Ph.D. Qualifying Examination
Fission-Engineering

1. (30 min.) A commercial LWR is operating in steady-state under the following conditions:

- Total core power = 3083 Mw
- Total mass of UO$_2$ = 9.99 x 10$^7$g
- Atom fraction of $^{235}$U = 0.0329
- Energy averaged fission cross section = 350 b
- Recoverable energy release per fission = 200 Mev/fission
- Fraction of energy directly deposited in clad & coolant = 0.05
- Core mass flow = 17.4 Mg/sec
- Core pressure = 15.5 Mpa
- Decay heat = 207 Mw
- Days into fuel cycle = 183 days

Find the core average neutron flux.

1 ev/sec = 1.60 x 10$^{-19}$ w

2. (30 min.) Consider the design of a nuclear power plant to generate power for the International Space Station. The maximum temperature ($T_m$) of the power plant cycle is fixed by metallurgical factors. Operating on orbit, the power plant can only reject heat by thermal radiation to space, which may be assumed to be essentially at the temperature of 0 °K. As a result, the heat rejected is $Q_R = \sigma \varepsilon A_R T_R^4$, where $\sigma$ is the Stefan-Boltzman constant, $\varepsilon$ is the emissivity of the radiator (assume constant), and $A_R$ and $T_R$ are the surface area and temperature of the radiator surface, respectively. The flat-plate radiator represents by far the largest mass in the power plant system. Because of high launch costs, low power system mass is more desirable than high efficiency in space applications.

(a) (60%) Derive the relationship between mass of the radiator and cycle efficiency for this concept for a given electric power (assume the plant operates on a Carnot cycle).

(b) (40%) Find the optimum efficiency at which the radiator mass is minimized.
3. (30 min.) A new design for high burn up fuel has the objective of reducing fuel swelling by maximizing fission gas release to the free volume of the pin. To do this, the fuel itself will be operated at very high temperatures to increase fission gas atom mobility. Instead of a gas gap between the fuel and clad, the gap will be evacuated so that the heat transfer from fuel to clad will be by radiation. The gap will be continually purged of released fission gas to maintain the vacuum conditions.

(a) Calculate clad inner surface temperature.

(b) Calculate the maximum fuel temperature.

For the following conditions.

Fuel pellet radius: 0.85 cm
Outside clad radius: 0.95 cm
Clad outer surface temperature: 315°C
Clad conductivity: 0.20 W/cm°C
Fuel conductivity: 0.025 W/cm°C
Linear power of the fuel pin: 20 W/cm
Emissivity: 0.3
Stefan Boltzman constant: 5.67 x 10^{-12} w/cm^2 · K^4

Ignore the gap thickness.
For the scaled storage cask concept of radioactive waste management as illustrated in the Figure (on the next page), assume a simplified model of the heat transfer behavior. Heat is released from the 0.48 m diameter carbon steel flask by convective heat transfer to an air stream flowing up the annulus gap at a rate of 0.28 m³/s and by the inner surface of the 0.79 m inside diameter concrete gamma/neutron shield.

Calculate the heat removal rate by convection from both surfaces of the annular gap. Compare the results with the manufacture stated best release rate of 5 kw. Assume that the inner annulus surfaces are maintained at uniform temperatures of 182°C and 99°C. The average air stream temperature is 35°C.

For the calculation, assume the following physical properties for the air:

Density ($\rho$) = $1.146 \text{ kg/m}^3$ ;

Viscosity ($\mu$) = $1.83 \times 10^{-4} \text{ kg/ms}$ ;

Thermal conductivity ($k$) = $2.68 \times 10^{-2} \text{ w/m °C}$;

Specific heat ($c_p$) = $1025.8 \text{ J/Kg.°C}$

The convective heat transfer coefficient can be evaluated from:

$$St = 0.023 \text{ Re}^{-0.2} \text{ Pr}^{-0.6}$$

where

$$St = \frac{h}{(\rho \cdot v \cdot c_p)} = \text{ Stanton number}$$

where h is the heat transfer coefficient and v is the flow velocity.
Concrete gamma-neutron shield

Cap

inside surface temperature = 99 C

Carbon steel cask contains canister (5 KW decay heat) surface temperature = 182 C

concrete support pad

Air out (43 C)

Air in (27 C)