Xenon Effects in Reactor Physics

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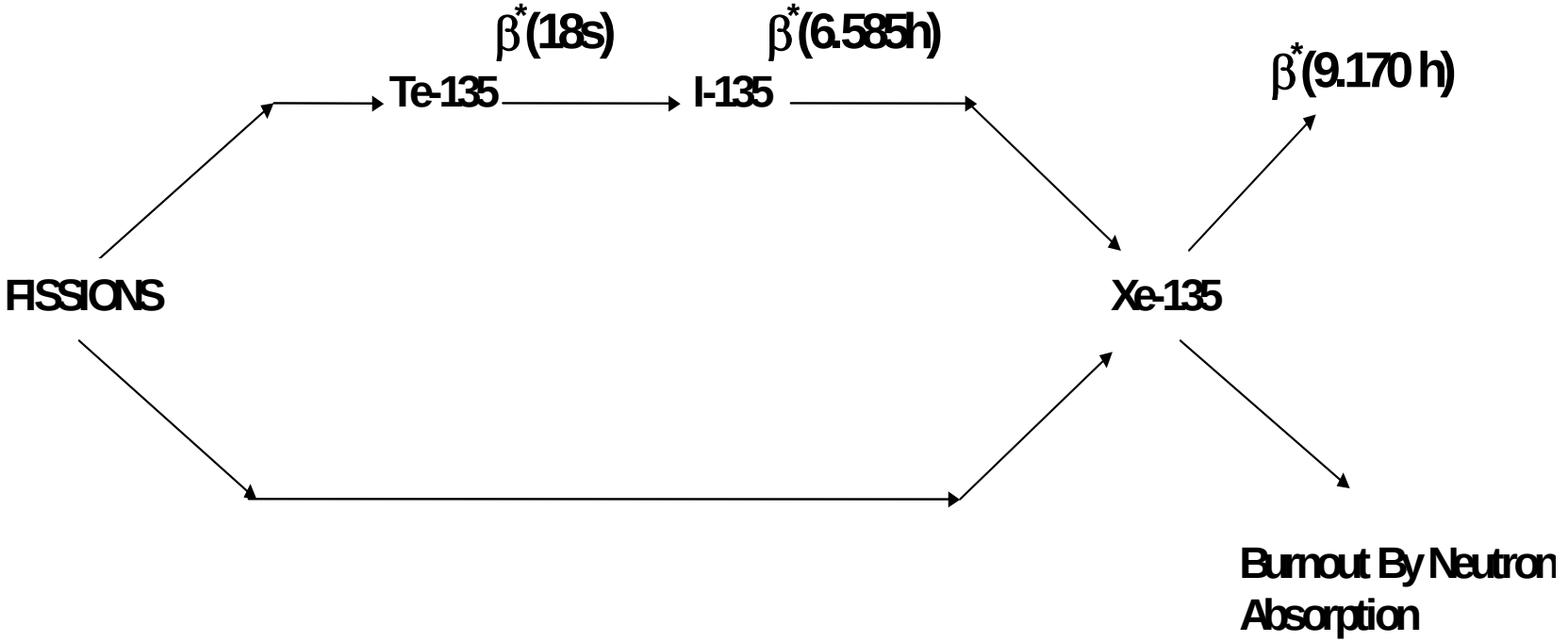
Effects of Xenon Poison

- Saturating fission products are fission products whose concentration in fuel operating in a steady flux (i.e., at steady power):
  - depends on the flux level, and
  - comes to an asymptotic, finite limit even as the value of the steady flux is assumed to increase to infinity.
- The most important saturating fission product is ^{135}Xe, but other examples are ^{103}Rh, ^{149}Sm and ^{151}Sm. In each case the nuclide is a direct fission product, but is also produced by the β-decay of another fission product.

^{135}Xe and ^{135}I

- ^{135}Xe is produced directly in fission, but mostly from beta decay of precursor ^{135}I (half-life 6.585 hours).
- Is destroyed in two ways:
  - By its own radioactive decay (half-life 9.169 hours), and
  - By neutron absorption to ^{136}Xe.
- See Figure "$^{135}Xe/^{135}I$ Kinetics".



