1. (15 min.) A fuel pin with UO$_2$ fuel has a fuel pellet radius of 0.7 cm and a clad thickness of 0.05 cm. The conductivity of the fuel is $k_f = 0.025$ w/cm°C. The clad outer temperature is 320°C. There is a gas gap between the fuel and the clad. The temperature drop across the gas gap is 35°C and the gap conductance is 0.85 W/cm²°C. What is the fuel centerline temperature?

2. (25 min.) This problem deals with possible design changes for a commercial PWR. Conventional PWR characteristics are listed in the table below.

It is proposed that the PWR assemblies be enclosed in assembly cans similar to those in a BWR. This canning allows the coolant flow through the assemblies to be tailored individually.

(a) (20%) Calculate the hot assembly outlet temperature for the conventional PWR using the information given in the table.

<table>
<thead>
<tr>
<th></th>
<th>Conventional PWR</th>
<th>“Canned” Assembly PWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak-to-Avg Assembly Power Ratio</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Core Avg $T_{hot}$</td>
<td>520°F</td>
<td>to be determined</td>
</tr>
<tr>
<td>Core $T_c$</td>
<td>460°F</td>
<td>460°F</td>
</tr>
<tr>
<td>Core Power</td>
<td>3200 MW(t)</td>
<td>to be determined</td>
</tr>
</tbody>
</table>

(b) (40%) For the canned design, the flow to each assembly is adjusted by inlet orificing such that the $T_{hot}$ of all the assemblies is the same and equal to the hot assembly outlet temperature of the original design found in Part (a).

Calculate the ratio of the new total core thermal power to the original core thermal power assuming the total mass flow through the core remains unchanged.

(CONTINUED ON NEXT PAGE)
(c) (40%) All assemblies in the original core had the same flow rate, \( \dot{m}_{\text{avg}} \). Total core flow rate \( \dot{m} \) is kept the same for both the old and the "canned" cores.

Calculate the ratio of the flow rate in the new core's highest power assembly (\( \dot{m}_{\text{h,nc}} \)) to the flow rate in the original core's highest power assembly (\( \dot{m}_{\text{h,c}} \)).

3. (15 min.) A phenomenon of concern in high burnup fuel is oxidation of the outer boundary of the fuel pin cladding. As the oxidation layer grows, it can undergo "delamination" when the oxide layer separates from the zircaloy but is still attached to the fuel pin. Then spallation can occur when the oxide layer is swept away by the coolant.

Sketch clad inner surface temperature versus time at an axial position where an oxide layer builds up, then delaminates, and then spalls. Show how the clad inner surface temperature changes during these events, and clearly mark your plot to show when each occurs.

4. (20 min.) Commercial BWRs use in-vessel jet pumps.

(a.) (25%) Draw a jet pump schematic showing the internal flow paths and external connections.
(b.) (50%) Explain the principle of operation of a jet pump.
(c.) (25%) Why use a jet pump versus some other type of pump?

5. (15 min.) Commercial LWRs in the US have been tending toward smaller diameter fuel pins and greater numbers of pins per assembly over the past 20 years. For example, BWRs may now use 10x10 assemblies and PWRs 19x19 assemblies even though overall core dimensions remain the same.

(a.) Describe the pros and cons of this trend.
(b.) Why has this trend happened? What is the driving design issue? Explain.
6. (30 min.) For the sealed 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 m$^3$/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 manufacturer 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:

\begin{align*}
\text{Density (} \rho \text{)} &= 1.146 \, \text{kg/m}^3; \\
\text{Viscosity (} \mu \text{)} &= 1.83 \times 10^{-5} \, \text{kg/m} \cdot \text{s} \\
\text{Thermal conductivity (} k \text{)} &= 2.68 \times 10^{-2} \, \text{W/m \cdot °C} \\
\text{Specific heat (} c_p \text{)} &= 1025.8 \, \text{J/kg \cdot °C}
\end{align*}

The convective heat transfer coefficient can be evaluated from:

\[ St = 0.023 \, Re^{-0.2} \, Pr^{0.6} \]

where

\[ St = h / (\rho \cdot v \cdot c_p) = \text{Stanton number} \]

Where \( h \) is the heat transfer coefficient and \( v \) is the flow velocity.
Concrete gamma-neutron shield

Cap

Air in (27 C)
Air out (43 C)

Inside surface temperature = 99 C

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

Concrete support pad