Negative temperature feedback, reactor stability and controllability – an introduction

Jim Thomson

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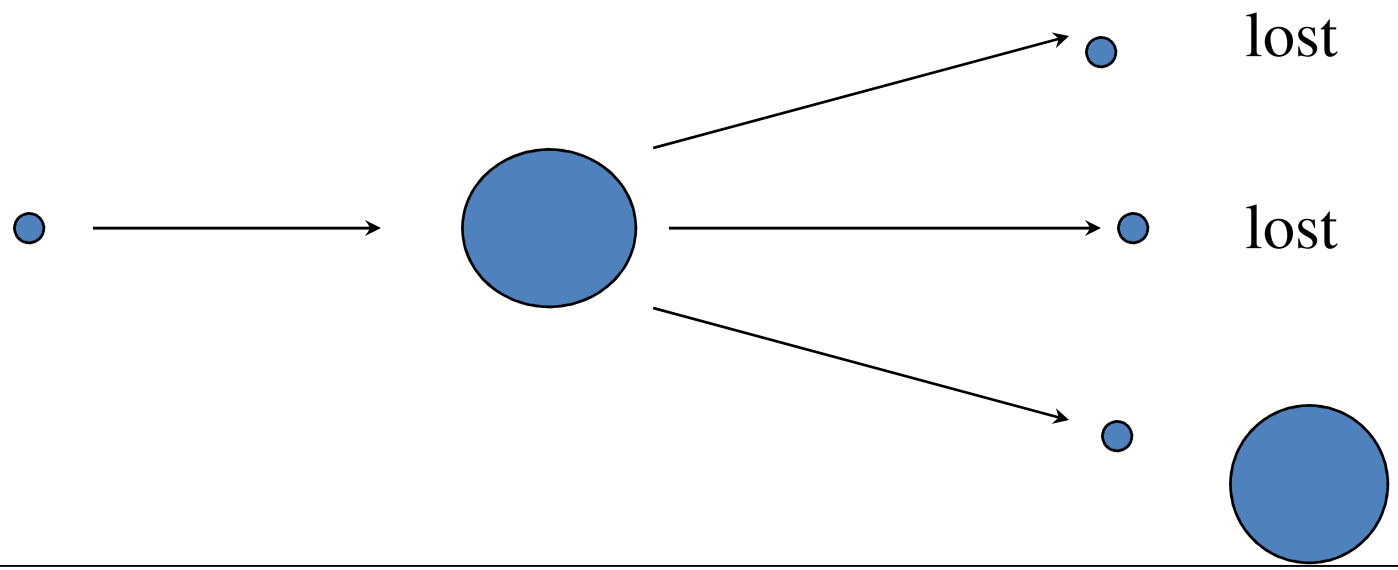


Effective multiplication factor k_{eff} =
(no. of fissions in one generation)/(no. of fissions in succeeding generation)

Reactivity $\rho = (k_{eff} - 1.0)/k_{eff}$ which is ~ $(k_{eff} - 1.0)$ for practical purposes.

Prompt neutron lifetime (the time between a neutron being expelled from a nucleus, and hitting another one) is typically about one-thousandth of a second.

The ***'lost'*** neutrons are absorbed by non-fissionable materials. These include:

