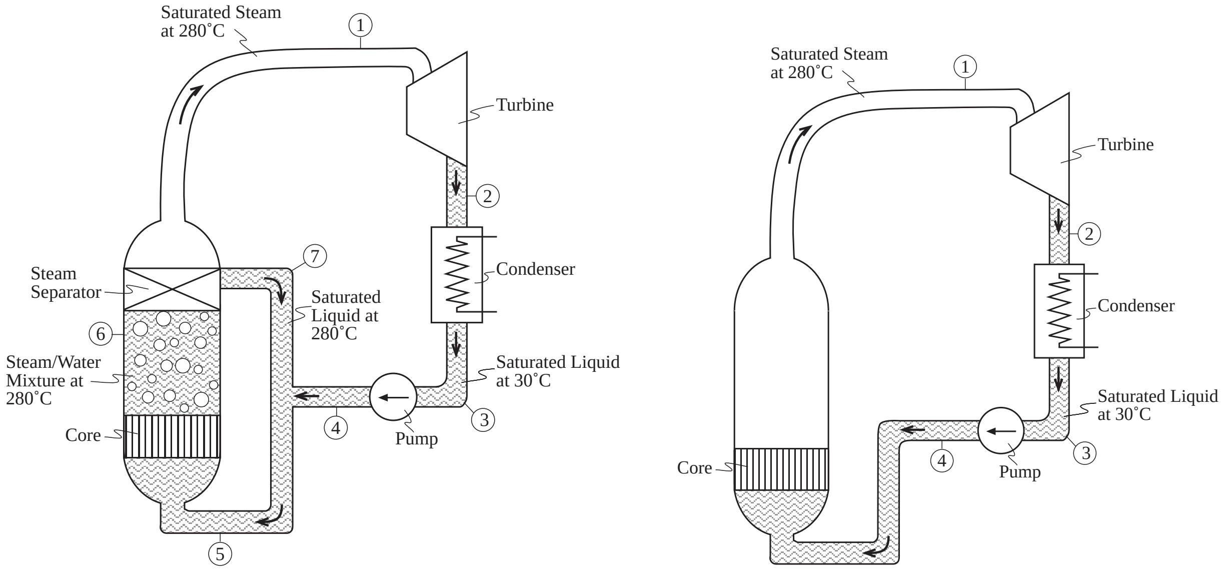
22.312 **ENGINEERING OF NUCLEAR REACTORS**

Thursday, October 14th, 2004, 9:30 – 11:00 a.m.

OPEN BOOK QUIZ #1 1.5 HOURS

Problem 1 (45%) – Power Cycle for a Simplified BWR

The power cycle of a simplified BWR is shown in Figure 1a. Steam at 10% quality exits the core. The steam is separated from the water in a steam separator, and then is directed to the turbine, then completely condensed and pumped back to the reactor. The separated water is mixed with the feedwater coming from the pump, and recirculated to the core inlet.



a) With recirculation b) Without recirculation

Figure 1. Schematic of a simplified BWR plant.

i) Sketch the T-s diagram for the cycle of Figure 1a. Make sure to include the effect of recirculation. (10%)

ii) Using the data below, calculate the cycle thermal efficiency. (15%)

iii) Consider now the same cycle but **without recirculation**, i.e., the feedwater from the pump goes directly to the core, the steam quality at the core outlet is 100%, and there is no steam separator (Figure 1b). Sketch the T-s diagram and calculate the thermal efficiency for this cycle. How does the thermal efficiency compare to that of the cycle with recirculation? (15%)

iv) Given the results in “iii”, what are the advantages/disadvantages of using the cycle with recirculation? (5%)

Assumptions:

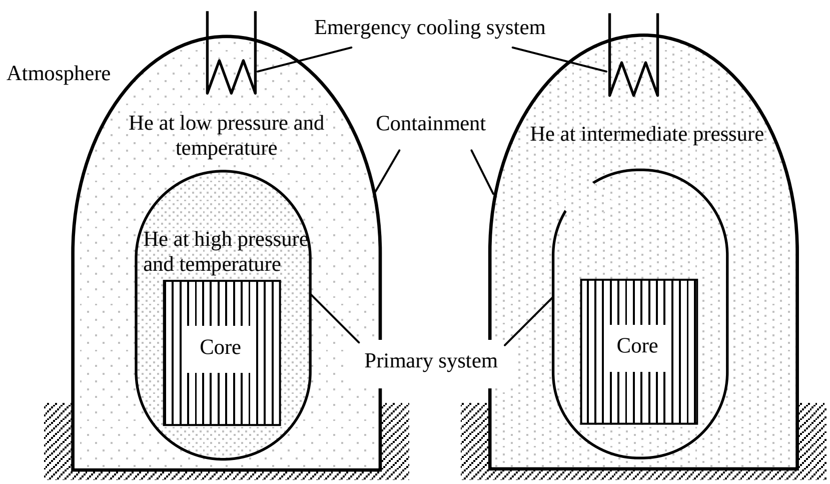
- Assume perfect steam/water separation in the steam separator.
- Assume ideal turbine and pump.
- Assume constant water density in the pump.
- Neglect kinetic and gravitational terms.

Data for saturated water:

T (°C)	P (bar)	v_f (m^3/kg)	v_g (m^3/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kg·K)	s_g (kJ/kg·K)
30	0.04	1.0×10^{-3}	32.9	126	2556	0.4	8.4
280	64	1.3×10^{-3}	0.03	1236	2780	3.1	5.9

Problem 2 (55%) – Containment sizing for a gas-cooled reactor with passive emergency cooling

An advanced helium-cooled graphite-moderated reactor generates a nominal thermal power of 300 MW. To prevent air ingress in the core during a Loss Of Coolant Accident (LOCA), the reactor containment is filled with helium at atmospheric pressure and room temperature (Figure 2a). The reactor also features an emergency cooling system to remove the decay heat from the containment during a LOCA. To function properly, this system, which is passive and based on natural circulation of helium inside the containment, requires a minimum containment pressure of 1.3 MPa.



a) Normal operating conditions b) Post-LOCA situation

Figure 2. Helium-cooled reactor with helium-filled containment.

i) Find the containment volume, so that the pressure in the containment is 1.3 MPa immediately after a large-break LOCA occurs (Figure 2b). (Assume that thermodynamic equilibrium within the containment is achieved instantaneously after the break) (40%)

ii) Assuming that the emergency cooling system removes 2% of the nominal reactor thermal power, calculate at what time the pressure in the containment reaches its peak value after the LOCA. (Calculate the decay heat rate assuming infinite operation time) (10%)

iii) To reduce the peak pressure in the containment, a nuclear engineer suggests venting the containment gas to the atmosphere through a filter. What would be the advantages and disadvantages of this approach? (5%)

Assumptions:

- Treat helium as an ideal gas.
- Neglect the heat contribution from fission and chemical reactions.
- Neglect the thermal capacity of the structures.

Data:

Gas volume in the primary system: 200 m^3
Initial primary system temperature and pressure: 673 K, 7.0 MPa
Initial containment temperature and pressure: 300 K, 0.1 MPa
Helium specific heat at constant volume: c_v=12.5 J/(mol·K)
Helium atomic weight: A=0.004 kg/mol
Gas constant: R=8.31 J/(mol·K)