427.00-11

XENON, A FISSION PRODUCT POISON

THIS SECTION IS NOT REQUIRED FOR MECHANICAL MAINTAINERS

OBJECTIVES

At the conclusion of this lesson the trainee will be able to:

1. Explain why xenon is the most important fission product poison.
2. Explain how xenon is produced in, and how it is removed from the reactor.
3. Sketch xenon concentration as a function of time for a shutdown/trip from full power.
4. Discuss "xenon poison out".

XENON, A FISSION PRODUCT POISON

Many fission products will absorb neutrons. Most have small absorption cross sections and can be regarded as insignificant in short term operation. However, Xenon-135 has a cross section of approximately 3,000,000 barns, over 4000 times that of U-235. About 6.6% of all fissions produce a nuclide of Xenon-135, either directly as a fission fragment or indirectly as a fission product daughter. Because of its large yield and its ability to absorb neutrons, xenon is a major problem in our reactors.

Xenon Production

Xenon is produced directly from fission. 0.3% of the fission fragments are Xe-135. It is also produced by the decay of iodine via the following decay scheme:

$$^{135}_{53}\mathrm{I} \xrightarrow[t_{1/2}\,=\,6.6\ \mathrm{hr}]{} \beta + {}^{135}_{54}\mathrm{Xe}$$

Iodine-135 constitutes 6.3% of all fission fragments. Thus, approximately 95% of the total production of xenon is due to the decay of iodine. (6.3/6.6 = 0.95). Iodine-135 does not absorb neutrons.

Xenon Loss

Xenon is "removed" from the reactor by decay:

$$^{135}_{54}\mathrm{Xe} \xrightarrow[t_{1/2}\,=\,9.1\ \mathrm{hr}]{} {}^{135}_{55}\mathrm{Cs} + \beta$$

or by neutron absorption:

$$^{135}_{54}\mathrm{Xe} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{136}_{54}\mathrm{Xe} + \gamma$$

For CANDU reactors at full power neutron absorption constitutes about 90% of the loss of Xe-135. Neither Xenon-136 or Cesium-135 is a neutron absorber.

Equilibrium Xenon Load

When a reactor has been shutdown for a long time (or has never been operated) there is no xenon present. After the reactor is started up, the xenon will slowly build up to an equilibrium level which will depend on the steady state power of the reactor. Figure 11.1 is a graph of xenon load in milli-k versus time for various power levels. For CANDU reactors the full power xenon load will build up to approximately -28 mk in about 50 hours.

