Ph.D. Qualifying Examination  
Fission Engineering

1. (15 min.) A common approach to accounting for the presence of porosity in nuclear fuel is to apply a "porosity correction factor" to the thermal conductivity. This is usually done in the form

\[ k_p(T) = f(p) \cdot k_{\infty}(T) \text{ W/cm}^\circ\text{C} \]

where \( k_p(T) \) is the thermal conductivity of the ceramic fuel (typically oxide) at porosity \( p \) and temperature \( T \). The porosity correction factor is \( f(p) \), and the temperature dependent conductivity is \( k_{\infty}(T) \) for 100% dense material. Several forms for the porosity correction factor have been proposed. Three examples are

\[
\begin{align*}
  f(p) &= 1 - p_p \\
  f(p) &= 1 - p_p^{2/3} \\
  f(p) &= e^{-p_{\text{np}}} \\
\end{align*}
\]

where \( p \) is the fractional porosity in the pellet, i.e., for 5% porosity, \( p = 0.05 \).

(a) (30%) Make plots of \( f(p) \) as a function of \( p \).
(b) (40%) Based on the characteristics of \( \text{UO}_2 \), qualitatively which form do you think would be the best representation and why?
(c) (30%) For a large value of \( p \), can such formulas be used and why?

2. (25 min.) A new water reactor design is being proposed to operate at supercritical coolant conditions in order to eliminate two phase flow issues for normal operation. Water at 3400 psia exits the reactor vessel and is directed into the high pressure turbine. The low pressure turbine exhaust is saturated vapor at 212°F, 14.7 psia. No liquid water has formed during the expansion.

(a) (25%) Draw the \( T-s \) diagram for this turbine expansion.
(b) (50%) Calculate the turbine inlet temperature.
(c) (25%) Does this temperature present any problems for conventional, commercial core materials?

State any simplifying assumptions.

3. (25 min.) An Advanced Boiling Water Reactor operates at an electrical output of 1356 MWe. Its thermodynamic efficiency is 34.5%. The core inlet enthalpy is 520 BTU/lb
\(_{\text{hr}}\) and the core inlet mass flow rate is \( 1 \times 10^8 \text{ lb/hr} \). The reactor pressure is 1000 psia.

(a) (25%) Find the average core outlet enthalpy.
(b) (25%) Find the average outlet quality.
(c) (25%) Find the total steam flow out of the reactor.
(d) (25%) Under the assumption of homogeneous flow, what is the outlet void fraction? To what flow regime does this correspond?

(The Steam Tables are included for your use.)
4. (15 min.) The steam generator of a test PWR system is fed by gravity-driven flow from a vast lake. The steam output goes to the atmosphere. Assume that flow friction losses can be neglected everywhere and that the lake level remains constant and is at the same elevation as the water level in the steam generator. Neglect radiative and conductive heat losses to the environment. Atmospheric pressure is always constant. If the reactor is initially operated at 1000 MW(th) for \( T_s = 10 \) days (and then shut down) and the initial steam flow rate is 500 kg/s, find the steam flow rate \( t_s = 100 \) days after reactor shut down.

Use: \[ \frac{P}{P_0} = 0.066 \left[ t_s^{-0.2} - (t_s + T_s)^{-0.2} \right] \]
where \( T_s \) and \( t_s \) are in units of seconds

5. (20 min.) A centrifugal pump empties the water tank shown below. In order to provide a siphon break, the outlet of the pump feeds into the open top of a 6-inch I.D. smooth drain pipe. The vertical drain pipe is 5 feet tall and transitions at the bottom to a 1-inch I.D., 30 foot long smooth horizontal pipe. This pipe carries the water to an outside open drain (i.e., atmospheric pressure at the outlet). At steady state, what is the maximum allowable pump flow rate (Q gpm) that will avoid overflow of the vertical drain pipe?

State and justify any simplifying assumptions that you make.

Given:

- Temp = 75°F for water: 8.34 lbm/gal.
- \( \mu = 2.2 \) lbm/ hr-ft
- \( g_c = 32.2 \) lbf-ft/lb/ft-sec²
- \( \rho = 62.2 \) lbm/ft³
6. (20 min.) A uniformly enriched commercial PWR has an initial power distribution proportional to a cosine in the axial dimension and a $J_0$ function in the radial dimension. An equilibrium fuel cycle core utilizing typical fuel management techniques may have a maximum assembly power to average assembly power ratio as shown below.

Relative Power Factors

uniform fueling  
$q''''_{\text{max}} (z) / q''''_{\text{avg}} = \pi/2$

managed fueling  
$q''''_{\text{max}} (R) / q''''_{\text{avg}} = 1.37$

$\frac{q''''_{\text{max}} (R)}{q''''_{\text{avg}}} = 2.32$

(a) (30%) Describe and explain the dominant fuel management technique used to level core power.

(b) (35%) What are the maximum/average power ratios for the uniformly enriched core and for the equilibrium core?

(c) (35%) Calculate the percent increase in power achievable by the equilibrium fuel cycle core compared with the uniformly enriched core.

State and explain your assumptions.