1. **(10 min)** Given that it takes 19.5 collisions to thermalize a 1.0 MeV neutron:
   
   (5 min) Calculate the mean lethargy gain per collision.
   
   (5 min) How many collisions would be required to thermalize a 1.5 MeV neutron?

2. **(10 min)** A monodirectional, monoenergetic source of neutrons impinges on a small target. Assume that scattering from the target material is linearly anisotropic and that 65% of the scattered neutrons have scattering angles between 0 and 90° (0° < θ ≤ 90°). Determine:
   
   (5 min) $\bar{\mu}_d$, the mean scattering cosine,
   
   (5 min) The fraction of neutrons scattered into angles of less than 45°.

3. **(20 min) 3-Group Diffusion Equation**
   
   (5 min) Write the detailed form of the 3-group k-eigenvalue diffusion equations. Ignore upscattering and assume that the fission source exists only in the fast group.
   
   (15 min) Assume a bare homogeneous reactor core and derive the 3-group expressions for $k_{eff}$ (to get credit you must clearly show your logic and state all your assumptions).

4. **(20 min)** Compute the power peaking factor for a critical, bare homogeneous spherical reactor.

   Reference Identity: \[ \int x \sin(x) dx = \sin(x) - x \cos(x) \]

5. **(20 min)** Develop an expression for the steady-state concentration of $^{135}\text{Xe}$ in an operating thermal reactor. Show that this quantity has a limiting value as flux increases.

6. **(15 min)** Explain why a tradeoff is required between the fuel-management objectives of low power peaking to minimize the fuel temperature and low neutron leakage to minimize pressure vessel fluence. Illustrate your answer in appropriate sketches.
7. (15 min) Consider both heavy-water moderated and graphite-moderated reactor systems cooled with a light water coolant.

(5 min) Explain the physical mechanism that can be responsible for a positive reactivity feedback in these systems.

(5 min) Explain the effect such feedback has on reactivity control.

(5 min) Compare the feedback mechanisms in graphite moderated systems cooled by light water or helium.

8. (10 min) The diffusion approximation in 1-D slab geometry is consistent with the following approximation for the angular flux (particles/cm²·sec·steradian):

\[ \psi(\mu) = \phi \frac{3J \mu}{4\pi} + \frac{3J \mu}{4\pi} \]

where \( \phi \) is the scalar flux and \( J \) is the \( x \) component of the current.

Use this approximation together with Fick’s law to derive the Marshak vacuum boundary condition at the left face of a slab:

\[ \left[ \phi - 2D \frac{d\phi}{dx} \right]_{x=x_L} = 0 \]

where \( x = x_L \ (cm) \) is the position of the left boundary and \( D \) is the diffusion coefficient.