Reactor, Boiler & Auxiliaries - Course 133

REACTIVITY MECHANISMS

FUNCTIONS OF REACTIVITY MECHANISMS

Reactor reactivity mechanisms represent the final control elements which cause changes in the neutron multiplication factor k, or reactivity Δk and hence, reactor power.

There are two separate requirements of a reactor control system which are fulfilled by two, preferably completely, independent systems which are:

1. The REGULATING SYSTEM which (a) regulates the value of k to unity for steady power operation so that $\Delta k = 0$ and (b) allows Δk to become +ve or -ve to change reactor power at a required rate.
2. The PROTECTIVE SYSTEM which provides large -ve Δk in a short time period for rapid reactor shutdown or TRIP. (US reactor terminology uses the term SCRAM for this protective system shutdown operation.)

As we shall now see, because of the requirement to insert a large negative reactivity within a few seconds for the protective system it is difficult to design the same physical mechanism for both (1) and (2). The most important reason however, is that safety requirements require them to be independent systems, at least as far as the trip and regulating instrumentation is concerned, even though the physical mechanism may be the same. For example, moderator level regulation and moderator dump protection is essentially the same physical system. Units larger than Pickering A have or will have complete physical and control isolation between the protective systems and the regulating systems.

REQUIREMENTS OF REACTIVITY MECHANISMS

As well as independence between (1) and (2) the complex physical and nuclear changes occurring in core during reactor operation mean that an effective regulating system will have to consist of more than one type of reactivity mechanism. A convenient breakdown of the various in core reactivity changes which require compensating/regulating controls is listed in Table 1 and grouped in terms of the most important parameters of any reactivity mechanism namely:

(i) reactivity worth (or depth) Δk (mk).

This must be somewhat larger than the reactivity change for which the mechanism must compensate or control, and

(ii) operational time interval.

This is the time period during which the mechanism has to be able to supply or remove reactivity and this will hence determine the ramp reactivity rate or $\Delta k/\Delta t$ (mk/sec) specification of the device.

Each of the tabulated reactivity changes is now briefly described and typical Δk worths necessary to adequately control these changes as they occur in our stations are shown for comparison in Table 2. Where these values change from fresh fuel to equilibrium fuel load conditions then the difference is noted.

IN CORE REACTIVITY CHANGES

(a) Power Changes

Changes occur in fuel and coolant temperatures as reactor power is changed during start up and shut down. This in turn produces a reactivity change, the largest variation occurring from cold shut down to hot full power operation. Under normal (ie non excursion) type conditions there will be a negative reactivity change called the power coefficient of reactivity. This compensating reactivity which is inserted as power increases is tabulated for our reactors in Table 2. Small power change control is generally classified under the term TRIM CONTROL.

(b) Moderator Temperature Changes

Normally moderator temperature is kept fairly constant (typically 70°C maximum in the calandria and 40°C at the heat exchanger outlets) but variation could be obtained by changing the rate of heat removal from the heat exchangers. The accompanying reactivity change is usually -ve with increasing temperature for a freshly loaded core but changes to a small +ve value at equilibrium fuel burn up as shown in Table 2. Control of this effect will be relatively fine control and is usually included in TRIM CONTROL.

(c) Fresh Fuel Burn Up

From an initial fresh fuel charge to equilibrium fuel burn up there is a large increase in negative reactivity load over a period of 6 - 7 months as a result of build up of long lived neutron absorbing fission products (not including Xe^{135}) and depletion of fissile material. Figures for our reactors are quoted in Table 2. The reactivity control device used to compensate (or simulate) this long term fuel burn up loading as it builds up is called SHIM CONTROL as it is a slow but continuous reactivity change.

(d) Equilibrium Fuel Burn Up

At equilibrium fuel burn up, when SHIM CONTROL reactivity changes have been essentially completed and the operating target excess reactivity has been reached, fission products continue to be built up and fissile material continues to be depleted. Continuous on power refuelling is of course the most important method of compensating for this continual depletion of fissile material at equilibrium burn up. The rate of reactivity loss for our reactors without refuelling is shown in Table 2 and for comparison the reactivity increases due to the refuelling of a single typical central channel are also listed.

