

Ph.D. Qualifying Examination
Fission Engineering

1. (20 min.) The empirical expressions for the friction factor and Nusselt number for turbulent flow in a cylindrical channel are shown below.

$$f = 0.316 \text{ Re}^{-0.25} \quad \text{Nu} = 0.023 \text{ Re}^{0.8} \text{ Pr}^{0.33}$$

$$\Delta p = f (L/d) (\rho V^2)/2 \quad \text{Nu} = h d / k$$

Answer the following questions:

- Describe the fundamental hydrodynamic phenomena that control heat and momentum transfer.
 - Given your description in part (a), explain how the expressions for pressure drop and heat transfer are consistent; i.e. why is the friction factor Reynolds number to a negative power and Nusselt number Reynolds number to a positive power?
 - Explain the concept of hydraulic diameter and when it applies.
 - Explain the difference in heat transfer experienced by high Prandtl number versus low Prandtl number fluids.
2. (20 min.) Consider a MOX reactor fuel pellet. Assume that the plutonium is all Pu^{239} with a half-life for alpha decay of 23,500 years. The radius of the fuel pellet is 0.5 cm, and the conductivity of the fuel is 0.025 W/cm °C. Prior to insertion into the reactor, the fuel rod in ambient air at 20 °C has a centerline temperature of 80 °C. Assume that the effective heat transfer coefficient from the surface of the pellet to the air is 0.1 W/cm²-°C.

In an effort to make the fuel less attractive and less desirable to diversion, Pu^{238} is added so that it makes up 2% of the plutonium. The added Pu^{238} results in a higher fuel temperature in the fresh fuel. Pu^{238} has a half-life of 87 years and also emits an alpha.

Assuming that the alpha decay energies of Pu^{238} and Pu^{239} are equal, calculate the new centerline temperature of the fuel pellet in air.

3. (20 min.) A heavy metal cooled fast reactor using liquid lead as the coolant operates at 500 MW thermal. The core coolant outlet temperature is 780 °C. Because of the high melting point of lead, assume that the core inlet temperature is 380 °C. The energy from the reactor is used for multiple purposes including producing hydrogen using a thermochemical process that requires temperatures from 500 °C to 720 °C, generating electricity through a Rankine cycle, and manufacturing fresh water through a multi-stage flash desalination process requiring temperatures of 120 °C.

Make a sketch of this system.

Indicate approximate temperatures at various stages and the overall heat balance.

Indicate and discuss how re-heat would be used in this plant?

State your assumptions.

4. (20 min.) An advanced PWR core is operating at a power of 3000 MWth. It consists of 203 fuel clusters each containing 193 rods loaded in a square lattice with a pitch of 1.28 cm. The rods have an outer radius of 0.52 cm, pellet radius of 0.46 cm and active fuel height of 360 cm. The inlet coolant temperature is 305 °C and the total coolant flow rate is 18500 kg/s.

Calculate:

1. The average volumetric power density in the pellet.
2. Evaluate the coolant velocity.
3. Obtain the average heat transfer coefficient using the Dittus-Boelter correlation from problem 1.
4. Evaluate the average temperature increase of the coolant.

Consider:

