Nuclear Theory - Course 227

METHODS OF REACTOR CONTROL

We have seen, from the previous lessons, that a reactor is critical, if the chain reaction is just being maintained, the multiplication factor, k, is unity and the reactivity, δk, is zero. We have also seen that the reactor power will increase if the neutron losses are reduced so that k becomes greater than unity, δk becomes positive and the reactor is supercritical. Reactor power is decreased if the neutron losses are increased so that k becomes less than one, δk becomes negative and the reactor is subcritical.

In this lesson, then, we will discuss methods by which neutron losses can be increased or decreased to make k negative or positive.

General Requirements of a Control System

Any method or system used for controlling a reactor must be capable of: -

(1) keeping the value of $k=1$ and $k=0$ during steady power operation and therefore allowing for changes that occur in δk due to burning up fuel or other causes

(2) allowing δk to become negative to decrease the power and to become positive for increases of power and

(3) decreasing k sufficiently to give δk a large negative value for rapid shutdown of the reactor under any circumstances which might prove hazardous to personnel or equipment.

In view of these general requirements the control system must perform two functions which are: -

(1) REGULATION which involves small changes in reactivity either to maintain the power at some predetermined level or to change the power as may be required. The regulating system is the means by which the multiplication factor, k, is adjusted and controlled to shutdown or start up the reactor or to keep the reactor operating at some desired power level.

(2) PROTECTION which provides the automatic rapid shutdown of the reactor should some dangerous condition develop. This rapid shutdown is known as TRIPPING the reactor and the protective system is the means by which this is achieved.

Methods of control

It is not intended, at this stage, to discuss the hardware or components of regulating and protective systems, but rather the principles on which they operate. There are several basic methods of reducing neutron losses to increase k and the methods of control will be discussed under these headings. These are: -

(1) Decreasing neutron absorption in materials other than U-235. This increases the number of neutrons available to cause fission and increases the value of k. The reverse process of increasing neutron absorption in nuclei other than U-235 decreases the value of k.

This method of control is achieved by inserting absorbers of neutrons into the reactor core or by withdrawing absorbers out of the core. Such control methods are illustrated in Figs. 1 and 2.

Fig. 1 shows the conventional method of inserting the absorber into the reactor core in the form of control rods, which are normally made of either boron or cadmium.

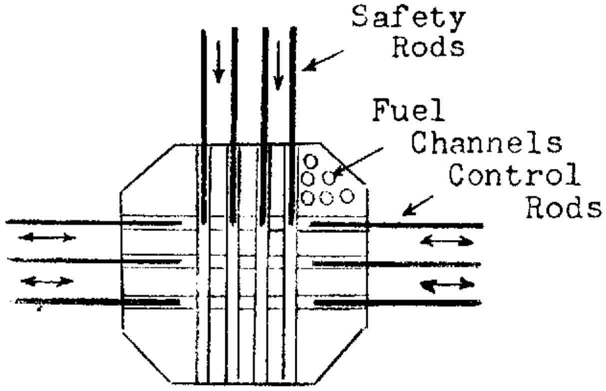

Fig. 1

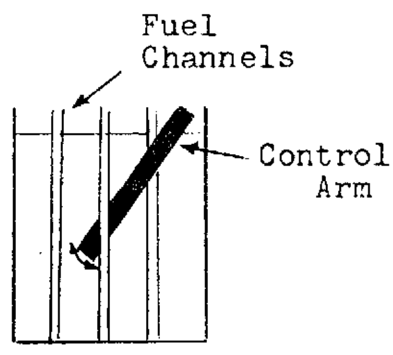

Fig. 2

When the rods move further into the core, the reactivity is reduced. When the rods move further out the reactivity increases. In Fig. 2 the absorber is in the form of a control arm which is pivoted at the top end and moves in and out of the core in much the same way as a railway signal arm.

Rapid reduction of reactivity is achieved by quick insertion of safety or shutdown rods, which normally drop vertically into the core. These are also made of cadmium or boron. The control rods frequently move in and out along horizontal channels and provide the regulation. The safety rods move along vertical channels so that they drop rapidly under gravity and they provide the protection.

(2) The value of k can also be increased by increasing the amount of fuel so that the neutron absorption in fuel nuclei is increased. When the amount of fuel is decreased the value of k is reduced. This is not a widely used method for reactor control but it is worth nothing that it is used in Canadian power reactors when additional reactivity is required to overcome poison build-up.

The method is illustrated in Fig. 3. The fuel rod, known as a BOOSTER ROD, is inserted in the reactor along a horizontal channel as shown or along a vertical channel.

