Nuclear Theory - Course 227

NEUTRON FLUX DISTRIBUTION AND ITS EFFECT ON POWER

The meaning of neutron flux was introduced in the last lesson. It was also indicated that neutron flux was a maximum in the centre of a reactor and that the power produced in a reactor was proportional to the neutron flux.

We will now discuss, in greater detail, the manner in which neutron flux varies from one point to another and how this affects the power output of a reactor.

Neutron Flux Distribution in a Reactor

We have seen that the flux is a maximum at the centre of the reactor but we do not know as yet how the flux varies across the reactor. In a reactor, we have fast neutrons produced during fission and the fast neutrons, that are not lost, are slowed down until they become thermal neutrons. Since it is the thermal neutrons that cause fission, it is the distribution of thermal neutron flux with which we are concerned.

The thermal neutron flux distribution (ie, the way the flux varies from one point to another in a reactor) will depend, very much on the shape of the reactor. Since the reactor is a solid, three-dimensional system, there could be different flux distributions in three perpendicular directions. Two reactor shapes only will be mentioned.

(1) Cubical Reactor

Fig. 1 shows a cubical reactor, without a reflector, each side of which has length "a". The centre point of the reactor is at O. Taking O as the origin, three perpendicular axes Ox, Oy, and Oz have been drawn parallel to the sides of the cube.

In the case of a cube the flux distribution is the same in each of these three directions. Thus in the Ox direction it follows the relation:-

$$\phi = \phi_m \cos\left(\frac{\pi x}{a}\right) \quad . . . (1)$$

That is to say the flux ϕ at a distance x from O, along the Ox direction is given by equation (1). In this equation, ϕ_m is the maximum thermal neutron flux at O, the centre of the reactor.

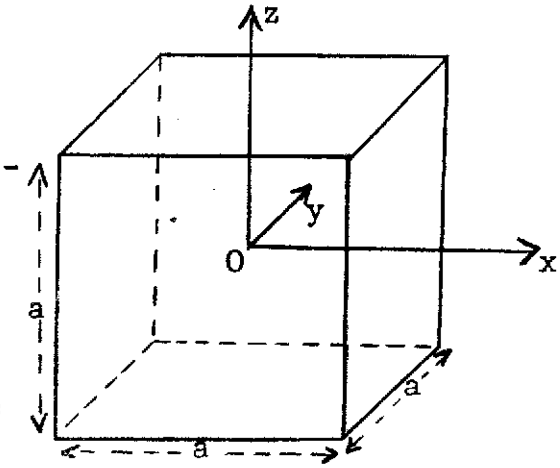

Fig. 1

If we substitute values of x in equation (1), and remember that $\pi = 180°$ we can calculate the corresponding values of ϕ. If ϕ is then plotted against x, the curve in Fig. 2 is obtained.

Fig. 2, then, shows the cosine distribution of the thermal neutron flux, not only along Ox, but also along Oy and Oz.

