Nuclear Theory - Course 127

REACTOR STABILITY

Many aspects of reactor theory have been considered, particularly those effects or changes which cause changes in reactivity, eg, xenon buildup and temperature coefficients.

Two factors which can affect the inherent stability of a reactor are temperature changes and xenon poisoning.

Temperature and Reactor Stability

When a study is made of the stability of a reactor, the regulating system and its response to various conditions in the reactor is normally included. The reactor itself may be more or less inherently stable. However, depending on its temperature coefficients, if an overall power or temperature coefficient is negative, this will help to prevent power transients. (This was demonstrated at NRX as discussed in the earlier lesson on the effects of temperature changes.)

In addition to the large relatively slow transient, it is also possible to have the reactor power oscillate with a high frequency due to various time delays in the reactor and the regulating system. Time delays can be associated with:

(1) The response time of the regulating system and control method.

(2) The time associated with flux changes, ie, there is a small interval of time between a flux disturbance occurring in one part of the core and the change in flux being detected by ion chambers in another part of the core.

(3) The materials in the core (such as moderator) have an appreciable heat capacity. This results in a time lag between a change in power and the resultant temperature change.

If the system stability is good, any changes in power which tend to start an oscillation are quickly damped out. In this respect, the delayed neutrons are important since they tend to slow down any change in reactor power.

Because of the time delay associated with the heat capacity of the core material, the fuel temperature coefficient or power coefficient may have a more important influence on the reactor stability than the other coefficients. A reactor may have an overall positive temperature coefficient and still be inherently stable, provided that the fuel temperature coefficient is negative. Even though the positive moderator temperature coefficient is greater than the negative fuel temperature coefficient, the response time of the fuel is considerably less than that of the moderator. Thus, when an increase takes place in the power, the fuel temperature rises soon after the power increase but moderator temperature rise will be delayed because of its large heat capacity and moderate thermal conductivity. Hence, a transient increase in fuel temperature will be counteracted promptly by the effect of the negative temperature coefficient long before the positive moderator coefficient can have an effect. The reactor would, therefore, be inherently stable against transient temperature changes.

Xenon Oscillations

When xenon and samarium buildup was considered, it was assumed that the poisoning and the reactivity load applied to the reactor as a whole. No account was taken of the possibility of localized changes in xenon poisoning which can have a very important effect on reactor stability.

Suppose, for the sake of argument, that the automatic control system is "frozen" and unable to change reactivity one way or the other when the xenon poison has reached equilibrium concentration. Now suppose that a small decrease in flux occurs. This will decrease the rate of removal of xenon without appreciably changing its rate of production. The xenon concentration increases and, since the control system is unable to counteract the xenon load, the reactor becomes subcritical. The flux decreases further, there is a further increase in xenon, and the reactor "poisons out".

Many hours later, after all the iodine has gone and the xenon has decayed, there will be enough reactivity for the reactor to become critical, since the control system is still frozen. The flux will increase and more xenon will be removed and the reactor becomes supercritical. It will remain supercritical until the xenon builds up sufficiently for it to become subcritical once more. So the flux and power will oscillate, and the effect is known as XENON OSCILLATIONS.

The above considerations suppose that the regulating system remains frozen whereas, normally, the regulating system counteracts any flux disturbance as soon as it takes place, and thereby keeps the reactor power constant. However, a local disturbance can be set up in a reactor by on-power refuelling, for example. Refuelling causes a sudden localized lowering of xenon concentration which, in turn, causes the flux to increase in this locality. The above cycle is, then, initiated unless corrected by the regulating system. However, corrective measures by the regulating system may not be effective if the reactor is so large that different regions in the reactor function as independent units.

If the neutrons produced in one region of the reactor do not cause significant fissions in another region, then the two regions can act independently of one another. The criterion that determines whether or not this is possible is the degree of neutron leakage from the one region to the other. In a reactor such as NPD the core is small enough to permit a disturbance started in one region to have an effect in another region. The xenon and flux changes would therefore affect the whole core and a regulating system based on flux measurements in one locality can correct the flux disturbance and prevent xenon oscillations from being initiated.

If the reactor is large, or if different regions of the core are separated by a region of high neutron absorption, leakage of neutrons between regions is very small. A disturbance started in one region has little effect in another region. Thus, if a flux increase occurs due to the fuel change in one region, a nonregional regulating system would compensate for this and maintain steady power by lowering the flux in another region to keep the average flux across the core constant. This would set up a xenon oscillation in the second region exactly out of phase with that in the first region. When the first region becomes supercritical the second region becomes subcritical and when the first region becomes subcritical the second region becomes supercritical.

The period of the flux and power oscillations in any one region is about 20 to 30 hours. Such oscillations of power are most undesirable and so, in large reactors, different regions of the core must have some independence of control. Neutron absorber rods are better suited for such independent control. As at Douglas Point, regional absorber rods are regulated by an independent control mechanism fed by independent local flux detectors. At the same time, moderator level control is used for general reactor regulation.

ASSIGNMENT

1. (a) What basic condition helps a reactor to be stable to temperature changes?

1. (b) What factors may cause high frequency power instabilities?

   (c) How can a reactor be inherently stable, even though the condition in (a) is not satisfied, provided that it has a negative power or fuel temperature coefficient?

2. (a) Why are xenon oscillations more likely to occur in a large reactor than in a small one?

   (b) Describe how such xenon oscillations occur in such an inherently unstable reactor.

   (c) How are such xenon oscillations prevented?

A. Williams