UNENE Graduate Course Reactor Thermal-Hydraulics Design

McMaster University
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Design Requirements

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General Principles

- Nuclear reactor generates power using the concept of a heat engine
  - Direct cycle
  - Indirect cycle
- Most important features of a reactor are:
  - Fuel
  - Coolant
  - Moderator
- Basic neutron cycle and the role of the moderator
  - Thermal nuclear reactor
  - Fast nuclear reactors

Nuclear Fuels

- Thermal reactors can use the following fuels:
  - U^{235} – only 0.7% in natural uranium
  - U^{233} – from Th^{232}
  - Pu^{239} – from U^{238}
- Most thermal reactors use:
  - Enriched uranium with U^{235} (up to 5%)
  - Natural uranium – with 0.7% U^{235}

Heat Transfer Considerations

- Most important for a nuclear reactor is to provide heat sink at all times
- Heat transfer is proportional to the surface area
- Designs with high ratios of area to volume best suitable for heat transfer
- Possible geometries of fuel assemblies (cross-section)
  - Circular
  - Rectangular
  - Annular
- Considerations
  - Uranium enrichment
  - Manufacturing cost
  - Heat transfer features

Uranium Fuel Forms

- Desirable Fuel Properties
  - Low cost – constituents and fabrication
  - Good neutron economy
  - Good corrosion resistance to coolant
  - Physical stability under effects of irradiation, temperature, pressure
  - Safeguards – production of Pu
  - Environmental aspects (radiological and non-radiological)
- Fuel Materials
  - Uranium metal
  - Uranium / other metal alloy
  - Ceramic uranium dioxide
  - Uranium carbide
  - Uranium silicide

Fuel Claddings

- Desirable Cladding Properties
  - Corrosion resistance to coolant
  - Mechanical durability
  - High operating temperature capability
  - Good neutron economy
  - Low cost – base material and fabrication
  - Impermeability to fission products
  - Low reprocessing cost
  - Environmental aspects (radiological and non-radiological)
- Fuel Cladding Materials
  - Aluminum
  - Magnesium (Magnox)
  - Stainless steel
  - Zirconium
  - Ceramics

Control Materials

- Desirable Control Material Properties
  - Corrosion resistance to coolant
  - Mechanical durability
  - High absorption capability which is controllable with operating time
  - Low cost – base material and fabrication
  - Stability in high pressure and temperature (fluid or solid)
  - Environmental aspects (radiological and non-radiological)
- Fuel Control Materials
  - Hafnium (4 isotopes)
  - Silver-Indium-Cadmium alloys
  - Rare-Earth oxides (samarium, europium, gadolinium)
  - Gadolinium (nitrate)
  - Dysprosium
  - Boron-containing materials (boron alloys, boron carbide)
  - Boric acid solutions

Reactor Coolants

- Desirable Coolant Properties
  - High heat capacity
  - Good heat transfer properties
  - Low neutron absorption
  - Low neutron activation
  - Low operating pressure at high operating temperature
  - Non-corrosive to fuel cladding and coolant system
  - Low cost
  - Environmental aspects (radiological and non-radiological)
- Reactor Coolant Materials
  - CO_2 gas
  - Helium
  - Ordinary water
  - Heavy water
  - Organic fluids
  - Liquid metals

Reactor Moderators

- Desirable Moderator Properties
  - High moderator efficiency
    - High logarithmic energy decrement
    - High cross section for neutron scattering (slowing down)
    - High moderation ratio
  - Low neutron absorption
  - Low neutron activation
  - Resistance to damage (irradiation and corrosion)
  - Low cost (raw material, manufacture, installation)
  - Environmental aspects (radiological and non-radiological)
- Reactor Moderator Materials
  - Graphite
  - Ordinary water
  - Heavy water

Moderating Arrangements

- Integral with coolant
  - Coolant and moderator are integrated
  - PWR and BWR reactors use this concept
- Integral with fuel
  - Fuel and coolant are imbedded into the moderator (graphite)
- Integral with moderator
  - Fuel and moderator separate from coolant
  - Pebble bed reactors
- Separate
  - Fuel and coolant are in separate channels (separate from moderator)
  - CANDU reactors use this principle

Reactor Core Arrangements

- Core lattice arrangements
  - Square
  - Hexagonal
  - Triangular
- Fuel assembly arrangements (in order of most area for given perimeter)
  - Circular
  - Hexagonal (best)
  - Square
  - Triangular

HTS Design Requirements

- HTS main objective is to provide heat transfer at high thermal efficiency
  - Continuous coolant flow must be provided
  - Cost should be minimized
  - Layout should minimize radiation exposure and enable fast construction
  - Provide pressure and inventory control
  - Ensure sufficiently reliable system (minimize down time)
  - Ensure high process efficiency
  - Enhance constructibility
  - Take into account aging effects
  - Meet safety and licensing requirements
- Design involves fine balance and trade off in design features (and occasionally conflicting requirements)

Questions?