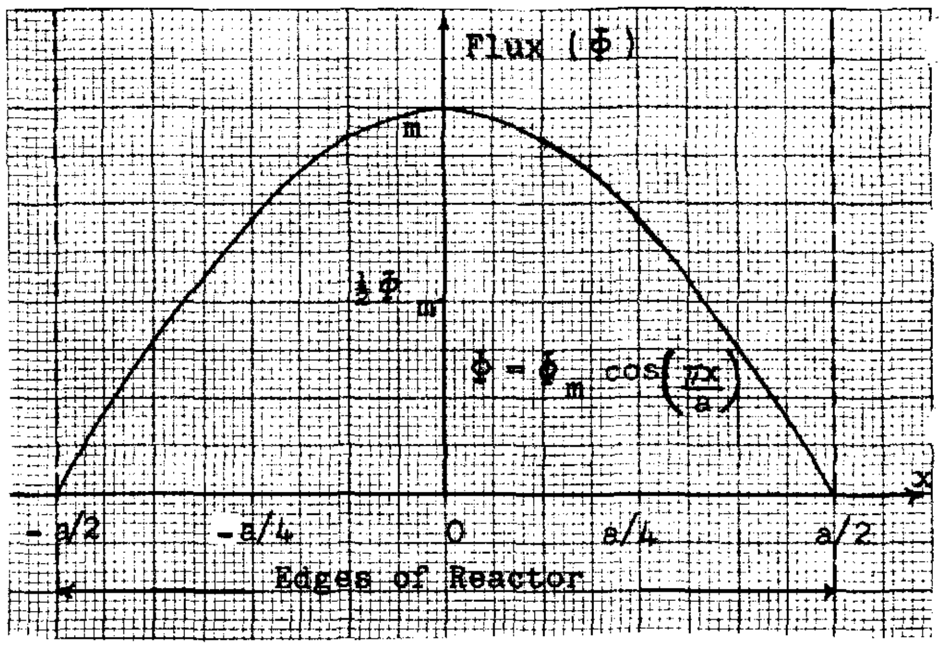

Fig. 2

(2) Cylindrical Reactor

Fig. 3 shows a cylindrical reactor of radius R and length L. Again O is the centre of the reactor. In this case there are only two directions along which the neutron flux distributions have to be considered. These directions are along any radius Or from O (known as the radial distribution) and along Oz, the axis of the cylinder (the axial distribution).

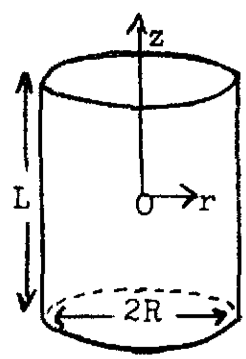

Fig. 3

The radial flux distribution is given approximately by

$$\phi = \phi_m \cos\left(\frac{\pi r}{2R}\right)$$

The flux distribution along the axis is given by $\phi = \phi_m \cos\left(\frac{\pi z}{L}\right)$ where ϕ_m, in each case is the maximum flux at O.