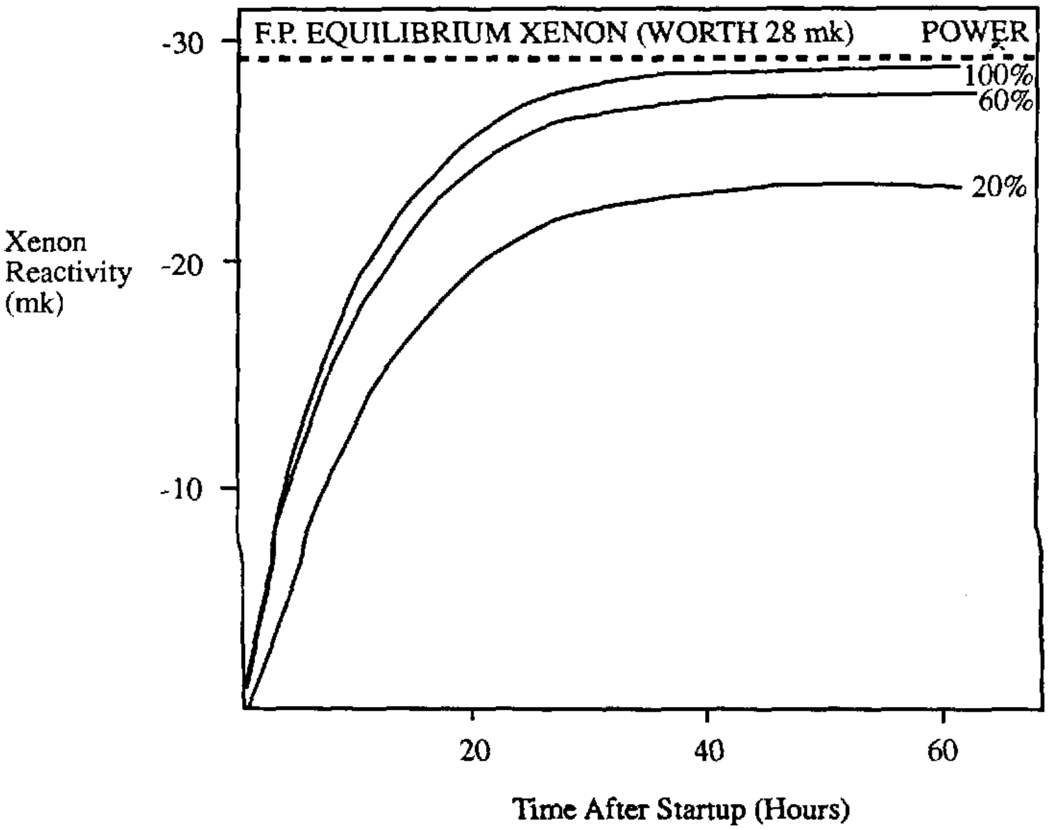

Figure 11.1: Xenon Buildup to Equilibrium

This negative reactivity (-28 mk) will always be present in normal steady operation, except during the first several hours after startup. There is enough excess positive reactivity designed into our reactors to compensate for the -28 mk load. This excess reactivity creates an operational problem in the first hours of operation when the xenon is not present.

Negative reactivity worth must be added to the reactor on startup to compensate for the lack of xenon. To accomplish this a soluble poison (Boron or Gadolinium) is added to the moderator. As xenon levels increase the poison is removed by burnout or ion exchange purification.

Xenon Transients

After operating for around 50 hours, xenon has built up to it's equilibrium level. It causes little problem unless the reactor power level is changed. Consider what happens to the production and loss of xenon following a reactor trip (a fast power reduction to 0%).

a) Production

- from fission (5%) - stops immediately
- from decay of iodine (95%) - continues

b) Loss

- by decay (10%) - continues
- by neutron absorption (90%) - stops immediately

Thus, immediately following a trip, xenon production continues virtually undiminished while xenon loss is drastically reduced. Figure 11.2 is a graph of xenon load versus time after a trip from full power.

Note the negative reactivity from xenon peaks approximately 10 hours after shutdown, at a level considerably higher than the equilibrium level.

Each reactor has a maximum excess positive reactivity (15 to 20 mk) which can be achieved by withdrawing adjuster rods (inserting booster rods at Bruce "A"). If the negative reactivity due to xenon exceeds this, the reactor will be sub-critical with no way to restart it. It is said to be "poisoned out". Figure 11.3 shows the xenon transient reactivity and the maximum reactivity available.

The reactor will be poisoned out 30 to 40 minutes after a trip and remain shutdown for up to 40 hours. If the reactor is started up during the 30 to 40 minute poison override time and brought up to power before poisoning out, the xenon will be burned up rapidly and a poison out may be prevented.

