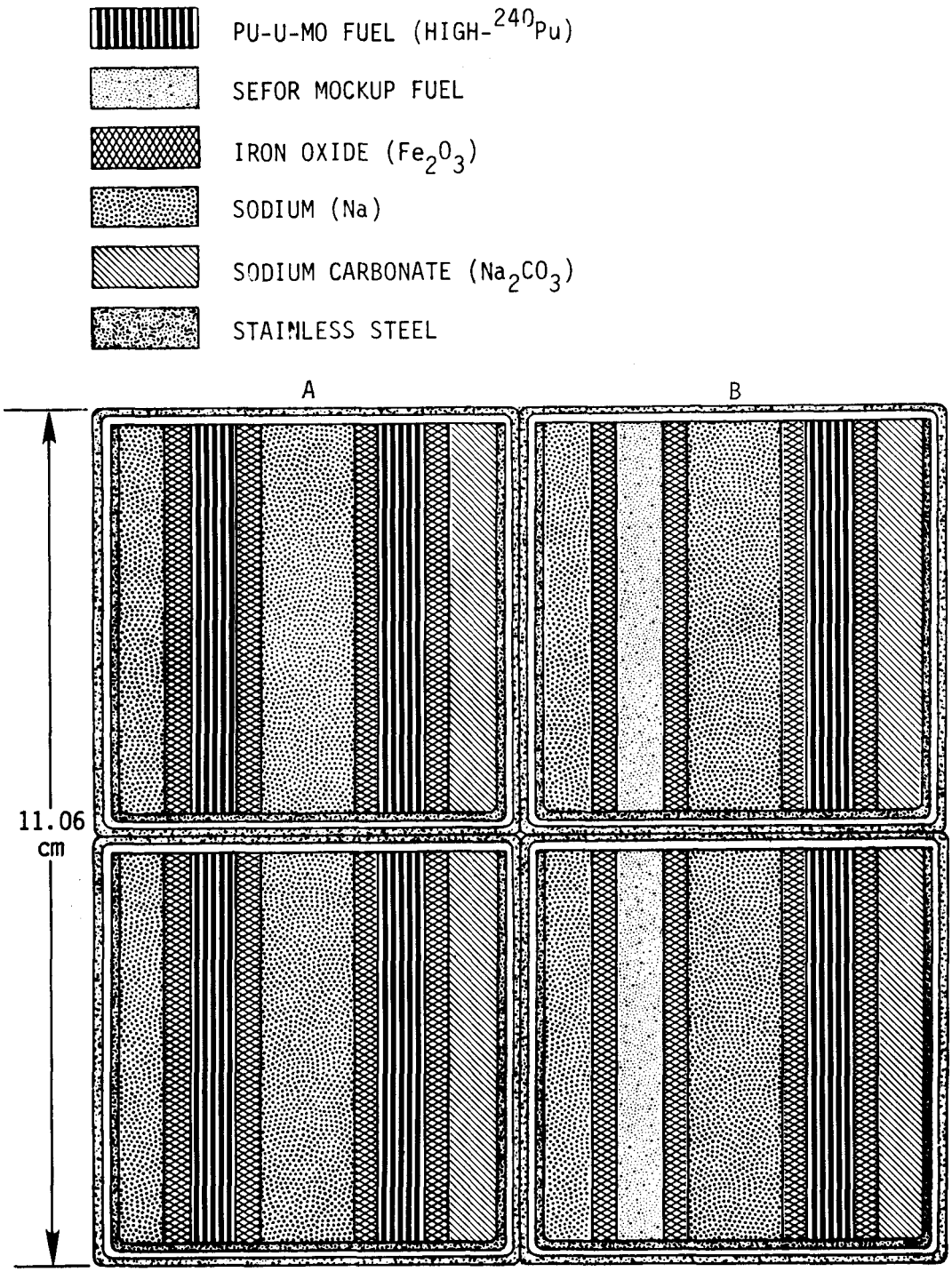

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FIGURE 5. Platelet Loading Pattern of OD EXP with High-^{240}Pu OD Composition 1 (762349-7).

