DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR
MID SEMESTER EXAMINATION, AUTUMN 2018-2019
Subject: ME60223 Nuclear Power Generation and Safety, No of students: 15 (DD/ B Tech)
Date: 17-9-2018 (AN), Time: 2 hrs, Full marks: 60

1. (a) Why are fission products radioactive, typically undergoing beta decay?
   (b) Explain the physical mechanism of nuclear fission.

5 marks

2. In order to have a small size, a nuclear reactor uses uranium dioxide, UO_2, containing 50 percent enriched uranium, as fuel and water, H_2O, as moderator. The moderator to fuel ratio is 15:1. Assuming a homogeneous reactor model calculate the value of the infinite multiplication factor, k_∞. Use the data

Substance	σ_a (barns)	σ_s (barns)	ξ
^{235}U	680	10	0.0085
^{238}U	2.72	8.3	0.0084
O	0	3.8	0.1209
H_2O	0.66	50	0.920

Substance	σ_f (barns)	ν
^{235}U	579	2.42

The resonance escape probability and the fast fission factor are given by

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

$$\epsilon = \left[1 + 0.690\frac{N(^{238}\mathrm{U})}{N(\mathrm{H_2O})}\right] \Big/ \left[1 + 0.563\frac{N(^{238}\mathrm{U})}{N(\mathrm{H_2O})}\right]$$

where $\Sigma_s/N(^{238}\mathrm{U})$ is in barns.

Using the modified one-group equation it can be shown that, for the reactor to be critical, the 'radius' of the core, R, is approximately given by

$$R^2\frac{k_\infty - 1}{M^2} = \pi^2$$

Using this relation, estimate the radius of the core for the fuel and moderator combination specified above. For water the square of the diffusion length, L^2, is 8.1 cm^2 and the square of the slowing down length, L_s^2, is 27 cm^2.

20 marks

3. When a beam of neutrons with neutron flux ϕ_0 is incident on a slab of purely absorbing material, it can be shown that at a distance x from the face on which the beam is incident the neutron flux is given by $\phi(x) = \phi_0 e^{-\Sigma_a x}$, where Σ_a is the macroscopic absorption cross-section of the material of the slab. Further assuming that the slab is infinitely thick it can be shown that the mean free path for absorption is $\lambda_a = 1/\Sigma_a$. Now consider a spherical annulus of neutron absorbing material with inner and outer radii r_1 and r_2. There is a neutron source at the centre because of which neutrons are incident on the inner surface of the annulus with neutron flux ϕ_1. If the macroscopic cross-section is again Σ_a, calculate what is the neutron flux ϕ in the annulus as a function of radius. For neutrons which are incident on the inner surface of the annulus, calculate what is the mean free path for absorption in the annulus, assuming $r_2 \to \infty$. Is this the same as or different from the mean free path in a slab? Give a physical explanation for your finding.

20 marks

4. A light water reactor contains 9.5 m^3 of uranium dioxide, UO_2. This has a density of 10^4 kg/m^3 and the uranium is 3.2 percent enriched. Assuming that the atomic masses of ^{235}U, ^{238}U and O can be taken to be 235, 238 and 16, what is the number of kmols of ^{235}U in the reactor? Assuming that binding energy per nucleon is about 7.6 MeV for ^{235}U and 8.5 MeV for the fission fragments, what is the energy released due to fission of one nucleus of ^{235}U? Once the reactor starts operating, ^{235}U starts getting used up. Simultaneously ^{239}Pu is produced due to capture of a neutron in ^{238}U followed by two beta decays. Some of the ^{239}Pu also undergoes fission. The total amount of fissile material keeps decreasing with time and the reactor has to be shut down for refuelling when the total amount of fissile material is not sufficient to maintain criticality. By the time the reactor has to be shut down for refuelling, the total energy released in the reactor is equal to what would be released if the entire ^{235}U present initially were to undergo fission. If the thermal power of the reactor described above is 3500 MW, after what length of time would the reactor need to be shut down for refuelling. Avogadro's number, $N_A = 6.023 \times 10^{26}$ kmol^{-1} and 1 MeV $= 1.602 \times 10^{-19}$ MJ.

15 marks