Ref. No.: Ex/PG/NuE/T/129F/2024

Master of Nuclear Engineering 1st Year 2nd Semester Examination - 2024

Reactor Thermal Hydraulics

Time: 3 hrs **Full marks: 100**

(Use separate answer scripts for each part)

Part I

Answer Any Five Questions

1. (a) Briefly describe the basic operating principles of a *Pressurised Water Reactor* (PWR). How does it differ from that of a Fast Breeder Reactor (FBR)?

   (b) Which thermodynamic cycles are normally followed for the operation of the power reactors?

(6+4)

2. Derive the expression for volumetric heat generation rate in a nuclear reactor in terms of microscopic fission cross section and neutron flux by assuming single energy group neutron and uniform fuel material composition. Express the same in terms of linear heat rate and surface heat flux considering a single fuel rod. (10)

3. (a) Explain the operation of a *pressuriser* in a PWR and PHWR.

   (b) Discuss the process of containment pressurisation following a *Loss of Coolant Accident.*

(5+5)

4. Consider a heavy water moderated reactor with uniform distribution of enriched UO_2 fuel in a cylindrical unreflected reactor core. Calculate the power generated in a fuel rod located mid-way between the core centerline and its outer boundary assuming the following parameters -

   Core radius (R) = 3.0 m

   Core height (L) = 10 m

   Fuel pellet outside diameter = 2.0 cm

   Maximum thermal neutron flux = 1200 neutrons/(cm² s)

   Assume the following relation between volumetric heat generation rate and neutron flux -

$$q''' = 8 \times 10^{-7} \phi$$

[Turn over

with ϕ in neutrons/(cm^2 s) and q''' in W/m^3. How would the power generated in a fuel rod change if the reactor core was designed to be spherical? How would the power generated change if the neutron reflectors were considered in the core design? (10)

5. Compute the work done in a molten UO_2-sodium interaction assuming that 30,000 kg of molten fuel and 5000 kg of sodium coolant expand independently and isentropically to 1 atmosphere. Other conditions are as follows:

Initial fuel temperature = 3000 K

Initial sodium temperature = 500 K

Specific heat capacity of molten fuel = 560 J/KgK

Specific heat capacity of liquid sodium = 1300 J/KgK

Final mixture temperature = 1154 K

Latent heat of vaporization for sodium = 2.9 x 10^6 J/Kg (10)

6. (a) Discuss ways to improve the efficiency of a nuclear reactor. What is the best possible way, in your opinion, to achieve an optimum operating condition of a nuclear reactor?

(b) What is the basic objective of thermal design of a nuclear reactor? How is it achieved?

(5+5)

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PART II

Full marks: 50

Answer all questions

(*Use separate answer sheets*)

1. **Short Questions** **(5 × 2)**
   a) Why is a certain degree of porosity desirable in nuclear fuel oxide?
   b) Describe the effect of temperature on the thermal conductivity of a nuclear fuel element.
   c) What are difference between steady-state flow and uniform flow in a single phase flow?
   d) What do you mean by 95% theoretical density of nuclear fuel material?
   e) Define the non-dimensional Brinkman number for single-phase heat transfer.
2. **Broad Questions** **(4 × 10)**
   a) Derive Lagrangian form of the mass conservation and momentum equation. 4+6
   b) What are difference between inviscid and viscous flow? Derive an expression for the mass flow rate through a nozzle for an incompressible and inviscid fluid. 3+7

   or

   c) During a shutdown condition in a PWR, the flow is driven through the loop by natural circulation at a rate corresponding to about 1% of the full flow rate provided by the pumps. Assuming that the total flow rate is $\dot{m}_t$= 4600 kg/s in the full flow condition and that there are approximately 3800 tubes of 0.025 m inside diameter in the steam generator of average length 16 m, determine
      1. Whether the flow is turbulent or laminar.
      2. The value of the friction factor.
      3. The friction pressure loss between the inlet and outlet of one tube (neglecting the pressure loss due to the tube bend of 180°).

      Use ρ = 990 kg/m^3 and μ = 0.001kg/m s or Pa s. 10
   d) State the mathematical expression for the Nusselt Number and explain its physical significance. How is the Nusselt Number calculated for geometries other than a round tube? What is the significance of the hydrodynamic and thermal boundary layers? 3+3+4
   e) Compare the maximum temperature and heat transfer rate for solid and annular pellets. Briefly describe how the thermal conductivity of UO_2 changes with PuO_2 content, pellet cracking, and burnup. 4+6