Changes in Reactor Power with time

Neutron Life

- Average distance travelled <1m
- Life time 0.001 sec

Power Increase

$$P_{1gen} = P_0 \times k$$

$$P_{2gen} = P_0 \times k \times k = k^2$$

$$P_{ngen} = P_0 \, k^n$$

If a generation is 0.001 second then after 1 second

$$P_{1000} = P_0 \times k^{1000}$$

Power Increase

If a generation is 0.001 second then after 1 second

$$P_{1000} = P_0 \times k^{1000}$$

For a ½ mk reactivity insertion

$$P_{1000} = P_0\, 1.0005^{1000} = 1.64\, P_0$$

This is not the case!!!!

We have not taken into account the effect of the delayed neutrons.

Reactor Period

For small changes in reactivity it can be shown that

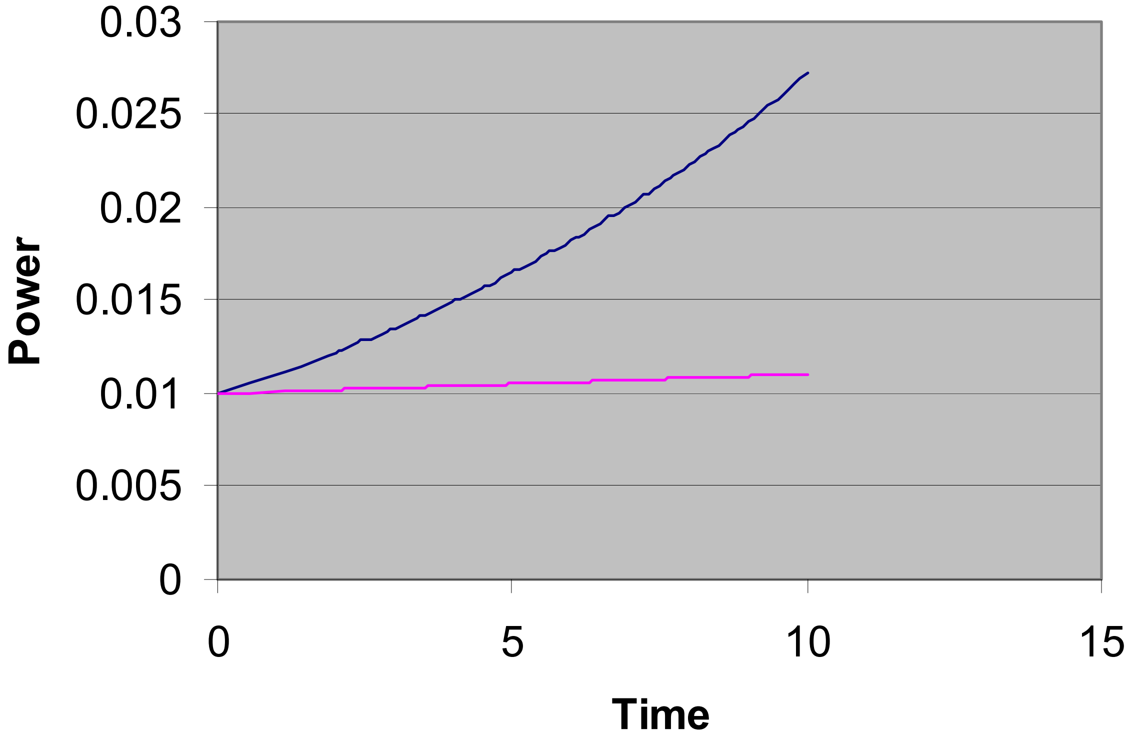
$$P = P_0 e^{t/\mathrm{T}}$$

Where $\mathrm{T} \approx \dfrac{l}{\Delta k}$ for small Δk

Reactor Period

- The time it takes for reactor power to increase by a factor of *e*
- Need to be long to control the reactor
- Proportional to average neutron life time
- Inversely proportional to changes in reactivity Δk

Reactor Power Changes



Reactor Periods of 10 and 100 sec

Effect of delayed neutrons

≈ 0.65% of all neutrons are delayed

Average life time of delayed neutrons is ≈ 13 sec.

This drastically alters the average neutron life time

$$l = .9935 \text{ x } 0.001 + .0065 \text{ x } 13 = 0.085 \text{ seconds}$$

Effect of Delayed Neutrons

Now our one-half millik change in reactivity after one second

$$T = \frac{l}{\Delta k} = \frac{0.085}{.0005} = 170$$

$$P = P_0 e^{t/T} = P_0 e^{1/170} = 1.006 P_0$$

A much more manageable power increase.

Prompt Critical

- Previous approximation for small Δk
- For large Δk the effect of the delayed neutrons is negated
- Reactor power changes with prompt neutrons only
- Rapid power changes

