1. (20 minutes) Answer the following questions:
   a. (5 minutes) Describe what you consider to be the biggest structural difference between BWR and PWR fuel assemblies. Boiling is not a structural difference.
   b. (5 minutes) Explain why this difference exists.
   c. (10 minutes) A certain conventional PWR is designed with 193 fuel assemblies. The maximum power assembly has an assembly power to core average assembly power ratio of 1.37 (i.e. the hot assembly has 1.37 times more power than the core average assembly). Find the percent increase in total core power if all assemblies could be operated at the hot assembly power level. Show all calculations and state your assumptions.

2. (10 minutes) Reactors for naval vessels are designed to have very long lifetimes without the need to refuel. Discuss possible techniques that can be used to maintain criticality over the core lifetime as $^{235}\text{U}$ is consumed.

3. (20 minutes) Answer the following questions:
   a. (10 minutes) Consider light water, heavy water and graphite as a moderator in a power reactor. What are the advantages and disadvantages of using each of these materials?
   b. (5 minutes) Why can CANDU reactors use a lower enrichment uranium fuel than PWRs?
   c. (5 minutes) Explain the advantages and disadvantages of using helium instead of water as a coolant.

4. (30 minutes) High-level liquid waste is stored in a vessel whose diameter $D$ is 6 m. The liquid level $h$ in the vessel is 5 m, and the fission product heat is removed by cooling with water that passes through coils of 5-cm outside diameter stainless steel tube, the coils being immersed in the waste liquid. The water enters the coils at 20 °C and leaves at 25 °C. The liquid waste is generating 14 kW/m$^3$ of fission product decay heat and must be maintained at a temperature less than 35 °C to minimize corrosion. Calculate the water flow rate needed to maintain cooling and the length of tube required in the coils, assuming an overall heat transfer coefficient $U$ of 350 W/(m$^2$ K). Assume a specific heat $c_p$ of 4.18 kJ/(kg K) for water and ignore the volume occupied by the coils.
5. (10 minutes) Discuss possible environmental and technical problems associated with each of the nuclear waste disposal options:
   a. (5 minutes) Geothermal disposal,
   b. (5 minutes) Waste processing and transmutation.

6. (30 minutes) In a certain boiling water reactor fuel assembly the inlet coolant is saturated liquid at 7 MPa. It is estimated that the exit flow quality is 0.15 and the assembly mass flow rate is 17.5 kg/s. The coolant receives energy at a uniform heat rate. The slip ratio is given as \( S = 1.5 \) and the flow area of the assembly is \( 1.2 \times 10^{-2} \text{ m}^2 \). Calculate:
   a. (6 minutes) The average exit void fraction.
   b. (6 minutes) The exit steam superficial velocity.
   c. (6 minutes) The average exit void fraction assuming homogeneous flow.
   d. (6 minutes) The heat rate to the coolant (kJ/s).
   e. (6 minutes) The friction pressure drop gradient at the assembly exit assuming the homogeneous flow model and a friction factor of 0.03.

See the steam data at 7 MPa provided below.