**22.312** **ENGINEERING OF NUCLEAR REACTORS**

Thursday, October 9th, 2008, 9:30 – 11:00 a.m.

OPEN BOOK QUIZ 1 1.5 HOURS

**Problem 1 (55%) – Heat up of the waste canisters following a ceiling collapse at the Yucca Mountain spent fuel repository**

The Department Of Energy (DOE) plans to store the spent fuel from the U.S. nuclear power plant fleet in a permanent repository at Yucca Mountain in Nevada. The Yucca Mountain repository is a system of underground tunnels which will accommodate the waste canisters containing the spent fuel assemblies. Consider the situation shown in Figure 1, in which it is hypothesized that the ceiling of a tunnel has collapsed, thus creating a sealed "chamber" within the tunnel.

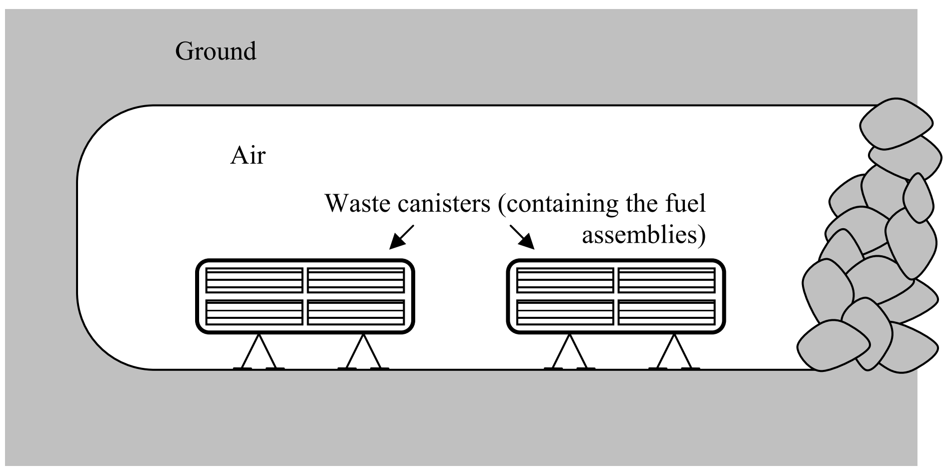


**Figure 1. The "chamber" created by a ceiling collapse in a repository tunnel.**

i) Assuming that the decay power from the spent fuel assemblies in the chamber is 200 kW (constant for the purpose of this calculation), write a complete set of equations that would allow you to find the time it takes for the chamber temperature to rise to 200 °C after the ceiling collapses. (30%)

ii) Numerically solve the set of equations developed in Part 'i', and find the final pressure in the chamber. (15%)

iii) If a substantial amount of liquid water had been present in the chamber at the time of the ceiling collapse, would the time to reach 200 °C be shorter, longer or stayed the same? (5%)

iv) In light of your answer in Part 'iii' should the Yucca Mountain engineers keep the tunnels flooded or not? What would be the advantages and disadvantages of this approach? Please think broadly, i.e., beyond the thermal-hydraulic performance of the repository. (5%)

*Data*

Total volume of air in the chamber: 3500 $m^3$
Initial relative humidity of air: 80%
Initial temperature of air: 50°C
Initial pressure in the chamber: 101 kPa (atmospheric)
Initial temperature of waste canisters: 100°C
Mass of waste canisters: 600 tons ($6\times10^5$ kg)
Average specific heat of waste canisters: 470 J/kg-K
Air specific heat at constant volume: 719 J/kg-K
Air gas constant: 286 J/kg-K

*Assumptions*

- Include the thermal capacity of the waste canisters in your calculations
- Use the steam tables below to calculate the properties of water in the air (do not interpolate)
- Treat air as a perfect gas
- The air and waste canisters in the chamber are in thermal equilibrium at the final conditions
- Neglect kinetic and gravitational terms
- Neglect heat transfer to the ground

*Properties of Saturated Water*

| T (°C) | P (kPa) | $v_f$ ($m^3$/kg) | $v_g$ ($m^3$/kg) | $u_f$ (kJ/kg) | $u_g$ (kJ/kg) | $h_f$ (kJ/kg) | $h_g$ (kJ/kg) | $s_f$ (kJ/kg·K) | $s_g$ (kJ/kg·K) |
|---|---|---|---|---|---|---|---|---|---|
| 50 12 | .5 | $1.01\times10^{-3}$ | 12 | 209 24 | 43 20 | 9 25 | 91 | 0.7 | 8.1 |
| 200 15 | 50 | $1.15\times10^{-3}$ | 0.13 | 850 25 | 94 85 | 2 27 | 92 | 2.33 | 6.43 |

*Properties of Superheated Steam*

**T=50°C**

| P (kPa) | v ($m^3$/kg) | u (kJ/kg) | h (kJ/kg) | S (kJ/kg·K) |
|---|---|---|---|---|
| 10 | 14.9 | 2443 | 2592 | 8.2 |
| 8 | 18.6 | 2444 | 2592 | 8.3 |
| 6 | 24.8 | 2444 | 2593 | 8.4 |

**T=200°C**

| P (kPa) | v ($m^3$/kg) | u (kJ/kg) | h (kJ/kg) | S (kJ/kg·K) |
|---|---|---|---|---|
| 25 | 8.7 | 2660 | 2879 | 8.5 |
| 15 | 14.9 | 2661 | 2879 | 8.7 |
| 5 | 43.7 | 2661 | 2880 | 9.2 |

## Problem 2 (45%) – Aircraft nuclear propulsion

In the 1950s the U.S. Air Force studied the development of a nuclear-powered airplane to be used as a strategic bomber in missions over the Soviet Union. The airplane was to be equipped with two turbojet engines, each powered by a small direct-cycle nuclear reactor. In these engines, air taken from the atmosphere undergoes the following processes:

- Compression in the compressor (1→2)
- Isobaric heating in the reactor core (2→3)
- Expansion in the turbine (3→4)

The air at the outlet of the turbine is discharged back to the atmosphere.

*Data*
Each reactor (thermal) power is 30 MW. The compression ratio of the cycle is 4.
The isentropic efficiencies of the turbine and compressor are 0.9 and 0.9, respectively. Pressure losses can be neglected throughout the cycle. Air can be treated as a perfect gas with $R_a$=286 J/kg·K, $C_p$=1005 J/kg·K and $\gamma=C_p/C_v$=1.4

i) Sketch the T-s diagram for the air processes in the engine. (5%)

ii) Assume that the nuclear airplane is flying at 180 m/s through air that is at pressure 80 kPa and temperature 253 K, and that the air intake port for each engine has a flow area of 0.8 $m^2$. Calculate the air mass flow rate through each engine. (10%)

iii) Calculate the maximum air temperature in the engine, and the net power developed by the engine. (30%)