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Local Flux Distributions in ORR Fuel Elements

A detailed study of the thermal neutron flux distribution in the ORR is being made by the Operations Division of the Oak Ridge National Laboratory. Results to date have indicated that rather large flux gradients exist radially across the MTR type fuel element employed in this reactor and that these gradients are strongly dependent on the fuel concentration in the element being investigated as well as that of the adjacent elements.

The technique used to measure flux is the one considered as standard at the ORR (*1*). Basically the method consists of measuring the induced activity in a 20-mil cobalt wire. The wires are put into aluminum holders which are placed in the coolant channels between fuel plates. The wires are then irradiated for one hour at a power level of 20 kw.

Figure 1 shows the geometrical pattern of the standard ORR core, and Table I presents the complete set of fuel weights loaded in the core for each experiment represented by the subsequent figures. Because of the operating schedule of the ORR and the time lapse between data gathering and analysis, loading of identical cores was impossible. A flux traverse along the center plane of the "4" column at a distance 16 in. from the top of the fuel plates is shown in Fig. 2. The traverse is shown at 16 in. because the peak axial flux occurs at approximately 16 in. from the top of the fuel plates. Fluxes have been normalized to the highest measured value in the "4" column at the 16 in. level.

It must be pointed out that 131 g of U^{235} in the shim rod gives the same fuel density in its fuel plates as that for a 200-g fuel element. However, due to the structure of the shim rod, the metal to water ratio of the fuel follower is not the same as it is for a fuel element.

It is interesting to note that the ratio of maximum extrapolated flux to minimum measured flux along the center plane is 2.3 for A-4 and 1.3 for E-4. It is perhaps more interesting to observe that the ratio of maximum extrapolated flux to center flux is 1.4 for A-4, 1.3 for C-4, and 1.1 for E-4. For routine core flux measurement in the ORR, it is common practice to measure fluxes in the geometric center of each fuel element. However, one sees that such a measurement gives a value far below the maximum flux in certain cases. The implications of such a situation

	1	2	3	4	5	6	7	8	9
A	Be	Be	Be	F	F	F	Be	Be	Be
B	Be	Be	F	S	F	S	F	Be	Be
C	Be	Be	F	F	F	F	F	F	Be
D	Be	F	F	S	F	S	F	F	Be
E	Be	F	F	F	F	F	F	F	Be
F	Be	Be	Be	Be	Be	Be	F	Be	Be
G	Be	Be	Be	Be	Be	Be	Be	Be	Be

F – FUEL
S – SHIM ROD
Be – BERYLLIUM REFLECTOR

Fig. 1. Core loading pattern of ORR

TABLE I
Fuel Weight in Grams Loaded in ORR for the Various Flux Measurements

Position	Figs. 2 and 3	Fig. 4	Fig. 5
A-4	163	176	169
A-5	169	161	169
A-6	166	168	167
B-3	193	192	192
B-4	142	46	132
B-5	153	140	156
B-6	110	120	102
B-7	189	189	188
C-3	131	112	148
C-4	148	151	147
C-5	163	140	163
C-6	146	200	180
C-7	157	147	157
C-8	161	157	200
D-2	159	179	159
D-3	189	173	175
D-4	91	102	82
D-5	161	138	160
D-6	69	131	60
D-7	188	157	157
D-8	142	170	121
E-2	160	183	157
E-3	189	189	172
E-4	188	188	200
E-5	158	152	179
E-6	159	173	175
E-7	187	156	158
E-8	162	142	200
F-7	148	158	148