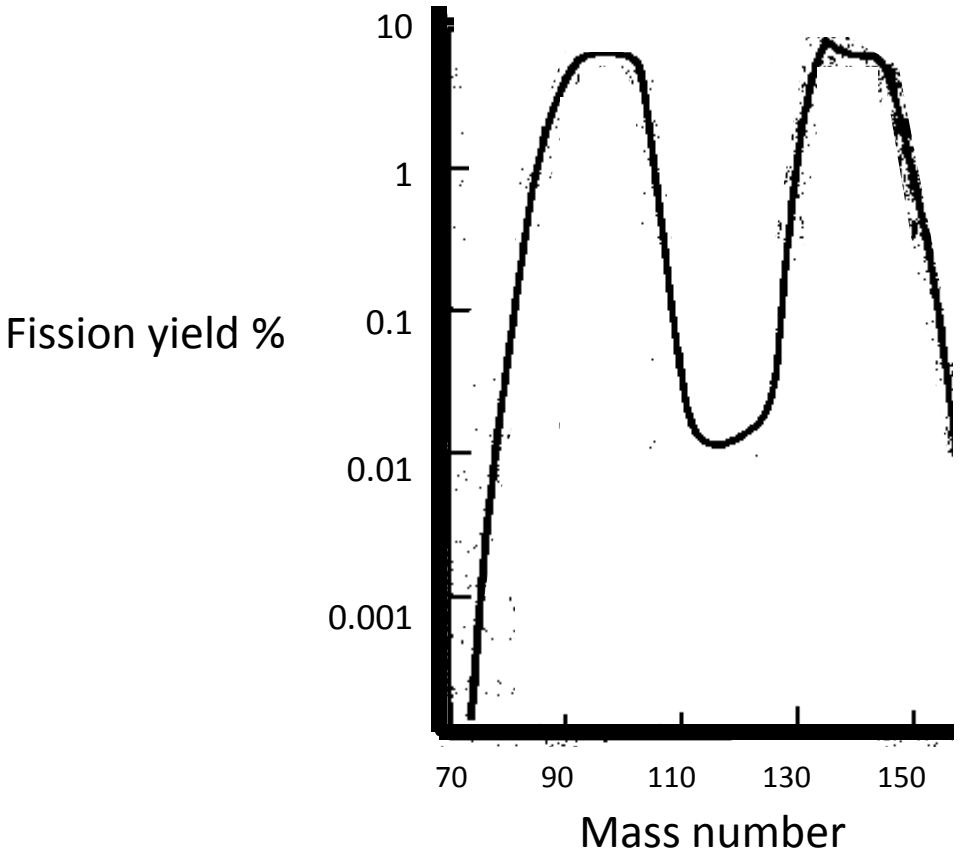
- Shielding,
- Structural steel,
- Moderator,
- Uranium-238

Delayed neutrons

Some neutrons (typically 0.65%) emitted in the fission process are ***delayed*** by up to several tens of seconds. The remaining 99.35% are released immediately upon fission (‘***prompt neutrons***’).

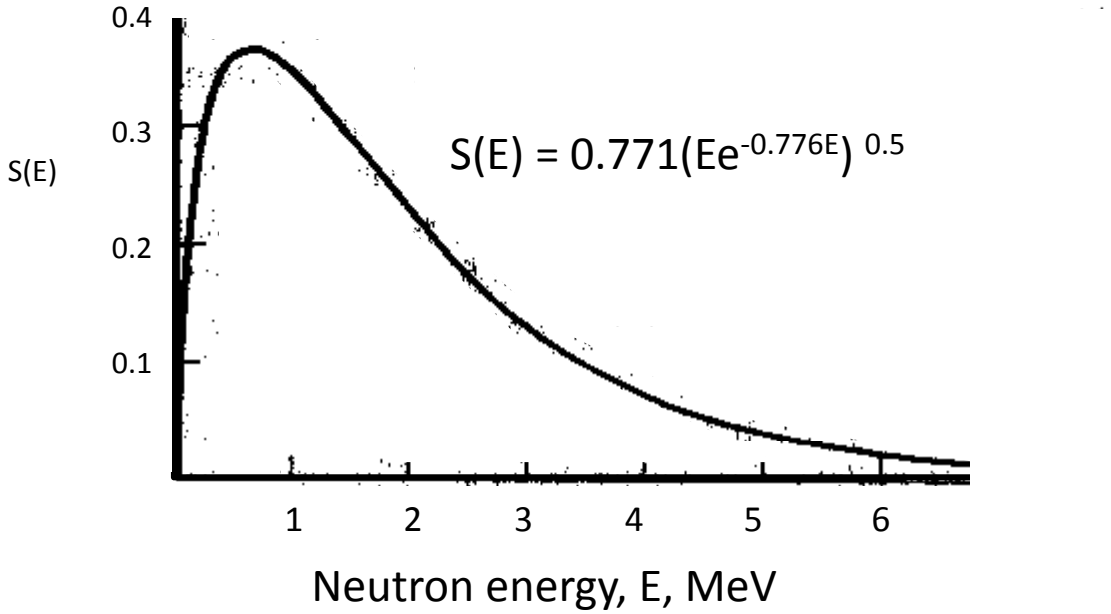
This phenomenon gives a margin for control of nuclear reactors.

Reactors operate in a so-called ‘***delayed critical***’’ state, compared to bombs which are ‘***prompt critical***’.



