National Exams May 2016

08-Nuc-A1, Introduction to Nuclear Physics and Nuclear Engineering

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate should submit with the answer paper a clear statement of any assumptions made.
2. This is an OPEN BOOK EXAM.
3. Only approved calculators are permitted
4. The candidate should solve any 10 of the 13 problems and specify which problems were solved. Only the 10 problems specified as having been solved will be marked.
5. In solving each problem, the candidate should only use the data and values of natural constants given in the problem and should not use data or values of natural constants not specifically given in the problem. Should the candidate believe that a problem cannot be solved solely based on the data provided, (s)he should specify which additional data (s)he used.
6. Each question is worth 10 points.

Problem 1 (10p)

According to the liquid-drop model, the rest energy of a nucleus with atomic number Z and mass number A can be approximated using the following formula:

$$Mc^2 = ZM_pc^2 + (A-Z)M_nc^2 - \alpha A + \beta A^{\frac{2}{3}} + \gamma \frac{Z^2}{A^{\frac{1}{3}}} + \zeta \frac{(A-2Z)^2}{A^2} + \delta \frac{1}{A^{\frac{1}{2}}}$$

where the constants have the following meaning and values:

Quantity	Meaning	Value
M_nc^2	Rest energy of neutron	939.573 MeV
M_pc^2	Rest energy of proton	938.280 MeV
α	Volume term coefficient	15.57 MeV
β	Surface term coefficient	17.23 MeV
γ	Coulomb term coefficient	0.697 MeV
ζ	Asymmetry term coefficient	23.285 MeV
δ	Pairing term coefficient	0 for A odd
		12.0 MeV for Z and (A-Z) odd
		-12.0 MeV for Z and (A-Z) even

Based on the information given above, calculate the energy liberated in (the Q value of) the following reaction:

$$^{235}_{92}U + n \rightarrow ^{99}_{42}Mo + ^{133}_{50}Sn + 4n$$

Problem 2 (10p)

Radionuclide X can decay into three separate stable nuclide types: Y, Z & V with branching factors 0.2, 0.3, and 0.5, respectively. The composite half-life of X is 30 days. Find the approximate (within 0.1%) number of nuclei of each type (Y, Z, V) present after one year (365 days) if the initial number of radionuclides of type X is 10,000. Explain your method and approximations, if any.

Problem 3 (10p)

A $^{242}_{94}Pu$ nucleus initially at rest undergoes alpha decay according to the equation below

$$^{242}_{94}Pu \rightarrow ^{A}_{Z}X + \alpha$$

The Q value of the reaction is 5.000 MeV.

a) (2p) Determine the atomic number Z and mass number A of the daughter nucleus, X.
b) (8p) Assuming the daughter nucleus is left on its ground state, calculate the kinetic energy of the alpha particle and the recoil energy of the daughter nucleus in MeV. You can use classical, non-relativistic, mechanics and assume the atomic weight of each nucleus and particle involved to be approximately equal to its mass number, A.

NOTE: The atomic weight is the numerical value of the atomic mass expressed in *atomic mass units*.

Problem 4 (10p)

A neutron with kinetic energy equal to 500keV undergoes elastic collision with a stationary ^{12}C nucleus and is scattered at an angle of 90°. Calculate the kinetic energy of the scattered neutron in keV. (The atomic/nuclear weight can be approximated by the mass number. Classical, non-relativistic, mechanics can be used.)

Problem 5 (10p)

10^{20} nuclei of ^{235}U undergo fission with a delayed neutron yield of 0.0125 and a delayed neutron fraction of 0.005.

a) (5p) What is the total neutron yield per fission?
b) (3p) How many precursors are produced?
c) (2p) How many emitters are eventually produced?

Problem 6 (10p)

A cubical reactor with the side equal to 150 cm is made of a homogeneous material with the following one-group macroscopic cross sections:

$$\nu\Sigma_f = 0.002\,[cm^{-1}]$$
$$\Sigma_a = 0.001\,[cm^{-1}]$$

The reactor has a positive reactivity of 10mk (1mk = 0.001). Calculate the diffusion coefficient.