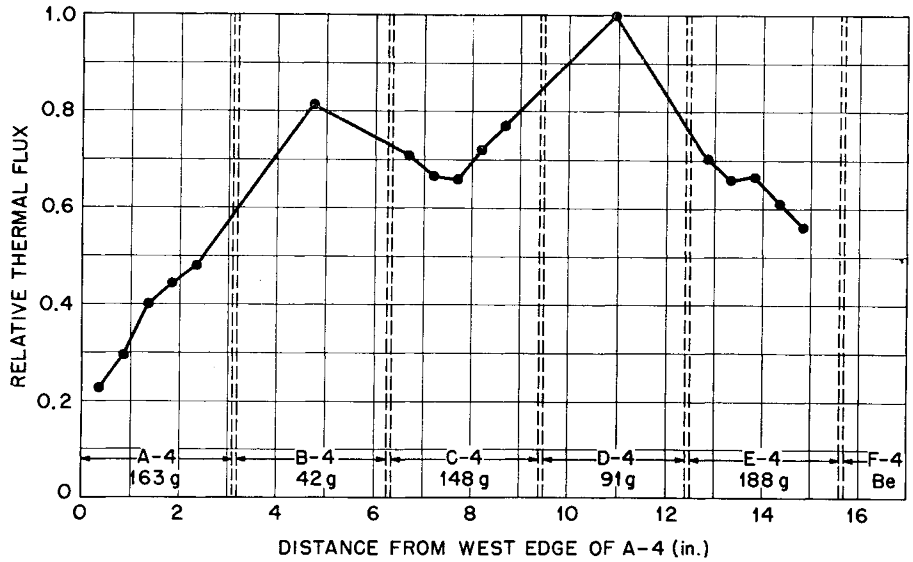

FIG. 2. Flux traverse along center plane of "4" column

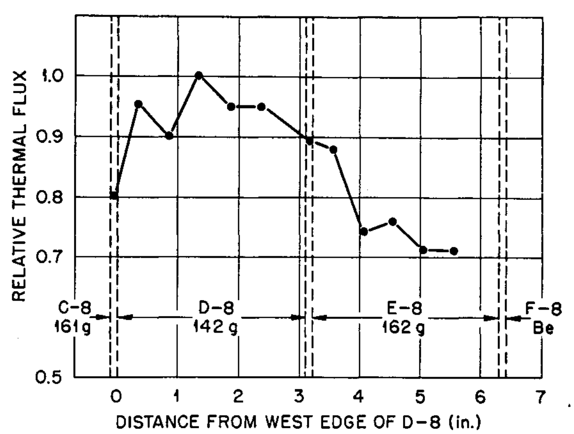

FIG. 3. Flux traverse for D-8 and E-8 12 in. from top of fuel.

for hot spot analyses and fuel consumption calculations are evident. The validity of the flux interpolation between elements, and of the flux shape in the shim rod is shown in Figs. 3 and 4. In order to check the validity of the interpolation, flux monitors were placed in core positions D-8 and E-8 between elements in C-8 and D-8 and between D-8 and E-8. Results are shown in Fig. 3 and indicate a smooth flux transition between elements.

Due to the construction of the upper portion of the shim rod, only one wire could be accurately placed in an irradiated rod. However, it was possible to place three wires in a new shim rod.

A flux traverse taken through the 131-g shim rod fuel section and a 200-g adjacent element showed only a small ripple, indicating that the difference in metal to water ratio existing between a normal fuel element and a shim rod fuel section does not have a drastic effect on flux distribution. This result, however, did not settle the problem of interpolation between a central flux value in the fuel section of a burned shim rod and the flux values in the

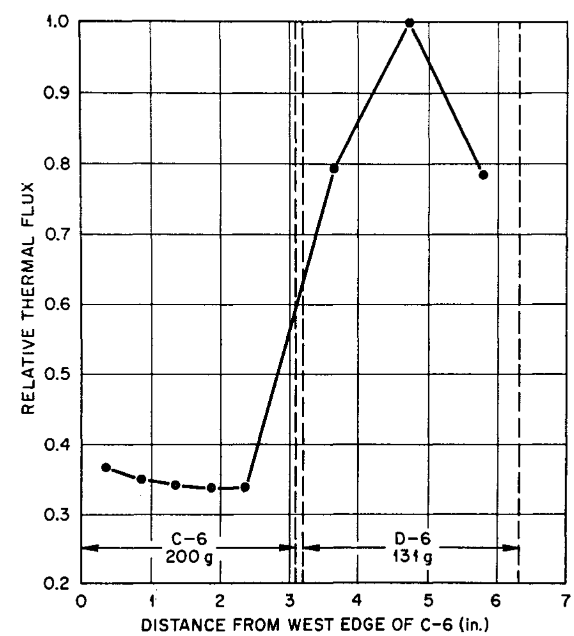

FIG. 4. Flux traverse for C-6 and D-6 at water gap in shim rod.

adjacent elements. Figure 4 shows a flux traverse through the two-inch water gap located between the fuel and the poison sections of the shim rod. The flux has the same general shape as that assumed on Fig. 2. It is felt that the results shown in Figs. 3 and 4 validate the smooth flux traverse between elements and the general pattern of the peaking in the shim rods.

A measurement of the flux distribution from side plate to side plate was also made. Four wires were placed at equal distances in a polyethylene holder. Four of these holders were placed in coolant channels in each of two new fuel elements. The two elements were then placed in positions C-8 and E-8. Five wires were placed in the element located in position D-8. From the 37 flux values thus measured an iso-flux pattern for the three elements C-8, D-8, and E-8 could be plotted. Such a pattern is shown in Fig. 5 for a cut 16 in. below the top of the fuel. The iso-flux lines are normalized to the highest flux measured in position E-8. The fluxes shown as greater than one were extrapolated from plots of flux across the channels.

