Nuclear Theory - Course 127

THE FUNCTION AND PROPERTIES OF THE REFLECTOR

Reduction of neutron leakage by increasing the reactor core size has already been considered. The core size is increased until neutron losses are balanced by neutron production. However, the resulting flux distribution leaves a lot to be desired, particularly from the point of view of fuel utilization.

Neutron leakage from the core can also be reduced by surrounding the core with a substance which scatters or reflects neutrons back into the core. Such a substance is known as a REFLECTOR. Such a reflector also has desirable effects on the flux distribution.

The Function of the Reflector

Fig. 1 below shows the function of a reflector diagrammatically. Fig. 1(a) shows a "bare" core with many neutrons escaping. In Fig. 1(b) a substance has been placed around the core to reflect most of the neutrons back into the core.

It is evident that, with the reflector, more neutrons are available for fission because the leakage is smaller. Therefore, the core size does not have to be increased as much in order for the reactor to go critical. That is, the critical size of a reflected core is smaller than that of a bare core. Alternatively, if the size of the core is kept the same, higher fuel burnups can be achieved with consequent reduction in fuel costs.

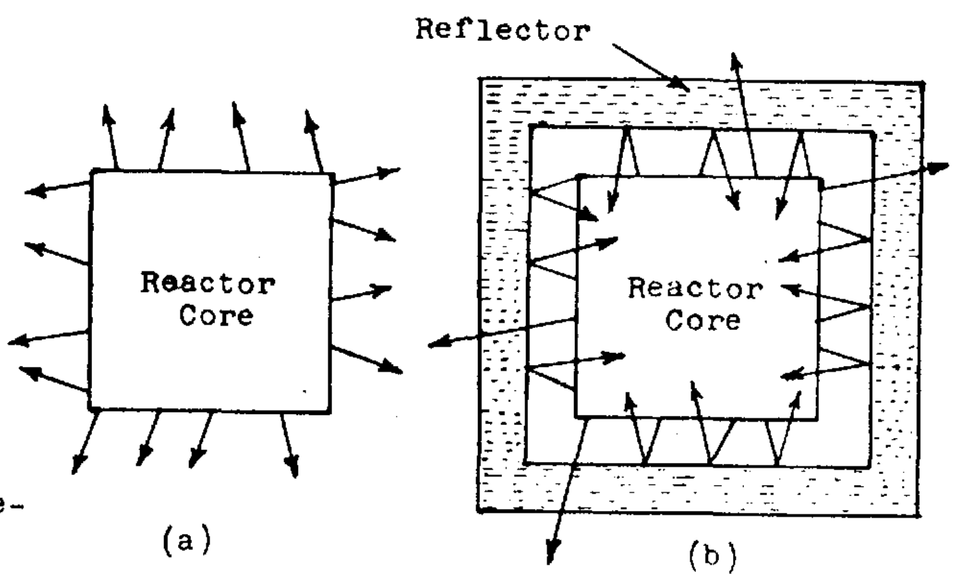

Fig. 1

Reflector Properties

The neutrons are reflected back into the core by scattering collisions between the neutrons and the reflector nuclei. The efficiency of a substance as a reflector is measured by a quantity known as the REFLECTOR COEFFICIENT (β).

The reflector coefficient may be defined as the fraction of the neutrons entering the reflector which are reflected back into the core.

For a reflector in the form of a slab, the reflector coefficient for thermal neutrons is connected with the diffusion length L by the equation:

$$\beta = 1 - \frac{4D}{L} \quad \text{..................(1)}$$

where D is a quantity known as the DIFFUSION COEFFICIENT which depends on the scattering and absorption cross sections of the material.

Although Equation (1) only applies to slab geometry, it can be used to illustrate that the greater the value of L and the smaller the value of D the closer β becomes to unity, ie, the more efficient the material is as a reflector. The values of D and L and the maximum value of β that could be obtained with an infinitely thick reflector are tabulated below for H_2O, D_2O, graphite and beryllium.

