NEUTRON FLUX CONTROL

THIS SECTION IS NOT REQUIRED FOR MECHANICAL MAINTAINERS

OBJECTIVES

At the conclusion of this lesson the trainee will be able to:

1. Explain why a flat flux distribution is desirable.
2. Explain how each of the methods used in CANDU reactors flattens the flux.
3. Explain what flux oscillations are and how liquid control zones are used to prevent them.

NEUTRON FLUX CONTROL

If nothing is done to flatten the flux in our reactors it would look something like the distribution shown in Figure 13.1. The flux would be a maximum in the center of the reactor (where neutrons are moving in from all directions) and decrease toward the boundaries (where neutrons are escaping into the shielding).

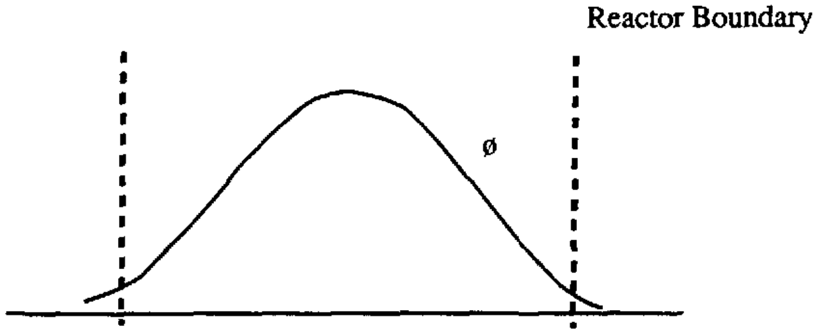

Figure 13.1: Unflattened Flux Distribution

Unfortunately with a distribution like this, the average flux is only about 30% of the maximum flux. This means that when the fuel bundle in the center of the reactor is producing the maximum power it can safely produce, the reactor is producing only 30% of the power it could safely produce if the flux were evenly distributed ($\emptyset_{avg} = \emptyset_{max}$).

While it is not possible to achieve a completely flat flux distribution, CANDU reactors achieve an average flux which is about 60% of the maximum flux, using the methods we are about to discuss.

You should appreciate that increasing the average flux without increasing the maximum flux has enormous economic benefits. For example, without flattened flux, Pickering NGS would be producing only half the power it now produces for roughly the same capital investment.

Reflectors

In module 8 we noted that adding a reflector to our reactors reduced leakage. That is only part of the advantage of reflectors. They also help flatten the flux distribution in the radial direction. Figure 13.2 shows the flux distribution in a reactor without a reflector and with a reflector added. With the same maximum flux, (limited by the maximum allowed power level for the fuel) the average flux has been increased due to the neutrons reflected back into the reactor.

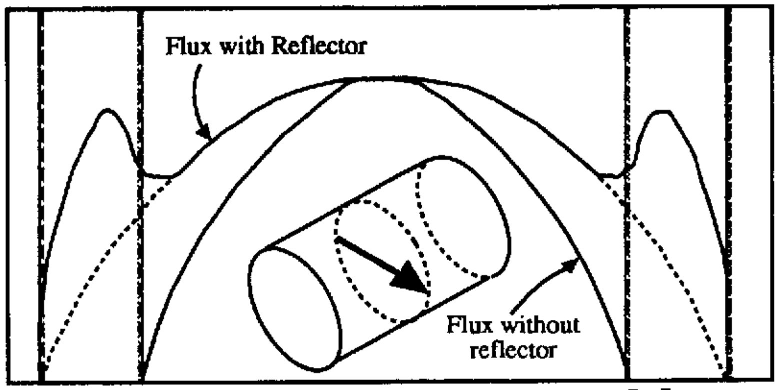

Figure 13.2: Effect of Adding a Reflector

Bi-Directional Fuelling

If adjacent fuel channels are fuelled in opposite directions as they are in all of our reactors an automatic flux flattening effect arises in the axial direction. This is shown in Figure 13.3.

We do not change all the fuel bundles when a channel is refuelled so the newer fuel (at the input end of the channel) generates more neutrons than the highly burned up fuel at the exit end. How much flattening is obtained in this way actually depends on how many bundles are fuelled in each visit to the channels. The less the better, from this point of view.