^{135}Xe / ^{135}I Kinetics

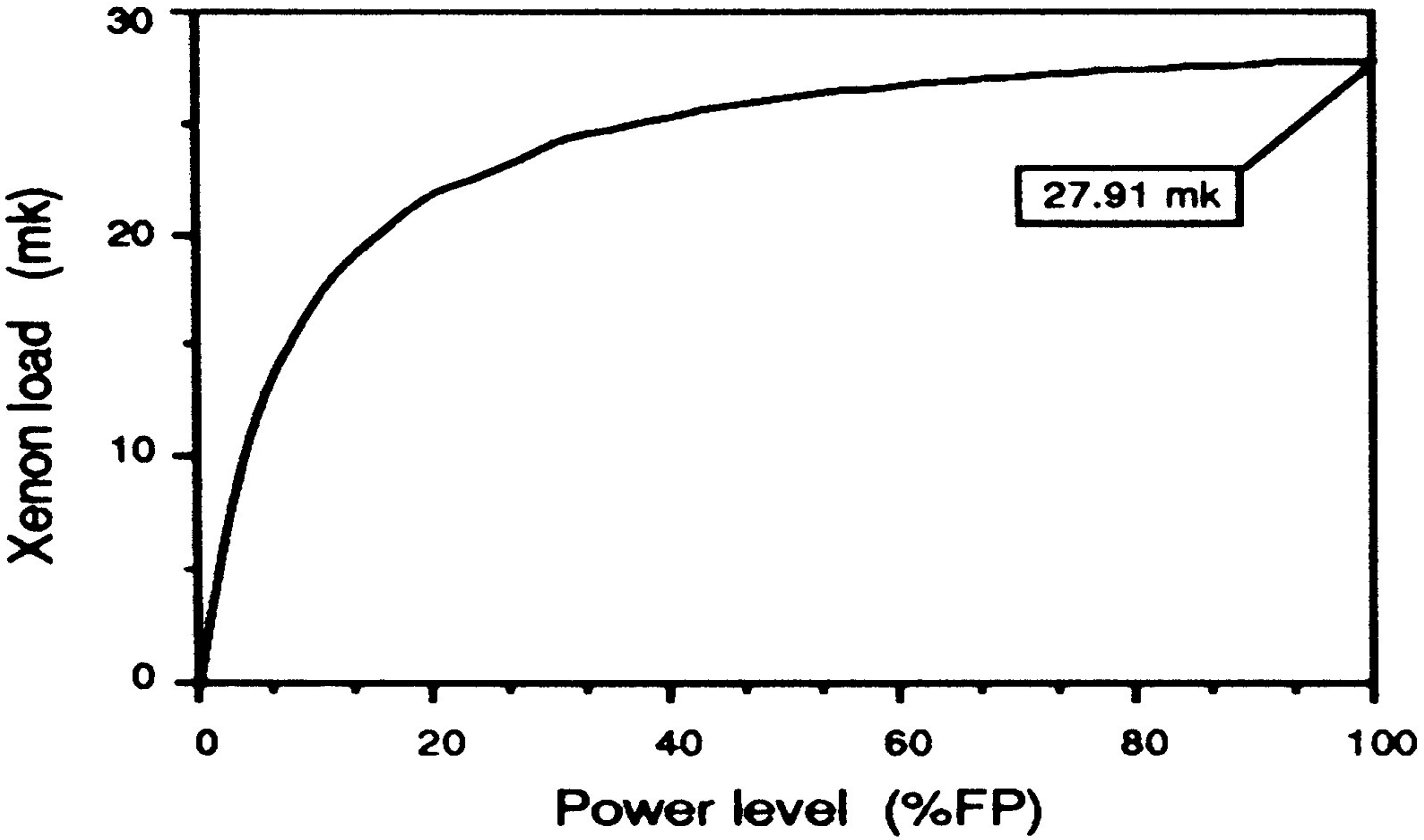
^{135}Xe and ^{135}I

- ^{135}Xe has a very important role in the reactor
- It has a very large thermal-neutron absorption cross section
- It is a considerable load on the chain reaction
- Its concentration has an impact on power distribution, but in turn is affected by the power distribution, by changes in power, and by movement of reactivity devices.