TABLE I

Material	L (cm)	D (cm)	β for an Infinite Slab	β for a Slab Thickness 2L
H_2O	2.76	0.17	0.780	0.772
D_2O	100	0.88	0.966	0.965
Beryllium	21	0.54	0.901	0.900
Graphite	64	0.94	0.944	0.940

The desirable properties of a thermal neutron reflector material may be summarized as follows:

1. Thermal neutrons are reflected by elastic scattering between them and reflector nuclei. Therefore, the macroscopic elastic scattering cross section, Σ_s, should be

high. If this is the case, the value of D will be low. Thus the density and the value of σ_s, must be high. Table I shows that H_2O has the lowest value of D.

2. The capture or absorption cross section, σ_a, should be low so that as few neutrons as possible are lost by capture. This requirement ensures a high value of L. However, since the escaping neutrons would have been lost, in any case, without the reflector, a low value of σ_a is not quite as important as it is in a moderator. Hence, H_2O is quite acceptable as a reflector for a natural uranium-fuelled reactor, even though it is not as efficient as D_2O. A light water reflector is also an excellent fast neutron shield and its use might well help to avoid the use of a thermal shield.

These desirable properties are, of course, almost identical with those expected in a moderator. The best thermal neutron reflectors are those materials that make the best moderators because they have small σ_a / σ_s ratios.

In the case of fast neutrons the most effective scattering mechanism is inelastic scattering. The best fast neutron reflectors are, therefore, the heavier materials. Hence, uranium or thorium are the materials used as reflectors in fast reactors such as the Enrico-Fermi reactor. Such a reflector is frequently referred to as a BLANKET since production of fissile material from fertile material occurs in the reflector.

How thick should a reflector be? The reflector coefficient β increases, initially, as the reflector thickness increases. However, as shown in Fig. 2, very little is to be gained by increasing the thickness beyond a value equal to 2L. Table I also shows that the value of β , for a reflector thickness of 2L, is within 1% or less of the maximum possible value. Since the desirable reflector properties are so similar to those of the moderator, it would be an

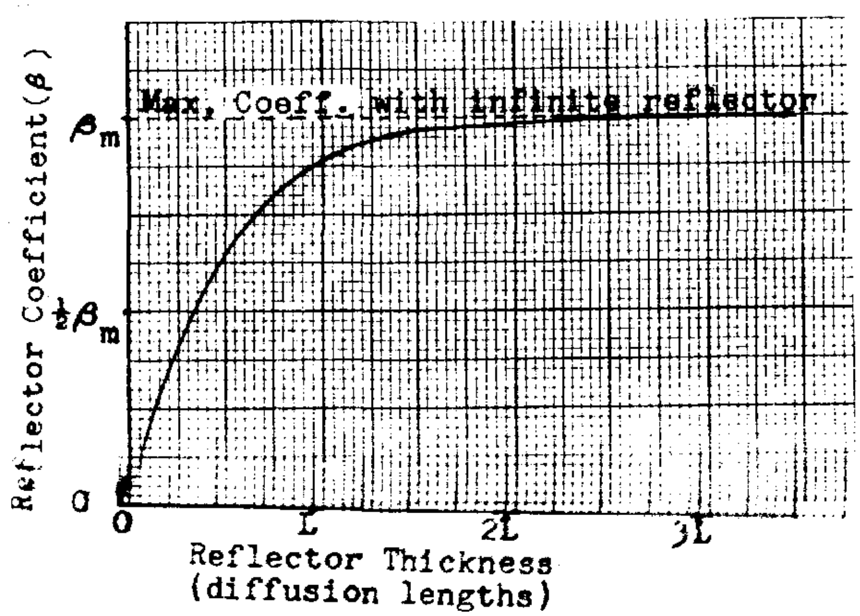

Fig. 2

advantage for the reflector to be merely an extension of the moderator so that both can be enclosed in the same reactor vessel.

With H_2O a thickness of 2L is only 5.5 cm, whereas for D_2O it is 200 cm. It would require a considerable amount of D_2O to extend the moderator by 200 cm, since this additional D_2O is being placed on the outside of the core.