(e) Equilibrium Xe Load Build Up

Following a long reactor shutdown (>2 - 3 days) and with a freshly fuelled core an equilibrium reactivity load (up to 28 mk see Table 2(e)) will be built up due to Xe^{135} accumulating in the fuel after start up. As noted in Table 1 this build up takes up to 2 days and similar to (c) above its compensating reactivity control comes under the term SHIM CONTROL also, although the $\Delta k/\Delta t$ removal rate will be much faster.

(f) Xe Transient Build Up

Within 12 hours of a reactor shutdown (or large derating due to operational problems, or a load following situation) there is a very large transient rise in Xe poison concentration (up to -80 mk above the equilibrium level at Pickering, Table 1). To enable us to restart the unit, Xe OVERRIDE or BOOSTING CAPABILITY is provided to compensate for this reactivity loading providing an override time, measured after shutdown, which gives reactivity capability of restarting a unit within this time. Actual reactivities available and the override times thus obtained are listed in Table 2 for all our stations.

(g) Flux Tilting

As localized flux/power changes occur in the core (from, for example, refuelling part of a channel or movement of a localized control rod) these can result in quite large undamped power swings (or Xe oscillations, Xe instabilities or flux tilts as they are sometimes called) from side to side (radial instabilities) or end to end (axial instabilities) in the core, being set up with periods between 15 - 30 hours. To counter-balance then, what would effectively be oscillating unbalanced reactivity loads in various regions (called ZONES) of the core, the ZONE CONTROL system is used. Total reactivity worth of these systems are shown in Table 2, and are actually larger than required to control only the flux tilts as these systems are also used for some TRIM CONTROL such as (a) and (b). As Table 2 shows, NPD does not have a zone control system due to two factors:

1. its small reactor core and
2. low average thermal neutron flux. (3×10^{13} n's/cm^2/s)

All our other reactors and future ones control, or will have to control, this type of reactivity change, which being roughly proportional to the above factors, will in fact become more important as reactor size increases.

ASSIGNMENTS

1. Which of the seven listed in core Δk changes are completely <u>independant</u> of other changes? Which are <u>dependant</u> on on other Δk changes?

2. From Table 2 compare and explain the differences and similarities in the various station reactivity loads.

D. Winfield

Source of in-core reactivity changes.	Δk depth	time interval
(a) Power changes, start up, shut down.	medium (+ve, -ve)	seconds, minutes
(b) Moderator temperature change.	small (+ve, -ve)	minutes
(c) Fresh fuel burn up.	large (-ve)	6 - 7 months
(d) Equilibrium Xe load build up.	large (-ve)	40 hours
(e) Xe transient build up.	large (-ve)	<12 hours
(f) Flux Tilting. Zonal Oscillations. Xe Instabilities.	medium (+ve, -ve)	15 - 30 hours
(g) Equilibrium fuel burn up.	small (-ve)	days (continuous)

TABLE 1

In-core reactivity changes requiring regulating system controls.

TABLE 2: COMPARISON OF STATION REACTIVITY LOADS

REACTIVITY CHANGE		NPD	DOUGLAS POINT	PICKERING A & B	BRUCE A & B
(a) Power Coefficient	fresh fuel	-3.3 mk	-6 mk	-7 mk	-11 mk
0 - 100% FP	equilibrium fuel	-1.2 mk	-5 mk	-3 mk	-5 mk
(b) Moderator Temperature	fresh fuel	-0.08 mk/°C	-0.06 mk/°C	-0.06 mk/°C	-0.07 mk/°C
Coefficient	equilibrium fuel	+0.01 mk/°C	+0.03 mk/°C	+0.08 mk/°C	+0.09 mk/°C
(c) Fresh Fuel Burn Up		-9 mk	-20 mk	-26 mk	-22 mk
(d) Xe Equilibrium Load		-24 mk	-28 mk	-28 mk	-28 mk
(e) Xe Override Capability*		+2.4 mk	+10 mk	+18 mk	+15 mk
Xe Override Time		35 min	30 min	45 min	40 min
(f) Zone Control Reactivity Worth		NONE	±3 mk	±5.4 mk	±6 mk
(g) Reactivity Loss (Equilibrium Fuel)		-0.15 mk/day	-0.3 mk/day	-0.3 mk/day	-0.5 mk/day
Reactivity Gain/Refuelled Central Channel		+0.1 mk	+0.2 mk	+0.2 mk	+0.5 mk

*New elements only, will decrease by ~30% at end of life burn up.