LATE B+

Critical Reactor Laboratory

# FLUX MAPPING and
# POWER CALIBRATION

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## ABSTRACT

The hot spot of the quadrant occurs in plate 2 of element 34 at a height of 12 inches with a peak to average flux of 2.486745. The average thermal flux in the core was measured to be 1.57 x $10^7$ n/cm$^2$-sec corresponding to an average core power output of 4.408 watts. This occurred at 50 percent of full scale on the linear power channel.

1/3

## PURPOSE:

The objective of this experiment was the determination of the relative flux distribution thruoghout a quadrant of the core, and by a symmetry argument, throughout the entire core. This information is useful in planning experiments and in safety analysis, since 'hot channels' and 'hot spots' can be located. The absolute flux at several locations was measured at 50% of full scale on the highest range of the linear power channel. By knowledge of the flux distribution, the absolute flux is determined throughout the core and consequently the power distribution and average power.

## THEORY:

Thin, one-quarter inch diameter U-235 foils were placed on fuel plates and irradiated at constant power for 30 minutes. The activity of the fission products is proportional to the flux in the foil at its location. Count rates, after correction for decay, are thus a measure of the flux at the point. Since the foils are thin, flux depression in the foils can be neglected. They are assumed not to perturb the flux shape in the core, since only a negligible mass is present. By placing the foils in suitable locations throughout a quadrant, the relative flux distribution can be obtained.

Since the steady state power of the reactor is proportional to the thermal flux, absolute determination of the thermal flux at a point will yield the reactor power at the point. Knowledge of the thermal flux distribution thus gives the power distribution. Since the thermal flux only is needed, a means of separating the thermal from higher energy fluxes is needed. If foil activation is used to measure the flux, bare and cadmium covered foils will separate the activation from the two neutron sources. Cadmium has a large thermal absorbtion cross section which decreases by more than three orders of magnitude at 1.45 ev. ? 0.4 eV Bare foils are activated by both fast and thermal neutrons, whereas cadmium covered foils are activated by fast neutrons only since all thermals are absorbed in cadmium.

The thermal flux is:

$$\varphi_{TH} = \frac{(C^{198}_{bare} - C^{198}_{cd})\, e^{+\lambda t_w} A^{197}}{(1-e^{-\lambda t_i})\, \varepsilon M_{Au} A_v \sigma_a^{197}}$$

mistake in handout

And the power is: $P = \frac{M A_v \sigma_f}{A^{235}} \varphi (3.2 \times 10^{-11})$ watts

where $C^{198}$ = count rate of foils from $Au^{198}$
$\lambda$ = decay constant of $Au^{198}$
$A$ = Atomic mass
$t_w$, $t_i$ = waiting and irradiation times
$M_{Au}$ = mass of gold foil
$M$ = mass of uranium in core
$A_v$ = Avogadro's Number

PROCEDURE:

Uranium foils are taped to plates 2, 5, and 8 at heights of 0, 1, 3, 6, 8, 10, 12, 15, 18, 21 inches from the beginning of the meat. Foils were also taped across plate 5 at 10 inches to account for flux depression at the centerline of the plate. The reactor was brought critical on the 4 rod bank for 30 minutes and then shutdown. The timing for the power run was begun a factor of 'e' before power was reached. This ensured that the net energy release was the same for all runs.

After counting, the following scheme was used to compute the flux distribution (see computer output).

1. input count rates
2. subtract background from count rates
3. correct foils for decay
4. normalize all count rates to a single run
5. sort data by position
6. obtain radial flux average by Simpson's rule
7. correct for radial flux depression
8. obtain average plate activity by trapezoidal rule
9. average plate activities to obtain element average
10. linearly extrapolate element activities to obtain element average in those elements that were not measured
11. average element activities to obtain core average
12. normalize all activities to core average

To obtain the absolute flux, bare gold foils were taped to plate 5 of element 33 at the 6 and 15 inch marks and at the 10 inch mark of plate 5 of element 55. Cadmium covered gold foils were placed in the core in symmetric positions (plate 5, at 6 and 15 inches of element 55, and plate 5, 10 inches of element 33). The foils were irradiated at power for 20 minutes and counted.

DISCUSSION:

The results are plotted and listed in the computer output. The output consists of a listing of the foil normalization decay factors, gold foil and background count rates, data debug information, and plots of the radial and axial flux distributions, data points being indicated by a star ('*'). The average plate, element and core activities and the normalized flux distributions are listed last. Before discussing the flux trends in the core, the methods used to obtain the numerical results should be considered.

Since the flux was not measured in the thermal column or in the control rods, their average element activities were extracted from the adjacent element activities using a linear extrapolation. Needless to say, this does not represent the actual situation since, in the control rods, the flux is depressed much more severely in the poison, than in the fuel at that height in the adjacent elements. Conversely, the thermal flux is strongly peaked in the thermal column, the extent of which is not indicated in the adjacent elements. The extrapolated control rod activities are higher than actual, while the extrapolated thermal column activity is lower than actual. These should be at least partially compensating in normalizing the flux, and in the absence of more data, the best that can be done. Core locations are indicated on the output as follows:

Element 1 = Element 22
" 2 = " 23
" 3 = " 32
" 4 = " 33
" 5 = " 34
" 6 = " 43

Plate 1 = Plate 2
" 2 = " 5
" 3 = " 8

The radial flux depression in the elements are plotted. It can be seen that the depression is not symmetric due to the fact that surrounding elements are not equally reactive. The points are plotted from 1 to 5 with 1 being closest to the core center. The most outside point has the highest activity since it has a large amount of water adjacent in which neutrons can thermalize. The flux depresses rapidly due to absorbtion in fuel. The slight peak at 3 is due to reflector effects which occur approximately 1 inch in from the edge of the core. The activity rises slightly at one, but is less than that at 5 due to fuel in adjacent element 33.