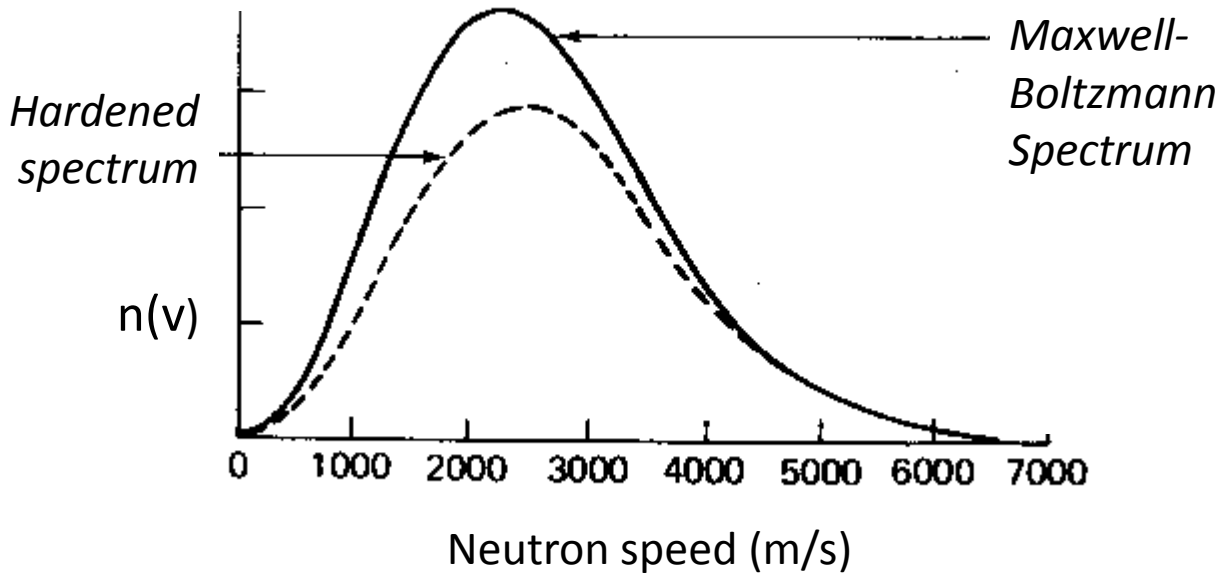
The fission product spectrum for uranium 235

Fission is a random process……
all sorts of elements get produced as *fission products……*



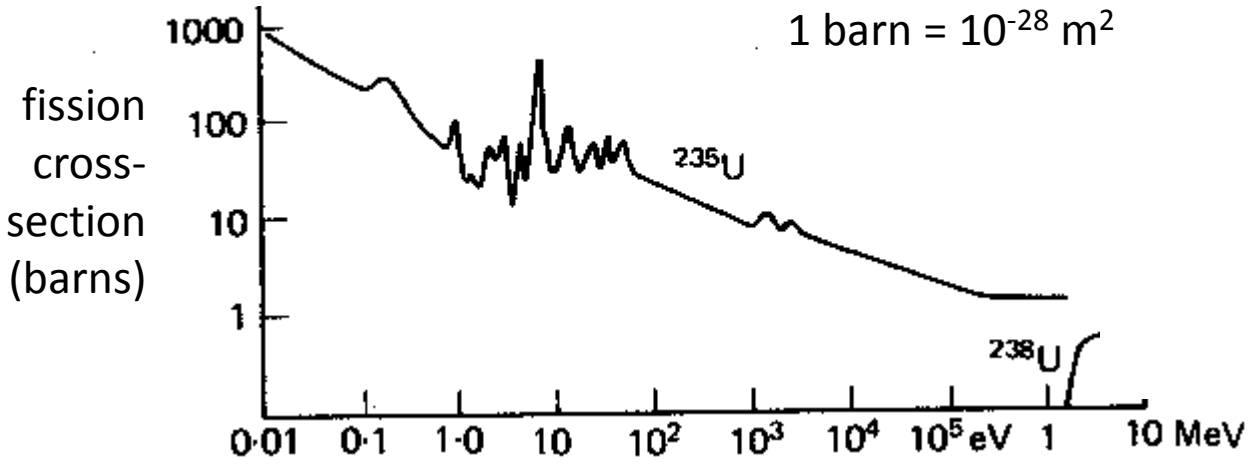
The fission neutron energy spectrum

……and the neutrons get released at a wide range of speeds (or *energies*)……..