$$\text{liquid density} = 700.5 \text{ kg/m}^3$$

$$\text{specific conductivity} = 0.539 \text{ W/m} \cdot \text{C}$$

$$\text{viscosity} = 8.4 \times 10^{-5} \text{ Pa} \cdot \text{s}$$

$$\text{specific heat capacity} = 5923 \text{ J/kg} \cdot \text{C}$$

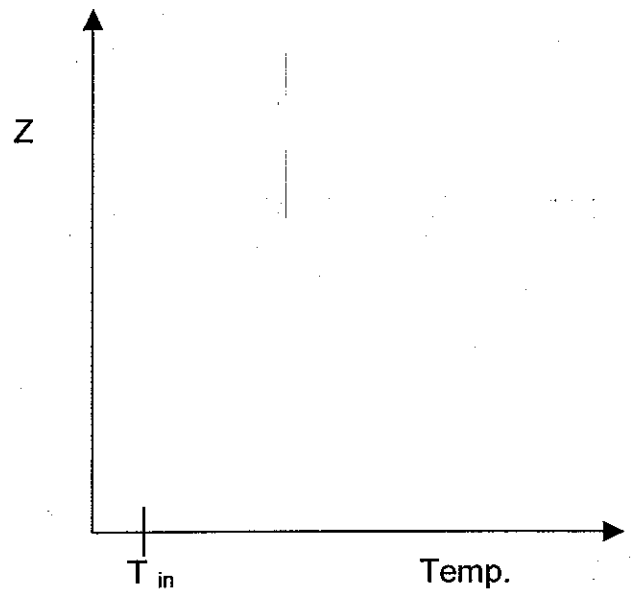
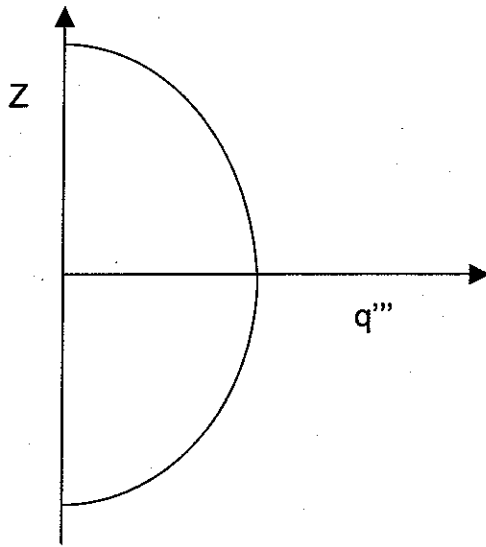
5. (20 min.) The four figures below show the volumetric energy generation rate, q''' , for different sub-channels as a function of position up the channel. The figures also show the bulk coolant temperature axis as a function of position for that channel.

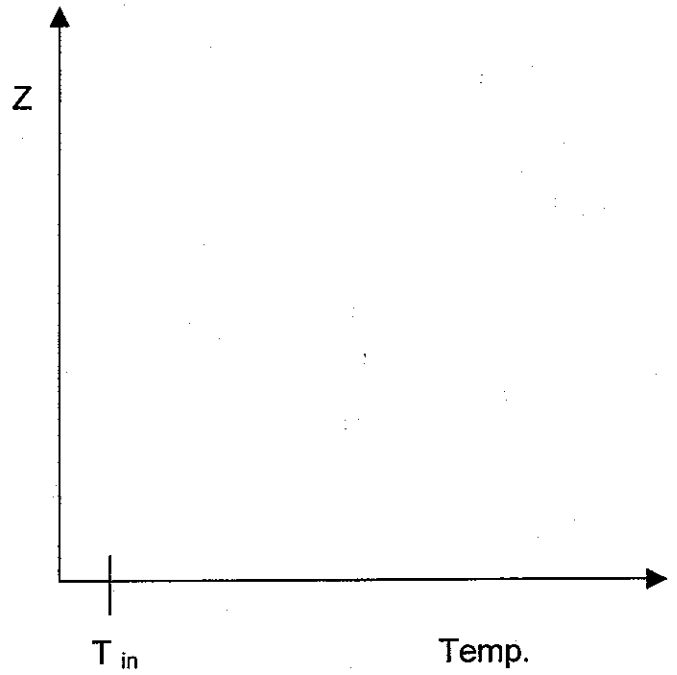
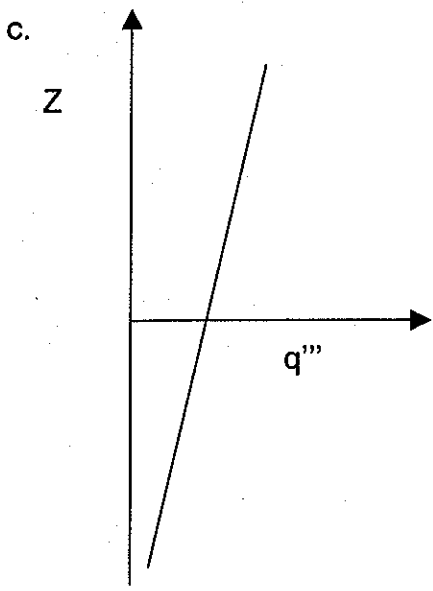
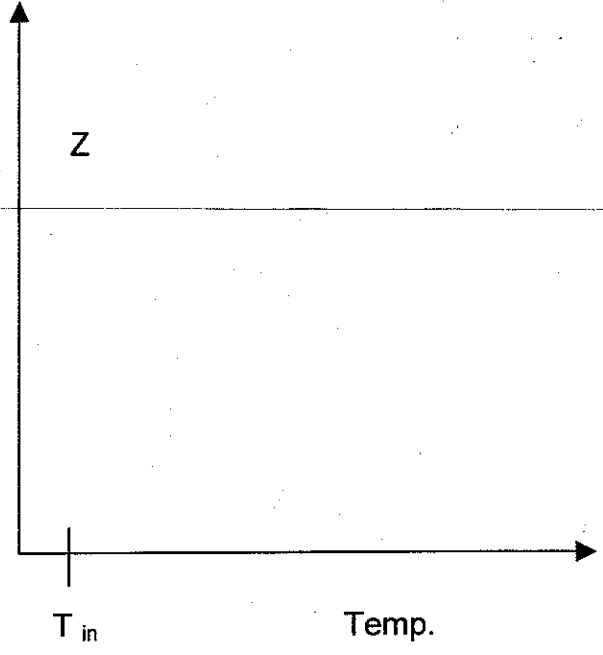
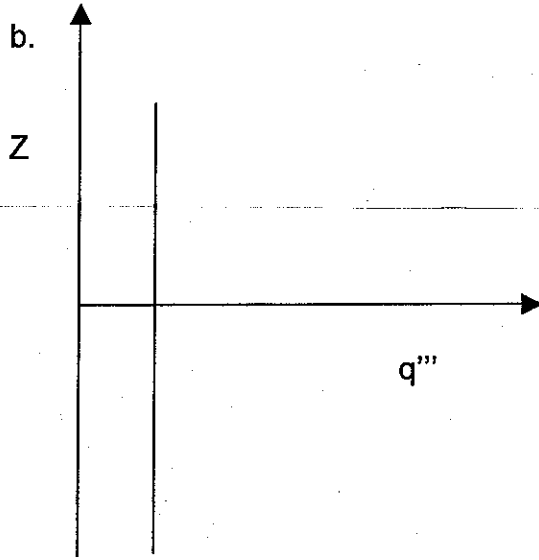
Each shape deposits the same total amount of power in a channel and each channel remains sub-cooled.

