NE-150 - Introduction to Nuclear Reactor Theory

Spring 2018

Homework 2

Due February 22, 2018

For nuclear data and cross section plotting use the Web Site of the National Nuclear Data Center (NNDC) : http://www.nndc.bnl.gov
Periodic Table of the Elements: https://www.nist.gov/pml/periodic-table-elements
Interactive Periodic Table of the Elements:
http://www.rsc.org/periodic-table ;
http://www.ptable.com/
http://periodic.lanl.gov/index.shtml
Chart of Nuclides
http://www.nndc.bnl.gov/chart/
For atomic rest masses use: http://www.nndc.bnl.gov/masses/mass.mas12

For neutron cross-section plotting: http://atom.kaeri.re.kr/nuchart/
Submit this homework by e-mail to NE-150 GSIs.

1) Plot the binding energy per nucleon vs. the atomic mass number A (specify the source of the diagram!).
   a) Explain, based on this diagram, the fission and fusion processes.
   b) For the following D-D nuclear reaction

$$ {}_{1}^{2}H + {}_{1}^{2}H \rightarrow {}_{2}^{3}He + {}_{0}^{1}n + Q $$

   determine the binding energy per nucleon for ${}^{2}H$ and ${}^{3}He$, the value of Q, and the kinetic energies of ${}^{3}He$ and n. What assumptions did you make?

2) For the given ${}^{235}U$ fission nuclear reaction, calculate the nuclear reaction energy, Q. How is this energy distributed? Determine the binding energy per nucleon for each nuclide in this fission reaction. What is the difference between the mass defect and the mass excess?

$$ {}_{0}^{1}n + {}_{92}^{235}U \rightarrow \left({}_{92}^{236}U\right)^{*} \rightarrow {}_{53}^{136}I + {}_{39}^{99}Y + 1\,{}_{0}^{1}n + Q $$

3) A material has a microscopic neutron cross-section of 2.50 x 10^{-24} cm^2/nuclei, and contains 5.20 x 10^{23} nuclei/cm^3.
   a) What is the macroscopic cross section?
   b) What is the mean free path of neutrons in this material?
   c) If neutrons impinge perpendicularly on a slab of the material that is 2.0 cm thick, what fraction of them will penetrate the slab without making a collision?

d) If the parallel neutron beam has intensity of 7 x 10^7 n/(cm^{2}s) and a cross-sectional area of 2 cm^2, determine how many collisions per second the neutrons will undergo?

4) For each nuclide: ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu, plot the capture and fission cross-sections on the same diagram for entire energy range .
Now, on the same diagram include the plots the capture and fission cross-sections of of ^{235}U and ^{239}Pu, but focus on the lowest-laying energy resonance of ^{235}U and ^{239}Pu. For each of these isotopes estimate:
   (a) The resonance energy;
   (b) The resonance cross-section;
   (c) The capture-to-fission ratio at the resonance peak;
   (d) The capture-to-fission ratio at 0.0253 eV.

5) Li and Na are frequently used in molten salt type reactors but they present high absorption resonances: plot ^{6}Li (n,α)T and ^{23}Na(n,γ)^{24}N cross section over the entire range from 0.0001eV to 20 MeV. What is the energy and cross section of their lowest energy resonance? What type of cross section dependence on energy do we have below the resonance?

6) Boron and gadolinium are used as neutron absorbers in LWR. By which reaction they absorb neutrons? Plot the corresponding cross sections. Which of their isotopes is the most absorbing at 0.0253 eV?

7) Lead is often used for neutrons shielding: fast neutrons loose energy scattering with lead and then are thermalized by a lighter material before being absorbed. Why is lead used to slow down fast neutrons? Which kind of scattering reaction is used? Would it work for neutrons at any energy? Compare the scattering cross section of lead with that of H over the entire energy spectrum.

8) Fissile isotopes ^{233}U and ^{239}Pu are generated by (n, γ) reactions on ^{232}Th and ^{238}U. Plot the capture cross-section for those isotopes and suggest what would be the best neutrons energy range to enhance these reactions.

9) Define the mean free path, the mean time to collision, and the mean collision frequency. Now, determine the mean free path, the mean time to collision, and the mean collision frequency for C-12, B-10, Fe-56, Xe-135, Pb-207, U-235 at 0.0253 eV and 1 MeV.

10) The fuel for a certain breeder reactor consists of pellets composed of mixed oxides, UO_2 and PuO_2, with the PuO_2 comprising approximately 30 wt% of the mixture. The uranium is essentially all ^{238}U, whereas the plutonium as the following isotopes: ^{239}Pu (70.5 wt%), ^{240}Pu (21.3 wt%), ^{241}Pu (5.5 wt%) and ^{242}Pu (2.7 wt%). Calculate Σ_f at 0.0253 eV (the pellet density is about 10.6 g/cm^3).