The rod, which is normally made of enriched uranium, is only inserted when additional reactivity is required. When it is not required the rod is withdrawn from the core and the U-235 nuclei are therefore conserved.

Continuous "on-load" refuelling of the Canadian power reactors, is also a method of controlling reactivity by fuel insertion since it compensates for loss in reactivity due to burnup of U-235.

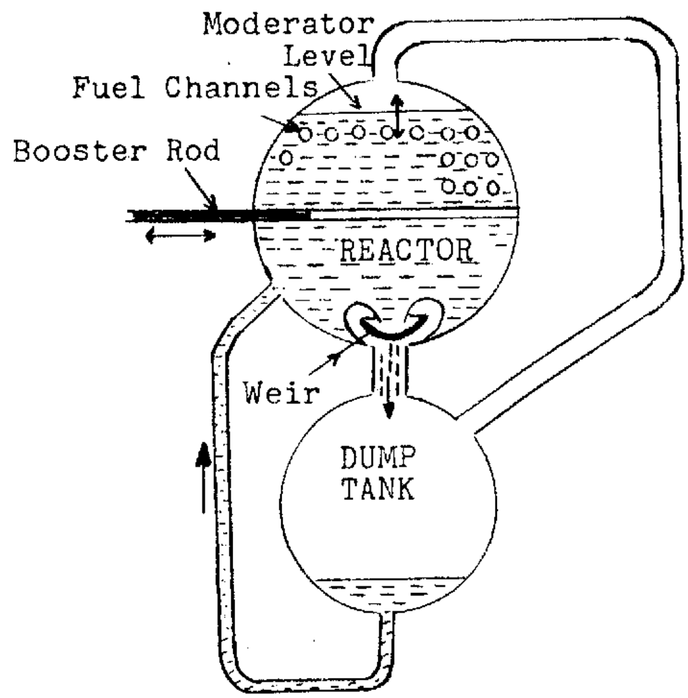

Fig. 3

(3) Decreasing neutron leakage from the reactor will provide more neutrons for fission. Conversely, if neutron leakage is increased the value of k decreases. The neutron leakage can be controlled in one of two ways: -

(a) By addition or removal of reflector. The reflector prevents neutron leakage by reflecting neutrons back into the core. If the reflector thickness is reduced or part of the reflector is removed, neutron absorption is increased and the reactivity decreases.

Fig. 3 illustrates how this method is used in Canadian power reactors. Heavy water moderator continually circulates from the dump tank to the reactor vessel, overflows over the weir and flows back into the dump tank. When it is required to fill the reactor vessel, a pressure differential is established between the dump tank and the top of the reactor vessel. This reduces the flow over the weir and the vessel fills up to the level required.

The outer regions of the moderator acts as a reflector and so the thickness of reflector above the core can be changed by raising or lowering the moderator level. This is used as a means of regulation.

If the protective system causes a reactor trip, the pressure in the dump tank becomes equal to that in the reactor vessel and the reactor vessel is emptied of moderator in a few seconds. This is called "dumping the moderator" and is the means used for protection at NPD.

(b) By increasing or decreasing the core size. The easiest way to do this is by addition or removal of moderator. This method, which is used for coarse control on NRX at AECL, is illustrated in Fig. 4. As the moderator level rises, more and more fuel is covered and the core size increased. This decreases the surface area relative to the volume and a smaller fraction of the neutrons produced escape.

Here again the moderator can be emptied rapidly for a quick shutdown.

Although each method of control has been discussed separately, two or more of them may be used on any one reactor.

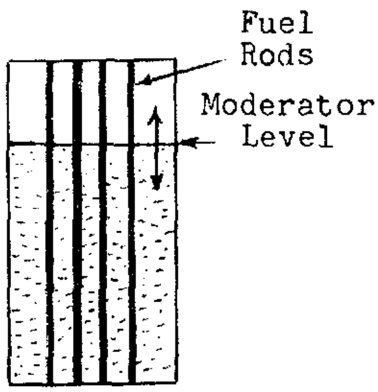

Fig. 4

For instance, on NPD, the reflector thickness variation is used for fine control, continuous refuelling is used for day to day reactivity control and a booster rod is used when additional reactivity is required.

In Douglas Point the above three methods are used and in addition, control rods are used to prevent power fluctuations and cadmium sulphate is used as a neutron absorber in the moderator to enable the reactor to operate with a full tank even when the fuel is new.

ASSIGNMENT

1. What are the three general requirements of a reactor control system?

2. Explain the difference between the regulating and protection functions of a control system.

3. Explain the three basic methods by which neutron losses can be decreased or neutron utilization increased, and describe, briefly, the control methods based on these.

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