ME60223 Nuclear Power Generation & Safety

Class Test, Date: 6-9-2018, Time: 1.5 hrs, Full marks: 40

1. (a) Explain using a rough sketch how the binding energy per nucleon varies with the mass number and explain why the graph has that nature. Which are the elements that can be used to generate nuclear energy?

   (b) A free neutron is unstable with an average lifetime of approximately 12 minutes. Explain why neutrons inside the nucleus do not decay. On the N vs Z plot show which is the region of stable nuclei. What is the type of radioactive decay that a nucleus undergoes if N is larger or smaller than in the stable range for that value of Z?

   (c) From calculations of the infinite multiplication factor we know that natural uranium with light water as moderator cannot sustain a chain reaction. However, a uranium mine in Gabon, Africa, is believed to have functioned as a natural reactor about 2 billion years ago. How was this possible?

10 marks

2. A beam of neutrons, all moving with the same speed in the same direction, is incident on a pure scattering medium. Derive the expression for the mean free path for scattering in terms of the scattering cross-section. If the medium is graphite which has atomic mass 12, density 1.6×10^3 kg/m^3, microscopic scattering cross-section $\sigma_s = 4.7$ barns, and 1 barn $= 10^{-28}$ m^2 and Avogadro's number $N_A = 6.023 \times 10^{26}$ kmol^{-1}, calculate the value of the mean free path.

   The mean free path can be estimated by a different approach. Assume that each atom of graphite occupies a cube and all the cubes fit together to occupy the entire volume. What is the size of the cube? It can be assumed that the nucleus occupies $(10^{-4})^2 = 10^{-8}$ fraction of the area of any face of the cube. Therefore, a neutron would have to traverse 10^8 layers of atoms in order to undergo a collision. Use this argument to compute the mean free path. How does this compare with the value obtained earlier?

15 marks

3. In a scattering and absorbing medium, using the continuous slowing down model, derive an expression for the fraction of neutrons which escape absorption while slowing down from energy E_1 to E_2. If Σ_s and Σ_a are assumed to be independent of energy show that this reduces to

$$p = \left(\frac{E_2}{E_1}\right)^{\frac{1}{\xi}\frac{\Sigma_a}{\Sigma_s+\Sigma_a}} \quad (1)$$

   In a reactor core, which consists of graphite and natural uranium (containing 0.715 percent of ^{235}U) in the ratio 300:1, calculate the resonance escape probability using the relation

$$p = \exp\left[-\frac{2.73}{\bar{\xi}}\left\{\frac{\Sigma_s}{N(^{238}\mathrm{U})}\right\}^{-0.514}\right] \quad (2)$$

   where $\Sigma_s/N(^{238}\mathrm{U})$ is in barns. Assume that $\bar{\xi}$ can be approximated by the value for pure graphite and that the contribution of the fuel to the macroscopic scattering cross-section of the core can be neglected. For graphite $\sigma_s = 4.7$ barns and $\xi =$

0.158. If we assume that the reactor core can be modelled as a homogeneous mixture of graphite and uranium, that the only significant interactions are scattering with graphite and absorption in ^{238}U and that ^{238}U has a constant absorption cross-section during slowing down from 1.93 MeV to 0.025 eV, what should be the microscopic absorption cross-section σ_a of ^{238}U so that Eq. (1) gives the same value for p as obtained from Eq. (2)?

15 marks