Nuclear Theory - Course 227

STARTING UP A REACTOR AND INCREASING POWER

There are, basically, two stages involved in bringing a reactor up to power and these stages are: -

(1) The approach to critical during which the value of k is increased until the reactor becomes critical.

(2) Increasing the power until the operating power level is reached.

The Approach to Critical

Reactors are brought critical in many different ways: -

(1) By loading fuel into the reactor until a chain reaction is sustained. This is the method that would have to be used in a graphite moderated reactor where the moderator level cannot be changed.

(2) By withdrawing control rods until a chain reaction is sustained. All the fuel would have been loaded into the reactor beforehand and the core size is fixed.

(3) By increasing the size of the core. This is very conveniently done, in a reactor with moderator level control, by simply raising the moderator level to cover more and more fuel channels. Our discussions will be confined to this method.

During the approach to critical, the value of k is less than one and a chain reaction cannot be maintained. A source of neutrons must exist in the reactor if fissions are to occur at all. With fresh fuel in the core, the only source of neutrons are the spontaneous fissions that occur so infrequently. After the reactor has been operating for some time, fission products are produced in the fuel and these emit gamma rays. The gamma rays, in turn, produce photoneutrons in heavy water. It is, therefore, convenient to discuss the approach to critical under two separate headings: -

(1) The First Approach to Critical

This is the approach to critical when no photoneutron sources exist in the reactor. It is termed the "first approach to critical" because it is the approach that would have to be adopted when the reactor is loaded with fuel for the first time, ie, a fresh core. However, the same approach would have to be used if the reactor had been shut down for a long period of time and the fission products had decayed to such an extent that the photo-neutron sources had disappeared. The following problems exist during the first approach to critical: -

(a) It is not known what the moderator level will be when the reactor goes critical, ie, it is not known how many fuel channels have to be covered, although this can be estimated by calculations. This means that the moderator level has to be raised in small steps and held at each level until it can be determined whether or not the reactor is critical.

(b) The instruments which measure neutron power have not been calibrated and cannot be relied upon for measurements or for reactor regulation. The automatic regulating system cannot, therefore, be used and the approach has to be made under manual control, ie, the moderator level is raised by manipulating the controls by hand.

(c) The instruments, normally used to measure neutron power, are not nearly sensitive enough t o measure the neutron densities that are produced by spontaneous fissions. Very sensitive neutron detectors, such as fission chambers, are, therefore required which are inserted right into the core.

(d) Even with such sensitive detectors, the initial low neutron densities will not register and so a neutron source has to be inserted into the core to bring the instruments on scale.

With these problems in mind, the first approach to critical is made as follows:

The reactor is provided with a vertical access tube, down which the fission chambers are lowered, as shown in Fig. 1, so that they lie in the lower part of the core. Three such detectors are used and they are connected to counters rather than power instruments. Thus the neutron power is measured from the count rate on three separate detectors.

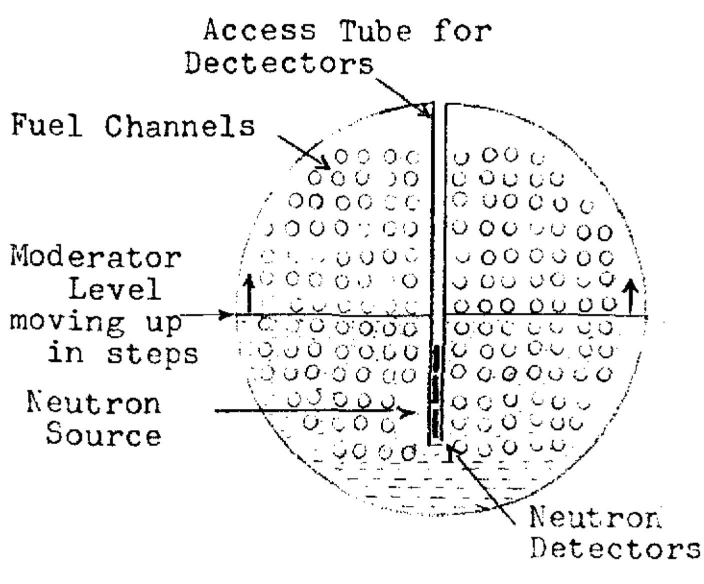


Fig. 1

A neutron source is also introduced into the core, again down some tube. The moderator level is now raised in small steps. Fig. 2 shows how the power or count rate increases for different values of k. When k is 0.5 the count rate levels out rapidly, but as k increases, it takes longer and longer for the count rate to level out. The time to level out must be allowed for each time the moderator is raised.