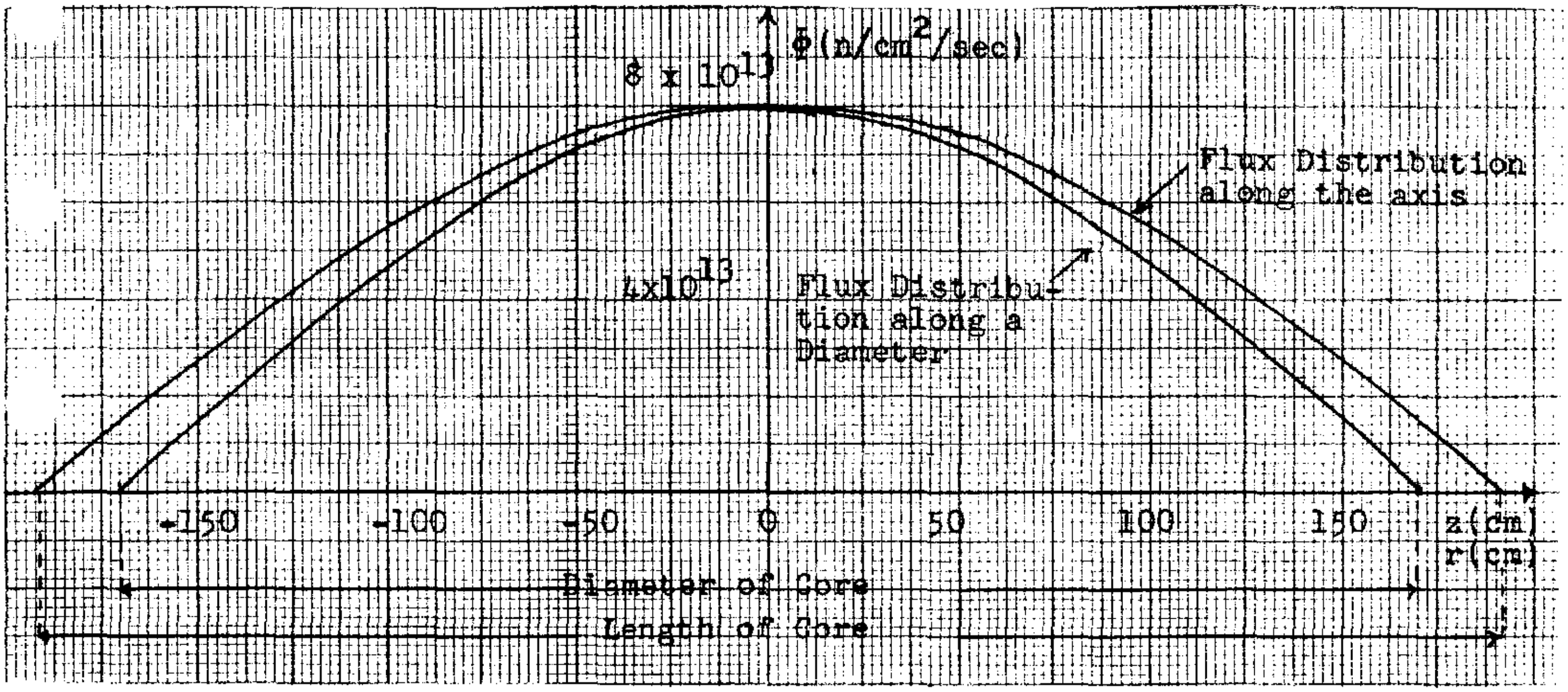

Fig. 4

Figure 4 shows the radial and axial flux distribution for the NPD reactor, without its reflector, for which R = 169 cm, L = 384 cm and ϕ_m is approximately 8×10^{13} neutrons/cm^2/sec.

Again the thermal neutron flux at any point is given by a cosine formula.

From the curves in Figs. 2 and 4, we can list several interesting conclusions, as follows: -

(1) In all cases the neutron flux falls to zero at the edge of the reactor and therefore very little power is being produced by fuel in the outer regions of the reactor core.

(2) The flux has a very definite maximum value at the centre of the core and, therefore, the maximum power is being produced near the centre.

(3) The total power produced by the reactor depends on the average thermal neutron flux. Due to the type of flux distribution that we have in the cylindrical reactor, the average flux is only about 27.5% of the maximum flux or the maximum flux is 3.6 times greater than the average flux.

Thus the fuel in the centre is producing 3.6 times more power than the average fuel in the core.

(4) The only way to increase the total power produced is by increasing the average flux and this can only be done by increasing the maximum flux still further. However, this would increase the heat released in the fuel at the centre and the amount of heat that can be produced is usually limited by the fuel rating and the heat removal capacity of the heat transport system.

In summary, then, we can say that, in a reactor without a reflector, the thermal neutron flux distribution leads to the following disadvantages: -

(1) Poor use of fuel, in the outer regions of the core, to produce power.

(2) Limitation of the total power produced because of the high ratio of the maximum flux to the average flux, ie, the average flux and, therefore the total power, could be much higher but for the fact that the average flux cannot be increased without exceeding the limit on fuel rating for fuel in the centre of the reactor.

Effect of a Reflector Around the Core

A reflector is a substance, placed around the reactor core, to reflect neutrons back into the core. This makes more neutrons available for fission so that the critical size of the reactor is smaller or with the same size of reactor a higher fuel burnup can be obtained.

Let us now see how the thermal neutron flux distribution is affécted by surrounding the core with a reflector. To illustrate the effect of the reflector we will again take, as a specific example, the radial flux distribution in NPD. Fig. 5 shows the same radial flux distribution, as in Fig. 4 without a reflector. It also shows, for comparison, the flux distribution when the core is surrounded by a reflector.

An examination of Fig. 5 will lead to the following conclusions: -

(1) The flux, at the edge of the core is no longer zero. It drops down to only 37% of the maximum flux. Therefore much more power is being produced by the fuel in the outer regions.

(2) The flux still has a maximum value at the centre but the average flux is now around 42% of the maximum when both radial and axial distributions are allowed for.

(3) Due to the higher average neutron flux, the power produced is much greater than without the reflector, even though we have the same size core and the same maximum flux.

(4) The graph representing the flux distribution is still a cosine curve but it now becomes zero outside the core ie, the reflector has increased the effective core diameter.