Sketch the bulk coolant temperatures for the power profiles. **Explain** how you arrived at your answer.

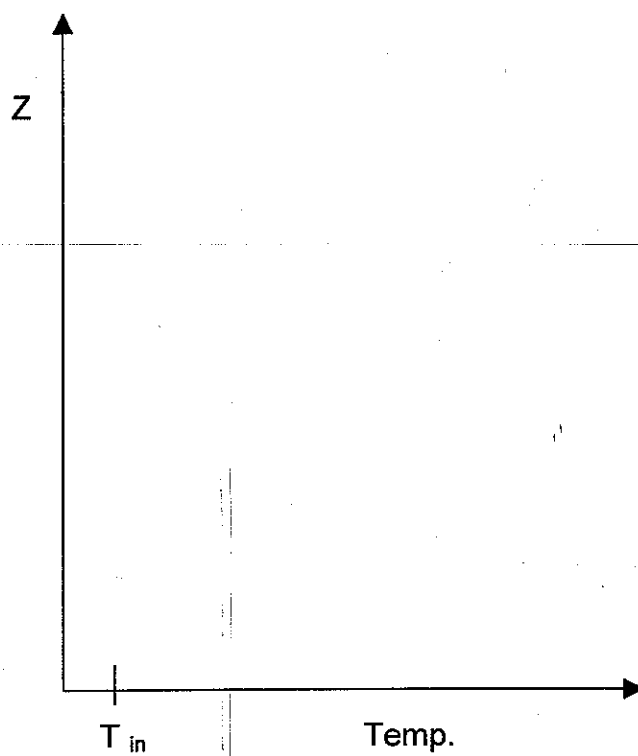
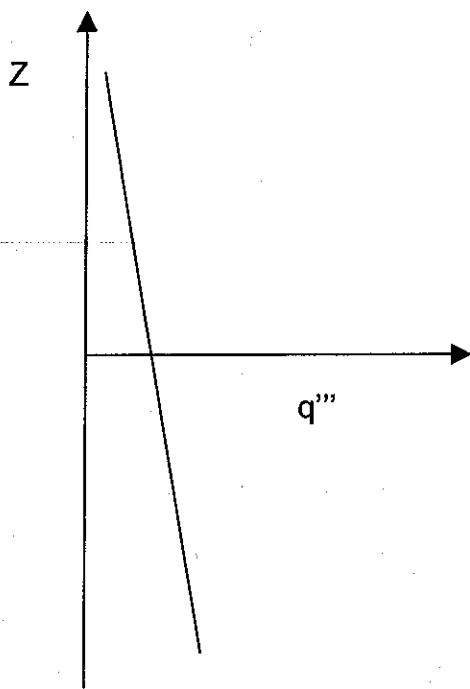
Assume each sub-channel is isolated.