^{135}Xe and ^{135}I (cont'd)

- Large absorption cross section of ^{135}Xe plays significant role in overall neutron balance, directly affects system reactivity, both in steady state and in transients.
- Also influences spatial power distribution in reactor.
- Limiting absorption rate at very high flux $\Rightarrow$ maximum steady-state reactivity load ~ -30 mk.
- In CANDU equilibrium load ~ -28 mk (see Fig.)

Equilibrium Xenon Load



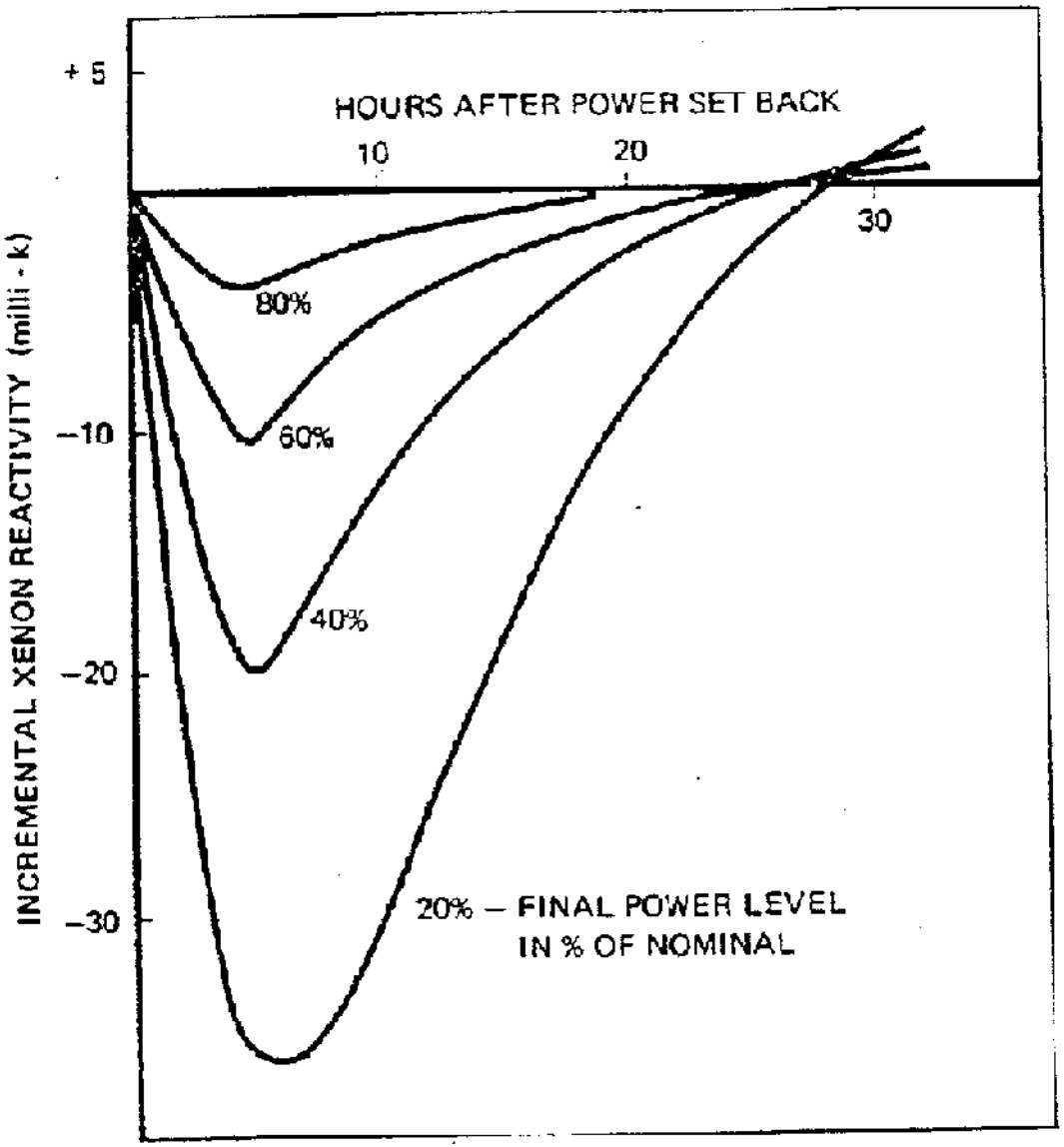
[from **Nuclear Reactor Kinetics**, by D. Rozon, Polytechnic International Press, 1998]