In the axial direction, a peak due to the reflector also occurs about 1 inch from the bottom of the fuel. A peak occurs at about the ten inch mark and then falls off, with additional depression due to the control rods which were partially inserted. Had the foils been axially symmetric, a slight increase due to the reflector would also have been observed in the upper part or the core. An anomaly occurs in plate 8 of element 23 (listed as plate 3 of element 2) in which there is a slight flux depression at 8 inches. Since this does not occur in plates 8 of either elements 32 or 34, which are approximately similar, this must remain unexplained.

The peak flux occurs in plate 2 of element 34 at the 12 inch mark. This is due to the large flow of thermal neutrons from the thermal column. There is more than a factor of 10 difference between the maximum and minimum fluxes in the core. Had the flux been monitored in element 44, much higher activities would have been obtained. This would not have indicated a hot spot however, since no heat generation occurs in the water. This points up the fact that the hot spot is directly related to the fission rate, not hte flux. The flux that we actually tried to measure is the flux entering the fuel since this gives the power. Placing foils on the fuel plates should be a good approximation to this since the cladding is fairly thin so that the foil is close to the meat.

The radial flux distribution in plate 5 indicates primarily the effects of two adjacent lattice positions -- those on which the plate abutts edge on. For plates 2 and 8 however, two lattice positions at each edge of the plate could have an effect on the radial distribution. However the major effect comes from the fuel in the plates themselves, and as can be seen from Simpson's Rule, the edges are not weighted very heavily in determining the correction factor. It is therefore useful and valid to assume that the plate 5 flux depression correction applies equally to all plates.

A similar flux depression would have been observed across the element if all plates had been mapped. This depression would have been slight in comparison due to the water gaps between plates which moderate neutrons. The flux average over three plates can probably be well represented by the central plate. Mapping plates 2, 5, and 8 gives a good average in the element.

The presence of foils in the reactor certainly perturbed the reactor. But a change in reactivity does not matter so long as the flux distribution remains unchanged with the reactivity change. This of course did not occur, but since the changes were small it is valid to assume that all foil locations afected the flux similarly. Our measurements thus yield a true representationof the flux.

Location and minimization of hot spots is important since they impose primary safety limitations on the power level.

Element 43, since it is adjacent to a fuel plate in 44 is more reactive than element 34 which is adjacent to a water gap. Neutrons in 43 are more important since the former have a higher probability of being absorbed in fuel.

In determining the power, the cadmium should be thick enough so that it absorbs all thermal neutrons, yet thin enough so that only a small fraction of fast neutrons are absorbed. If these conditions are not satisfied, or to check that they are, one can apply the cadmium correction factor found in ANL-5800. In addition it would be possible to use any other foils in this experiment, provided they do not perturb the flux shape too much.

The indicated reactor power is based not only on the thermal flux, but also fast and gamma fluxes. In the steady state these are all proportional so that the indicated power is linear with thermal flux at successive critical positions.

as we operate, fission products buildup so that with uncompensated ion chambers, the indicated power may slowly increase even though we are at a constant power level. In our case, F.P. buildup is not a problem, but with a commercial reactor, compensated ion chambers would certainly be required

CALCULATIONS:

$$\varphi_{TH} = \frac{(C^{198}_{bare} - C^{198}_{cd})\, e^{-\lambda t_w} A^{197}}{(1 - e^{-\lambda t_i})\, \varepsilon M_{Au} A_v \sigma_a}$$

$$\lambda = \frac{\ln 2}{t_{1/2}} = 1.768 \times 10^{-4}\ hr^{-1}$$

$$\varphi_{th} = \frac{(C^{198}_{bare} - C^{198}_{cd}) \exp(-1.786 \times 10^{-4} t_w)(196.966555)}{(1 - 3.5658 \times 10^{-3})(.035)(.602 \times 10^{24})(98.8 \times 10^{-24} M_{Au}}$$

$$= 2.65 \times 10^{4} \frac{(C^{198}_{bare} - C^{198}_{cd})}{M_{Au}} \exp(1.786 \times 10^{-4} t_w) \frac{n}{cm^2\text{-}hr}$$

at 6" $\varphi_{th} = 2.08 \times 10^{7}$ n/cm²-sec

Normalization factor = 1.325689

$\bar{\varphi}_{th} = 1.569 \times 10^{7}$ n/cm²-sec

at 10" $\varphi_{th} = 2.557 \times 10^{7}$ n/cm²-sec

Normalization factor = 1.652468

$\bar{\varphi}_{th} = 1.548 \times 10^{7}$ n/cm²-sec

at 15" $\varphi_{th} = 1.956 \times 10^{7}$ n/cm²-sec

Normalization factor = 1.226971

$\bar{\varphi}_{th} = 1.594 \times 10^{7}$ n/cm²-sec

Average $\bar{\varphi}_{th} = 1.57 \times 10^{7}$ n/cm²-sec