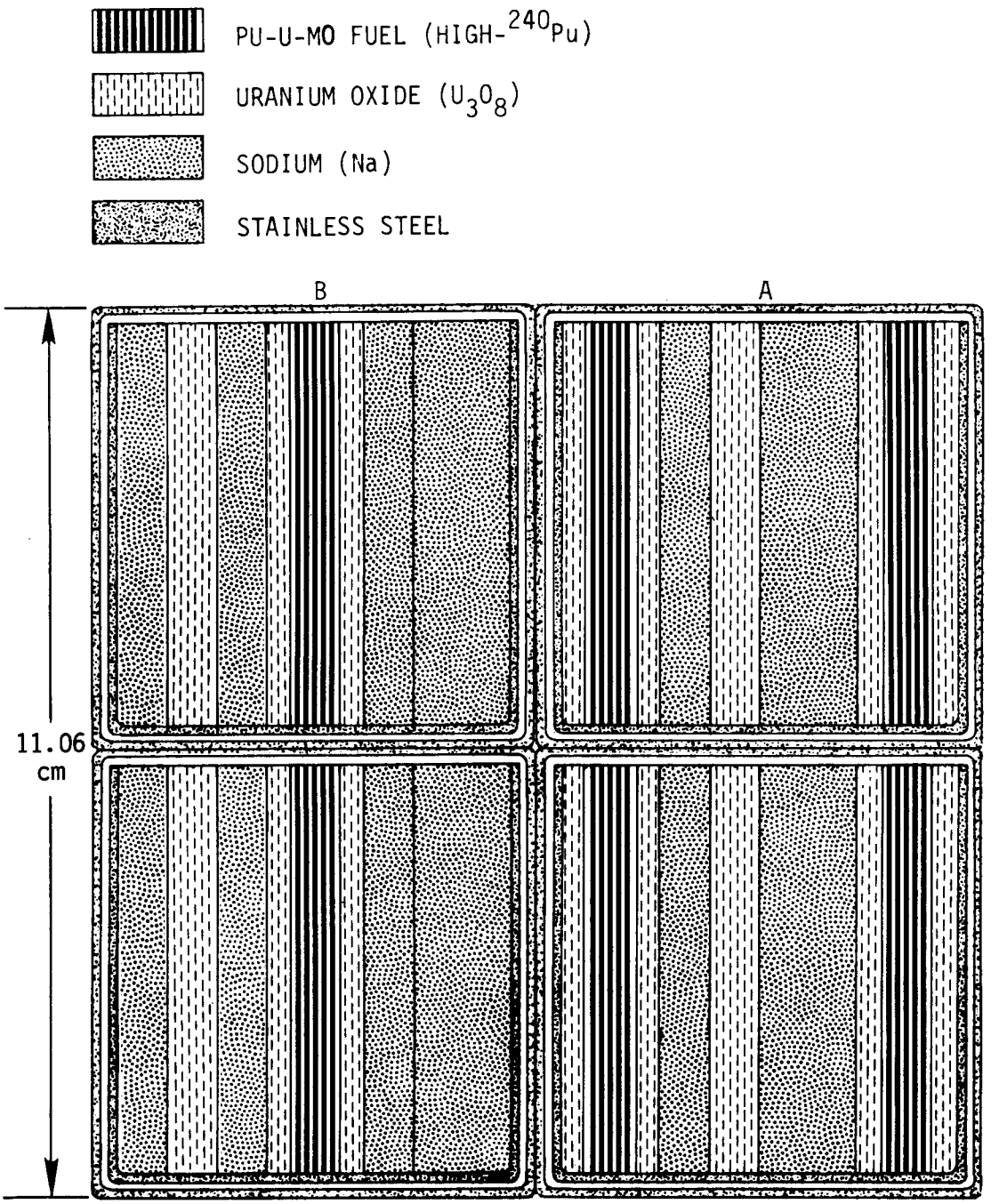

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FIGURE 6. Platelet Loading Pattern of ID EXP with High-^{240}Pu ID Composition 2 (762349-2).

