22.01 Fall 2016, Problem Set 7

November 7, 2016

Complete all the assigned problems, and do make sure to show your intermediate work.

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1 Skill-Building Questions (50 points)

1.1 MIT Reactor Modifications (24 points)

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 two energy group criticality relation would be affected? Explain why, using your knowledge of neutron absorption and leakage, and how they affect criticality.

(a) Passing silicon through the reactor to dope with phosphorus by transmutation ***(this really happens)***
(b) Throwing quarters directly in the core of the reactor like a wishing well ***(this actually happened!)***
(c) Replacing the water coolant with liquid sodium
(d) Closing all the beam ports which let neutrons out for experiments
(e) Raising the temperature of the coolant
(f) Increasing the enrichment of the fuel

1.2 North Korean Nuclear Weapons (16 points)

- (12 points) Calculate the radius of a perfectly critical sphere of ^{239}Pu using one-group diffusion theory, assuming it is surrounded by vacuum.
- (4 points) Assuming some sort of explosive charge compressed the ^{239}Pu to make it go supercritical, why wouldn't it work well as a nuclear weapon? In other words, what would happen as soon as the sphere goes supercritical, and how would it turn the weapon into a dud?

1.3 Power Manipulations (10 points)

Explain, using your knowledge of criticality and feedback, every noticeable feature in your personal manipulation of the MIT reactor. Use your own data from your personal power manipulation for this question. In particular, how does the MIT reactor *not* behave like a more simple feedback system, and what is the physics behind this difference?

2 Noodle Scratchers (50 points)

2.1 The Ultracold Nuclear Reactor (20 points, answer not given)

A new reactor concept would use liquid hydrogen as its coolant and moderator, instead of water. One unique feature of this reactor is a new type of moderator, which works so well that a significant fraction of the neutrons are *ultracold*, or have energies well *below* the thermal energy of the surrounding atoms. This means that ultracold neutrons can undergo *upscattering* to the thermal group. In order to fully analyze this reactor, one needs to consider three groups of neutrons: fast (f), thermal (th), and ultracold (uc).

Develop a fully symbolic criticality condition (k_{eff}) for this reactor, in terms of its materials and geometry. Assume the following:

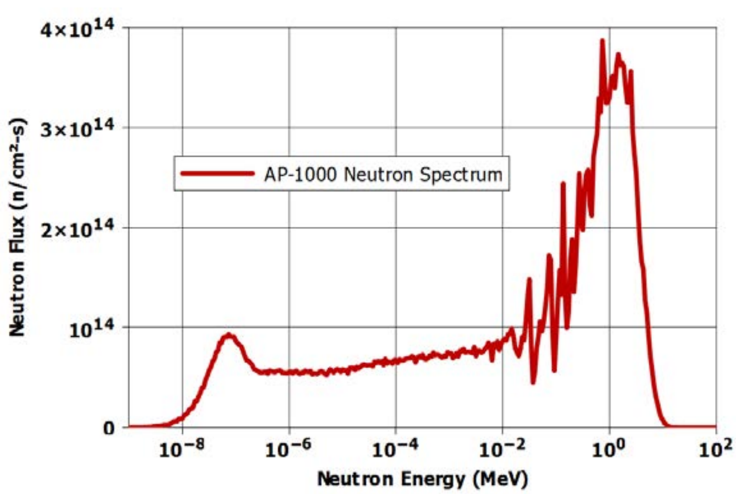
- All fission neutrons ($fraction\ (1-\beta)$) are born fast.
- All delayed neutrons ($fraction\,\beta$) are born thermal.
- The reactor is a homogeneous cylinder, both of height radius H.
- Define any symbols (cross sections, fluxes, diffusion coefficients, etc.) needed to solve this problem.

2.2 Will It Blend: AP-1000 Edition (30 points, answer not given)

Read the >>>AP-1000 spec sheet<<<, and answer the following questions:

(a) (25 points) Assuming that the core is completely homogeneous (blended) mix of fuel, cladding, coolant, and structural materials, **calculate the criticality** (k_{eff}) **of the AP-1000 using homogeneous, two energy-group neutron diffusion theory**. You may assume that the core contains only four materials: coolant/moderator (H_2O), fuel (UO_2), cladding ($assume\,pure\,Zr$), and structural materials ($assume\,pure\,Fe$). Ignore control rods, assume they are all out of the reactor during normal operation. Also ignore the reactor vessel or any other materials. You will have to calculate averaged cross sections considering each material, each isotope's natural abundance (or uranium enrichment level), for each energy group. ***Hints:*** You will have to take into account:

- Reactor operating temperature in Kelvin and density in $\left(\frac{g}{cm^3}\right)$ of the materials in the reactor
- Different diffusion coefficients for the two energy groups, and their different extrapolation distances for the geometric buckling
- Perform your *microscopic* cross section averages using tabulated data from the ENDF/B-VII.1 cross section database for *incident neutrons*. Note that you can export the data directly, so you can perform the integrals in Excel or something similar. Discretize the energy integral using any method you see fit.
- Neglect photofission, (n, in) reactions, and anything else complicated
- Use the >>>attached AP-1000 tabulated neutron flux profile<<< to compute your averaged macroscopic cross sections. Here is a plot of the flux spectrum:



(b) (5 points) What are the largest three factors which you believe make your k_{eff} not equal to unity? Be specific about what each would do to the two energy group criticality relation.