

22.01 Fall 2015, Problem Set 7 (Normal Version)

Due: November 20, 11:59PM on Stellar

November 21, 2015

Complete all the assigned problems, and do make sure to show your intermediate work. Please upload your full problem set in PDF form on the Stellar site. Make sure to upload your work at least 15 minutes early, to account for computer/network issues.

1 Conceptual/Analytical Questions

1. Explain, using your knowledge of criticality (the four and six factor formulas) and nuclear reactions, why water makes a fantastic moderator.
 - (a) What could you do to the reactor to increase moderation without changing the coolant?
 - (b) Can you think of a material that would moderate neutrons better than water, and why?
 - (c) For what reasons do some reactors (such as CANDU reactors) use heavy water as a moderator instead of light water? What disadvantages does it have?
2. Consider the fission of ^{235}U in these questions:
 - (a) Analyze the likelihood of forming each of these fission products, by computing the Q-values of the nuclear reactions that form each of these fission products by a thermal neutron: ^8Be , ^{16}O , ^{32}S , ^{64}Zn , ^{128}Te . How do these compare to the fission product yields in figure 12.12?
 - (b) For the case where one of the fission products is ^{128}Te , what is the average kinetic energy of the neutrons emitted following fission? You may assume that all the daughter products, including the neutrons, are emitted at equal angles from each other. For example, if two neutrons are emitted, the four daughters leave the compound nucleus at 90 degrees.
3. For these questions, consider the ability to induce fission in ^{84}Kr , and look through the ENDF/B-VII.1 cross sections in the [JANIS cross section database](#):
 - (a) Calculate the incoming neutron energy needed to induce the reaction of ^{84}Kr that releases one neutron at the least excited state ($(n,n'1, \text{MT}=51)$). Compare this with the energy at which the cross section for fission releasing one neutron begins from the JANIS database.
 - (b) Repeat your analysis for emission reactions producing one neutron from more and more excited states (these are the reactions that look like $(n,n'15)$). Using JANIS, graph the maximum cross section vs. the neutron's energy state, and the energy of non-zero cross section vs. excited state. What patterns do you see, and how can you explain the deviations you see in these patterns?
4. Explain why delayed neutrons are the key to controlled neutron reactivity. Also explain why fast reactors are inherently more difficult to control.

2 Designing Effective Shielding

Your job is to design effective shielding for the MIT nuclear reactor, knowing that fission products decay with all manners of different mechanisms.

1. State which class of materials are best for shielding beta particles, gamma rays, x-rays, and neutrons, and state why using your knowledge of cross sections and stopping power.
2. What layers of shielding between the fuel and experimentalists outside the reactor will shield against all potential types of radiation, and in which order? Consider types of radiation produced when others interact with some of the layers of shielding. Estimate the required thicknesses of shielding in each case to remove 99.99% of the radiation emanating from the reactor.
3. Given your shielding array in the previous question, what would happen in terms of radiation exposure if the water in the MIT reactor were to boil away? Assume that the reactor continues producing neutrons for some time.

3 Applied Questions

For these questions, consider the MIT reactor in its critical state, and the various experiments that we do with it. [Here](#) is a cross section of the relevant parts of the MIT reactor:

What would be the effect of each of the following changes on the reactor's criticality, and which of the terms in the six factor formula would be affected? Explain why, using your knowledge of neutron absorption and leakage, and how they affect criticality.

1. Passing silicon ingots through the reactor, to dope them with phosphorus by transmutation
2. Inserting a small piece of stainless steel directly in the core of the reactor
3. Replacing the coolant with liquid sodium
4. Closing all the beamports which let neutrons out for experiments
5. Raising the temperature of the coolant by 30 Kelvin
6. Increasing the enrichment of the fuel

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22.01 Introduction to Nuclear Engineering and Ionizing Radiation
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