Question 1
(20 minutes) Consider a small, fast-spectrum power reactor coupled to a Brayton energy conversion system. Assume the reactor is designed to produce 200 kWt (40 kW_e). It is cylindrical, with a diameter of 50 cm.

(a) (5 minutes) Provide at least two supporting arguments for the assertion: “A small fast spectrum reactor can be modeled with less uncertainty than a moderated reactor design.”

(b) (5 minutes) Discuss the primary reactivity feedback components, including their relative magnitudes and time responses.

(c) (5 minutes) Discuss the effect of water submersion on \( k_{\text{eff}} \), assuming constant geometry.

(d) (5 minutes) Discuss the effect of core compaction on \( k_{\text{eff}} \). Core compaction may be experienced, for example, upon failure of spacecraft launch and subsequent reactor impact on earth.

Question 2
(20 minutes) The term flow instability refers to flow oscillations of constant or variable amplitude that are analogous to vibrations in a mechanical system. Consider LWRs, both PWRs and BWRs, and answer these questions:

(a) (10 minutes) Explain why flow oscillations are typically undesirable.

(b) (10 minutes) Explain why under normal operating and anticipated transient conditions in PWRs, no significant flow instabilities are expected in the primary system while BWRs operate closer to the instability threshold.

Question 3
(20 minutes) Consider a long fuel element in an axially flowing coolant. Assume that the flux shape is a cosine in the axial direction. Derive the steady-state centerline temperature of the fuel element as a function of axial position. Assume that the fuel element has no cladding.

Question 4
(20 minutes)

(a) (5 minutes) Sketch the primary and secondary-side flow paths in a PWR.

(b) (5 minutes) Draw a T-s diagram for an ideal Rankine cycle in a PWR. Number the points on the T-s diagram and locate these points on the PWR diagram. Assume no reheat or other measures to improve the thermal efficiency.
(c) (10 minutes) Explain how the thermal efficiency and the turbine work may change if regeneration is added to the system.

**Question 5**  
(25 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 axial heat rate. The slip ratio is given as \( S = 1.5 \) and the flow area of the assembly is \( 1.2 \times 10^{-2} \) m\(^2\). Calculate:

(a) (5 minutes) The average exit void fraction.

(b) (5 minutes) The exit steam superficial velocity.

(c) (5 minutes) The average exit void fraction assuming homogeneous flow.

(d) (5 minutes) The heat rate to the coolant (kJ/s).

(e) (5 minutes) The friction pressure drop gradient at the assembly exit assuming the homogeneous flow model and a friction factor of 0.03.

Use the steam data at 7 MPa provided below.

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<th>( T ) °C</th>
<th>( \dot{v} ) m(^3)/kg</th>
<th>( \dot{u} ) kJ/kg</th>
<th>( \dot{h} ) kJ/kg</th>
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Question 6  
(15 minutes) Reactor power upgrades produce more plant revenue as a result of increased power output achieved by core re-design effects. The graph below shows plots of Revenue Improvement and Cost for a range of upgrade effects. The abscissa, $F$, is the extent of the upgrades implemented shown as a fraction from 0 to 1. The ordinate is the Revenue Improvement achieved by the upgrade and the Cost to achieve that upgrade, both in mills/(kw-hr).

The Revenue Improvement equation is: 
$$ R \, [\text{mills/(kw-hr)}] = 1.2 \times F^2 - 0.2 \times F $$

The Cost equation is: 
$$ C \, [\text{mills/(kw-hr)}] = -1.2 \times F^2 + 2.2 \times F $$

Find the fraction of upgrade that should be implemented in order to maximize the Revenue Improvement for the plant, i.e. what is the optimum $F$? Explain your steps.