Effects of ^{135}Xe on Power Distribution

- High-power bundles have higher xenon load, lower reactivity $\Rightarrow$ xenon **flattens** the power distribution
- In steady state, ^{135}Xe reduces maximum bundle and channel powers by ~ 5% and 3% respectively.

Effect of Power Changes on ^{135}Xe Concentration

- When power is reduced from a steady level, ^{135}Xe concentration increases at first (^{135}Xe still produced by decay of ^{135}I, but burnout rate decreased in reduced flux).
- After some time, ^{135}I decay rate decreases and ^{135}Xe concentration reaches a peak, starts to decrease - see Figure.



Xenon Reactivity Transients Following Setback to Various Power Levels

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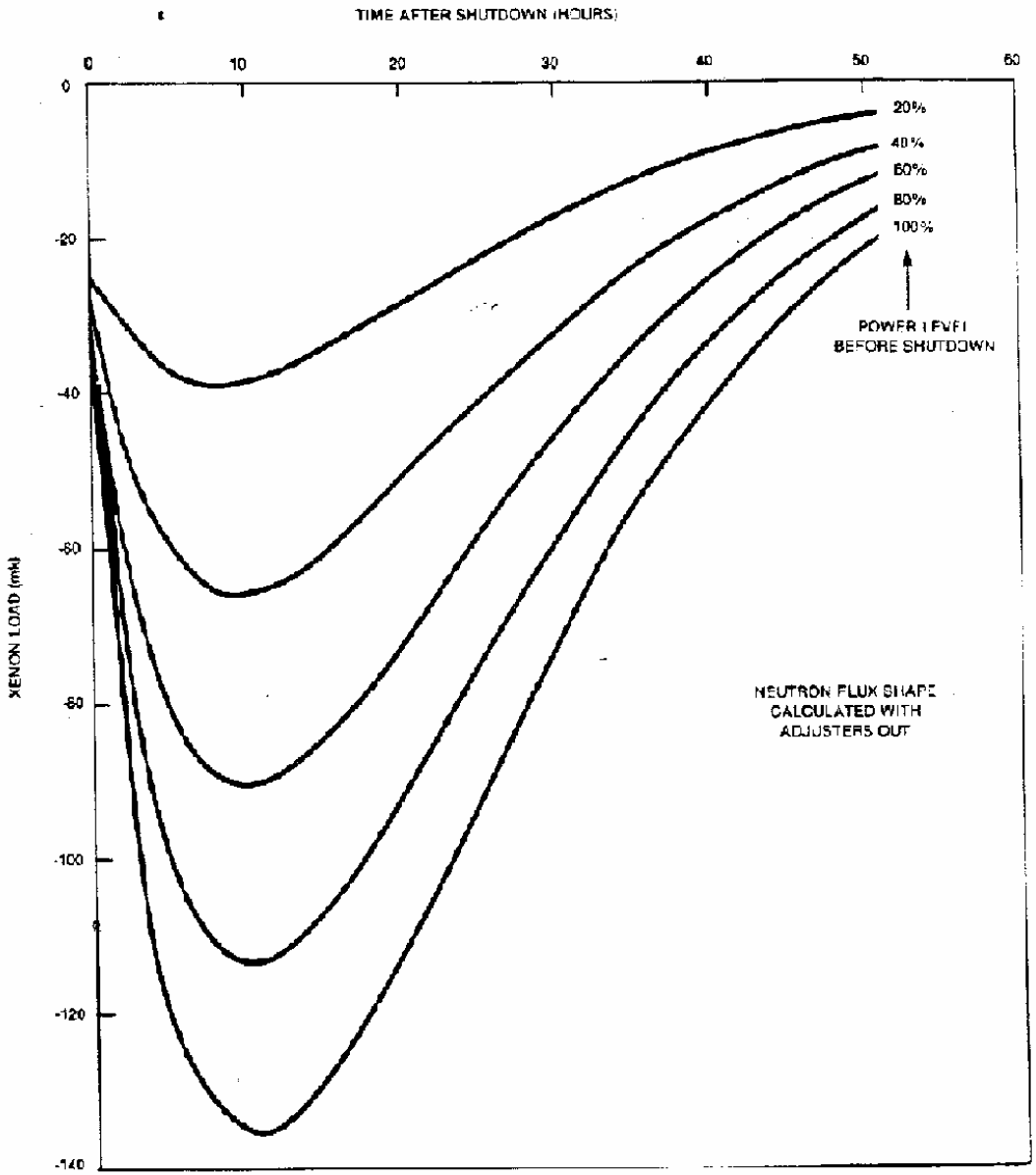
Xenon Transient Following a Shutdown