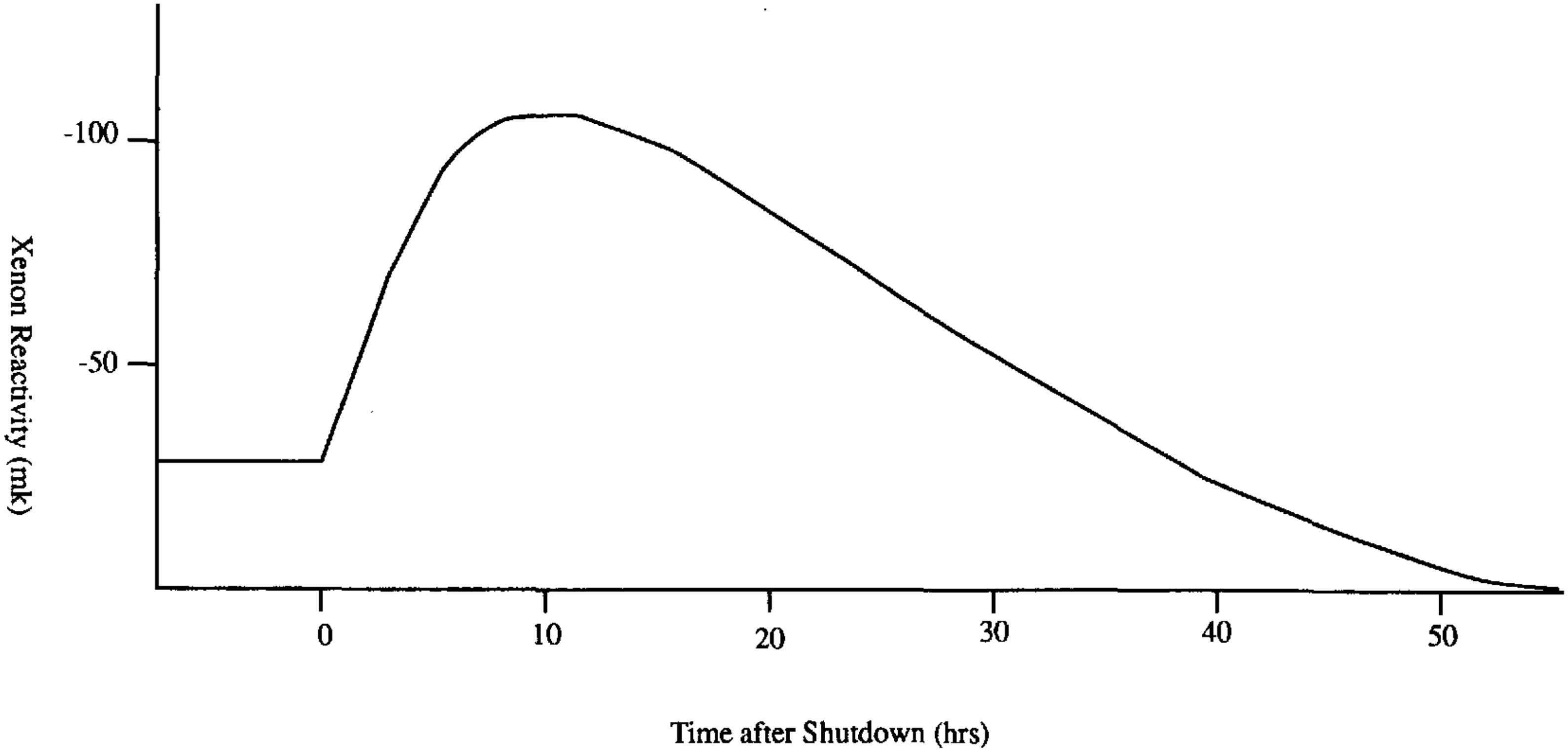

Figure 11.2: Behaviour of Xenon

Any reduction in power level will cause the xenon to peak; however, the smaller the power reduction the smaller the xenon peak. For example a power reduction of 40% from 100% to 60% still leaves a significant neutron flux available to burn out the xenon thereby reducing the magnitude of the peak. Figure 11.3 shows a typical reactivity variation for a power reduction to 60%.

It is important to realize that on a turbine trip it is economically sound to exhaust steam to atmosphere or a condenser in order to maintain reactor power greater than 60% thereby preventing a poison out. This mode of operation is called 'poison prevent'.

On a power increase after steady low power operation (say from 60% to 100%) the reverse effect occurs. Xenon burns out rapidly while production from iodine decay continues low. Reactivity increases and the control system must add negative reactivity to compensate.

In a large high flux reactor it is possible to have flux increasing in one part of the reactor while it is decreasing elsewhere. This operational problem caused by xenon is discussed in module 13.