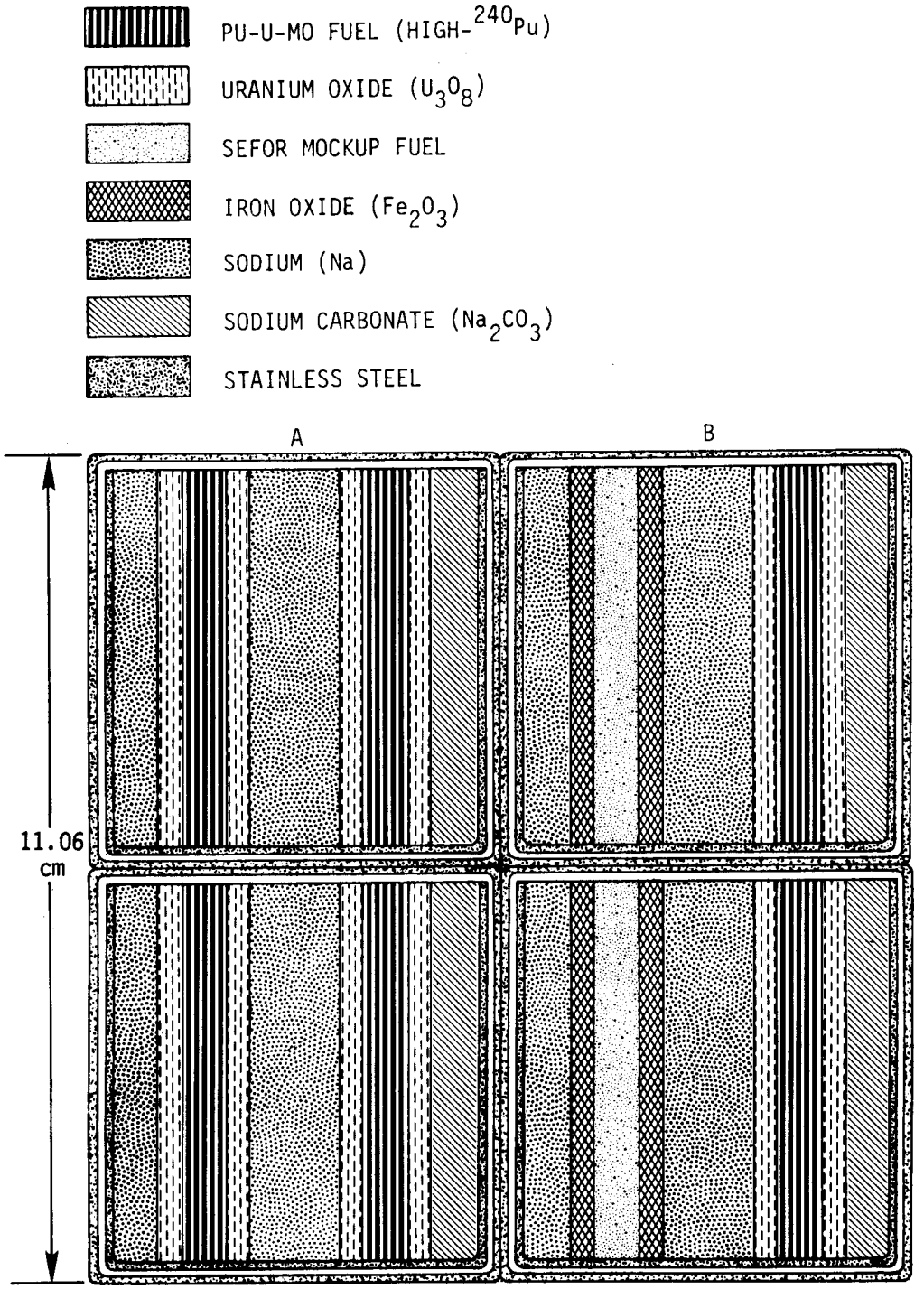

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FIGURE 7. Platelet Loading Pattern of OD EXP with High-^{240}Pu OD Composition 2 (762349-3).

