Nuclear Theory - Course 227

THE APPROACH TO CRITICAL

The initial approach to criticality is a procedure undertaken with a great deal of respect because the reactor is in a potentially dangerous condition. The reasons for this are:

1. Available reactivity is near its maximum value since there has been no fuel burnup and there are no fission products present. This excess positive reactivity is compensated for by moderator poison; however, the poisons are removable, hence the possibility of a large positive reactivity insertion exists.

2. Normal nuclear instruments (ion chambers and/or flux detectors) will be "off scale" at their low end ($\sim 10^{-5}$% of full power); therefore, the regulating system will not automatically control the reactor.

3. Although startup instruments (He-3 or BF_3 detectors) will be wired into the shutdown systems, their response becomes increasingly longer as the flux levels decrease.

4. The critical value of the control variable is not precisely known. For example if the approach to critical is being made by raising moderator level, the critical level is only a design estimate. (These are generally quite accurate.)

During the approach to criticality the reactor will by definition be subcritical. Therefore, you should review the behaviour of neutron power in a subcritical reactor. (lesson 227.00-9).

The First Approach to Critical

The most common method in the past has been to raise moderator level until enough fuel was covered to sustain a chain reaction. More precisely, k_∞ was fixed and the leakage was gradually reduced until k was exactly 1. This procedure was used at NPD, Douglas Point and Pickering Units 1 and 2.

Alternatively, with a high enough poison concentration in the moderator to ensure that criticality cannot be pospible. Start at a certain moderator level (nominally near full calandria). (This is known as guaranteed shutdown state.

The poison is then gradually removed until criticality is reached. In this case, the leakage is nearly constant, and k is increased by raising the value of f, the thermal utilization, until k becomes equal to 1. This was the procedure used at PNGS 'A' Unit 3, and BNGS 'A', which of course doesn't have moderator level control at all. It will be used on all future reactors.

Pickering Unit 1

The conditions prior to the startup were as follows:

1. A boron concentration of 7.25 ppm was chosen for the moderator system to achieve a first critical level just above 4 m. This figure was obtained from design calculations.

2. All adjuster rods were fully inserted, and all light water zone compartments were full.

3. The heat transport system was cold (46° C) and pressurized with the normal number of heat transport system pumps (12) running.

4. Three fission counters (designated NT9, NT8 and NT7), mounted in an aluminum tube, and one He-3 counter were located in channel U-11 which was otherwise empty (ie, no fuel or heat transport fluid).

5. Three more He-3 counters were mounted outside the core (in the ion chamber housing) to test a proposal to startup later Pickering units using out-of-core instruments alone.

6. The count rates from the in-core neutron counters were determined by feeding their output pulses to scalers, which counted all pulses arriving in a preset time (of the order of 5 minutes at low count rates).

7. The protective system trips were set on the output of ratemeters connected to the fission counters NT8 and NT9 and the He-3 counter in channel U-11. Trip levels were always maintained at about one decade above the prevailing count rate.

The approach to critical was monitored by devising an (approximately) linear plot which could readily be extrapolated to predict the critical moderator level. From lesson 227.00-9 recall that:

$$P_\infty = \frac{P_0}{1-k} = -\frac{P_0}{\Delta k}$$

Since the count rate on any detector is proportional to P_∞, we can now write:

$$\frac{1}{\text{count rate}} \propto 1 - k \quad \propto \Delta k$$

Since Δk is a direct function of moderator level (as level increase, k increases), we can plot the reciprocal count rate versus moderator level as shown in Fig. 1.

