

February 1997

Ph.D. Qualifying Examination
Fission Engineering

1. (15 min.) You are asked to obtain a first estimate for the thermal power output of a planned high temperature gas-cooled reactor (HTGR) power plant.

In this design hot gas exiting the reactor core will be directly fed to a gas turbine. As a result of material considerations, the turbine inlet temperature cannot be allowed to exceed 1300 K, even for a very short period of time. The plant will be located in the vicinity of the North Atlantic, providing a constant heat sink temperature of 278 K. It is desired to produce 300 MWe power output from this plant.

(a) (50%) What is the theoretically minimum steady-state thermal power that the reactor is required to produce in order to meet the electric power output specification?

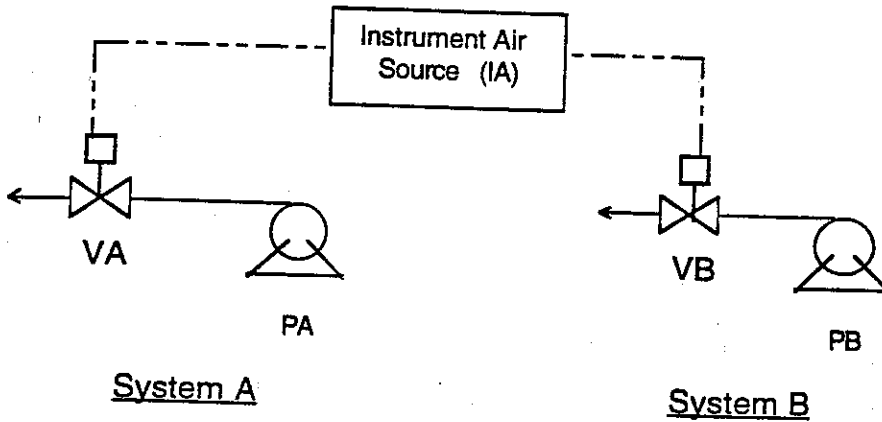
(b) (50%) Considering the effects of transient temperature profiles and an approximate temperature overshoot factor of 20%, explain what will happen if you attempt to design and operate the reactor using the steady-state thermal power you calculated in part (1). How do you suggest correcting for such a situation in your analysis? Explain.

2. (20 min.) A PWR system is operating with once through steam generators. T_{Hot} from the reactor is 520°F at 2,000 psia. The steam generators are producing saturated steam at 500 psia with a feedwater inlet temperature of 300°F and a pinch point temperature difference of 20 F°.

- (a) (20%) Sketch the temperature versus position plot for the steam generator.
(b) (60%) Calculate the ratio of primary to secondary mass flow rates.
(c) (20%) Find T_{Cold} , the steam generator primary outlet water temperature.

Steam Tables supplied.

3. (20 min.) Systems A and B provide emergency cooling water on demand at a nuclear power plant. Both systems receive instrument air from the same source (IA) but employ separate, independent valves (VA and VB) and pumps (PA and PB). The instrument air source, pumps, and valves are sketched below; the reliability of the remaining components of systems A and B may be ignored for the purposes of this problem.



For system A to "succeed," the IA source must provide pressure, PA must start, and VA must open. For system B to "succeed," the IA source must provide pressure, PB must start, and VB must open. The applicable component failure probabilities are

P(PA)	- Pump A fails to start	--	0.20
P(VA)	- Valve A fails to open	--	0.15
P(PB)	- Pump B fails to start	--	0.22
P(VB)	- Valve B fails to open	--	0.15
P(IA)	- Instrument Air source fails	--	0.25

- (40%) Calculate the probability that system A fails regardless of whether system B fails or succeeds.
- (60%) Calculate the probability that system A fails AND system B succeeds.

Some potentially useful probability relations:

- For independent events X and Y --

$$P(X \text{ or } Y) = P(X) + P(Y) - P(X \text{ and } Y)$$

$$P(X \text{ and } Y) = P(X) \cdot P(Y)$$

- For interdependent events X and Y --

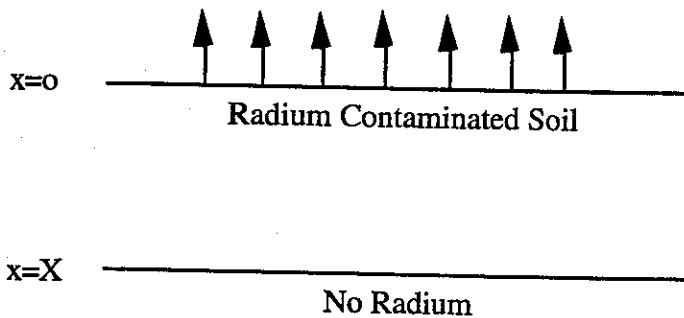
$$P(X \text{ and } Y) = P(X) \cdot P(Y|X) = P(Y) \cdot P(X|Y),$$

where $P(X|Y)$ is the probability that X occurs given that Y has already occurred.

4. (20 min.)

- (a) (75%) Starting with the steady-state equation of continuity, derive the steady-state equation which governs the surface flux of radon from a radium contaminated soil. (Hint: For an infinitesimal volume in the soil at steady-state, radon generation from the decay of radium equals the loss rate by decay and from leakage.) Use the following terms:
- (b) (25%) What are the appropriate boundary conditions for a surface layer of radium contaminated soil of thickness X .

