2020 Basic Nuclear Engineering I Lecture note (6)

- Nuclear Reactor Design -

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6. Nuclear Reactor Design

6.1 Elements of nuclear reactor

(1) Fuel element …

- Fuel: Uranium oxide
  - Plutonium oxide
    - (nitride)
    - (metal)
- Cladding:
  - Zirconium alloy
  - Stainless steel
  - Silicon carbide (SiC)

(2) Moderator (in thermal reactor only)

…
- Light water (H_2O)
- Heavy water (D_2O)
- Graphite (C)

(3) Coolant (to remote heat from the fuel)

… { Light water (H_2O)
Heavy water (D_2O)
Sodium (Na)
Helium (He)

(4) Reactor vessel … Stainless steal

6.2 Fuel element

・Light water reactor (LWR) (Thermal reactor with light water moderator)

- Pressurized Water Reactor (PWR)
- Boiling Water Reactor (BWR)

Fuel : Uranium oxide (UO_2) stable in higher temperature
Enrichment : 3 ~ 5 % (2000℃)

Cladding: zirconium alloy

- Low thermal neutron capture cross section

Tolerance for high temperature water < 400℃

Weak point: production of hydrogen by chemical reaction with very high temperature water

・Fast Breeder Reactor (FBR)　(Monju)

Fuel: Uranium-plutonium mixed oxide

(UO_2-PuO_2 : ratio of PuO_2 is about 20%)

Cladding: Stainless steel

Small neutron capture cross section because of high neutron energy

6.3 Moderator

Moderation ratio … An index of the performance of moderator

Definition

$$\text{Moderation ratio} = \xi \frac{\sigma_s}{\sigma_a}$$

ξ: Index to decrease of the neutron energy by a scattering

σ_s: Scattering cross section

σ_a: Absorption cross section

A material with large moderation ratio

→ Good moderator

Moderation ratio	Moderator	Nuclear reactor
Large	Heavy water (D_2O)	Heavy water reactor
↕	Graphite (C)	Graphite moderated reactor
	Beryllium (Be)	(not used) Expensive, toxicity
Small	Light water (H_2O)	Light water reactor

6.4 Coolant

Requirements for coolant

(1) Chemical compatibility with the material of core and pipe in the operating temperature

(2) Less expensive and easy to get enough amount

(3) The pumping power for the coolant can be small

(4) The coolant pressure can be technically acceptable

(5) Stable in γ-ray and neutron irradiation

(6) Small neutron capture cross section

Coolants used in power reactor

Reactor type	Coolant	Max temp. (℃)	Pressure (MPa)
Pressurized Water Reactor (PWR)	Light water	320	15.0
Boiling Water Reactor (BWR)	Light water	280	7.0
Fast Breeder Reactor (Monju)	Sodium	530	0.1 (atmospheric pressure)
High Temperature Gas-cooled Reactor (HTTR)	Helium gas	950	4.0

6.5 Reactor vessel

・Reactor Pressure Vessel (RPV) : Contain reactor core

Made of stainless steel

High pressure tolerance

Used in light water reactor and high temperature gas-cooled reactor

(in fast reactors … simply Reactor Vessel

no need of high pressure tolerance)

・Primary Containment Vessel : Contain reactor vessel

made of thick steel plate or concrete

with steel plate

6.6 Reactor types

(1) Pressurized Water Reactor (PWR)

・Thermal reactor

・Fuel : low enriched uranium oxide

・Cladding : zirconium alloy

・Moderator : light water

・Coolant : light water

・Coolant water is highly pressurized so as not to boil in the core.

・Generate steam for turbine by steam generator

(2) Boiling Water Reactor (BWR)

・Thermal reactor

・Fuel : low enriched uranium oxide

・Cladding : zirconium alloy

・Moderator : light water

・Coolant : light water

・Boiling in the core to generate steam for turbine

(3) High Temperature Gas-cooled Reactor (HTGR)

・Thermal reactor

・Fuel : low enriched uranium oxide

・Fuel element : coated fuel particles with SiC coating

・Moderator : Graphite

・Coolant : Helium gas

・High temperature available

(4) CANDU (CANadian Deuterium Uranium heavy water reactor)

・Thermal reactor

・Fuel : uranium oxide

・Cladding : zirconium alloy

・Moderator : heavy water

・Coolant : heavy water

・Natural uranium used as the fuel

(5) Sodium-cooled Fast Reactor (Monju)

・Fast reactor

・Fuel : uranium, plutonium mixed oxide

・Cladding : stainless steel

・No moderator

・Coolant : Sodium

The feature: the amount of produced plutonium can be larger than that of consumed. (Breeder)