Criticality and time constants

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Time constants in fission

In a reactor with fuel elements and a moderator for slowing the neutrons to thermal energies, the neutrons are characterized by a time constant τ, which includes moderation time $\sim 10^{-6}$ s, and diffusion time until absorption $\sim 10^{-3}$.

The number of neutrons at a time t is

$$N(t) = N_0 e^{(k-1)t/\tau}$$

where k is the neutron reproduction factor for the reactor. The time constant for this exponential is $\tau/(k-1)$.

If $k = 1.01$ and $\tau = 10^{-3}$ s, then

$$\tau/(k-1) = 0.1 \text{ s}$$

and

$$N(t) = N_0 e^{t/(0.1 \text{ s})}.$$

Never underestimate an exponential. In one second, $N = N_0 e^{10} = 22\,000 N_0$.

In power reactors, $k < 1$ for *prompt* neutrons. k is pushed over 1 via the *delayed* neutrons released after the fission reactions. This gives the reactor a long enough time constant for easier control.

Delayed critical: $k \sim 1$ for delayed neutrons only. N rises at constant controllable rate. Power reactors.

Delayed supercritical: $k > 1$ for delayed neutrons.

Prompt critical: $k \sim 1$ for prompt neutrons.

Prompt supercritical: $k > 1$ for prompt neutrons. Very rapid neutron flux, power rise possible. In a critical mass of very enriched material, this makes a fission explosion.

Interesting sites on criticality safety

- Lawrence Livermore Superblock, modern handling of Pu:
  `http://www.llnl.gov/str/March01/Sefcik.html`

- The Criticality Safety Information Research Center (CSIRC), LANL report on incidents from the Manhattan project to 2000:
  `http://www.csirc.net/library/la_13638.shtml`