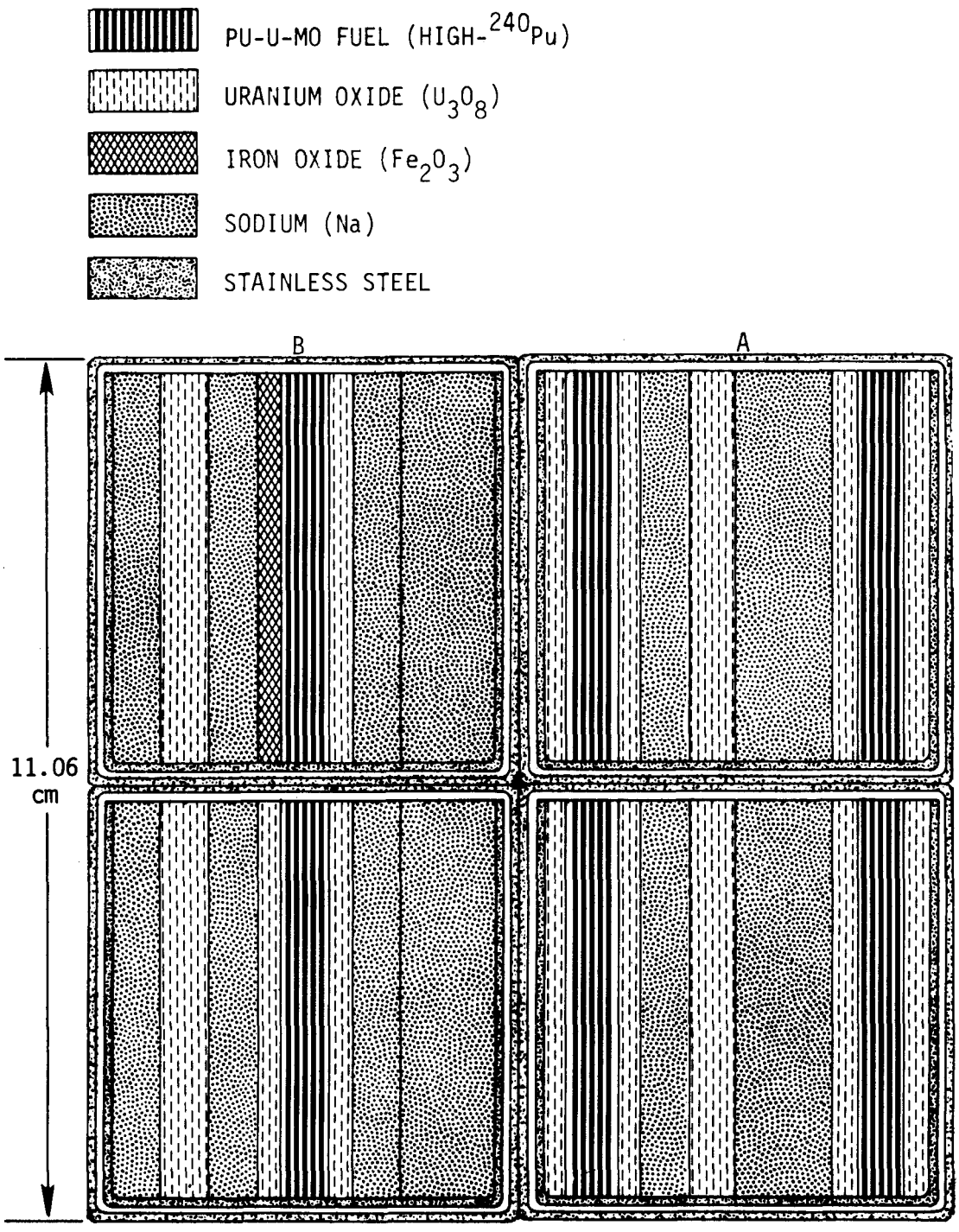

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FIGURE 8. Platelet Loading Pattern of ID EXP with High-^{240}Pu ID Null Composition (762349-4).