Summary

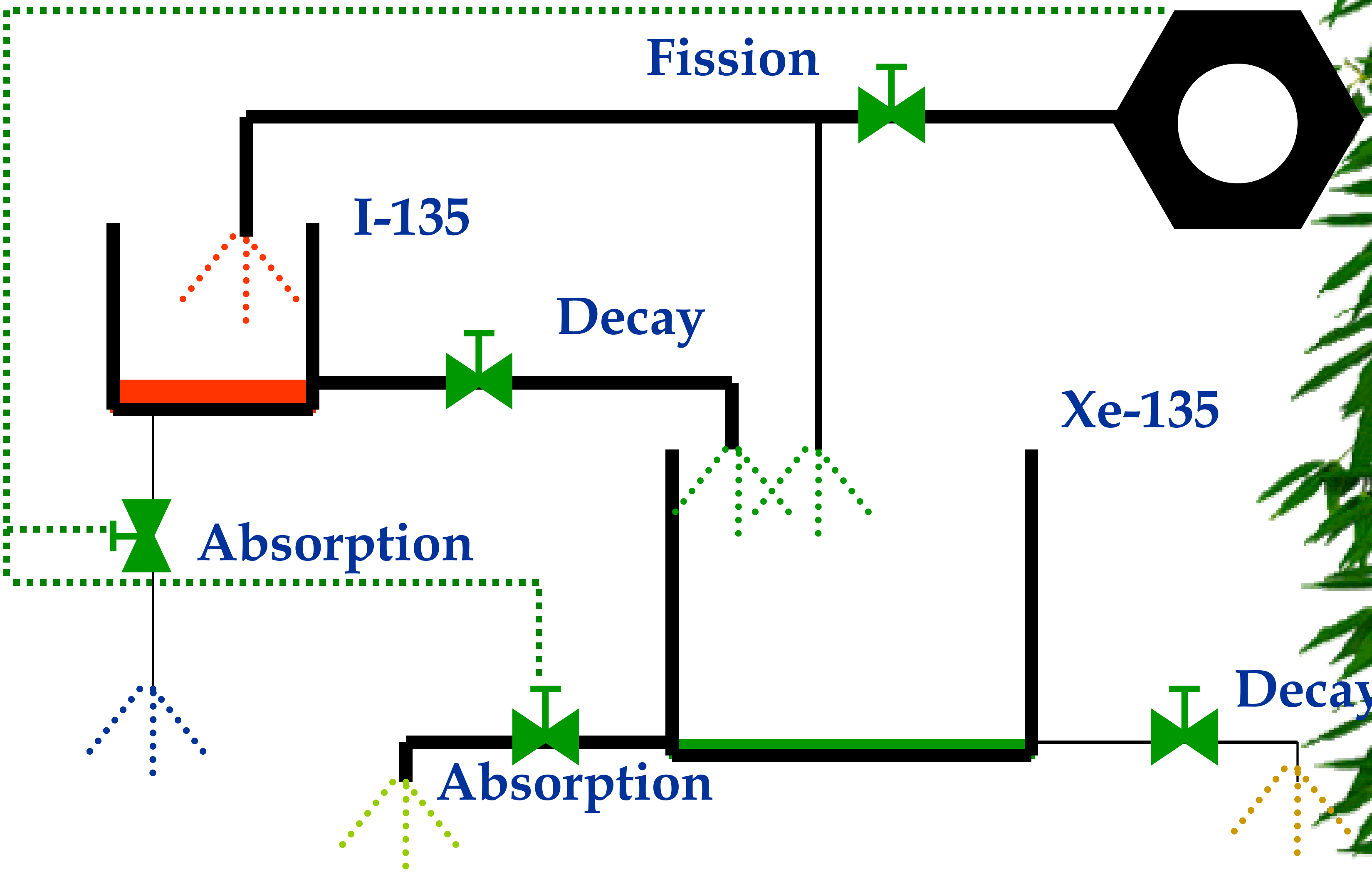
- Reactor period must be long for control to be possible
- Depends on average life-time of neutrons
- Most neutrons have a life time in the range of 1 msec.
  - These are prompt neutrons.
- Delayed neutrons appear after the fission process.
  - Delayed neutrons increase the average life time of the neutrons

