2019 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 (H₂O) Heavy water (D₂O) Graphite (C) (3) Coolant (to remote heat from the fuel)

... Light water (H₂O) Heavy water (D₂O) 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 (UO2)stable in higher temperatureEnrichment : $3 \sim 5 \%$ (2000°C)

Cladding: zirconium alloy

- Low thermal neutron capture cross section

Tolerance for high temperature water $< 400^{\circ}$ C

Weak point: production of hydrogen by chemical

reaction with very high temperature water

• Fast Breeder Reactor (FBR) (Monju)

Fuel: Uranium-plutonium mixed oxide

(UO₂-PuO₂ : ratio of PuO₂ 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

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

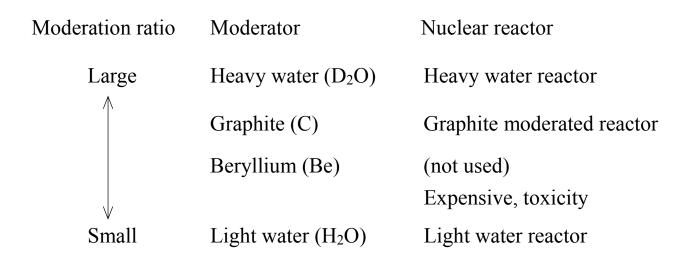
 ξ : Index to decrease of the neutron energy by a scattering

 σ_s : Scattering cross section

 σ_a : Absorption cross section

A material with large moderation ratio

 \rightarrow Good moderator



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. (°C) 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 © 2019 Toru Obara

- (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

 \cdot No moderator

•Coolant : Sodium

The feature: the amount of produced plutonium can be larger

than that of consumed. (Breeder)