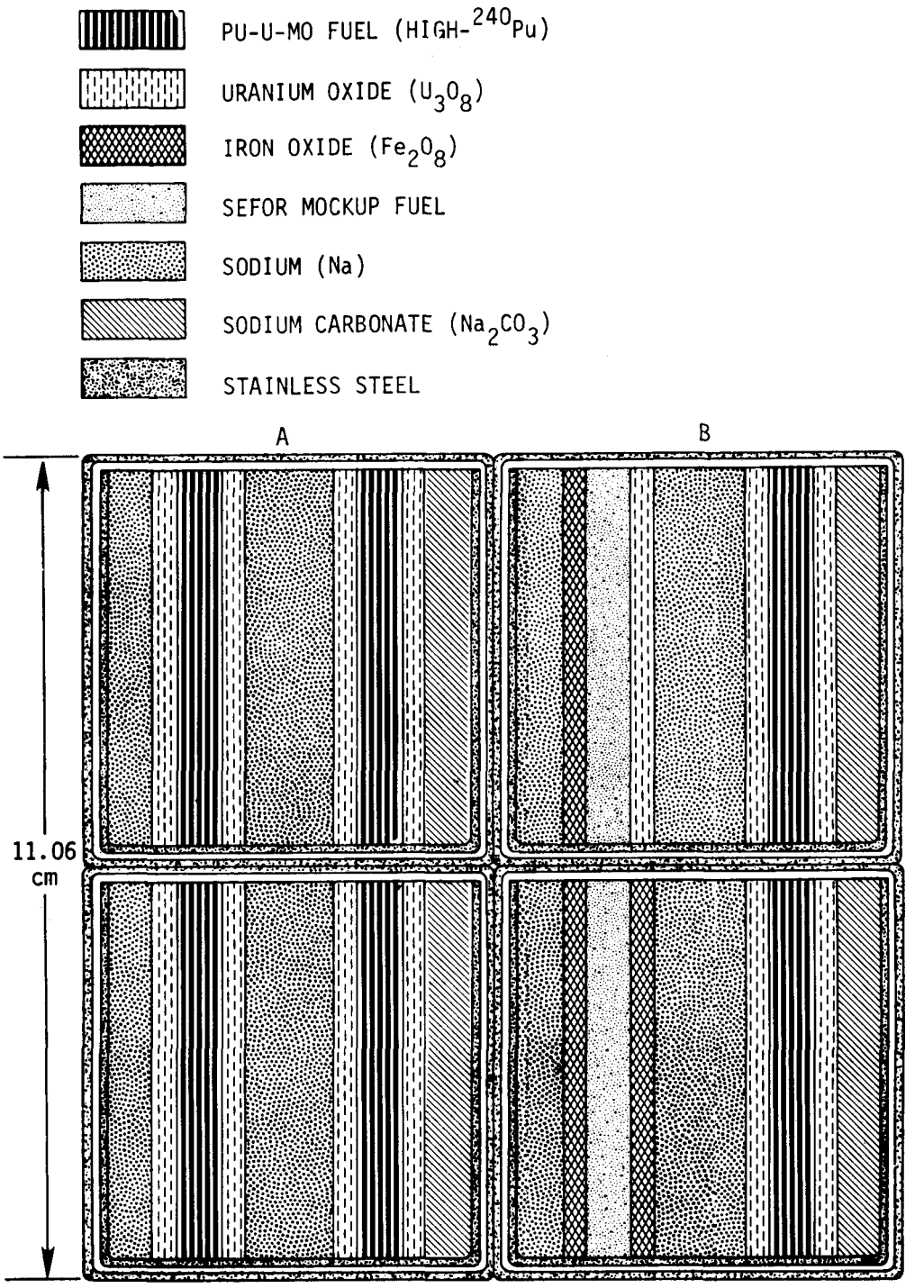

FIGURE 9. Platelet Loading Pattern of OD EXP with High-^{240}Pu OD Null Composition (762349-6).

TABLE I

EMC FUEL LOADINGS FOR THE HIGH-^{240}PU DRIVER WORTH MEASUREMENTS

Loading Identification	ID EXP	OD EXP
R[a]	Standard Inner Driver Composition	Standard Outer Driver Composition
I_1	High-^{240}Pu Inner Driver Composition 1	Standard Outer Driver Composition
I_2	High-^{240}Pu Inner Driver Composition 2	Standard Outer Driver Composition
I_N	High-^{240}Pu Inner Driver Null Composition	Standard Outer Driver Composition
O_1	Standard Inner Driver Composition	High-^{240}Pu Outer Driver Composition 1
O_2	Standard Inner Driver Composition	High-^{240}Pu Outer Driver Composition 2
O_N	Standard Inner Driver Composition	High-^{240}Pu Outer Driver Null Composition

a BOL-REF-5S.

The worths of the null compositions in ID EXP and OD EXP relative to the standard inner and outer driver compositions were obtained by comparing the measured reactivities of I_N and O_N with R. Also, additional values for the worth of U_3O_8 relative to Fe_2O_3 were obtained by comparing I_1 and I_N for the inner driver and O_1 and O_N for the outer driver.

The atom densities for each region of the EMC are given in Ref. 2. The atom densities for ID EXP and OD EXP with each of the loadings shown in Figs. 2 through 9 are given in Table II. The atom densities in each case are the average for the four-matrix tube array.

All measurements for this experiment were made with the reactor near critical. The reactivity of each state was defined as the excess reactivity that the assembly would have at 25°C if all ZPR-9 operational control and safety rods were in their most reactive configuration. This was determined from the position of the calibrated ZPR-9 fuel-bearing control rod used to maintain the assembly at the selected power level.

The experimental results are tabulated in Section 5.0.

TABLE II

ATOM DENSITIES OF SIMULATED SUBASSEMBLIES USED FOR HIGH-^{240}PU DRIVER FUEL WORTHS

Material or Isotope	ID EXP Atom Densities $\left(10^{21}\frac{\text{atoms}}{\text{cm}^3}\right)$				OD EXP Atom Densities $\left(10^{21}\frac{\text{atoms}}{\text{cm}^3}\right)$			
	R	I_1	I_2	I_N	R	O_1	O_2	O_N
^{238}Pu	0.0007	0.0017	0.0017	0.0017	0.0008	0.0017	0.0017	0.0017
^{239}Pu	1.326	1.2544	1.2544	1.2544	1.621	1.5508	1.5508	1.5508
^{240}Pu	0.176	0.4811	0.4811	0.4811	0.204	0.5092	0.5092	0.5092
^{241}Pu	0.020	0.0775	0.0775	0.0775	0.022	0.0793	0.0793	0.0793
^{242}Pu	0.003	0.0260	0.0260	0.0260	0.003	0.0261	0.0261	0.0261
^{235}U	0.012	0.0112	0.01375	0.01354	0.012	0.0107	0.0134	0.01362
^{238}U	5.396	5.0800	7.5191	7.3158	5.063	4.7416	7.1807	7.3840
O	12.944	12.9434	10.8687	11.0416	13.107	13.107	12.0866	12.0016
Na	8.787	8.7866	8.7866	8.7866	8.766	8.7664	8.7664	8.7664
Fe	16.503	16.4988	10.8004	11.2753	17.783	17.7836	12.7862	12.3698
Cr	3.092	3.0911	3.0911	3.0911	3.182	3.1842	3.1842	3.1842
Ni	1.432	1.4312	1.4312	1.4312	1.473	1.4777	1.4777	1.4777
Mn	0.243	0.2423	0.2423	0.2423	0.250	0.2503	0.2503	0.2503
Mo	0.350	0.3386	0.3386	0.3386	0.454	0.4429	0.4429	0.4429