a.

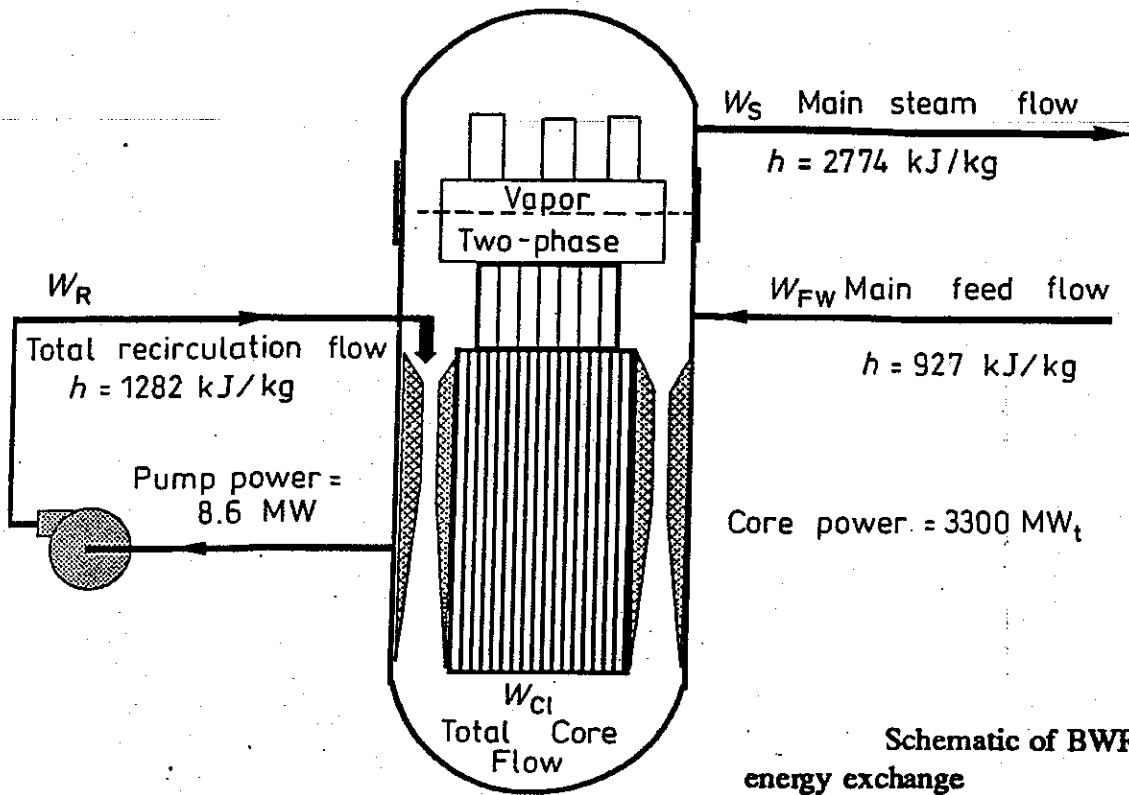




d.



6. (20 min.) Determine the steam flow for the standard BWR plant depicted in the figure. The operational data are also shown in the attached figure.



Schematic of BWR core-coolant energy exchange