Problem 7 (10p)

A small sample of material is placed in a wide parallel beam of monoenergetic neutrons moving at 2200 m/s. The total reaction rate in the sample is 1.000E+06 s^{-1}. What would the reaction rate (in s^{-1}) be if the sample moved at 3.000E+03 m/s in a direction perpendicular to the neutron beam?

Problem 8 (10p)

The term "controlled fission chain-reaction" refers to a process in which the total fission reaction rate is constant or is varied slowly, according to the desire of the operator. By contrast, an uncontrolled chain reaction usually refers to a situation where the fission rate increases indefinitely. Consider a device (reactor) which sustains a controlled fission chain-reaction using ^{235}U, for which approximately 2.43 neutrons are produced, on average, in each fission. Discuss how many of the 2.43 neutrons will induce new fissions, on average? Give an approximate number and explain your answer.

Problem 9 (10p)

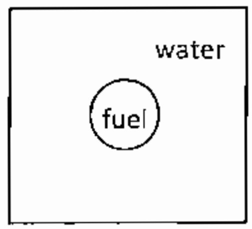
In a CANDU reactor, 94% of the fission power is deposited in the fuel and clad. The fuel pellet radius is 0.60 cm. The clad is collapsible and its outer radius is 0.65 cm. Each fuel bundle has 37 fuel elements and its length is 0.5 m. There are 12 bundles in each channel. Departure from nucleate boiling occurs for a heat flux of $2x10^6$ W/m^2. Assume the engineering hot channel (spot) factor to be 1.0, the radial hot channel (spot) factor to equal 2.31, the axial hot channel (spot) factor to equal 1.57 and the ratio between the maximum pin power to the average pin power in a bundle to be 1.1. Knowing that the core has 380 channels, calculate the maximum fission power for which departure from nucleate boiling does not occur anywhere in the core.

Problem 10 (10p)

The reactivity worth of one of the 14 Zone Control Units (ZCUs) of a CANDU reactor is approximately 0.5 mk (100% full to 0% full). The reactivity worth of one of the 21 Adjuster Rods is approximately 0.7 mk. A CANDU reactor is operating at full power with an average ZCU fill of 80% when one of the fuelling machines breaks down and all refuelling has to be stopped. After four days without refueling, the average ZCU level drops to 51%. Based on this information, calculate how many additional days the reactor can keep operating without refuelling if all adjusters are to be eventually extracted and the average ZCU level is not to drop below 20%.

Problem 11 (10p)

A PWR lattice cell consists of a fuel pin surrounded by water, as shown below.



The side of the square is equal to 1.5 cm and the radius of the fuel pin is 0.4cm. The one-group fuel and water macroscopic cross section and average neutron flux values for each of the two regions are:

$\Sigma_{a\,fuel} = 0.001 cm^{-1}$

$\Sigma_{a\,water} = 0.0001 cm^{-1}$

$\nu\Sigma_{f\,fuel} = 0.002 cm^{-1}$

$\nu\Sigma_{f\,water} = 0.000 cm^{-1}$

$\bar{\Phi}_{fuel} = 1\times10^{10}\, n/cm^2/s$

$\bar{\Phi}_{water} = 1.2\times10^{10}\, n/cm^2/s$

Calculate what fraction of the neutrons produced by fission in the fuel leak out through the cell boundary.

NOTE: The clad has been intentionally omitted for simplicity.

Problem 12 (10p)

A breeder reactor uses the ^{239}Pu - ^{238}U cycle with a conversion/breeding ratio of 1.10. There are initially 100 kg of ^{239}Pu in the reactor. What mass of ^{239}Pu is in the reactor after the reactor has generated 100,000 MWd of energy? Assume the atomic mass of Pu to be approximately 239amu. Assume that all fissions occur in ^{239}Pu, that 200MeV are liberated in each fission and that the capture-to-fission ratio for ^{239}Pu is $\alpha = 0.06$.

NOTE:

$1eV = 1.6\times10^{-19} J$

$N_{\text{Avogadro}} = 6.023\times10^{23}$

Problem 13 (10p)

An enrichment plant enriches uranium from 4.5 % to 15%. The enrichment of the tail is 1.9%. How much does the tail weigh (kg) after the production of 2000 kg of 15%-enriched product? Assume all enrichments to be by mass.