Xenon

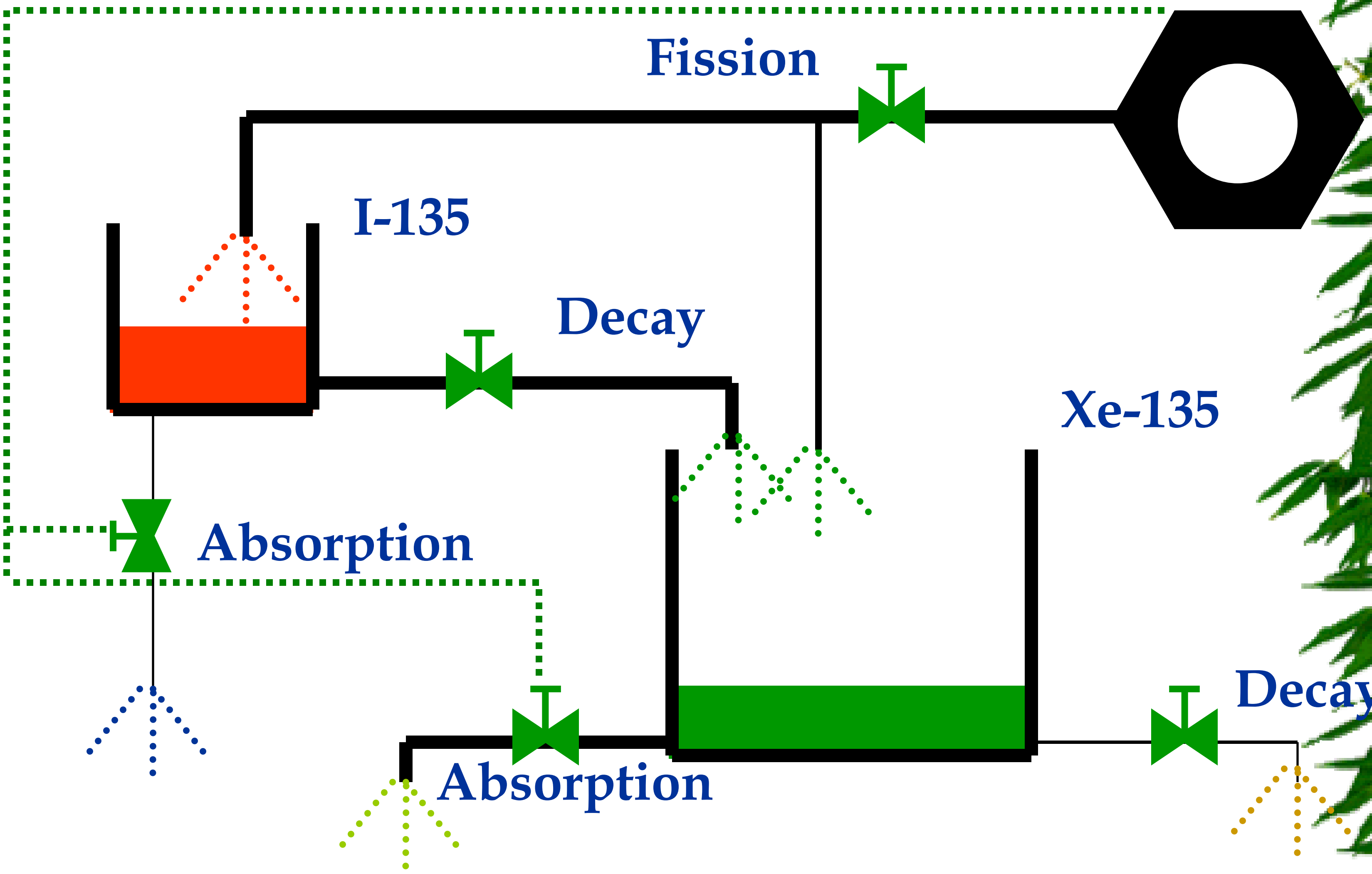
Xenon

A Fission Product Poison

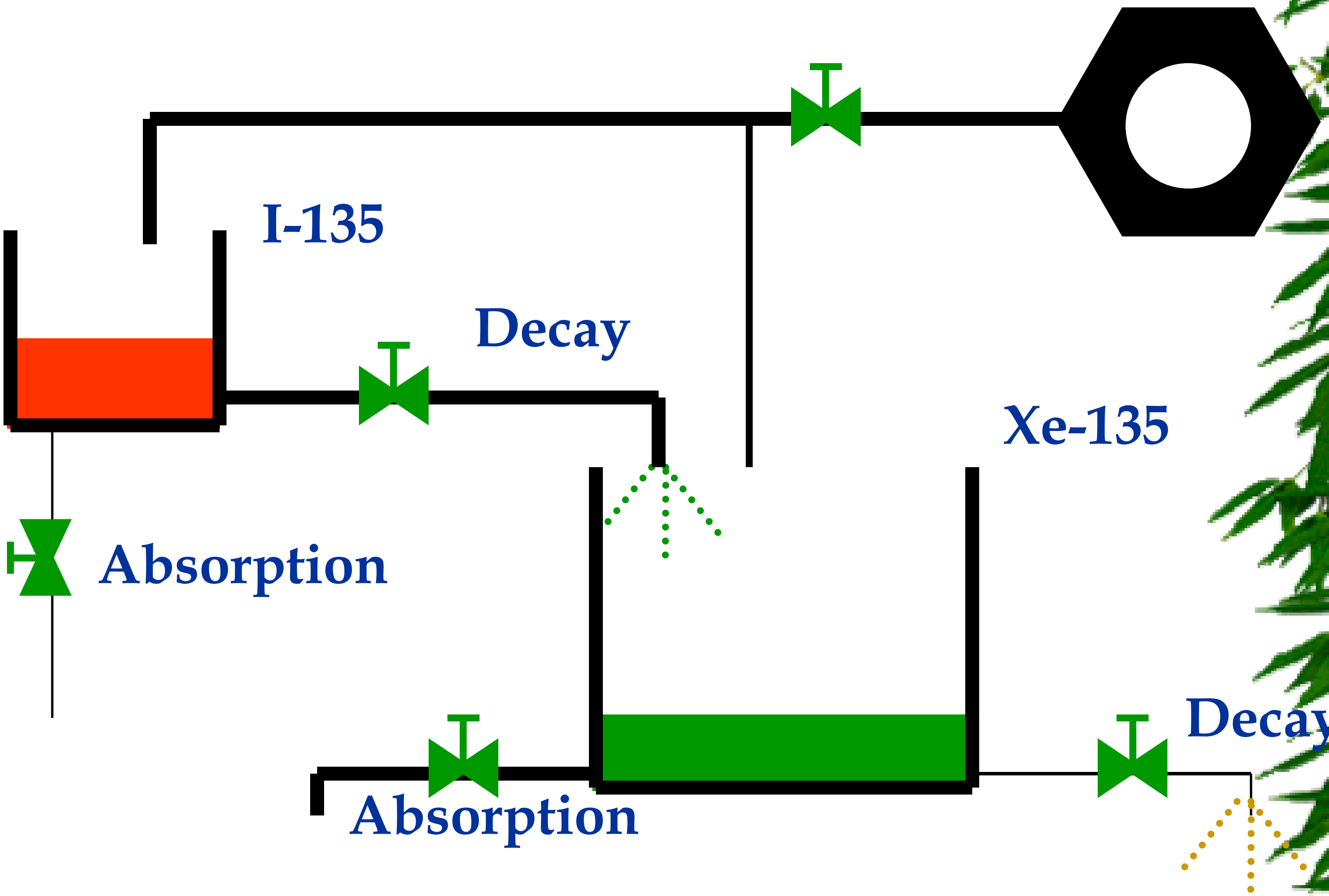
Xenon



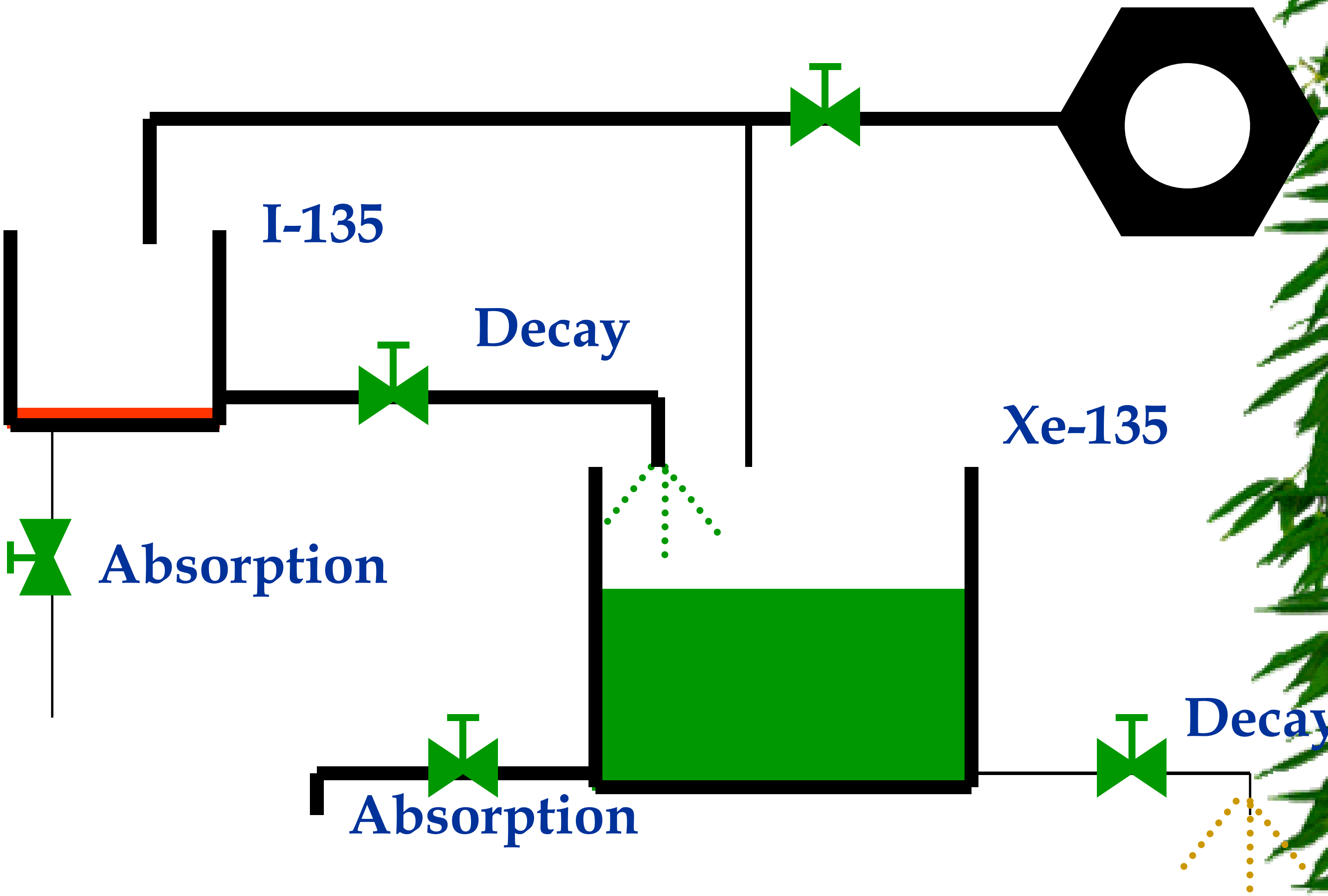
Equilibrium Xenon



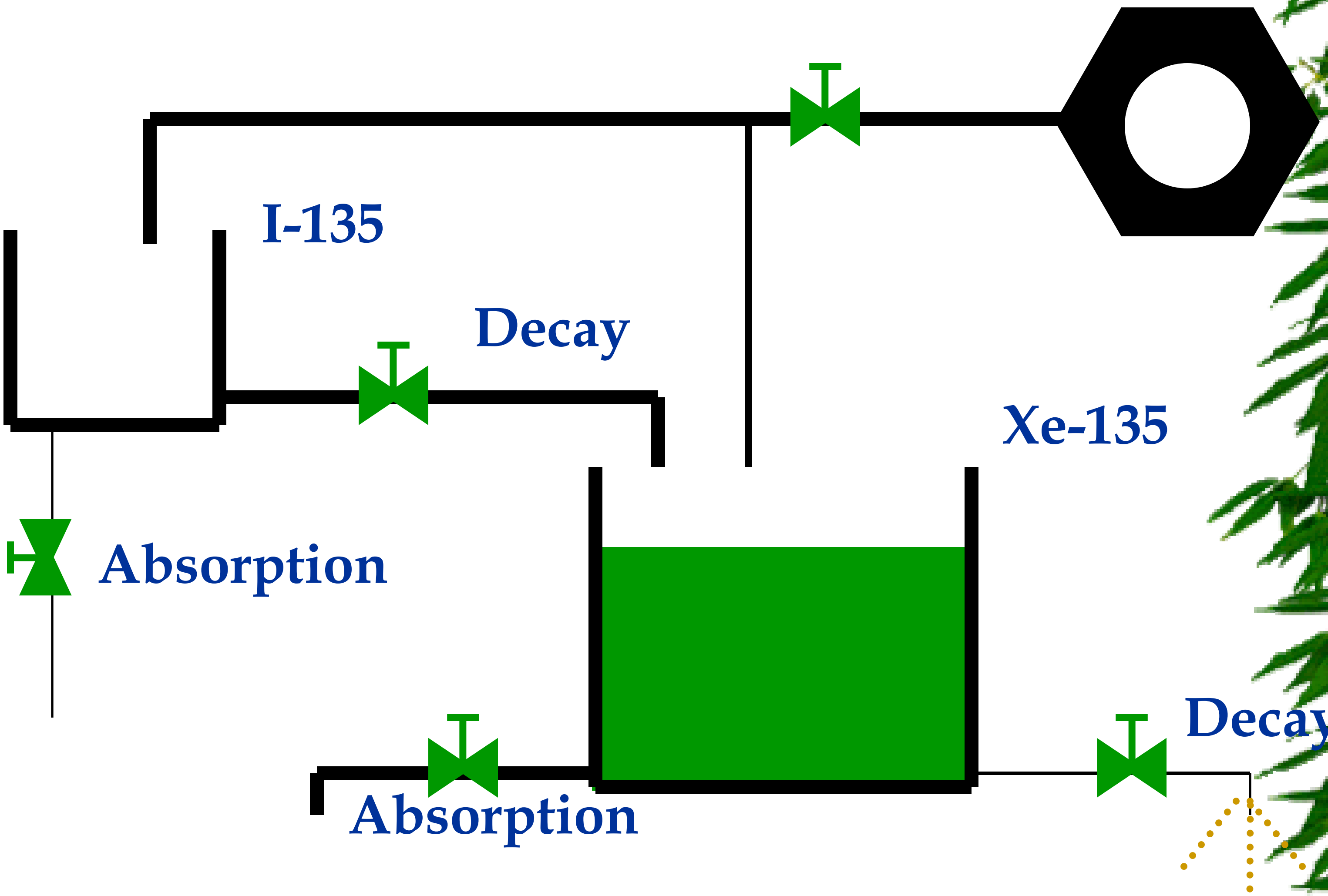
Xenon Immediately on stopping fission



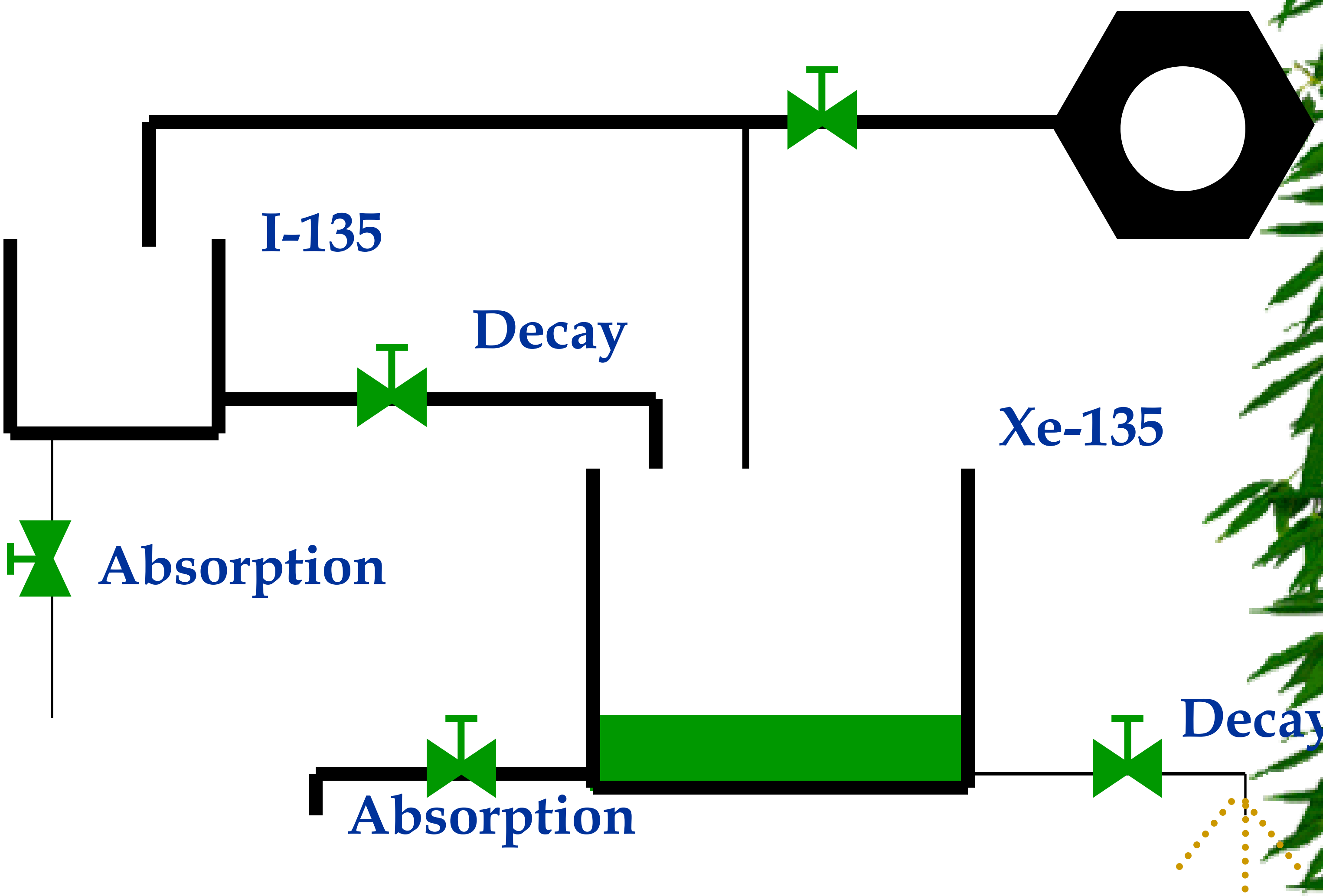
Xenon build up