- Following a reactor shutdown, the burnout of ^{135}Xe stops,
- whereas the production by means of ^{135}I decay continues for several hours.
- The net result is that there is an initial increase in ^{135}Xe concentration and a decrease in core reactivity.
- If the reactor is required to be started up shortly after shutdown, extra positive reactivity must be supplied.
- The ^{135}Xe growth and decay following a shutdown in a typical CANDU is shown in the next Figure.



Xenon Transient Following Reactor Shutdown

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Xenon Transient Following a Shutdown

- It can be seen that, at about 10 hours after shutdown,

  the reactivity worth of ^{135}Xe increases to several times its equilibrium full-power value.
- At ~35-40 hours the ^{135}Xe has decayed back to its pre-shutdown level.
- If it were not possible to add positive reactivity during this period, every shutdown would necessarily last some 40 hours, when the reactor would again reach criticality.

Xenon Transient Following a Shutdown

- To achieve xenon “override” and permit power recovery following a shutdown (or reduction in reactor power), positive reactivity must be supplied to “override” xenon growth; e.g., the CANDU-6 adjuster rods are withdrawn to provide positive reactivity.
- It is not possible to provide “complete” xenon override capability, this would require > 100 mk of positive reactivity.
- The CANDU-6 adjuster rods provide approximately 15 milli-k of reactivity, which is sufficient for about 30 minutes of xenon override following a shutdown.

