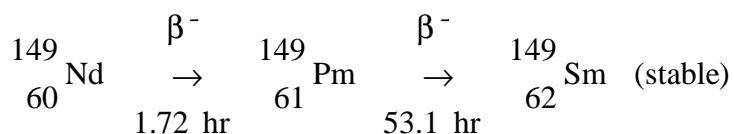

SAMARIUM AND OTHER FISSION PRODUCT POISONS

The fission product poison that has the most significant effect on reactor operations other than xenon-135 is samarium-149. Samarium-149 behaves significantly different from xenon-135 due to its different nuclear properties.

- EO 4.10** **DESCRIBE** how samarium-149 is produced and removed from the reactor core during reactor operation.
- EO 4.11** **STATE** the equation for equilibrium samarium-149 concentration.
- EO 4.12** **DESCRIBE** how equilibrium samarium-149 concentration varies with reactor power level.
- EO 4.13** **DESCRIBE** how samarium-149 concentration changes following a reactor shutdown from steady-state conditions.
- EO 4.14** **DESCRIBE** how samarium-149 concentration changes following a reactor startup.
- EO 4.15** **STATE** the conditions under which helium-3 will have a significant effect on the reactivity of a reactor.
-

Production and Removal of Samarium-149

Samarium-149 is the second most important fission-product poison because of its high thermal neutron absorption cross section of 4.1×10^4 barns. Samarium-149 is produced from the decay of the neodymium-149 fission fragment as shown in the decay chain below.



For the purpose of examining the behavior of samarium-149, the 1.73 hour half-life of neodymium-149 is sufficiently shorter than the 53.1 hour value for promethium-149 that the promethium-149 may be considered as if it were formed directly from fission. This assumption, and neglecting the small amount of promethium burnup, allows the situation to be described as follows.

Rate of change of ^{149}Pm = yield from fission - decay ^{149}Pm concentration

therefore:

$$\frac{dN_{\text{Pm}}}{dt} = \gamma_{\text{Pm}} \sum_f^{\text{fuel}} \phi - \lambda_{\text{Pm}} N_{\text{Pm}}$$

where:

$$N_{\text{Pm}} = {}^{149}\text{Pm concentration}$$

$$\gamma_{\text{Pm}} = {}^{149}\text{Pm fission yield}$$

$$\lambda_{\text{Pm}} = \text{decay constant for } {}^{149}\text{Pm}$$

Solving for the equilibrium value of promethium-149 gives the following.

$$N_{\text{Pm}}(\text{eq}) = \frac{\gamma_{\text{Pm}} \sum_f^{\text{fuel}} \phi}{\lambda_{\text{Pm}}}$$

The rate of samarium-149 formation is described as follows.

Rate of change of ^{149}Sm = yield from fission + ^{149}Pm decay - ^{149}Sm burnup

therefore:

$$\frac{dN_{\text{Sm}}}{dt} = \gamma_{\text{Sm}} \sum_f^{\text{fuel}} \phi + \lambda_{\text{Pm}} N_{\text{Pm}} - N_{\text{Sm}} \sigma_a^{\text{Sm}} \phi$$

where:

$$N_{\text{Sm}} = {}^{149}\text{Sm concentration}$$

$$\gamma_{\text{Sm}} = {}^{149}\text{Sm fission yield}$$

$$\sigma_a^{\text{Sm}} = \text{microscopic absorption cross section of } {}^{149}\text{Sm}$$

The fission yield of samarium-149, however, is nearly zero; therefore, the equation becomes the following.

$$\frac{dN_{\text{Sm}}}{dt} = \lambda_{\text{Pm}} N_{\text{Pm}} - N_{\text{Sm}} \sigma_a^{\text{Sm}} \phi$$

Solving this equation for the equilibrium concentration of samarium-149 and substituting $\gamma_{\text{Pm}} \Sigma_f^{\text{fuel}} \phi / \lambda_{\text{Pm}}$ for $N_{\text{Pm}}(\text{eq})$ yields the following.

$$N_{\text{Sm}}(\text{eq}) = \frac{\gamma_{\text{Pm}} \Sigma_f^{\text{fuel}}}{\sigma_a^{\text{Sm}}}$$

This expression for equilibrium samarium-149 concentration during reactor operation illustrates that equilibrium samarium-149 concentration is independent of neutron flux and power level. The samarium concentration will undergo a transient following a power level change, but it will return to its original value.

Samarium-149 Response to Reactor Shutdown

Since the neutron flux drops to essentially zero after reactor shutdown, the rate of samarium-149 production becomes the following.

$$\frac{dN_{\text{Sm}}}{dt} = \lambda_{\text{Pm}} N_{\text{Pm}}$$

Because samarium-149 is not radioactive and is not removed by decay, it presents problems somewhat different from those encountered with xenon-135, as illustrated in Figure 7. The equilibrium concentration and the poisoning effect build to an equilibrium value during reactor operation. This equilibrium is reached in approximately 20 days (500 hours), and since samarium-149 is stable, the concentration remains essentially constant during reactor operation. When the reactor is shutdown, the samarium-149 concentration builds up as a result of the decay of the accumulated promethium-149. The buildup of samarium-149 after shutdown depends upon the power level before shutdown. Samarium-149 does not peak as xenon-135 does, but increases slowly to a maximum value as shown in Figure 7. After shutdown, if the reactor is then operated at power, samarium-149 is burned up and its concentration returns to the equilibrium value. Samarium poisoning is minor when compared to xenon poisoning. Although samarium-149 has a constant poisoning effect during long-term sustained operation, its behavior during initial startup and during post-shutdown and restart periods requires special considerations in reactor design.

