22.312 ENGINEERING OF NUCLEAR REACTORS

Tuesday, October 18th, 2005, 9:30 – 11:00 a.m.

OPEN BOOK QUIZ #1 1.5 HOURS

Problem 1 (45%) – Two-unit nuclear plant with single containment building

A two-unit PWR nuclear power station features a single large containment building into which the coolant is discharged following a Loss Of Coolant Accident (LOCA) in either unit (see Figure 1). A suppression pool is located in the containment building to reduce the peak pressure when the LOCA occurs.

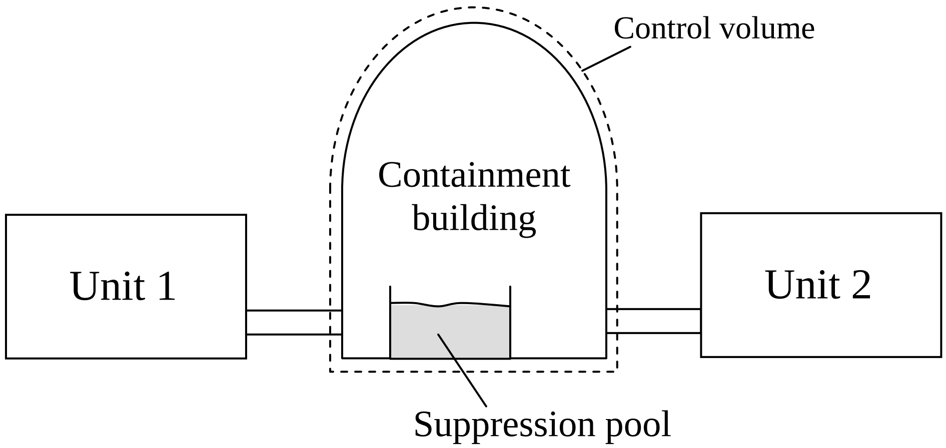

Figure 1. Two-unit nuclear power plant with single containment building.

i) Write a complete set of equations to calculate the pressure in the containment building two minutes after a small pipe rupture causes 20% of the secondary coolant inventory in Unit 1 to flow into the containment building. Identify the known and unknown parameters. (35%)

ii) Using your engineering judgment, identify the advantages and disadvantages of this single-containment building configuration vs. a more traditional configuration with one containment building for each unit. (10%)

Assumptions

- At t_2=2 min thermodynamic equilibrium exists in the containment building
- Neglect heat losses to the surroundings and the structures
- Neglect kinetic and gravitational terms
- Assume superheated steam conditions exist in the containment at t_2
- No mass or energy exchanged with Unit 2 during the accident
- Assume the enthalpy of the secondary coolant to be constant as it flows into the containment building.

Data

Containment building:

Free volume V_{a1}=70,000 m^3

Initial temperature T_1=300 K

Initial pressure P_1=0.1 MPa

Initial humidity ϕ=0%

Air constant R_a=286 J/(kg·K)

Air specific heat c_{va}=719 J/(kg·K)

Suppression pool water:

Mass M_{wsp}=5,000 kg

Density ρ_{wsp}=1,000 kg/m^3

Internal energy u_{wsp}=113 kJ/kg

Secondary water:

Mass M_{ws}=72,000 kg

Density ρ_{ws}=810 kg/m^3

Enthalpy h_{ws}=1,213 kJ/kg

Internal energy u_{ws}=1,205 kJ/kg

Problem 2 (55%) –Power cycle for a High Temperature Gas-Cooled Reactor

The layout of the Brayton power cycle of a High Temperature Gas Reactor (HTGR) is sketched in Figure 2:

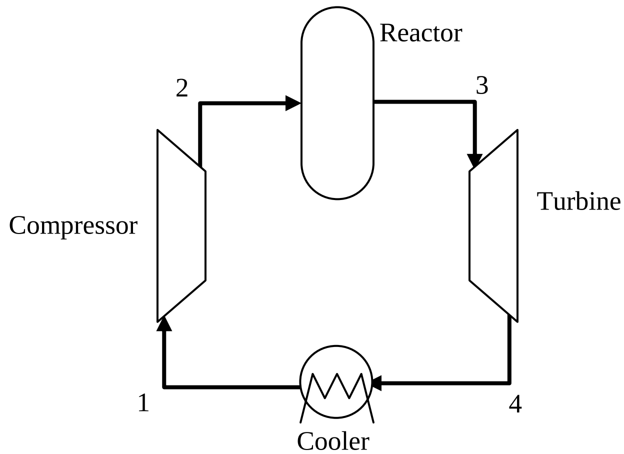

Figure 2. Simple Brayton cycle.

Assumptions and Data

- The transformations in the compressor, reactor and cooler are ideal
- The turbine isentropic efficiency is 90%
- The compressor inlet temperature and pressure are 100°C and 1.5 MPa, respectively
- The turbine inlet pressure is 7.5 MPa
- The reactor power is 3,200 MW_t
- Coolant (Helium):

  Mass flow rate: 2,000 kg/s

  Specific heat at constant pressure: 5,200 J/kg K

  $$\gamma = \frac{c_P}{c_V} = 1.667$$

  Helium gas constant: R_{He}=2,077 J/kg K

i) Sketch the T-s diagram for this cycle. (5%)

ii) Find the net electric power of the plant. (30%)

iii) The plant has been operating at full power for a long time when suddenly a turbine trip causes the reactor to scram (i.e., to shut down). However, forced circulation of helium in the core ensures the necessary removal of the decay heat. At t=60 min (after shutdown) a loss of offsite power causes the compressor to stop. As a result, the helium coolant does not circulate in the core anymore and the fuel is now thermally insulated. It takes about five minutes before the emergency diesel generators can energize the compressor again and restore efficient heat removal in the core. Calculate the fuel temperature rise during the five minutes the compressor is off. (20%)

Fuel volume: 4.045 m^3
Fuel density: 11×10^3 kg/m^3
Fuel enrichment: 90 wt% of ^{235}U
Fuel specific heat: 230 J/kg·K