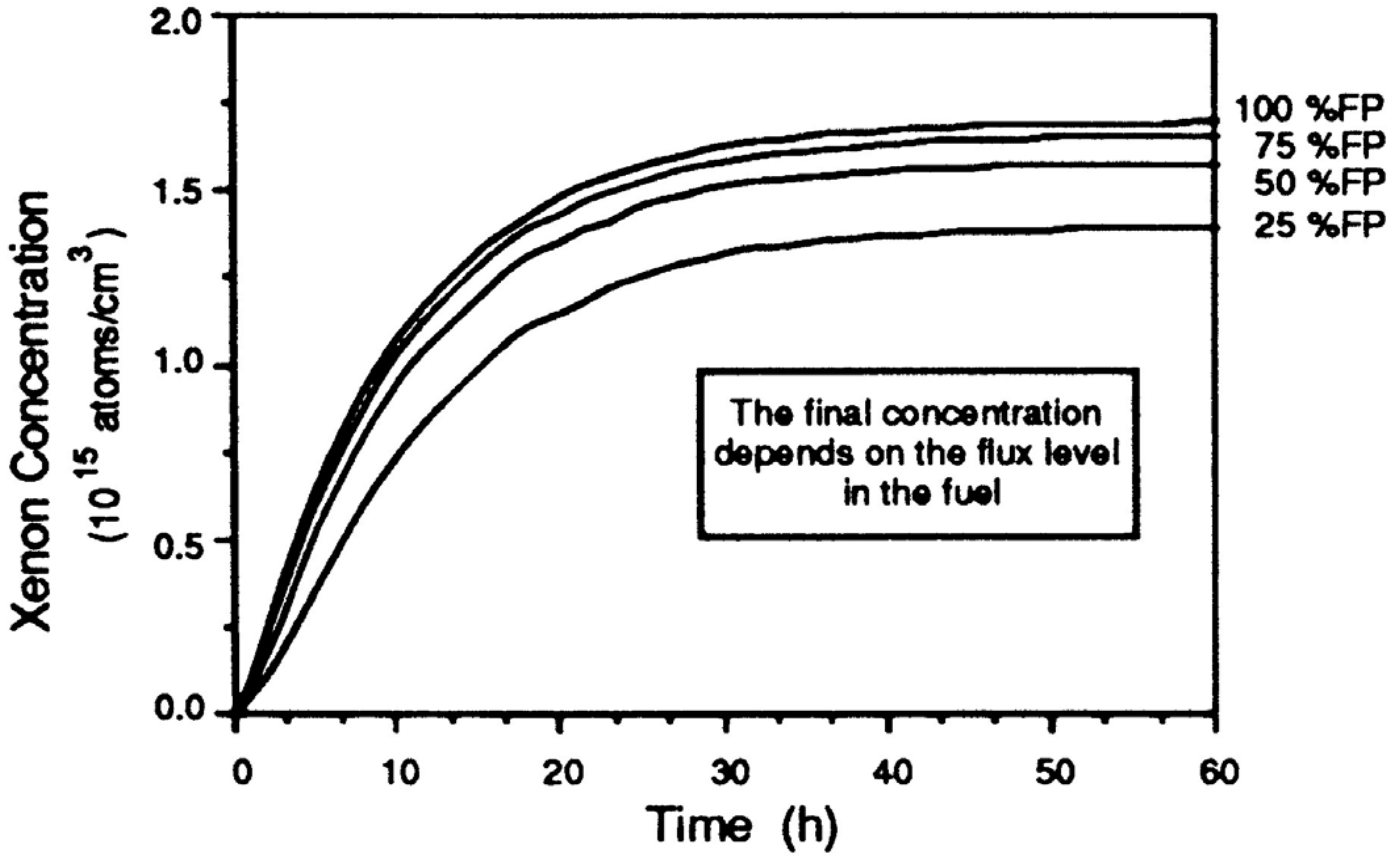
Effect of Power Changes on ^{135}Xe Concentration

- Conversely to the situation in a power reduction, when power is increased ^{135}Xe concentration will first decrease and go through a minimum.
- Then it will rise to its new saturated level.

Saturating-Fission-Product-Free Fuel

- In fresh bundles entering reactor, ^{135}Xe and other saturating fission products will build up (Fig.).
- Reactivity of fresh bundles drops in first few days as s.f.p. build in.
- “Saturating-fission-product-free fuel” will have higher power for first hours and days - effect may range up to ~10% on bundle power, and ~5% on channel power.

Accumulation of ^{135}Xe in Fresh Fuel



[from D. Rozon, **Nuclear Reactor Kinetics**, loc.cit.]

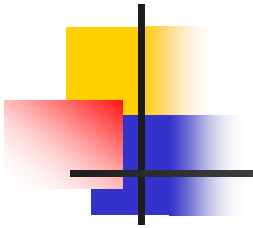
Saturating-Fission-Product-Free Fuel

- For accurate assessment of powers after refuelling, either perform calculations at close intervals (few hours) to capture building-in of s.f.p., or make “phenomenological” correction for fresh bundles.

Xenon Oscillations

- Imagine that power rises in part of the reactor (say one half), but the regulating system keeps the total power constant.
- What is such a situation? A channel refuelling!
- Therefore the power must decrease in the other half of the reactor.
- These changes will set off changes in ^{135}Xe concentration, in different directions in the two reactor halves.

Xenon Oscillations



- The ^{135}Xe concentration will increase in the reactor half where the power is decreasing.
- It will decrease in the half where the power is increasing.
- These changes will induce positive-feedback reactivity changes (why?)
- Thus, the Xe and power changes will increase with time at first.

Xenon Oscillations

- If not controlled, the effects will reverse after many hours (just as we have seen in the earlier figures).
- Xenon oscillations will ensue, with a period of ~20-30 h.
- These will be growing oscillations – the amplitude will increase!
- It's the zone controllers which dampen these oscillations – that's one of their big jobs!