1. (20 min.) A reactor is designed for space applications. For the launch, the reactor has a large negative reactivity margin. The neutronic parameters for the design are:

- Thermal utilization factor 0.44
- Fast non leakage probability 0.72
- Delayed neutron fraction 0.0063
- Thermal non leakage probability 0.75
- Fast fission factor 1.03
- Thermal fission factor 2.04
- Resonance escape probability 0.86
- Thermal efficiency 0.09

(1) What is the effective multiplication factor for this design?

(2) In the event that the launch failed and the reactor fell into the ocean, is the reactor subcritical? List your assumptions?

(3) Is this an accurate result?

2. (20 min.) Consider an infinite homogeneous slab \((0 \leq x \leq a)\) with reflective boundary condition at \(x=0\) and vacuum boundary condition at \(x=a\). Scattering is isotropic. The reactor is in the critical state. Assume that \(\Sigma_c\) \(\Sigma_f\) and \(q_f\) (energy release per fission) are given. The power of the reactor is \(P\). Determine the fundamental mode for the given reactor. Calculate the values of the scalar flux at the boundaries of the reactor. Use one-group diffusion approximation.

3. (20 min.) Consider a 300 mg sample (target foil) of natural sodium (100% \(N_a^{23}\), density of 0.97 g/cm\(^3\)). Take the neutron (radiative) capture cross section of \(N_a^{23}\) to be 0.32 barns and the neutron flux in the irradiation position of a reactor to be 1.0E+13 n/cm\(^2\)-s. Calculate the \(N_a^{24}\) radioactivity (the half life of \(N_a^{24}\) is 15 hours) for an irradiation time of 75 hours. You can assume that the number of target atoms (\(N_a^{23}\)) in the sample does NOT change during the irradiation.
4. (20 min.) A pebble bed modular reactor contains spherical fuel elements, approximately the size of tennis balls. It is cooled by helium passing through the fuel bed. The spherical fuel elements themselves contain a large number of coated particle fuel microspheres which are each approximately 450 microns in diameter. The fuel microspheres contain 19% enriched UO₂. The fuel microspheres are bound together by a graphite binder to make up the spherical fuel elements. There is sufficient graphite in the system so that this is a thermal reactor.

Make a sketch of the:

(1) Thermal neutron flux in a microsphere

(2) The overall thermal neutron flux in a spherical fuel element

(3) The radial thermal neutron flux across the core at the axial midplane of the reactor.

5. (20 min.) For a homogeneous medium, find k-infinity in terms of the three neutron (energy) group parameters. Eliminate all group fluxes from your relationship.

The three neutron (energy) group equations are:

\[
\begin{align*}
\text{Fast:} & \quad D_1 \nabla^2 \phi_1 - \left( \Sigma_{\text{a}1} + \Sigma_{1\rightarrow2} + \Sigma_{1\rightarrow3} \right) \phi_1 + \frac{1}{k_{\text{eff}}} \left( n \Sigma_{f1} \phi_1 + n \Sigma_{f2} \phi_2 + n \Sigma_{f3} \phi_3 \right) = 0 \\
\text{Resonance:} & \quad D_2 \nabla^2 \phi_2 - \left( \Sigma_{\text{a}2} + \Sigma_{2\rightarrow3} \right) \phi_2 + \Sigma_{1\rightarrow2} \phi_1 = 0 \\
\text{Thermal:} & \quad D_3 \nabla^2 \phi_3 - \Sigma_{\text{a}3} \phi_3 + \Sigma_{1\rightarrow3} \phi_1 + \Sigma_{2\rightarrow3} \phi_2 = 0
\end{align*}
\]
6. (20 min.) In solving the point reactor kinetics equations with six delayed neutron groups, it was found that the solutions for the flux and the precursor concentrations were of the form

\[ \phi(t) = \sum_{j=1}^{7} A_j \exp(\omega_j t) \]

\[ C_i(t) = \sum_{j=1}^{7} \tilde{A}_{ij} \exp(\omega_j t) \]

for \( i = 1, 2, \ldots, 6 \)

The values of the \( \omega_j \)'s are determined from the roots of the "reactivity" or "inhour" equation which states:

\[ \rho = \frac{\omega \ell}{1 + \omega \ell} + \frac{\omega}{1 + \omega \ell} \sum_{i=1}^{6} \frac{\beta_i}{\omega + \lambda_i} \]

a. Sketch the reactivity equation on a set of \( \rho \) versus \( \omega \) axes for a fixed set of values for \( \ell \), \( \beta_i \)'s and \( \lambda_i \)'s and \( i = 1, 2, \ldots, 6 \)

Show how the seven values of \( \omega \) are obtained for a specified value of \( \rho \).

b. Give quantitative expressions for the stable (asymptotic) reactor period for (1) small positive reactivities and (2) large negative reactivities.

c. Consider a U-235 fueled (thermal neutron induced fission) large power reactor that operates for a long time at a steady-state power level of 2 MW. Take \( t_1 \) equal to 0.0001 sec and ignore (reactivity) temperature feedback. If the operator wants to reach a new steady-state power level of 8 MW in 10 seconds and then stay at that power for \( t > 10 \) seconds, what should he/she do? Sketch the reactivity change(s) needed on a reactivity vs time plot. Also sketch the expected power vs time response of the reactor. Specify values for the required reactivity change(s), asymptotic reactor period and prompt jump(s)/drop(s). Figure 12-4 from Lamarsh's *Nuclear Reactor Theory* is provided for your use.
Fig. 12-4. Reactor period as a function of positive and negative reactivity for a $^{238}$U fueled reactor.