The difficulty in choosing the proper single point at which to measure flux is obvious. If one should choose the geometric center, physically the easiest point at which to make measurements, one measures only 0.91 times the highest flux in D-8, 0.74 times the highest flux in E-8, and 0.61 times the highest flux in C-8. The situation concerning the average flux is even more uncertain. It is interesting to note the effect of the beryllium reflector. One sees that the reflection very nearly makes the *iso*-flux lines symmetric about the center line of column "8."

At this point there are several conclusions which can be drawn. The first is that, when a heavily burned element (low fuel density) is placed next to a new element (high fuel density), the flux will peak in the burned element, and will show a depression in the new element. Such a condition is not unexpected, since, in first approximation, local flux varies as the inverse of the local macroscopic absorption cross section Σ_a, and the burned element will have a lower Σ_a. For the cases measured here, the magnitude of the peak to center ratio in the new element was as high as 1.6. The second conclusion is that the placing of large water gaps such as that which exists between the fuel and the cadmium sections in the shim rod can cause large peaks in the adjacent elements. If these peaks raise the flux in a high fuel density region, high-power density or, in other words, hot spots have to be expected. The case of a new element is clear because the fuel concentration is uniform. Thus, one may infer that placing new elements next to heavily burned ones or next to water gaps should be done with care being given to the subsequent flux peaks and power density peaks. The case of burned element is more difficult. It is evident that the geometrical variation of fuel density will be a function of the prior flux history. It is also evident that the high-density regions will locally suppress the flux. However, it is conceivable that a power density peak of unexpected proportion may be found at various spots.

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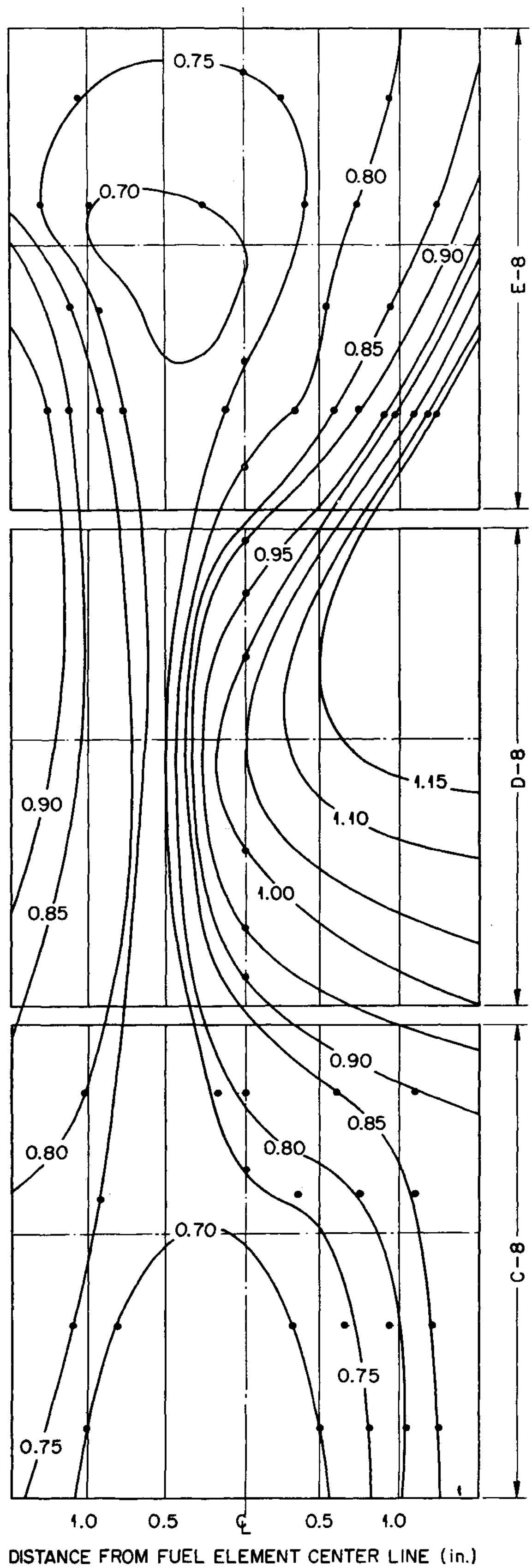

Fig. 5. Iso-flux for core positions C-8, D-8, E-8 normalized to highest measured values in E-8.

Natural Abundances of Er^{172} and Yb^{167}

Since the inception of the program for separating isotopes electromagnetically at Oak Ridge National Laboratory in