Nuclear Reactor Physics Lecture Note (13)
-Core Burnup(1)Effect of Fission Products-

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10. Core Burnup
10.1 Fission product poisoning
(1) Core composition change by nuclear reaction

Creation of fission products（FP）

Some of the fission products have large absorption cross section in thermal region.

ex. ^{135}Xe, ^{149}Sm, etc

Consumption of fissile material

Creation of trans uranium elements（TRU）

⇒ Change of reactivity, Change of power distribution, Change of spent fuel composition

(2) Concentration of ^{135}Xe

Large ^{135}Xe concentration→Negative reactivity

Equations of ^{135}I and ^{135}Xe number density change

$$\begin{cases} \dfrac{\partial \mathrm{I}}{\partial t} = \gamma_{\mathrm{I}} \Sigma_f \phi(\mathbf{r},t) - \lambda_{\mathrm{I}} \mathrm{I}(\mathbf{r},t) \\ \dfrac{\partial \mathrm{X}}{\partial t} = \gamma_{\mathrm{X}} \Sigma_f \phi(\mathbf{r},t) + \lambda_{\mathrm{I}} \mathrm{I}(\mathbf{r},t) \\ \qquad - \lambda_{\mathrm{X}} \mathrm{X}(\mathbf{r},t) - \sigma_a^{\mathrm{X}} \phi(\mathbf{r},t) \mathrm{X}(\mathbf{r},t) \end{cases} \quad \cdots (1)$$

where,

$\mathrm{I}(\mathbf{r},t)$: Nuclide number density of ^{135}I

$\mathrm{X}(\mathbf{r},t)$: Nuclide number density of ^{135}Xe

γ_{I} : Fission yield of ^{135}I

γ_{X} : Fission yield of ^{135}Xe

λ_{I} : Decay constant of ^{135}I

λ_{X} : Decay constant of ^{135}Xe

σ_a^{X} : Microscopic absorption cross section of Xe-135

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ϕ : One group neutron flux

Σ_f : One group macroscopic fission cross section

$X(\mathbf{r},t), X(\mathbf{r},t)$ can be calculated if $\phi(\mathbf{r},t)$ is known

Example 1, Startup of a clean core reactor (A core without FP)

Suppose that we suddenly bring the reactor to a steady-state flux level ϕ_0 at time t=0. (At the shutdown state, fission product poison concentrations are zero)

The concentrations of Xe and I at equilibrium after a long time from the startup

By setting $\frac{\partial X}{\partial t} = \frac{\partial I}{\partial t} = 0$

then

$$I_\infty = \frac{\gamma_I \Sigma_f \phi_0}{\lambda_I}$$

$$X_\infty = \frac{(\gamma_I + \gamma_X)\Sigma_f \phi_0}{\gamma_X + \sigma_a^X \phi_0}$$

Example 2, Reactor shutdown

When we suddenly shut a reactor down after a long period of time at a constant flux level ϕ_0.

Nuclide density of Xe-135 (=negative reactivity) depends on the flux level before shut down. No build up of Xe-135 following shut down will occur unless

$$\phi_0 > \frac{\gamma_X}{\gamma_I}\frac{\lambda_X}{\sigma_a^X} \quad (\cong 4 \times 10^{11} \mathrm{cm}^{-2}\mathrm{s}^{-1} \text{ in } {}^{235}\mathrm{U} \text{ fueled reactor})$$

It occurs in most of the power reactor.

Example 3, Xenon transients following power level changes

The xenon transient following a change in reactor flux level from ϕ_0 to ϕ_1

(3)Concentration of ^{149}Sm

By neglecting the ^{149}Nd and assuming fission yields ^{149}Pm directly,

For Promethium

$$\frac{\partial P}{\partial t} = \gamma_P \Sigma_f \phi(\mathbf{r},t) - \lambda_P P(\mathbf{r},t)$$

For Samarium

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$$\frac{\partial S}{\partial t} = \gamma_P P(\mathbf{r},t) - \sigma_a^S \phi(\mathbf{r},t) S(\mathbf{r},t)$$

The equilibrium concentrations

$$P_\infty = \frac{\gamma_P \Sigma_f \phi_0(\mathbf{r})}{\lambda_P}$$

$$S_\infty = \frac{\gamma_P \Sigma_f}{\sigma_a^S}$$

After shut down in equilibrium condition

$$S(t) = S_\infty + P_\infty(1 - \exp(-\lambda_P t)) \quad \overrightarrow{t \to \infty} \quad S_\infty + P_\infty$$

The smaller absorption cross section and yield fraction and longer precursor half-life characterizing samarium imply that it will lead to for less severe reactivity effects than ^{135}Xe.

(4)Effect of other fission products

The cross sections of fission products are not sufficiently large in most cases for their concentration to be depleted by neutron capture.

In general, concentrations of some of fission products with rather large absorption cross sections are calculated independently. Other fission products are lumped and treated as a pseudo fission product.

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