Effects of Adding a Reflector

The effects of placing a reflector around the core can be summarized as follows:

1. The neutron flux distribution is "flattened", ie, the ratio of the average flux to the maximum flux is increased. This is illustrated in Fig. 3 for a reactor in which all the neutrons are assumed to have the same energy (eg, a fast reactor). Fig. 4 shows the change in flux distribution in a thermal reactor. The hump in the reflected curve in Fig. 4 is due to the fact that fast neutrons escape into the reflector and become thermalized in the reflector.

   The flux at the edge of the core is now over 50% of the maximum instead of only 20% in the bare core. When both the radial and axial flux distributions are considered, in a reactor like NPD, the average flux is increased from 27.5% to 42% of the maximum flux.

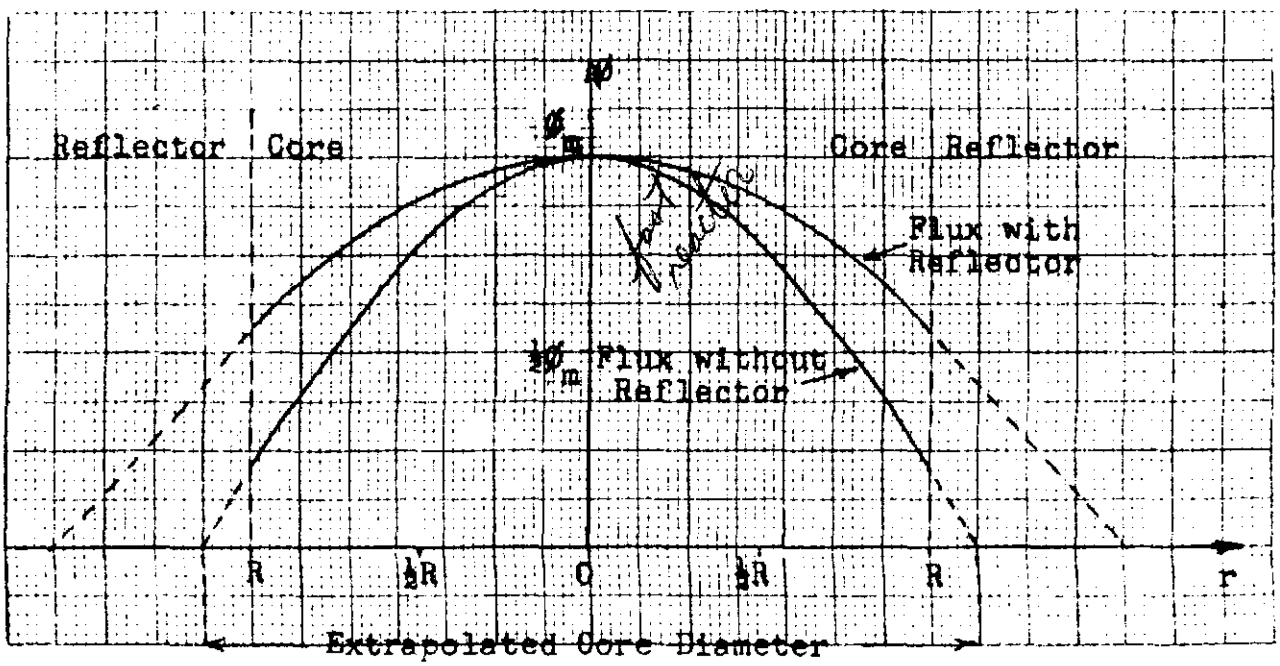

Fig. 3

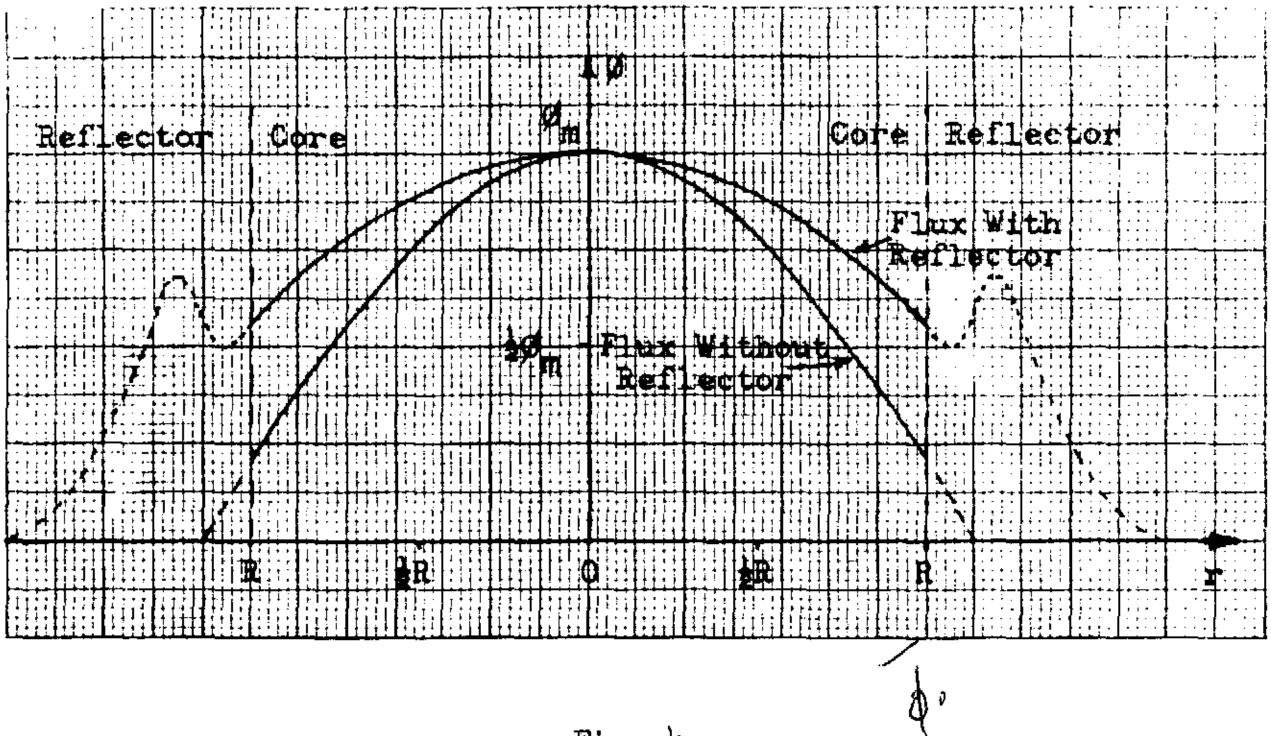

Fig. 4

2. Because of the higher flux at the edge of the core, there is much better utilization of fuel in the outer regions. This fuel, in the outer regions of the core, now contributes much more to the total power production.

3. The neutrons reflected back into the core are now available for fission. This means that the minimum critical size of the reactor is reduced. Alternatively, if the core size is maintained, the reflector makes additional reactivity available for higher fuel burnup.