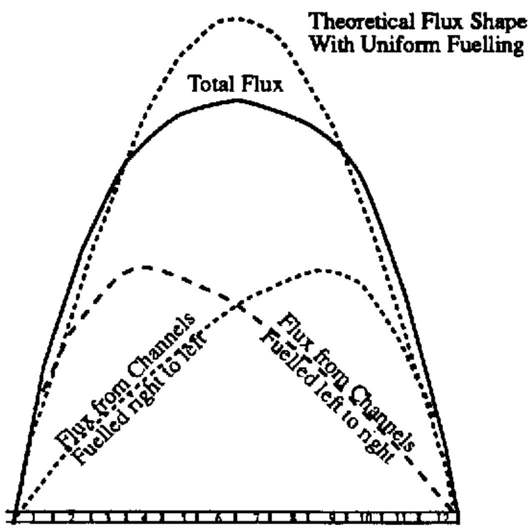

Figure 13.3: Effect of Bi-Directional Fuelling

Adjuster Rods

18 Adjuster rods are normally fully inserted in the central regions of the core to absorb thermal neutrons and in this way depress or 'adjust' the flux both radially and axially. Figure 13.4 shows the basic effect adjuster rods have on flux distribution. (Note: Bruce A reactors do not have adjuster rods).

Flux flattening with the use of these rods is quite effective but it does represent a loss in fuel burnup. We accept this because the benefits of increased power production greatly outweigh the higher fuel cost.

Several of the Ontario Hydro reactors use cobalt as the neutron absorbing material in the adjuster rods. The adjuster rods are replaced periodically, and the cobalt-60 is processed and marketed by AECL.

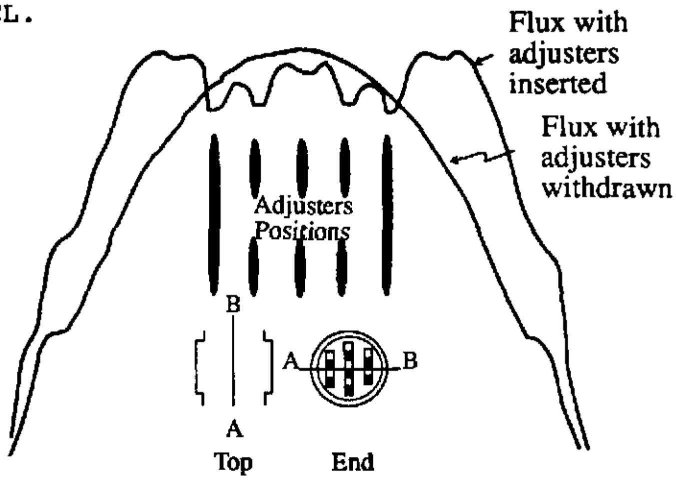

Figure 13.4: Effect of Adjuster Rods

Differential Fuelling

A different method of flux flattening was chosen for the Bruce "A" reactors, which use boosters rather than adjusters for xenon override. Differential fuelling means that the bundles in the central channels are left to reach higher than average burnups while bundles in the outside channels are removed at lower burnup. The central bundles therefore generate relatively fewer neutrons from fission, because they contain fewer fissile nuclei than the outer bundles.

Figure 13.5 illustrates this method of flux flattening.

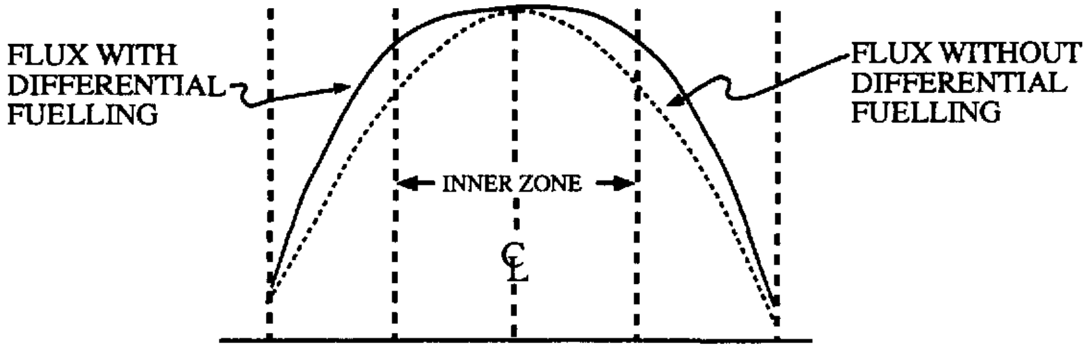

Figure 13.5: Effect of Differential Fuelling

The fuelling engineers at all our reactors plan the fuelling to maintain an optimum flat flux shape. For reactors with adjusters the amount of differential fuelling required to achieve this is relatively small.