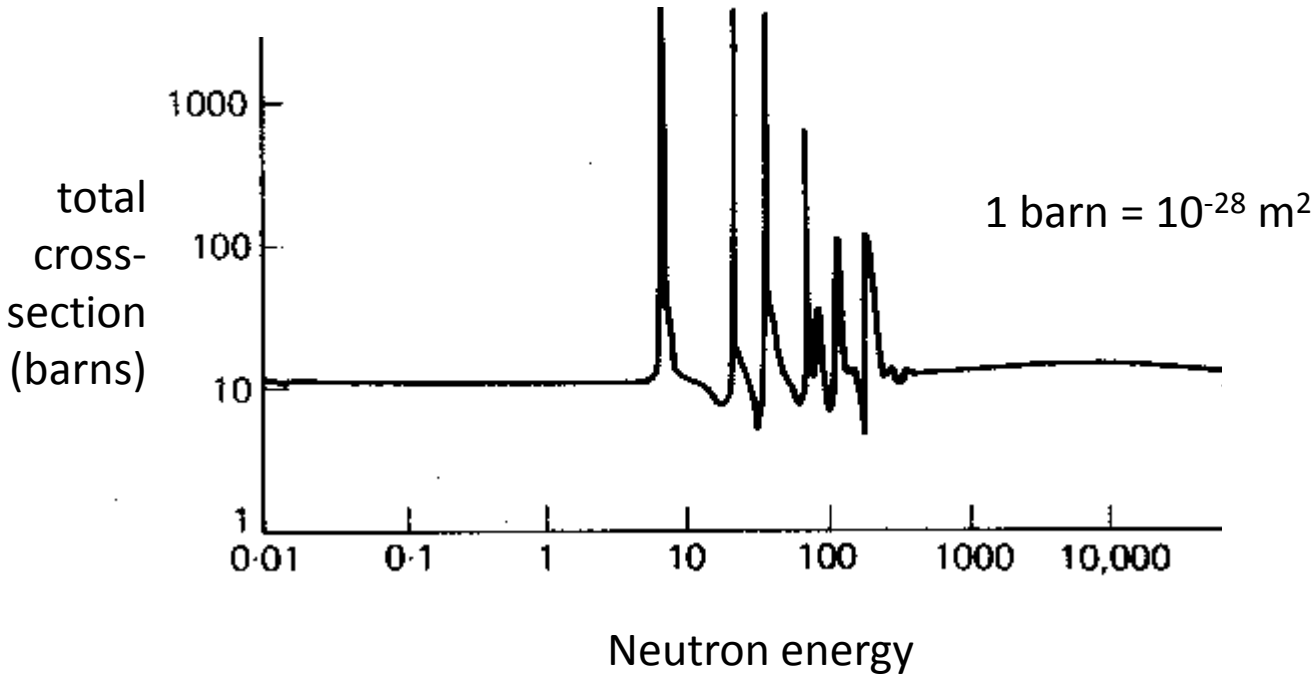
The Maxwell-Boltzmann distribution for thermal neutrons

…….and even after the neutrons have been slowed down (*moderated*) they still have a wide range of speeds……..



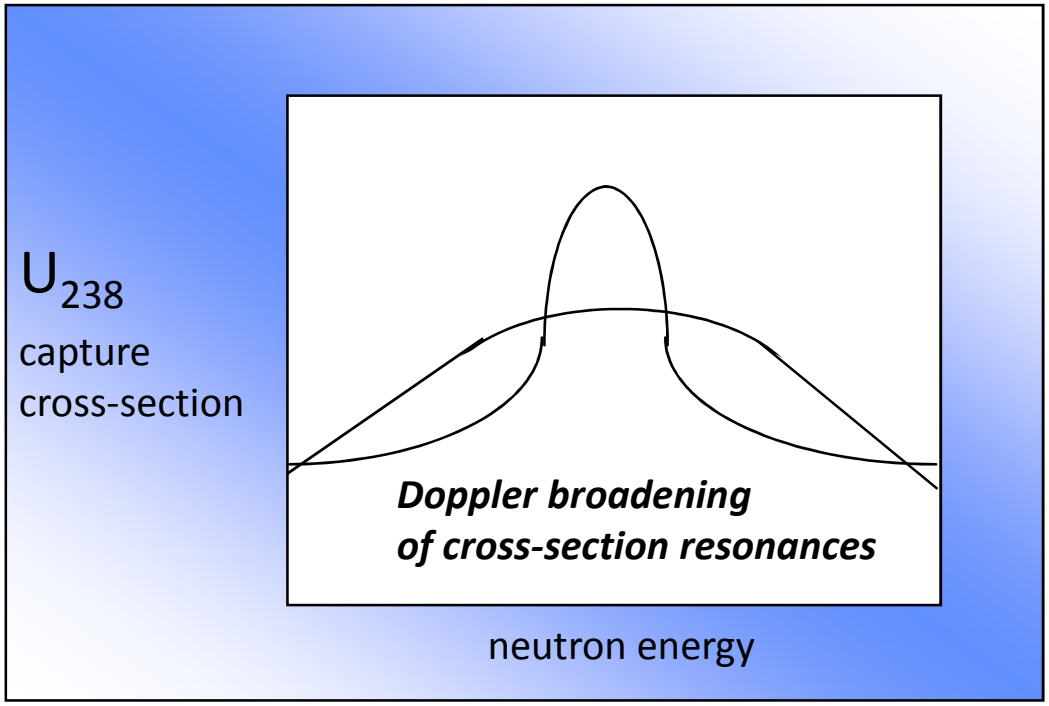
Fission cross-sections for uranium-235 and uranium-238

