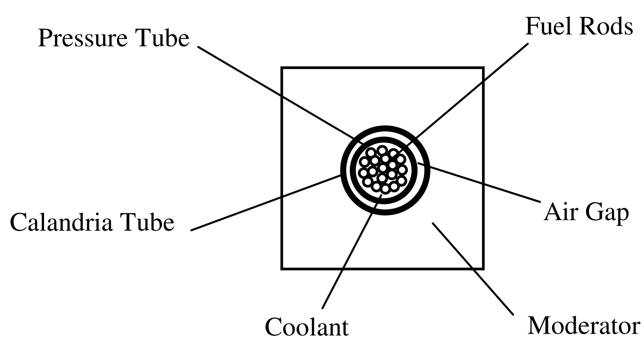
Assignment 3

1. A monoenergetic beam of neutrons having an intensity of 4 x 10^{10} neutrons/sq.cm-sec impinges on a target 1 sq cm area and 1 mm thick. There are 0.048 x 10^{24} atoms per cm^3 in the target and the total cross section at energy of the beam is 4.5 b. (a) what is the macroscopic total cross section? (b) How many neutron interactions per second occur in the target? (c) What is the collision density? (0.216 cm^{-1}, 8.64 X10^8 s^{-1}, 8.64 X10^9 cm^{-3} s^{-1})
2. The β^- emitter ^{28}Al (half life 2.30 min) can be produced by the radiative capture of a neutron by ^{27}Al. The 0.0253 eV cross section for this reaction is 0.23 b. Suppose that a small, 0.01 g aluminum target is placed in a beam of 0.0253 eV neutrons having an intensity of 3 x 10^8 neutrons/cm^2 , which strikes the entire target. Calculate (a) the neutron density in the beam; (b) the rate at which ^{28}Al is produced, (c) the maximum activity (in curies) which can be produced in this experiment. (1363 cm^{-3}, 1.54X10^4 s^{-1}, 4.16 X 10^{-7} Ci)
3. Calculate the mean free path of 1 eV neutrons in graphite (density = 1.6 g/cm^3). The total cross section of carbon at this energy is 4.8 b. (8.03 X 10^{22} cm^{-3}, 2.6 cm)
4. A beam of 2 MeV neutrons is incident on a slab of heavy water (D_2 O). The total cross section of deuterium and oxygen at this energy are 2.6 b and 1.6 b, respectively. (a) what is the macroscopic total cross section of D_2 O, at 2 MeV? (density = 1.1 g/cm^3) (b) How thick must the slab be in order to reduce the intensity of the uncollided beam by a factor of 10? If an incident neutron has a collision in the slab, what is the relative probability that it collides with deuterium? (0.225 cm, 10.23 cm, 76.5%)
5. Stainless steel type 304 having a density 7.86 gm/cm^3 has been used in some reactors. The nominal composition by weight of this material is as follows: carbon 0.08 percent; chromium 19 percent; nickel 10 percent; iron the remainder. Calculate the macroscopic absorption cross section of SS-304 at 0.0253 eV. The microscopic cross section (in barns) of C, Cr, Ni and Fe are respectively, 0.0034, 3.1, 4.42, 2.55. (0.2428 cm^{-1})
6. The typical unit cell of a Rajasthan Atomic Power Station (RAPS) is shown in the following figure.



The computed volumes of the various materials per unit length of the reactor are:

UO_2	29.2 cm^3
Zr (A=91)	20.3 cm^3
D_2O (coolant)	19.1 cm^3
Air gap	27.4 cm^3
D_2O (moderator)	426.6 cm^3

It may be assumed that air may be treated as a non-participating medium (does not react with neutrons) and the Uranium in UO_2 is natural.

(a) Given that the density of UO_2, Zr and D_2O to be 10.5, 6.5 and 1.1 g/cc respectively, calculate the homogenised number density of each material.

(b) Given the volumes as above, calculate the homogenised macroscopic absorption cross section of UO_2, Zr and D_2O, given the following(0.01012 cm^{-1}, .0003308 cm^{-1}, .0000130 cm^{-1})

Material	σ_a (barns)	σ_f (barns)
U^{235}	680	580
U^{238}	2.7	0.0
Zr	0.198	---
D_2O	4.6×10^{-4}	---
O	0.0	0.0

8. Gold consists of 100 % Au^{197} and captures neutrons (σ_a = 96 barns) to form radioactive Au^{198} (half life = 2.7 days) which emits beta particles. Consider a thin foil of 50 mg placed in a nuclear reactor for 10 minutes. After 2 hours of the removal from the reactor, the foil is found to emit 300 betas per second. Calculate the neutron flux in the reactor at the point the foil was placed.(1.740×10^9 n/cm^2-s)

9. Consider a slab of natural UO_2 (density=10.5 g/cc) 0.5 cm thick, intercepting a monoenergetic thermal neutron (2200 m/s) beam of intensity of 10^{12} neutrons/cm^2-s. Compute

(a) total number of thermal neutrons per unit area of the slab at any moment,

(b) the rate of generation of fast neutrons per second per unit area of the slab, and

(c) the thermal power generated in unit area of the slab (in W/cm^2)

Note the following

(i) Thin target approximation is not valid.