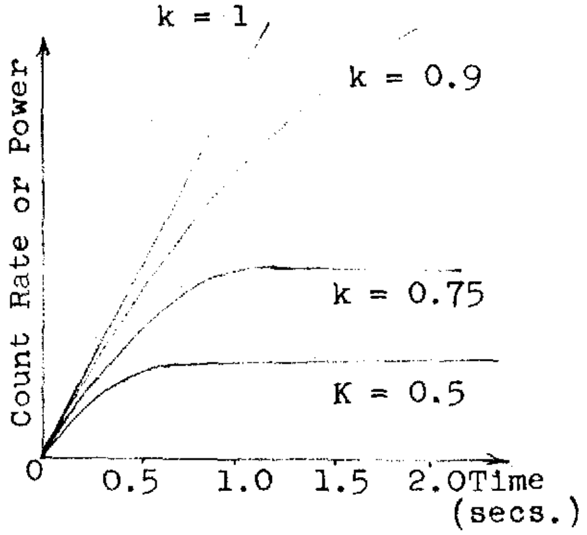
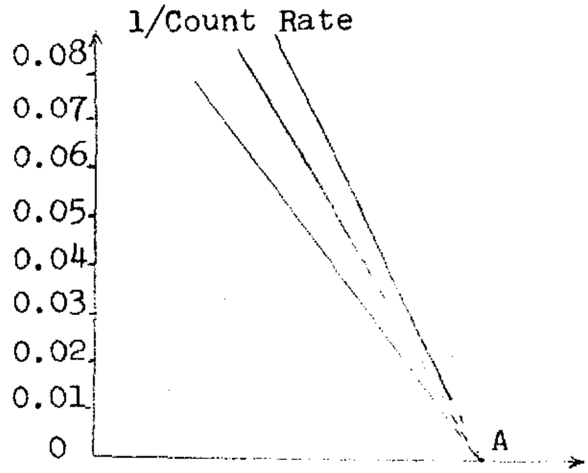


Fig. 2

As k increases, the neutron source increases and the count rate goes up. Thus, eventually the neutron source can be removed. Also the fission chambers have to be moved upwards along the access tube to keep the count rate on scale. When k becomes equal to 1.0 and the reactor is critical, the power and count rate do not level out, but continue to increase. This is how it is known when the reactor is critical.

It is, however, desirable to be able to predict what the moderator level will be when the reactor is critical. This prediction is obtained by noting the count rate at each moderator level and then plotting the reciprocal of the count rate against a function which depends on the moderator height. When the points are joined, they are found to be on a straight line which approaches the value of this function when the reactor is critical.



Function of Moderator Height

Fig. 3

Thus, in Fig. 3, the three lines, obtained from the three fission chambers approach the point A. A is the value of the function when the reactor is critical. So, from the value at A, we can calculate the critical height.

When the critical height is reached, or just exceeded, the power is allowed to rise very slowly until the normal instruments come on scale and can be calibrated. The automatic regulating system can then be adjusted and put into service.

(2) Subsequent Approaches to Critical

If the reactor has been operated until fission products have accumulated in the fuel, there will be photoneutron sources in the core when the reactor is shut down. These photoneutron sources are large enough to give a reading on the lower range of the most sensitive neutron power instrument. Therefore, for a startup after a reactor shutdown, we do not need a neutron source or special neutron counters.

However, the neutron power reading is still too low to allow the automatic regulating system to operate satisfactorily, unless, of course, the shutdown was very brief. So the approach to critical may still be made, initially, on manual control, using the normal neutron power instruments.

The moderator level is allowed to rise slowly, but steadily until the neutron power is high enough to allow the automatic regulating system to operate. The power level will then be about 0.01% of full power and when this level is reached, a switch over is made from manual to automatic control.

Subsequent approaches to critical are less hazardous than the first approach, because the critical moderator height is known, the instruments are calibrated and more reliable and poison levels in the fuel are at a much higher level, thus limiting the possible increases in reactivity.

Raising Reactor Power

Once the reactor is critical, it may be kept at any power level by adjusting the moderator level to keep $k = 1$ or $\delta k = 0$. If the power has to be increased, the moderator level is raised to make k just greater than unity, or δk slightly positive. Fig. 4, overleaf, shows such a raise in moderator level at A.

The figure also shows the corresponding changes in k and δk and the resulting exponential increase in power. The reactivity change possible is usually limited by design so that the reactor period during the power increase is long. There is also a reactor trip if this period becomes too small, ie, the rate of increase of power is too high.

At B, the required power level has been reached and the moderation level is returned to the point where $k = 1$ and $\delta k = 0$. This is somewhat different from the control method in conventional power plants.