…….and the chance that a neutron will hit another uranium-235 nucleus (and hence cause another fission) varies with the speed of the neutron……..

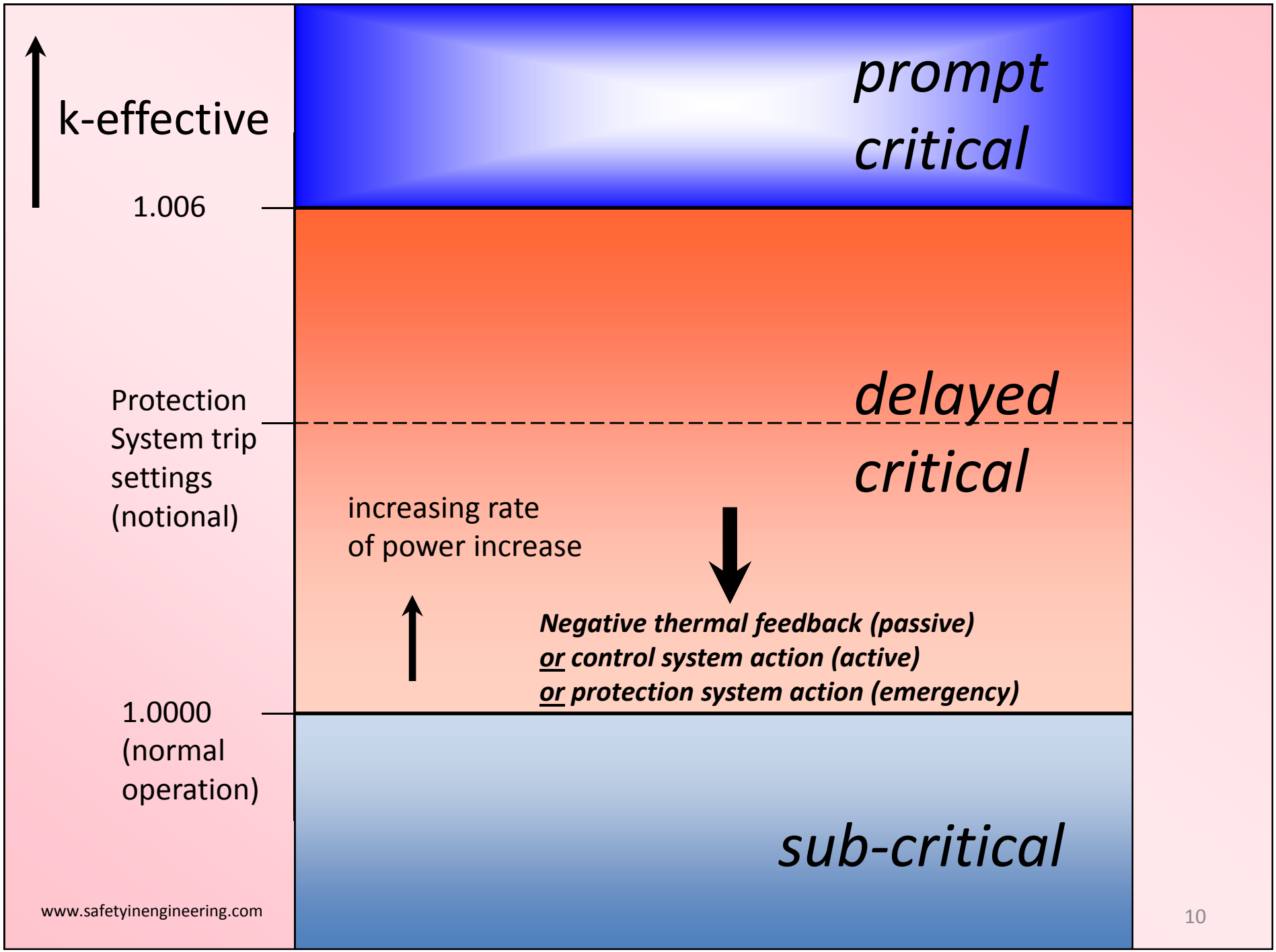


The total cross-section of uranium-238

……also the chance that the neutron will be captured by uranium 238 (and *not* cause fission) also varies with the neutron speed. The peaks ('resonances') are important, and are caused by quantum mechanics effects.....



<u>Doppler Broadening</u> – as U-238 gets hotter, the resonance peaks broaden due to vibration of the nuclei. The nett effect is that U-238 absorbs more neutrons (*without causing fission*) as the reactor temperature increases. Hence an increase in reactor temperature leads to a fall in reactivity.


k-effective
1.006
prompt critical
delayed critical
Protection System trip settings (notional)
increasing rate of power increase
Negative thermal feedback (passive)
or control system action (active)
or protection system action (emergency)
1.0000 (normal operation)
sub-critical

