October 1994

Ph.D. Qualifying Examination
Fission Engineering
(five problems)

Problem 1 (25 minutes)

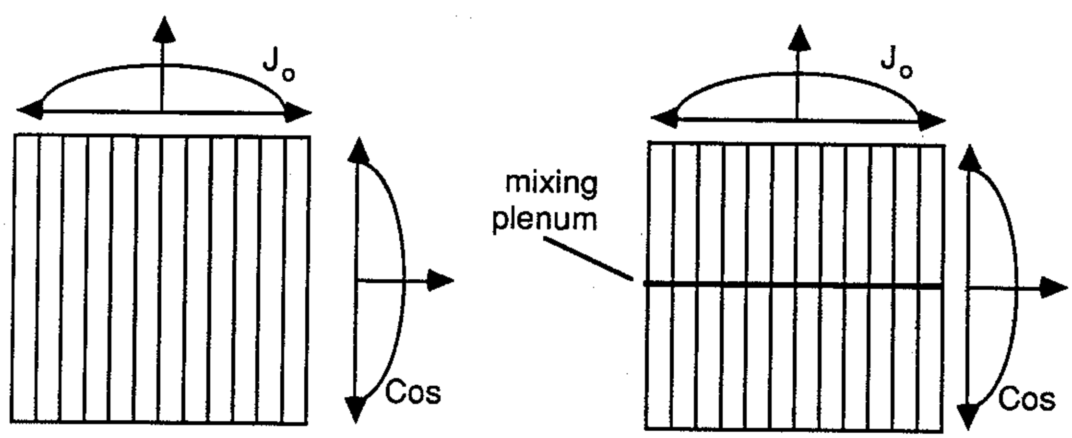
You are on a design team evaluating several possibilities for PWR core cooling flow paths. The conventional approach, Case 1, is shown in the figure below. Sub-cooled water enters the bottom of the core and is heated as it travels up the sub-channels. The **hot channel** exit temperature is just at saturation temperature.

The figure shows an alternative flow arrangement, Case 2, in which sub-cooled water enters the core bottom and is heated as it travels up the sub-channel. However, all the core flow is fully mixed at the axial mid-plane. The mixed water then proceeds up the remainder of the core. The **hot channel** exit temperature is just at saturation temperature.

The following assumptions apply:
1. the power peaking factors for both cores are the same.
2. the flow rate through each core is the same.
3. the cold water inlet temperature, T_c, to both cores is the same.
4. there is no inter-channel coolant mixing except in the plena.
5. the power peaking factors are:
   a. radially, a zero order Bessel function, J_0, peak/average = 2.32
   b. axially, a cosine function, peak/average = 1.52
6. the hot channel exit temperature, T_{hc}, of both cores is the same.

A. (20%) On your answer sheet on one graph, sketch (not plot) the bulk coolant temperature of the hot channel of each core as a function of axial position. Explain the curves.

B. (80%) Find the ratio of total core power in Case 2, Q_2, to total core power in Case 1, Q_1; i.e. find the ratio Q_2 / Q_1.



Case 1 Case 2

Problem 2 (20 minutes).

Consider a pipe break accident in an advanced boiling water reactor (ABWR). As the pressure drops by the activation of the automatic depressurization system (ADS), cold water is injected into the core by the gravity driven cooling system (GDCS). To perform an analysis of this event, would it be best to use an equilibrium or two-fluid two-phase model? Explain your reasoning thoroughly.

Problem 3 (30 minutes).

Assume that a Westinghouse-type PWR power plant is operating under normal steady-state conditions, producing 100% of its full power. Following operation of considerable time at this power level, the turbine is suddenly tripped and turbine valve closure takes place within ~0.1 sec. following the trip. Consider two distinct scenarios in which the steam bypass valve: (A) successfully opens, and, (B) fails to open.

