September 2000

Ph.D. Qualifying Examination
Reactor Theory and Experimentation

1. (20 min.) A liquid containing fissile material is held in a cylindrical drum whose height-to-diameter ratio, H/D, maximizes k-eff for a given volume. It is just critical. The material is reloaded into a spherical container of the same volume.

   (a.) What will be the change if any in the criticality condition?
   (b.) