(50%) 1) In Boiling Water Reactors with canned assemblies, differences in void and quality distributions can lead to flow redistribution such that the mass flux in the individual assemblies is different. This can be compensated for by orificing the individual assemblies (modifying the inlet loss coefficient).

Assuming the heat flux profiles are known for the average and hot channels, show how you would determine the channel inlet loss coefficient for the average channel such that the exit void fraction for the average and hot channels is equal. You can assume that no modifications are made to the hot channel (i.e. loss coefficients). Give all equations. Terms involving integrals may be left in integral form. If the solution requires iteration, it is sufficient to give the iteration equation (s), state which variable (s) is to be solved for and state to solve iteratively. You may assume an equilibrium model is valid and all necessary thermodynamic and state equations are available. You may assume the inlet subcooling is sufficiently low that all fluid properties in the subcooled region can be assumed constant at the saturation properties corresponding to the system pressure. The following information may be assumed known

**BOILING WATER REACTOR PARAMETERS**

- System Pressure \( P \)
- Lower Plenum Pressure \( P_0 \)
- Core Exit Pressure \( P_H \)
- Core Inlet Enthalpy \( h_{in} \)
- Fuel Height \( H \)
- Rod Diameter \( D \)
- Rod Pitch (square lattice) \( S \)
- Can Width \( S_b \)
- Number of rods per assembly \( n_{rods} \)
- Number of heated rods per assembly \( n_{heated} \)
- Number of assemblies \( n_{cans} \)
- Channel Exit Loss Coefficient \( K_{exit} \)
- Grid Loss Coefficients \( K_j \)
- Grid Locations \( z_j \)
- Hot Channel Inlet Loss Coefficient \( K_{inlet} \)
- Core Averaged Axial Heat Flux profile \( q^*(z) \)
- Hot Channel Heat Flux Profile \( q_{hot}^*(z) \)
- Fraction of Energy Deposited in the fuel \( \gamma_f \)
(25%) 2) Part of a feed train for a Pressurized Water Reactor is illustrated below. Due to differences in the control signals being sent to the feed control valves, the loss coefficient for feed control valve #2 is 20 percent higher than that for feed control valve #1. Assuming the steam generator pressures to be equal, develop an explicit expression for the feed flow rate to each steam generator. You may assume the overall loss coefficients for the individual lines are constant and include friction. You may also assume the feed pumps behave identically.

![Diagram of feed train](image)

The following data can be considered known:

**Problem Data**

- Feed Pump Inlet Pressure (Pmanifold 0) \( P_0 \)
- Steam Generator Pressures \( P_{sg1} \) & \( P_{sg2} \)
- Feed Temperature \( T_{feed} \)
- Feed Pump \( \Delta P \)
- Feed Pump Line Loss Coefficient (referenced to feed line flow) \( K_0 \)
- Feed line loss coefficients (excluding feed control valves) \( K_{fd} \)
- Feed Control Valve #1 Loss Coefficient \( K_{fcv1} \)
- Feed Pump Line Pipe diameter \( D_0 \)
- Feed Line Pipe Diameter \( D_1 \)

(25%) 3) Critical heat flux for the BWR in problem 1) has been correlated according to a critical boiling length correlation of the form

\[
x_{crit} = \frac{aL_{crit}}{b + L_{crit}}
\]

Show how you would determine the critical power ratio for this reactor. Give all equations. Terms involving integrals may be left in integral form. If the solution requires iteration, it is sufficient to give the iteration equation(s), state which variable(s) is to be solved for and state to solve iteratively. If needed, the following additional information can be assumed known

**Problem Data**

- Total Thermal Output \( \dot{Q}_{th} \)
- Total Power Peaking Factor \( F_q \)
- Axial Peaking Factor \( F_z \)
You may find all or some of the following relationships useful.