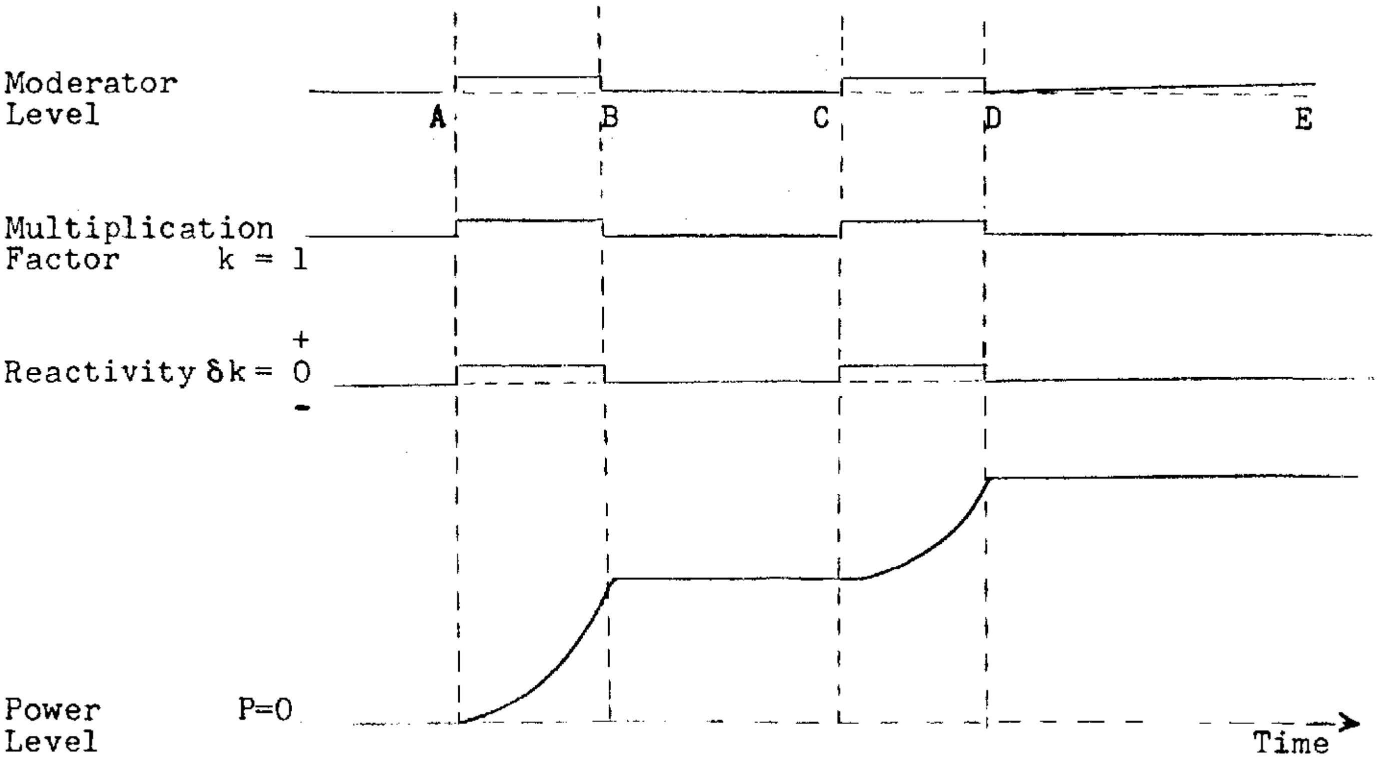


Fig. 4

In a conventional plant, when you want to increase the thermal power, you boost the firing rate by opening the fuel valve wider and increasing the air flow. The valve is then left open at the new setting. However, in nuclear plants, the moderator level is only raised while the power is being raised by increasing neutron density. When the correct power level is reached, the moderator is returned to the old level to prevent further increase in neutron density.

Another increase in power is shown at C which is completed at D. These moderator level adjustments can be made by hand, but they are normally made by the automatic regulating system, as a result of a demand for higher power by the system.

From D to E we see a gradual rise in moderator level that would be necessary to compensate for fuel burn-up or build up of poisons. Note that k is kept at a value of 1.0 and $\delta k = 0$.

ASSIGNMENT

1. What are the two stages involved in bringing a reactor up to power?

2. (a) Why is the first approach to critical different from any subsequent approach to critical?

   (b) Give three reasons why the first approach to critical is more hazardous than any subsequent approach.

   (c) What two additional items of equipment are required during the first approach to critical which are not required during subsequent approaches?

3. How is it known when the reactor is critical?

4. (a) After the critical moderator level is reached, how is the reactor power raised and then maintained at the required level?

   (b) In what way does this differ from the way in which thermal power is increased in, say, an oil fired boiler?

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