Flux Oscillations

So far we have assumed the flux distribution is static. Suppose now that without changing the total power of the reactor, the flux is increased in one region of the reactor. This typically happens when a channel is refuelled. In the region of increased flux, the xenon now burns out more rapidly than it did prior to the change, and its concentration decreases. This decrease in xenon concentration leads to a higher reactivity in this region, which, in turn, leads to another increase in flux. This again leads to increased local xenon burnup, increased local reactivity, increased flux, and so on.

Meanwhile the control system is keeping bulk power constant so the flux away from the "hot spot" is lower than before. In the region of decreased flux, the xenon concentration increases due to reduced burnup while iodine continues to decay. This increased xenon concentration decreases the reactivity in this region, which reduces the flux, in turn increasing the xenon concentration, and so on. The thermal flux, and hence the power density decreases in this region while it increases in the other, the total power of the reactor remaining constant.

These local power excursions do not continue without limit. In the region of increased flux, the production of xenon from iodine, which is now being formed more rapidly, ultimately reduces the reactivity there. The flux and power eventually decrease. Similarly, in the region of reduced flux, the accumulated xenon eventually decays, increasing the local reactivity and reversing the flux and power transient in that region.

In this way, the flux and power of a reactor may oscillate between different regions (end to end, side to side, top to bottom) unless action is taken to control them. Calculations show that these xenon oscillations (also called flux tilts) have a period of 15 to 30 hours.

Since xenon oscillations can occur at constant overall power they may go unnoticed unless the flux distribution is monitored at several points in the reactor. This must be done in order to prevent such oscillations, since they represent something of a hazard to the safe operation of a reactor. Conceivably, they may lead to dangerously high local fuel temperatures.

One of the purposes of the liquid zone control system is to limit such oscillations. Each reactor is controlled using 14 zones. Each zone has a flux detector which via the Digital Control Computer, controls the light water level in the zone control compartment.

As an example of how light water zones may be used, look at Figure 13.6. Assume there are only two zones and a flux tilt is developing such that the flux in Zone I is increasing and the flux in Zone II is decreasing. By raising the water level in Zone I control compartment more neutrons are absorbed. Conversely, lowering the level in the Zone II compartment reduces the neutron absorption in that zone. Thus, the action of the two zone control compartments returns the flux to a normal flat distribution.

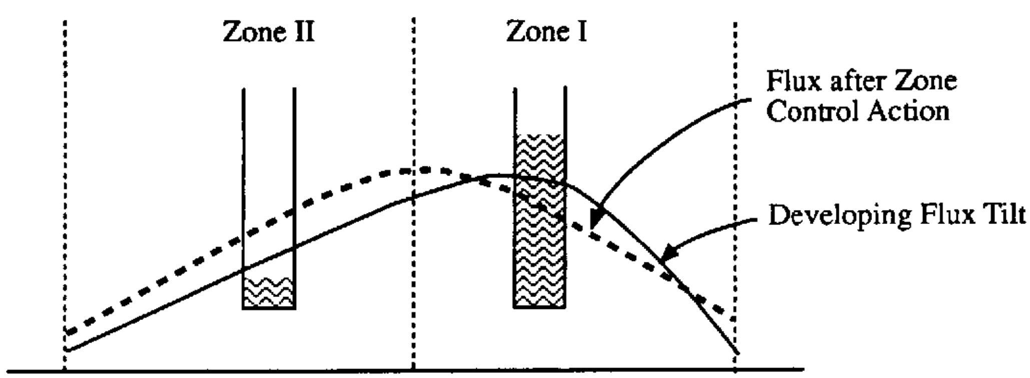

Figure 13.6: Zone Control System

ASSIGNMENT

1. List and briefly describe the four methods of flux flattening used in CANDU reactors.

2. Why is flux flattening desirable?

3. Explain how light water control zones are used to prevent flux oscillations.

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