4.0 ANALYTICAL METHODS

The purpose of the analytical work described in this report was to determine by comparison with the experimental results the extent that the calculations over or under predict the worths of the material substitutions made in the experiment.

The effective multiplication constant, k, was computed for each of the seven loadings listed in Table I using the diffusion theory code, 2DBS.[3] The calculations were done in two-dimensional X-Y geometry using thirty neutron-energy groups.

Previously prepared[4] cross sections for the EMC were used. The thirty-group cross section set for the EMC had been generated using the FTR Set 300[5] cross section library and a modified version[6] of the cross section preparation code, 1DX.[7] The plutonium and uranium cross sections were heterogeneously resonance self-shielded and adjusted to account for the spatial flux fine structure in the platelet geometry of the EMC inner and outer driver zones. A homogeneous resonance self-shielding treatment was used for the remainder of the materials. The cross sections were prepared for the platelet geometries shown in Figs. 2 and 3. These cross sections were not modified in any way in computing the worths of the high-^{240}Pu compositions.

The mesh spacing in the X and Y directions was 5.53 cm which was equal to the X-Y dimensions of the EMC matrix tubes, resulting in one mesh point per matrix tube (see Fig. 1). Within each tube the materials were homogenized conserving the total number of atoms for each isotope.

A space and energy independent axial buckling of 0.000565 was used in all the k calculations. When this value for the axial buckling is used with a two-dimensional X-Y model in thirty groups, it yields the same k_{eff} that is obtained from a three-dimensional X-Y-Z model for the reference configuration, R.[8]

Reactivity worths were obtained from the calculated k values using the definition given in Equation (1).

$$\Delta\rho = \rho_2 - \rho_1 = \frac{k_2 - 1}{k_2} - \frac{k_1 - 1}{k_1} = \frac{k_2 - k_1}{k_2 k_1} . \qquad (1)$$

5.0 RESULTS

5.1 Experimental Results

The measured reactivities were reported by ANL in Ref. 1. In order to determine material worths from reactivities measured at different times in Pu-fueled assemblies, it is necessary to account for the reactivity loss due to the radioactive decay of ^{241}Pu, which was determined experimentally[9] to be -0.205 inhours per day for the EMC. The reactivities reported by ANL have been adjusted to the same date to account for ^{241}Pu decay and the adjusted values are given in units of inhours in Table III. The estimated uncertainty of each reactivity value is ±2.4 inhours except for the reference loading, R, where the estimated uncertainty is ±1.7 inhours. The reactivities were converted from inhours to %(Δk/k) using a conversion factor of 1047.7 Ih/% (Δk/k).[10] The effective multiplication constant, k_{eff}, was determined from the measured reactivities by the relationship:

$$k_{eff} = \frac{1}{1-\rho} ,$$

where ρ is the reactivity in Δk/k. These results are included in Table III.

The measured worths of the substitution of high-^{240}Pu fuel for low-^{240}Pu fuel and of U_3O_8 for Fe_2O_3 were obtained from the reactivities given in Table III and are presented in Table IV. Also shown in Table IV are the worths of the null compositions relative to the standard EMC inner and outer driver compositions.

5.2 Calculated Results

The calculated multiplication constants, k_c, and the differences between the measured and calculated k's, k_e-k_c, are given in Table V. The convergence criteria in the calculations were chosen to make the uncertainties in the calculations due to convergence small compared to the experimental uncertainties. In general, the calculational uncertainties given in this report include only the uncertainty due to incomplete

TABLE III

REACTIVITY AND k_{eff} VALUES MEASURED IN HIGH-^{240}PU DRIVER FUEL WORTH EXPERIMENT

	Measured Reactivities[a]		
Identification	Inhours[b]	% $\Delta k/k$[c]	k_{eff}
R	59.1	0.0564	1.000564
I_1	117.6	0.1122	1.001124
I_2	52.3	0.0499	1.000499
I_N	56.0	0.0534	1.000535
O_1	99.9	0.0954	1.000954
O_2	62.5	0.0597	1.000597
O_N	58.4	0.0557	1.000558

a Adjusted for the effect of ^{241}Pu decay to the same measurement date.

b Experimental uncertainties are ±2.4 Ih except for R which is ±1.7 Ih.

c 1047.71 inhours/% ($\Delta k/k$), Ref. 10.