**Mixture Mass**
\[
A_x \frac{\partial \rho}{\partial x} + \frac{\partial \rho A_x}{\partial z} = 0
\]

**Mixture Energy**
\[
A_x \frac{\partial u}{\partial x} + \frac{\partial Gh A_x}{\partial z} = q'(z)
\]

**Mixture Momentum**
\[
\frac{1}{g_c} \frac{\partial G}{\partial x} + \frac{1}{g_c} \frac{\partial}{\partial z} \left( G \left( (1-x)^2 + \frac{x^2}{\alpha_i \rho_i \rho} \right) \right) = -\frac{\partial p}{\partial z} - \left\{ \sum_j f_j \frac{G^2}{2 \rho_j g_c} \delta(z-z_j) \right\} - \rho \frac{g}{g_c} \sin \theta + \Delta P \delta(z-z_\rho)
\]

**Zuber-Findlay Correlation**
\[
\alpha = \frac{x}{C_0 \left[ x + \frac{\rho_c}{\rho} (1-x) + \frac{\rho g V_g}{G} \right] + \frac{\rho g V_g}{G_x}} = \frac{1}{C_0 \left[ 1 + \frac{(1-x) \nu_j}{x \nu_g} + \frac{\rho g V_g}{G x} \right]}
\]

\[
C_0 = 1.13 \text{ and } V_g = 1.41 \left( \rho g \left( \rho - \rho_c \right) \right)^{1/4}
\]

**Fundamental Void-Quality-Slip Relation**
\[
\alpha = \frac{1}{1 + \frac{(1-x) \nu_j}{x \nu_g} S}
\]

**Profile Fit Model**
\[
x = x_e - \left( x_e \right)_d \exp \left( \frac{x_e}{(x_e)_d} - 1 \right)
\]

**Saha-Zuber Correlation**
\[
h_f - h_{id} = \begin{cases} 
0.0022 \times q^*(z_d) \times \frac{D e C_p}{k} & \text{Pe} < 70,000 \\
154 \times \frac{q^*(z_d)}{G} & \text{Pe} > 70,000
\end{cases}
\]
Two Phase Multiplier

\[ \phi_{\alpha}^2 = \left( 1 + \frac{20}{\chi} + \frac{1}{\chi} \right) (1 - x)^{1.80} \]

Martinelli parameter

\[ \chi^2 = \left( \frac{\mu_f}{\mu_g} \right)^{0.2} \left( \frac{1-x}{x} \right)^{1.8} \left( \frac{\rho_g}{\rho_f} \right) \]

Homogeneous Multiplier

\[ \Psi = 1 + \frac{u_{fg}}{u_f} x \]

Friction Factor

\[ f = f(Re, \varepsilon / D) \]

Heat Transfer Correlations

\begin{itemize}
  \item \textit{Dittus-Boelter Correlation} \hspace{1cm} \text{Nu} = 0.023 \text{Re}^{0.8} \text{Pr}^{0.4}
  \item \textit{Weisman Correlation} \hspace{1cm} \text{Nu} = C(S / D) \text{Re}^{0.8} \text{Pr}^{0.4}
  \item \textit{Nucleate Boiling Correlation} \hspace{1cm} q^* = \xi(P)(T_w - T_{sat})^m
  \item \textit{Chen Correlation} \hspace{1cm} q^* = h_{ref}(G, x, P)(T_w - T_o) + h_{NB}(G, x, P, T_w)(T_w - T_{sat})
  \item \textit{Bergles and Rohsenow} \hspace{1cm} q^*(z) = q_{ref}^*(z) \left[ 1 + \left[ \frac{q_{NB}^*(z)}{q_{ref}^*(z)} \left( 1 - \frac{q_{NB}^*(z_o)}{q_{NB}^*(z)} \right) \right]^{2} \right]^{-1/2}
  \hspace{1cm} q^*(z_o) = 15.6D^{1.156}(T_{ref}(z_o) - T_{sat})^{2.30}/\rho^{0.0234}
\end{itemize}