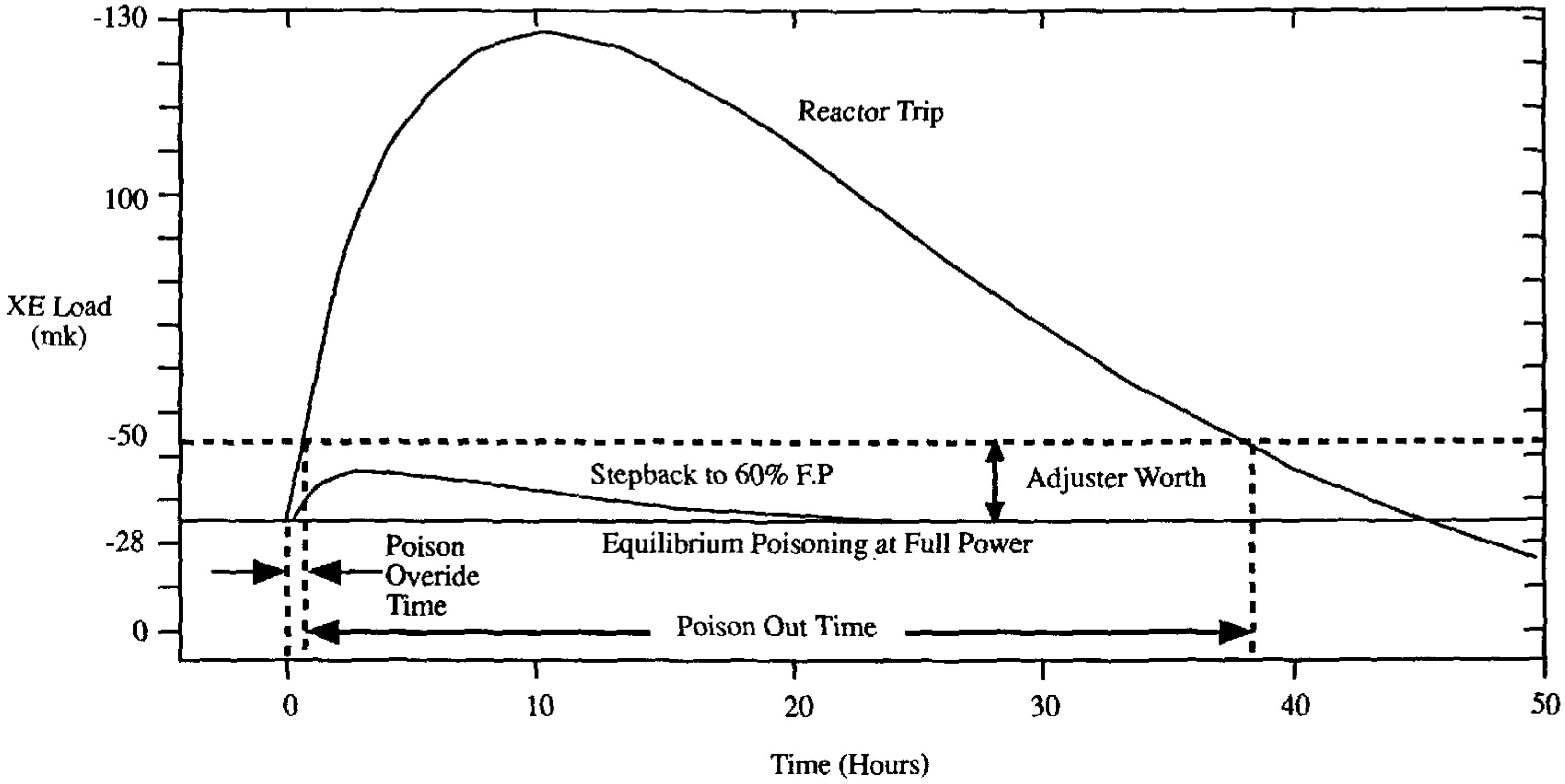

Figure 11.3: Transient Xenon Reactivity

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ASSIGNMENT

1. Sketch the behavior of xenon on a reactor trip from full power.
2. Explain why a xenon poison out occurs.
3. Discuss the production and loss of xenon including the relative magnitude of each term.

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