- R = radium concentration in soil (Bq/kg)
 ρ = soil bulk density (kg/m³)
 E = emanation coeff. (dimensionless)
fraction of radon produced in soil which reaches pores
 λ = radon decay constant (s⁻¹)
 D = radon diffusion coefficient in pores (m²/s)
 C = radon concentration in pores (Bq/m³)
 ϵ = porosity of soil (vol. of pores / total vol.)
 J = radon flux from soil (Bq/m²-s)
 x = direction normal to soil surface



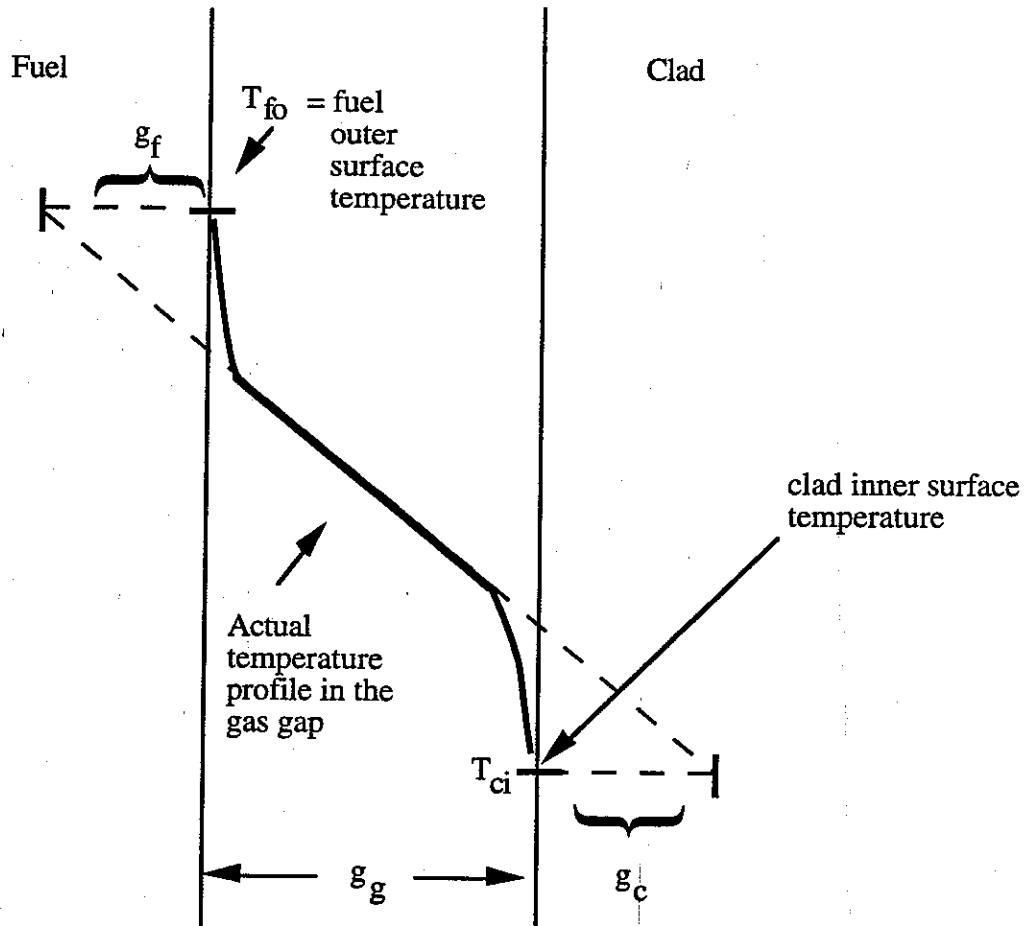
5. (25 min.) For a long term cooling test facility of passive safety reactors, a two-phase mixture of saturated liquid and vapor at atmospheric pressure flows through a round tube with a diameter of 1.2 cm. The flow rate is such that the mass flux is 400 Kg / m² s.

- (a) (50%) Estimate the value of the quality at which the transition from bubbly to slug flow is expected.
- (b) (50%) Calculate the friction pressure gradient assuming homogeneous flow.

Water properties at atmospheric pressure:

ρ_l (Kg/m ³):	958.3
ρ_v (Kg/m ³):	0.597
μ_l (μ Ns/m ²):	277.53
μ_v (μ Ns/m ²):	12.55

6. (20 min.)



Heat transfer across the fuel-clad gas gap is a complicated phenomenon. A representation of the temperature profile is shown above.

- (30%) Based on the kinetic theory of gases, explain qualitatively why the temperature profile takes the shape it does.
- (50%) An expression for the gap conductance to characterize the heat transfer across the gap is

$$h_{\text{gap}} = \frac{k_g}{g_g} \quad \text{W/cm}^2 \text{ } ^\circ\text{C}$$

Where k_g is the gas conductivity in $\text{W/cm } ^\circ\text{C}$ and g_g is the actual gap-width in cm. However, this representation is usually not considered adequate because the gap actually "looks" wider in a heat transfer sense. To account for this phenomena, the gap conductance can be written as

$$h_{\text{gap}} = \frac{k_g}{g_g + g_f + g_c} \quad \text{W/cm}^2 \text{ } ^\circ\text{C}$$

CONTINUED ON NEXT PAGE

Where $g_f + g_c =$ the "temperature jump distances" in the fuel and clad, respectively (so $g_g + g_f + g_c$ is a "virtual width").

Why is this a better approximation? What parameters and properties do $g_f + g_c$ depend on?

- (c) (20%) Write an expression for h_{gap} in terms of the heat flux into the gas gap and the outer fuel surface temperature, T_{fo} , and the clad inner temperature T_{ci} .