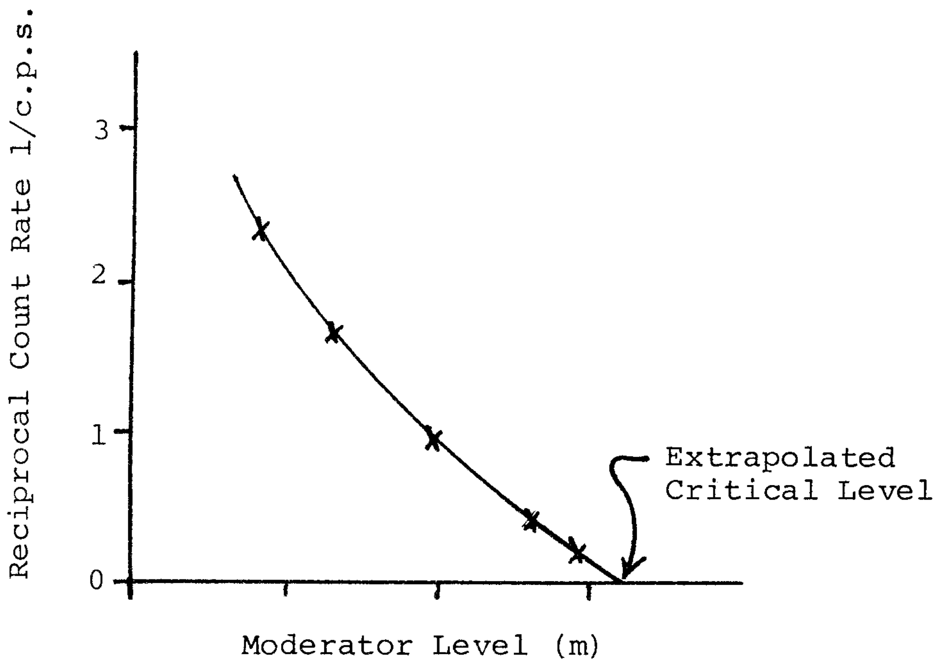
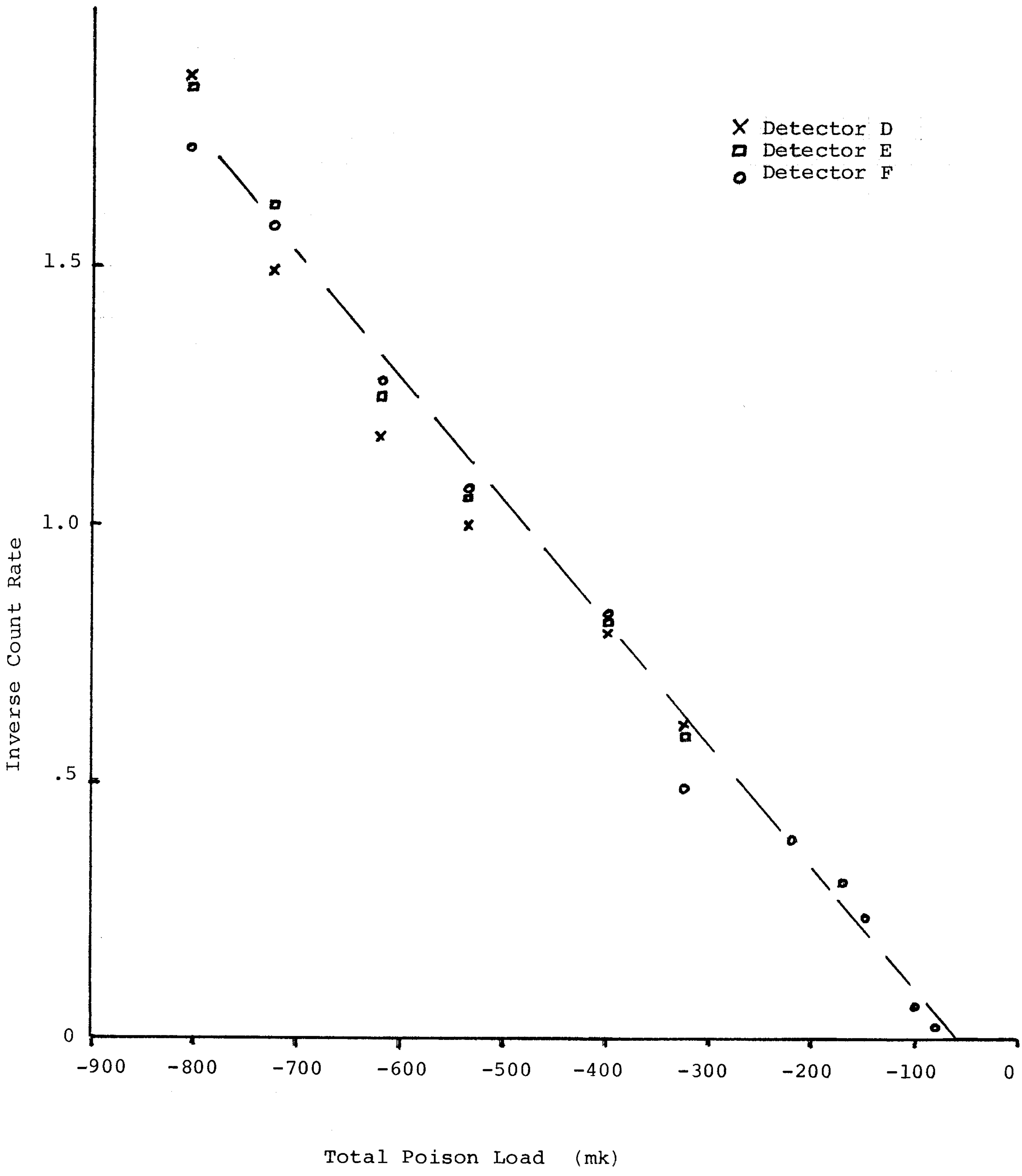


Figure 1

Approach-to-Critical Graph

The intercept of this curve with the moderator level axis should therefore give the critical level.

Pickering A, Unit 3 and all Bruce A units obtained initial criticality by removing poison (boron or a combination of boron and gadolinium) from the moderator. In these cases the moderator was at full tank throughout the startup. The multiplication constant (k) is a direct linear function of poison concentration (1 ppm boron = 8.85 mk; 1 ppm gadolinium = 31.42 mk). Because of this, total poison load may be directly calculated and a plot of poison load versus inverse count rate is a straight line. Figure 2 is a plot of inverse count rates from the incore detectors for the Bruce A, Unit 1 initial criticality. Note that they all give straight lines which accurately predicted the poison concentration at criticality.



Detector D
Detector E
Detector F
Inverse Count Rate
1.5
1.0
.5
0
-900
-800
-700
-600
-500
-400
-300
-200
-100
0
Total Poison Load (mk)

Figure 2

These types of approaches do not have to be repeated for every startup. Once sufficient fission products have been builtup to give a significant photoneutrons source, (ie, actual neutron power $>10^{-5}\%$) the reactor may be started up using installed instrumentation and automatic regulation.

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