

Teaching Notes

Operational Reactor Safety Course

Lecture: 4 – Fuel Depletion and Related Effects

Objective: Review the concept of burn up, transmutation, conversion and breeding and the role that samarium and xenon play in operations.

Key Points to Bring Out:

<u>Slide number</u>	<u>Points</u>
3	Present the depletion equation and provide a clear understanding of the definition of burnup, and what it physically means. This is a commonly used term that is frequently misunderstood.
4	Transmutation should be described as a general process where it's the ability to produce a particular type of nuclide which can be related to a neutron absorption and decay process. Thus where the chart of the nuclides comes in. We can make design choices to make cores that are converters namely users of the uranium, and also breeders to produce plutonium and other fuels. The key parameter in terms of being able to successfully being able to do that is the $\eta(n)$, which is a number of neutrons produced per fission. And the concept of conversion ratio should be explained.
5	Shows the various η s as a function of energy. The key point here is to show that plutonium 239, 241 and uranium 235 all have essentially the same η s at about 0.01ev. However there is an energy range where plutonium has certain advantages in terms of number of neutrons per fission (about 100ev).
6	A broader range of η s as a function of energy indicating that at high energies, the number of neutrons produced is greater which would suggest the breeder reactors need to be high neutron energy machines rather than converters to take advantage of these extra neutrons for breeding fissile Pu239 from fertile U-238.

- 7 Examples of conversion ratios for various types of reactors with the liquid metal fast breeder reactor having breeding ratios, not conversion ratios.
- 8 Presents the build up of plutonium during operation and the depletion of uranium 235 such that by the end core life, plutonium 239 and 241 produce a substantial amount of energy which compensates to a degree the consumption of U235. Shown also on the slide is a website for the chart of nuclides which is very useful in identifying typical cross sections of various isotopes which you could spend some time discussing.
- 9 Discusses the concept of reactivity penalties for different types of transmutation products. The buildup of neptunium and americum as a function of number or recycles negatively affects the ability to maintain criticality because these isotopes are neutron absorbers.
- 10 Begins the discussion of the need to keep track of some of these fission products in terms of their creation and how they affect the ability to have a critical reactor. The fission fragment balance equation is presented that ultimately will be used to discuss the buildup of samarium and xenon, which are fission products that can affect significantly the operation of reactors. Show students absorption cross-sections from the KAERI table of nuclides.
- 11 Shows the buildup of samarium as a function of the decay of the fission product neodymium. The chart shows how the decay chain functions in the buildup of Sm 149.
- 12 Shown is the effect of samarium buildup during the start up, shut down and restart. The key point is to write the fission fragment equations to see how the buildup of samarium occurs and it can only be destroyed by neutron absorption. The production occurs by the decay of fission products – a final balance is reached where the build up rate is matched by the burnup rate which is a function of flux level.
- 13 This chart is similar to the Samarium chart except it has another fission product decay chain source and Xe 135 also decays. Write the equations. Point out that if the reactor is not restarted within a certain period of time, it is very difficult to restart, to override the xenon poisoning the reactor. If not restarted one will have to wait until the peak xenon 14 has decayed.
- 14 This is an important slide since it relates the flux level of the core or power level to the ability to restart in a certain period of time.

For example, if the neutron flux is 5×10^{14} as shown in curve 4, there would be significant penalty due to xenon build up that may prevent the restart of the reactor since there would not be sufficient control rod worth in the core override the xenon to restart.

- 15 Summarizes some of the operational impacts associated with fission products. Xenon oscillations may occur during flux redistribution in the core (movement of control rods). Length of the fuel cycle is an important element in core design. Fuel management strategies need to be developed to assure that with the reactor can be refueled in ways the can have the core operated for the next fuel cycle of a fixed period. During the core design of the refueled reactor, peaking factors have to be limited for the cycle to avoid derates due to exceeding safety limits for transients.
- 16 Summarizes the process used to do reactor physics calculations. This is an important slide for the students to understand in terms of summarizing all the basic concepts to date. Knief has a good summary.

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