2019 Basic Nuclear Engineering I Lecture note (5)

- Temperature effect, Core burnup -

Toru Obara

Tokyo Institute of Technology

4.4 Temperature effect on multiplication factor

・Change of temperature of nuclear reactor

→ Cause the change of multiplication factor

A nuclear reactor is in critical condition at a temperature.

If the temperature increase

1. In the case of thermal reactors, the average energy of thermal neutrons become higher by the increase of moderator temperature.

   - The fraction of thermal neutrons that are absorbed by fissile changes. (Positive or negative reactivity)

2. More neutrons are absorbed by ^{238}U

   - Doppler effect of ^{238}U resonance absorption by the thermal motion of the nuclei. (Negative reactivity)

3. Leakage of neutrons from the reactor increase because of the expansion of the reactor core.

   - The results of the combination of material density reduction and surface area increase. (Negative reactivity)

4. Coolant density change by the expansion or the boiling.

   - It results in the change of fissions because of the change of neutron absorption, leakage and the spectrum.

     (Positive or negative reactivity)

Nuclear reactors

are designed to make the reactivity negative in temperature rise by the combination of the effects.

⇒ If the reactor power changes by some reason, the reactor power becomes the original power without the operating control rods. (Inherent Safety feature)

Constant power operation

(Critical) k = 1 or $\rho = 0$

By some reason

↙ ↘

Reactor power:	Increase	Decrease
	↓	↓
Reactor temperature:	Increase	Decrease
	Negative reactivity ↓	↓ Positive reactivity
Multiplication factor:	$k < 1$ ($\rho < 0$)	$k > 1$ ($\rho > 0$)
	Subcritical	Supercritical
	↓	↓
Reactor power:	Decrease	Increase

↘ ↙

The original power $k = 1$ ($\rho = 0$)

5. Core burnup

5.1 Accumulation of fission products

Fission Products (FP) … Light nuclei created by nuclear fission.

Usually two FPs are created by a fission.

Energy released by a fission (approximately 203 MeV)

Approximately 166 MeV … kinetic energy of FPs

↘ Heat in fuel

Approximately 37 MeV … kinetic energy of neutrons

γ-ray, neutrinos,

Energy released by the decay of FPs

↘ Heat in fuel + radiation

・Features of FP

① FPs created by fission → probabilistic low

In the case of thermal fission of ^{235}U

Mass number approximately 95 ~ 105,

approximately 135 ~ 145

② Most of the FPs are unstable.

They become stable by β-decay

→ Emission of β-ray (electron)

γ-ray (Electromagnetic wave)

(Neutron)

Heat in the fuel (decay heat)

Half life : 1 s ~ 10 million years

Important in the safety of nuclear reactor

The heating continuous after the stop of fission chain reaction.

③ Some of the FPs have large neutron absorption cross section

Accumulation of FPs → Increase of neutron absorption

Operation of power reactor

⇒ { Consumption of fissile
Accumulation of FPs

⇒ Fission chain reaction stops

Enough amount of fuel rods need to be loaded at initial to have excess reactivity

5.2 Transmutation

The transmutation of nuclei occurs by the neutron capture.

Example:

Transmutation of ^{238}U by neutron capture

$$^{238}U + n \rightarrow {}^{239}U \rightarrow \xrightarrow[\text{half-life 24 min}]{\beta \text{ decay}} {}^{234}Np \xrightarrow[\text{half-life 2.4 days}]{\beta \text{ decay}} {}^{234}Pu$$

fertile — half-life 24 min — half-life 2.4 days — fissile

・If ^{239}Pu absorbs a neutron

1. Fission → FPs + neutrons

   or

2. Capture the neutron (n, γ) reaction

In the case

$$^{239}Pu \xrightarrow{(n,\gamma)} {}^{240}Pu \xrightarrow{(n,\gamma)} {}^{241}Pu \xrightarrow{(n,\gamma)} {}^{242}Pu$$

non-fissile — fissile — non-fissile

^{241}Pu → β-decay, half-life 13 years → ^{241}Am

(Non-fissile, large neutron absorption cross section)

・Plutonium from the spent fuel of power reactor

1. It contains a lot of non-fissile Pu (20 ~ 30 %)

2. It becomes difficult to cause fission if the time passes.

   (^{241}Pu decrease, ^{241}Am increase)