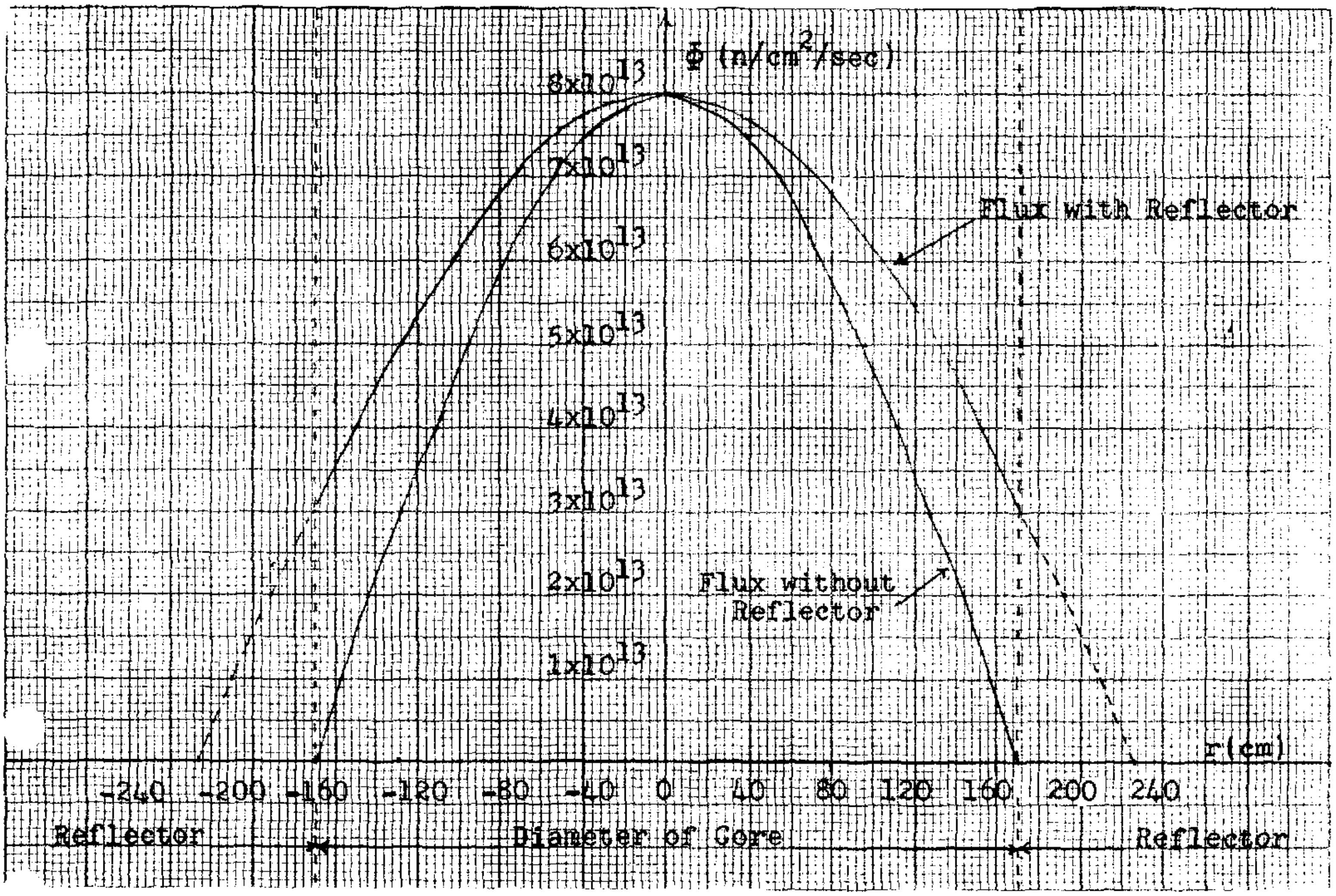

Fig. 5

ASSIGNMENT

1. Write down the equations giving the radial and axial flux distributions in a cylindrical reactor, without a reflector, explaining the meaning of the terms used.

2. If graphs were drawn of the equations in question 1, what three facts about the flux values could be learned from the graphs?

3. What effects has this type of flux distribution on the effective use of fuel and on total power produced by the reactor?

4. If a reflector is placed around the reactor core, what effect will this have on:

   (a) Flux distribution or flux values?

   (b) Reactor power?

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