TABLE IV

MEASURED REACTIVITY WORTHS OF MATERIAL SUBSTITUTIONS

MATERIAL SUBSTITUTION	WORTH, $\Delta\rho$(%Δk/k) ID EXP	OD EXP
1. 6 columns[a] of low-^{240}Pu fuel replaced with high-^{240}Pu fuel (from R, I_1 and O_1).	+0.0558 ± 0.0028	+0.0389 ± 0.0028
2. 12 columns of Fe_2O_3 replaced with U_3O_8 (from I_1, I_2, O_1 and O_2).	-0.0623 ± 0.0032	-0.0357 ± 0.0032
3. Worth of exchanging one[b] column of U_3O_8 for Fe_2O_3 (from 2 above).	-0.00519 ± 0.00027	-0.00297 ± 0.00027
4. 11 columns of Fe_2O_3 replaced with U_3O_8 (from I_1 and I_N).	-0.0588 ± 0.0032	—
5. 13 columns of Fe_2O_3 replaced with U_3O_8 (from O_1 and O_N).	—	-0.0396 ± 0.0032
6. Worth of exchanging one column of U_3O_8 for Fe_2O_3 (from 4 and 5 above).	-0.00535 ± 0.00029	-0.00305 ± 0.00025
7. Average worth of exchanging one column of U_3O_8 for Fe_2O_3 (from 3 and 6 above).	-0.00527 ± 0.00020	-0.00301 ± 0.00018
8. Reference configuration replaced by null configuration (from R, I_N and O_N).	-0.0030 ± 0.0028	-0.0007 ± 0.0028

a A column of material is a 36-inch stack of plates in the direction perpendicular to the plane shown in Figures 1 through 9.

b These values used with item 1 above to determine null compositions.

TABLE V

CALCULATED MULTIPLICATION CONSTANTS, k_c, AND k_e-k_c

Loading	k_c [a]	k_e-k_c
R	0.995727	0.004837
I_1	0.996383	0.004741
I_2	0.995532	0.004967
I_N	0.995600	0.004935
O_1	0.996227	0.004727
O_2	0.995742	0.004855
O_N	0.995704	0.004854

a The uncertainties in the calculated k's are $\pm 6 \times 10^{-6}$.

convergence and do not include uncertainties in the cross sections or analytical models. Bias factors are used to correct for inadequacies in these areas.

The calculated reactivity worths for the material substitutions and the ratio of calculated to experimental worths, C/E values, are given in Table VI. The uncertainties in the C/E values are primarily due to the experimental uncertainties. Also given in Table VI are the calculated predictions for the reactivity changes in going from the reference loading to the I_N and O_N loadings.

TABLE VI

CALCULATED REACTIVITY WORTHS AND C/E BIAS FACTORS FOR MATERIAL SUBSTITUTIONS

MATERIAL SUBSTITUTIONS	ID EXP		OD EXP	
	$\Delta\rho$, %($\Delta k/k$)[a]	C/E	$\Delta\rho$, %($\Delta k/k$)[a]	C/E
6 columns of Pu-U-Mo fuel replaced with high-^{240}Pu fuel	+0.06612	1.18 ± 0.06	+0.05040	1.30 ± 0.10
12 columns of Fe_2O_3 replaced with U_3O_8	-0.08579	1.38 ± 0.07	-0.04889	1.37 ± 0.13
11 columns of Fe_2O_3 replaced with U_3O_8	-0.07893	1.34 ± 0.07	—	—
13 columns of Fe_2O_3 replaced with U_3O_8	—	—	-0.05272	1.33 ± 0.11
Reference configuration replaced by null configuration	-0.01281	b	-0.00232	b

a Uncertainties in $\Delta\rho$ values are ± 0.00085.

b C/E values for these cases are not meaningful because experimental values are nearly zero within experimental accuracy.

6.0 COMPARISON AND DISCUSSION

When the high-^{240}Pu fuel was substituted for the low-^{240}Pu fuel, the total mass of fissile material, ^{235}U plus ^{239}Pu plus ^{241}Pu, remained nearly unchanged. Also the total mass of U plus Pu remained almost unchanged. However, the substitution resulted in a net positive reactivity change. This can be explained on the basis of the isotopic differences between the two types of fuel. The substitution can be seen as primarily a replacement of ^{239}Pu with ^{241}Pu and of ^{238}U with ^{240}Pu. Pu-241 is more reactive than ^{239}Pu because its fission cross section is larger over the range of the FTR-EMC neutron energy spectrum and ^{241}Pu has a greater neutron yield per fission (larger ν). Also ^{240}Pu is more reactive than ^{238}U due primarily to a larger spectrum-averaged fission cross section.