(ii) Only absorption needs to be considered (scattering is absent).

(iii) Fast neutrons being energetic do not react with fuel.

(iv) Energy per fission = 200 MeV

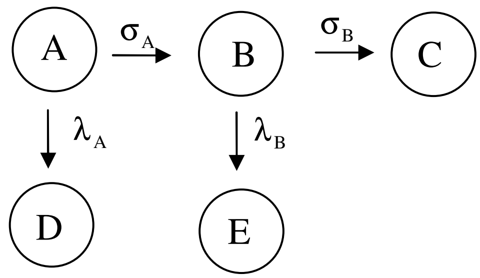
(v) Ratio of number of nuclei of U^{235}/ U^{238} in natural uranium = 7/993

Relevant data:

Material	σ_a (barns)	σ_f (barns)	ν
U^{235}	680	580	2.5
U^{238}	2.7	0.0	---
O	0.0	0.0	---

[Ans (a) 17.28×10^{21} cm^{-2}, (b) 9.385×10^{11} cm^{-2}, (c) 12 W/cm^2]

10. Consider a branched chain reaction taking place inside a nuclear reactor represented by the following diagram, where both radioactive decay and neutron absorption reactions proceed simultaneously. The relevant decay constants and absorption cross sections are as shown. The reactor may be assumed to be operating at a constant flux.

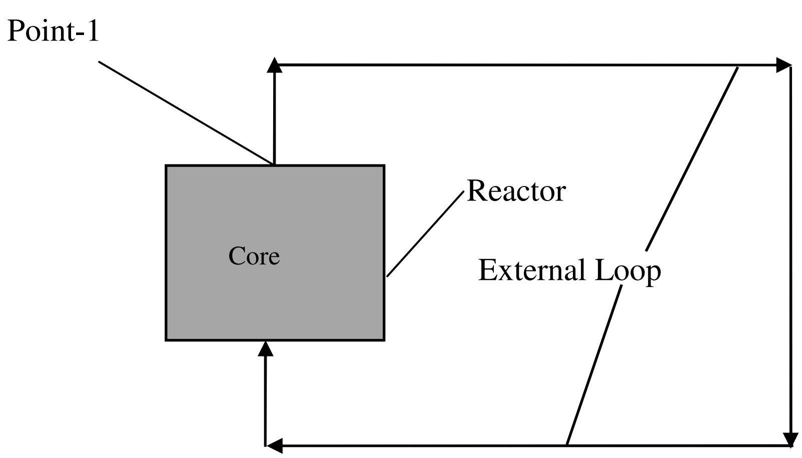


(a) Write down the rate equations that describe the time variation of concentrations of the nuclei, A, B, C, D and E.

(b) Solve for the variations of the concentrations of the nuclei, A, B, C, D and E with time. You may assume that the concentrations of A, B, C, D and E at time = 0 are N_{Ao}, N_{Bo}, N_{Co}, N_{do} and N_{Eo} respectively

(c) If the reactor operates for a time t and then shut down, sketch the variation of the concentration of A, B, C, D and E with time for t = 0-2t. Give qualitative arguments justifying the nature of curves. If multiple trends are possible, show all of them.

11. A radio-isotope is formed by activation (neutron reaction) in the circulating coolant of a reactor system as shown in the figure. On each pass, the coolant spends t_i seconds in the reactor and t_e seconds in the external loop. The decay constant of the radio-isotope may be assumed as λ. It may be assumed that its production rate inside the reactor is constant at 'p' nuclei/cc-s. Assuming that the activation process has reached equilibrium, (production-decay in the reactor, and its decay in the external loop are balanced), derive an expression for the activity at point-1 marked in the figure. How is the expression modified, if λ is very short or it is very long in comparison with t_i and t_e.



(Ans $\dfrac{p(1-e^{\lambda t_i})}{(1-e^{\lambda(t_i+t_c)})}$, p, $\dfrac{p\ \ t_i}{t_i+t_c}$)

12. In a particular reactor system (consider it to be an infinite system), the following are the computed macroscopic cross sections:

Σ_f of fuel = 0.5 cm^{-1}, Σ_a of fuel = 0.6 cm^{-1}. ν of fuel = 2.5, Σ_a of moderator = 0.4 cm^{-1} and Σ_a of others = 0.2 cm^{-1}.

(a) How much in terms of $\Sigma_{absorber}$ has to be added to maintain criticality

(Ans 0.05 cm^{-1})

(b) As this reactor operates, the fissile content will reduce, thereby reducing Σ_f. To compensate for this, $\Sigma_{absorber}$ has to be decreased to maintain criticality. Calculate the maximum fraction of the fuel nuclei that can be consumed after which the reactor can no longer maintain its criticality. For simplicity you may assume that the fission products do not absorb neutrons. (Ans 7.69%)