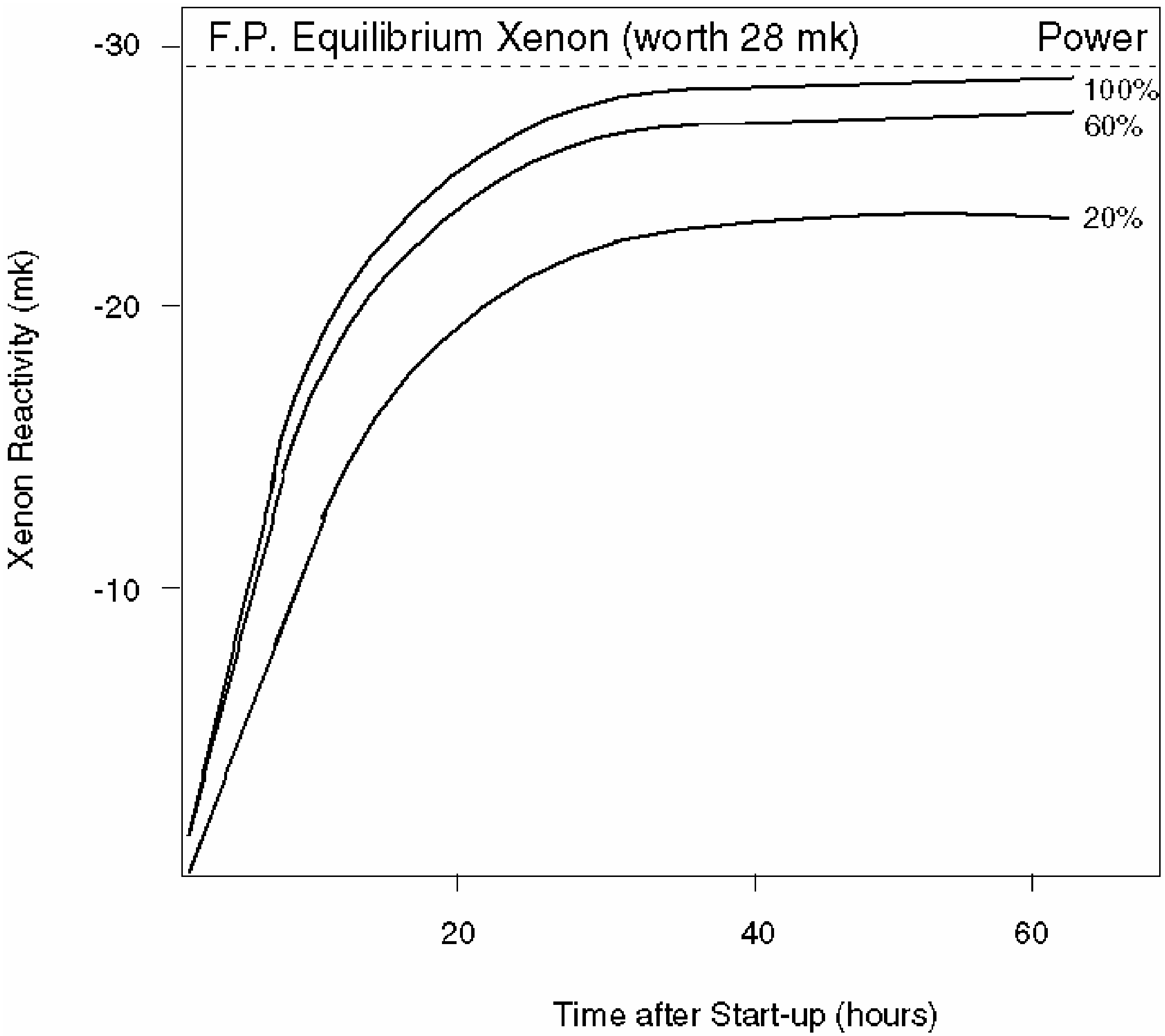
Iodine Disappears



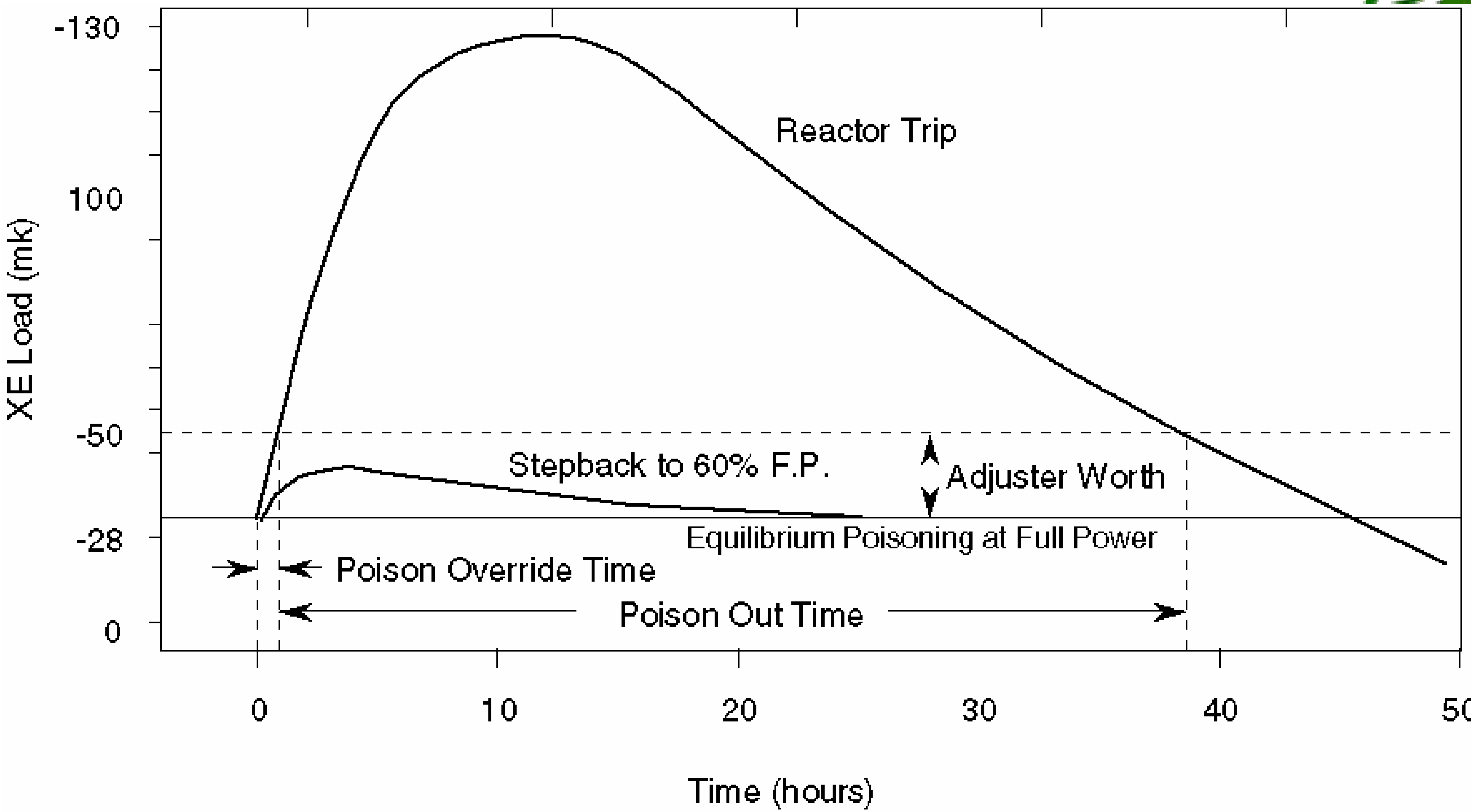
Xenon Disappears



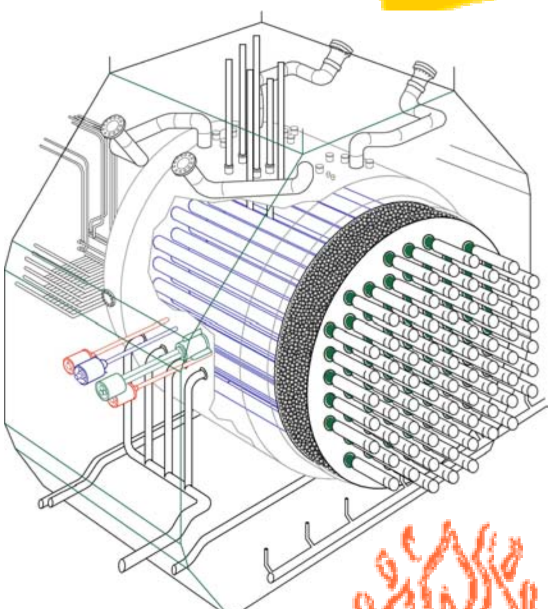
Equilibrium Xenon Concentration



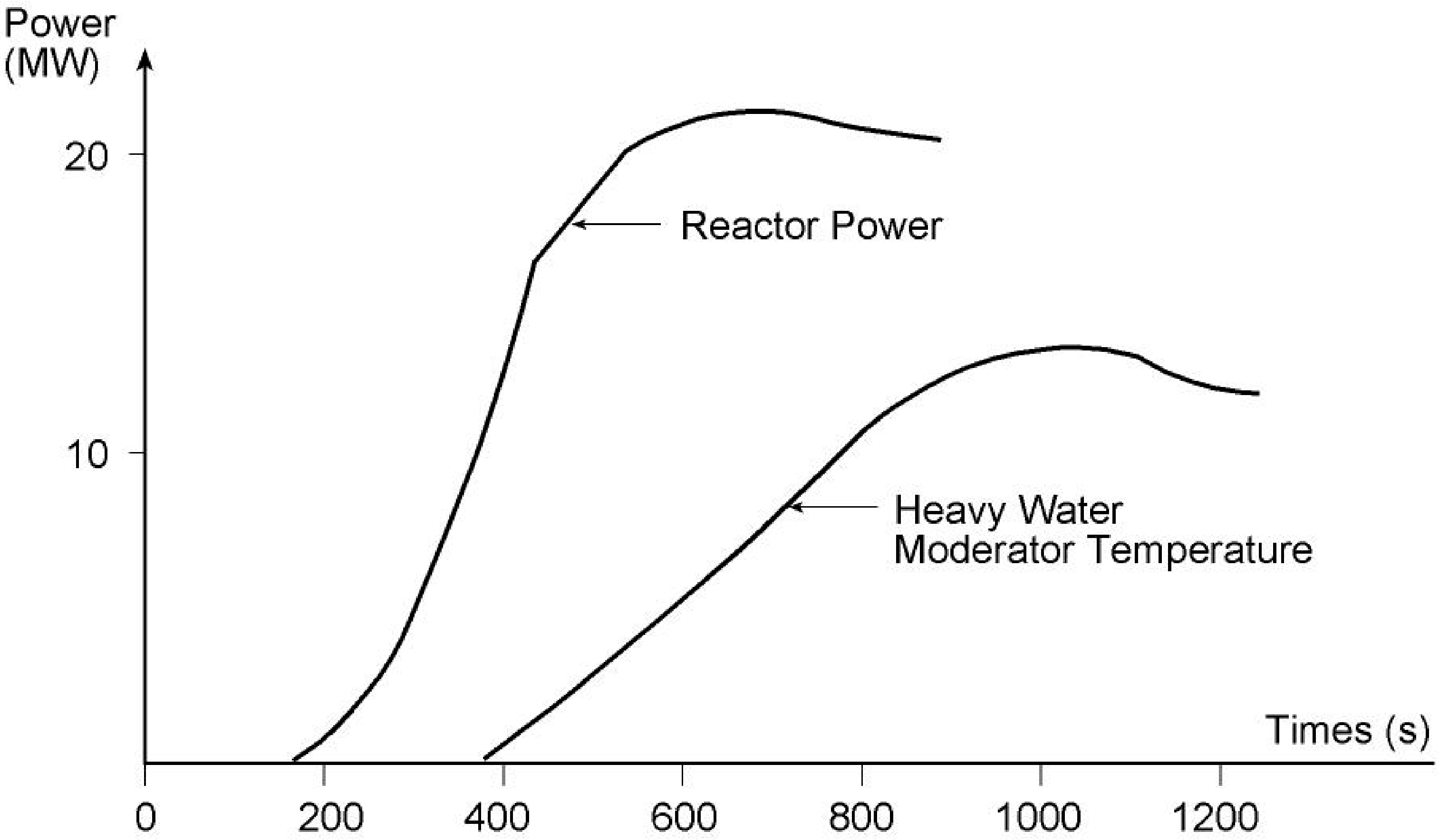
Xenon Transients



Reactivity Temperature Effects



NRX Experiment