   The decrease in the critical size of core required is known as the REFLECTOR SAVINGS.

4. The average flux, ϕ_a, in NPD is now given by:

$$\phi_a = 0.42 \times 8 \times 10^{13} = 3.32 \times 10^{13} \text{ n/cm}^2\text{/sec}$$

Therefore, for the same weight of uranium (10.9 tonnes) used in the previous lesson, the power P that can be produced is given by:

$$P = \frac{\phi_a U}{3 \times 10^{12}} = \frac{3.32 \times 10^{13} \times 10.9}{3 \times 10^{12}} = \underline{120} \text{ Mw}$$

This compares with 80 Mw, which can be produced with the same fuel in the bare core.

Alternatively, if the power output is kept the same, the weight of uranium required is given by

$$U = \frac{3 \times 10^{12} \times 80}{3.32 \times 10^{12}} = \underline{\underline{7.2}} \text{ tonnes}$$

This is a 30% decrease in the amount of fuel required.

ASSIGNMENT

1. (a) What is the basic purpose of a reflector?

   (b) What quantity is used to determine its efficiency?

2. (a) State two essential properties of a thermal neutron reflector.

   (b) Give two reasons why light water is suitable as a reflector but not as a moderator.

3. Why are the heavier materials the best fast neutron reflectors?

4. Why are reflector thicknesses never greater than twice the diffusion length of the reflector material?

5. (a) How does a reflector affect thermal neutron flux distribution?

   (b) State two important consequences of this change in flux distribution.

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