The ways in which temperature effects reactivity – passive control mechanisms

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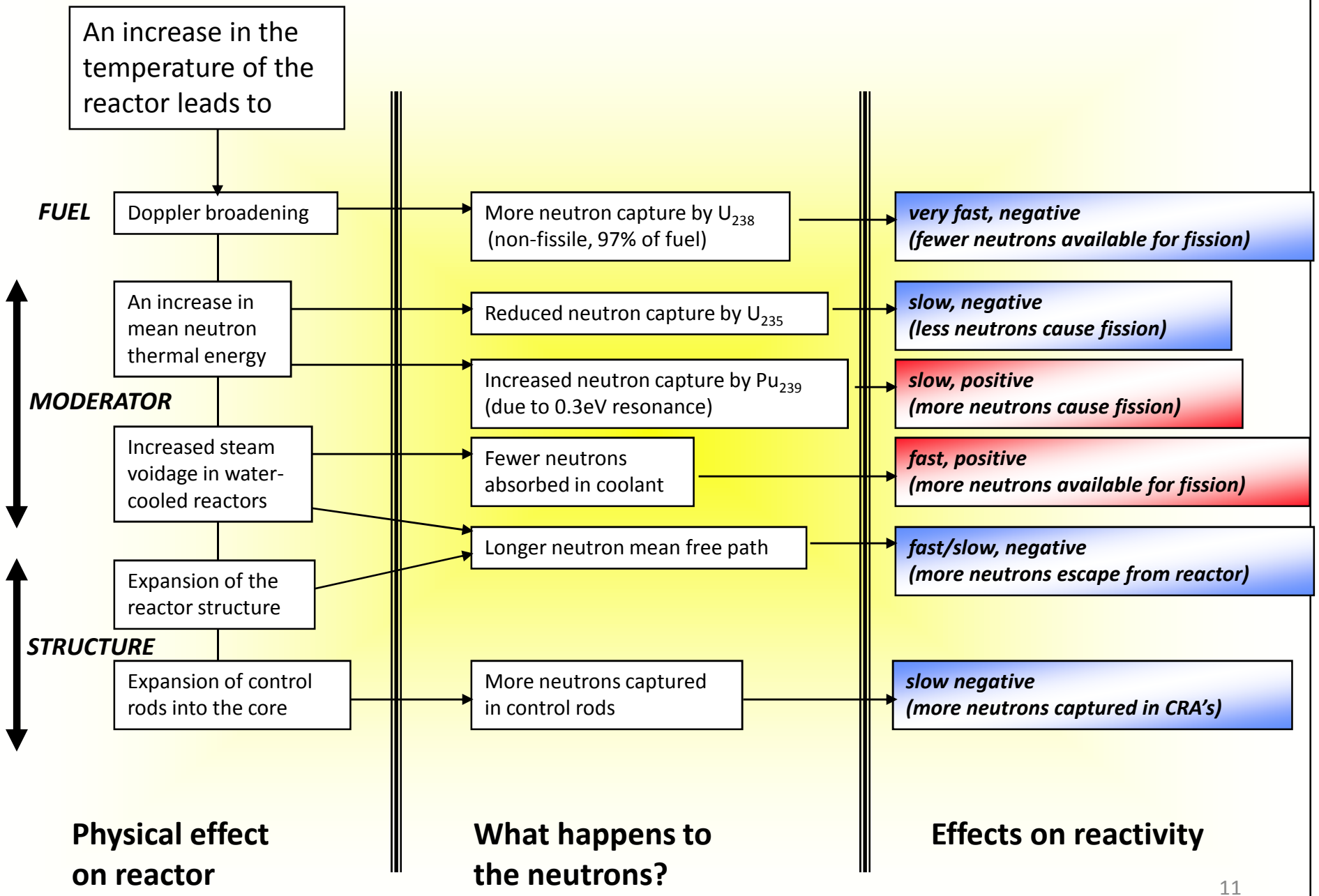