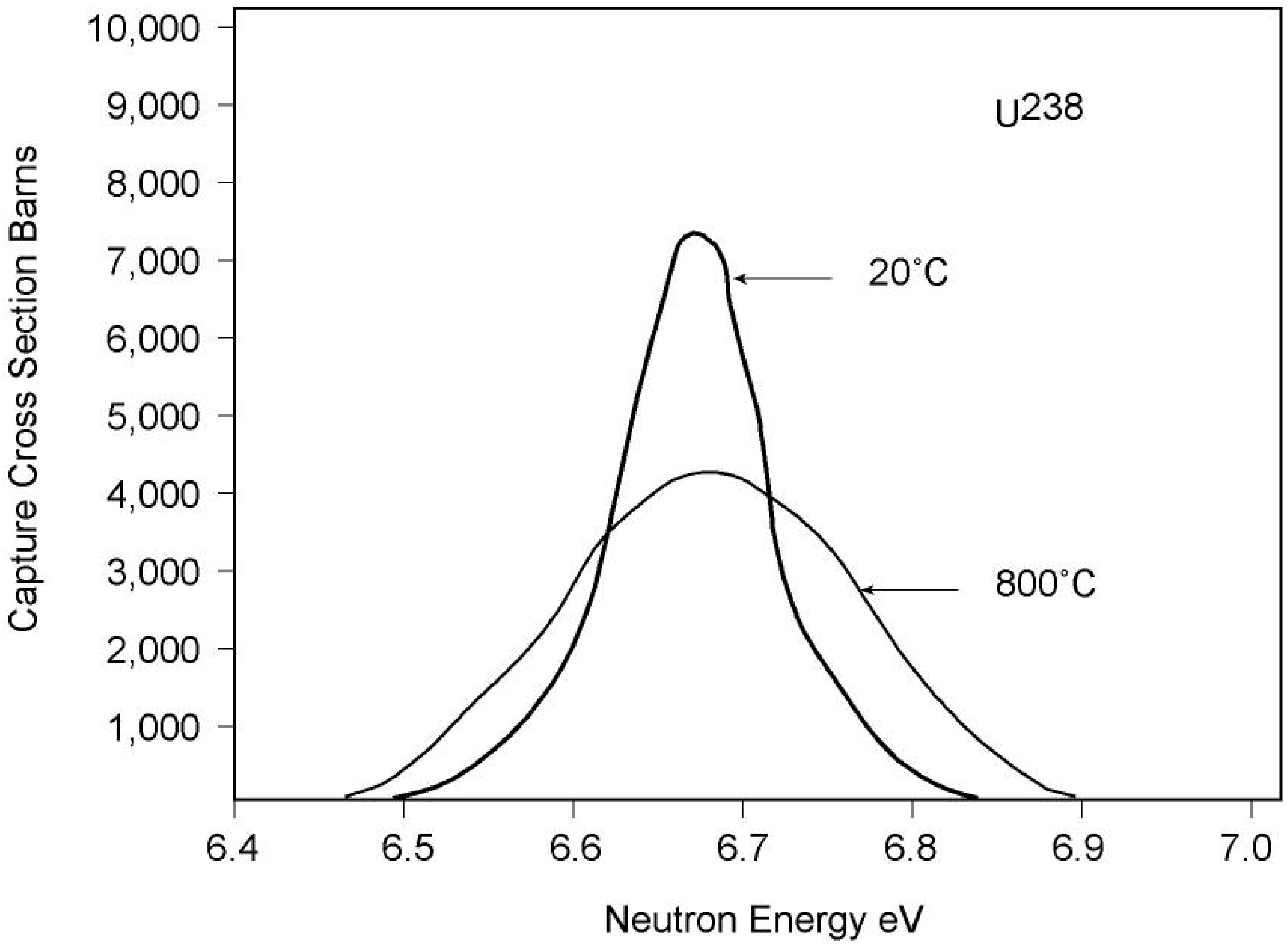
Temperature Coefficients

- mk/°C or μk/°C
- Moderator
- Heat Transport System
- Fuel
- Each is independent
- Each happens on its own time scale
- At power fuel predominates

Fuel

- Two effects
  - Increased resonance Capture
  - Changes in relative cross sections
- Coefficient is negative
  - Increase temperature adds negative reactivity

Increased Resonance Capture



Changes in cross sections

Probability of a fission

Probability of absorption in fuel

$$\frac{\sigma_f^{fuel}}{\sigma_a^{fuel}}$$

Decreases for U-235 (adds negative reactivity)

Increases for Pu-239 (adds positive reactivity)

In equilibrium fuel the Pu-2398 predominates

Plut like ‘em hot

Combined Effect

- Resonance broadening always predominates
  - Always negative
- More negative with fresh fuel
- Fresh fuel ≈ -0.013 mk/°C
- Equilibrium fuel -0.004 mk/°

Power Coefficient

- Total reactivity change for zero power hot to full power
  - Zero power hot is a term used to denote the moderator and HTS up to operating temperature but low fission power levels
- $\approx$ 5 mk

Void Coefficient

- Reactivity change for complete voiding of the HTS
- ≈+10 mk for complete voiding
  - This is a bad thing
- HTS cannot void completely instantly
- Reactor trips on high rate of power change and high power protect the reactor