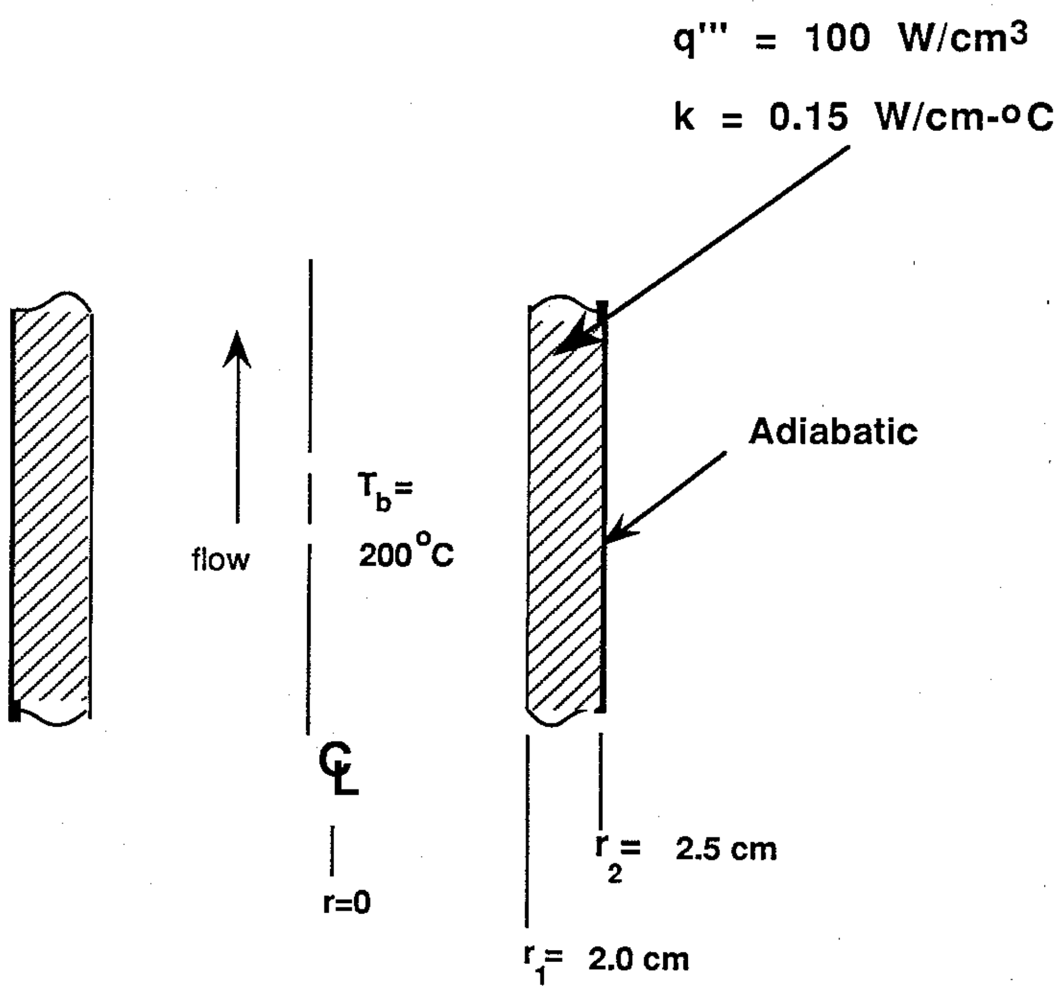
(20%) (1) For each of the aforementioned scenarios, briefly describe the sequence of events that follow the initial turbine trip.

(2) Sketch the transient responses of the following variables starting from the time the turbine trip occurs:

(15%) (2a) Secondary steam pressure (steam dome pressure),
(15%) (2b) Average core coolant temperature,
(15%) (2c) Neutronic power (neutron flux level), and,
(15%) (2d) Total core reactivity.

(20%) (3) During either of these two scenarios, do you anticipate exceeding the neutron flux and the system pressure safety limits? Briefly elaborate.

Problem 4 (25 minutes).



An annular fuel rod has coolant flowing through the center. At a certain elevation, the bulk coolant temperature is 200 ^{o}C and the heat transfer coefficient to the coolant is 0.8 watts/cm^2 - ^{o}C. The outer boundary of the fuel rod at r = 2.5 cm is adiabatic. The volumetric heat source in the fuel is 100 watts/cm^3. The fuel conductivity is 0.15 watts/cm- ^{o}C. Find the maximum fuel temperature at that elevation.

Problem 5 (20 minutes).

Answer the following questions. Be brief.

A. Explain the difference between the Eulerian and Lagrangian viewpoints in fluid dynamics. (Two to three sentences are sufficient.)

B. Experience has shown that in the range of engineering interest four basic laws must be satisfied for any continuous medium. What are they?

C. Explain the difference between the "control mass approach" and the "control volume approach" to engineering analysis. (Two to three sentences are sufficient.)

D. What is the definition of the term "heat transfer coefficient"? On what parameters does the heat transfer coefficient depend?

E. Is it possible to calculate heat transfer coefficients analytically in laminar flow? In turbulent flow? Explain briefly.

F. What is the expression for the thermal boundary condition at the clad surface/coolant interface for a fuel element being cooled by a forced convection flow? Use rectangular coordinates.