Table V shows that the k_e-k_c bias decreases when the high-^{240}Pu fuel is introduced and increases when the Fe_2O_3 is replaced with U_3O_8. In the outer driver these two effects cancel out almost completely for the null composition, O_N, i.e., the k_e-k_c bias is nearly the same for O_N and R. The trend is the same in the inner driver but the cancellation is not as complete. An understanding of the manner in which the k_e-k_c bias changes as a function of the isotopic composition of the fuel will be important for specification of enrichments for FTR fuel with LWR discharge Pu.

The C/E values for the fuel substitution (Table VI) are 1.18 ± 0.06 at the center of the core and 1.30 ± 0.10 in the outer driver, which indicates a probable spatial variation of the C/Es for this type of composition change. The average C/Es for the exchange of U_3O_8 for Fe_2O_3 are 1.36 ± 0.06 and 1.35 ± 0.10 for the inner and outer driver zones, respectively. It is expected that the C/E values for the worth of U_3O_8 versus Fe_2O_3 can be reduced by preparing new cross sections for the high-^{240}Pu fuel loadings in which the worths were measured. This is planned for the analysis of the high-^{240}Pu sector and central zone experiments.

The calculated reactivity changes in going from the reference configuration to the null configurations are more negative than the observed changes. This is due to the fact that the net changes are combinations of positive and negative components, and the C/Es for the negative components are greater than those for the positive components.

Table VII shows the number of columns of Fe_2O_3 plates that should be replaced with U_3O_8 to balance the positive effect of the high-^{240}Pu fuel substitution in the inner and outer core zones as determined experimentally and as predicted by calculation. The results, for the outer driver especially, illustrate that even though the C/E values are significantly greater than one, the calculated null loading is nearly correct because the C/Es for the positive and negative components were almost equal.

The worths of the material substitutions have also been computed by ANL using a perturbation code[1] rather than k calculations. ENDF/B version 3 cross sections were employed. At the center of the core the C/E values obtained by ANL were very similar to those given in this report; however in the outer core zone the ANL C/E values were about 10% higher than those in Table VI.

All of the C/E and k_e-k_c values derived in this report are based on a value of 1047.7 Ih/% ($\Delta k/k$). This conversion factor was computed[10] by ANL for the BOL-REF-5S configuration and is based on Keepin's[11] delayed neutron parameters. If the delayed neutron data in ENDF/B version 4[12] are used, the conversion factor would be 980.2 Ih/% ($\Delta k/k$)[13] and all C/E values would be reduced by about 7%. Since ENDF/B version 4 has the most recent delayed neutron data evaluation, the reduced C/E values are recommended for use in adjusting similar calculated worths for the FTR. This disparity in conversion factors is not expected to be important for calculations related to the introduction of high-^{240}Pu fuel in FTR, because it was shown that in determining the null compositions, overcalculation of positive and negative components tended to cancel each other.

TABLE VII

NUMBER OF U_3O_8 COLUMNS NEEDED FOR NULL COMPOSITION

	ID EXP	OD EXP
Experimental[a] Prediction	10.7 ± 0.7	13.1 ± 1.4
Calculated Prediction	9.2	12.4
Actual[b] Selection	11	13

a Based on items 1 and 3 from Table IV.

b Number of columns selected was the closest integral number to the experimental prediction.

The results obtained in this study are to be supplemented by additional comparisons between measurements and calculations based on the high-^{240}Pu sector and central zone experiments.[10] Also, additional information will be provided by the analysis of the EMC small sample worth measurements[14] which included samples containing ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{238}U.

In summary, replacement of low-^{240}Pu fuel with high-^{240}Pu fuel in the EMC, in a manner that conserved the total fertile and fissile masses, resulted in a net positive reactivity change. Calculations overpredicted this change by 18% at the center of the core and by 30% in the outer driver. When ENDF/B version 4 delayed neutron parameters were used instead of the older data used by ANL, the overprediction was reduced by about 7% to 1.11 and 1.23 for the inner and outer drivers, respectively. If similar changes are made in the FTR fuel, calculated reactivity increases should be reduced by the above factors.

In general, however, the measurements and calculations described in this report are not sufficient to provide bias factors for the reactivity effects of high-^{240}Pu fuel if the fertile and fissile masses are not conserved, which is likely to be the case in the FTR. Additional experiments have been performed in the EMC that will be of value for establishing bias factors. Analysis of these experiments, including preparation of new cross sections, is planned and should be completed before the high-^{240}Pu fuel pin enrichments are specified.

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