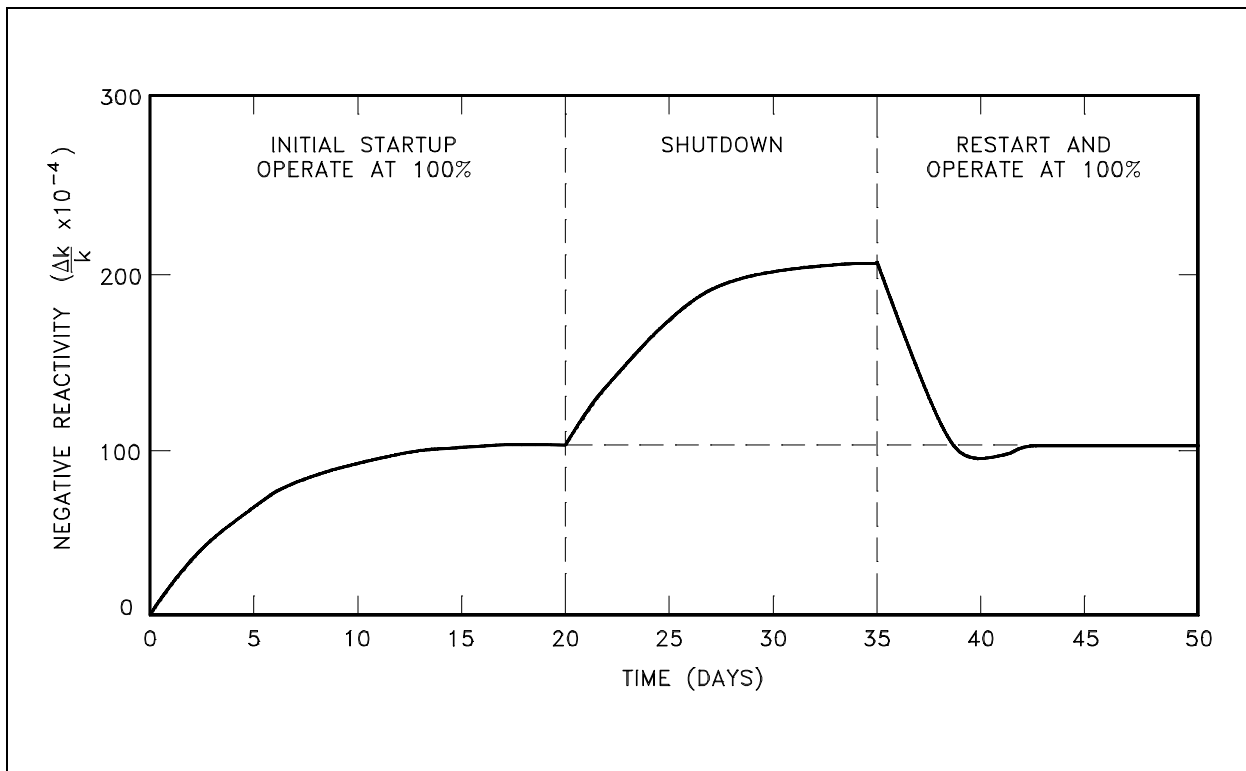


Figure 7 Behavior of Samarium-149 in a Typical Light Water Reactor

The xenon-135 and samarium-149 mechanisms are dependent on their very large thermal neutron cross sections and only affect thermal reactor systems. In fast reactors, neither these nor any other fission products have a major poisoning influence.

Other Neutron Poisons

There are numerous other fission products that, as a result of their concentration and thermal neutron absorption cross section, have a poisoning effect on reactor operation. Individually, they are of little consequence, but "lumped" together they have a significant impact. These are often characterized as "lumped fission product poisons" and accumulate at an average rate of 50 barns per fission event in the reactor.

In addition to fission product poisons, other materials in the reactor decay to materials that act as neutron poisons. An example of this is the decay of tritium to helium-3. Since tritium has a half-life of 12.3 years, normally this decay does not significantly affect reactor operations because the rate of decay of tritium is so slow. However, if tritium is produced in a reactor and then allowed to remain in the reactor during a prolonged shutdown of several months, a

sufficient amount of tritium may decay to helium-3 to add a significant amount of negative reactivity. Any helium-3 produced in the reactor during a shutdown period will be removed during subsequent operation by a neutron-proton reaction.

Summary

The important information in this chapter is summarized below.

Samarium and Other Fission Product Poisons Summary

- Samarium-149 is produced directly from fission and from the decay of promethium-149 during reactor operation. Samarium-149 is removed from the core by neutron absorption.

- The equation for equilibrium samarium-149 concentration is stated below.

$$N_{\text{Sm}}(\text{eq}) = \frac{\gamma_{\text{Pm}} \Sigma_f^{\text{fuel}}}{\sigma_a^{\text{Sm}}}$$

- The equilibrium samarium-149 concentration is independent of power level.
- Following a reactor shutdown, the samarium-149 concentration increases due to the decay of the promethium-149 inventory of the core and the loss of the burnup factor.
- If the reactor is restarted following a shutdown, the samarium-149 concentration decreases as samarium is burned up and returns to its equilibrium operating value.
- Helium-3 will become a significant neutron poison if significant amounts of tritium are left in a reactor during a shutdown period that lasts longer than several months.