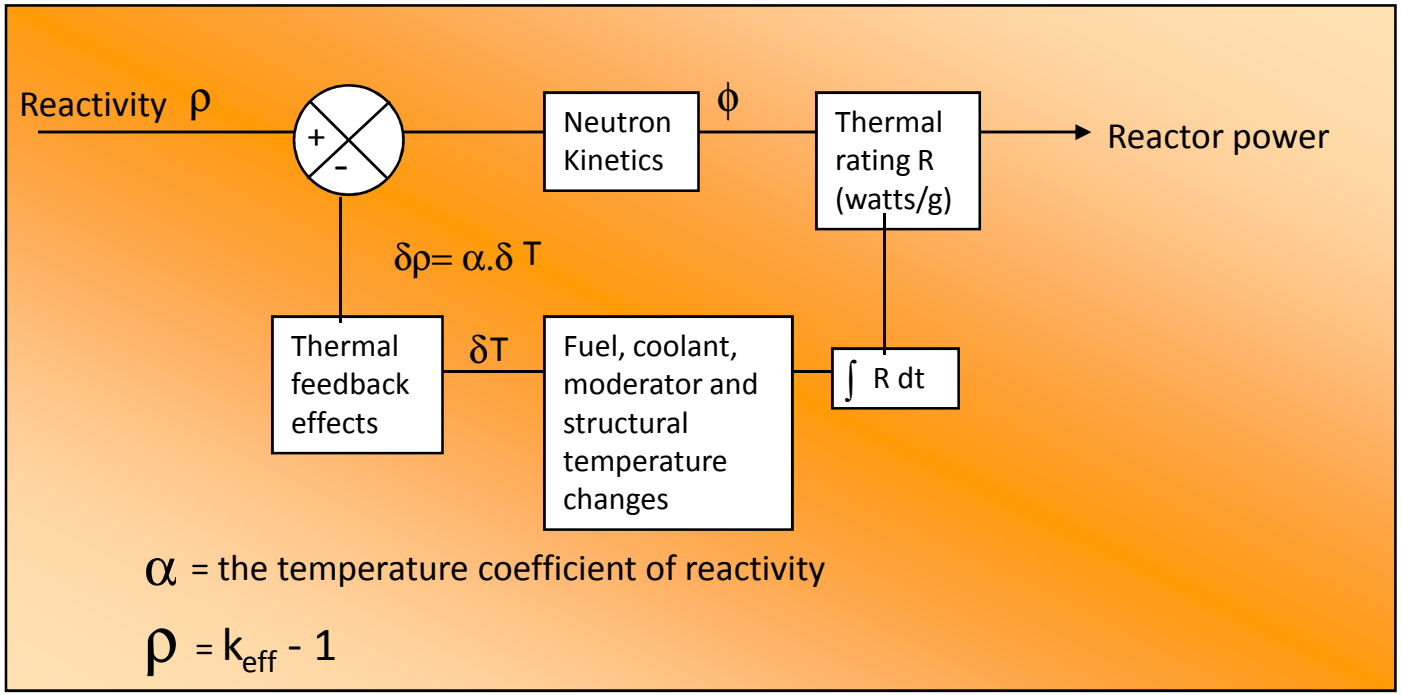


Passive thermal feedback



SUMMARY

Delayed neutrons make a nuclear reactor controllable.

Doppler broadening makes a nuclear reactor stable.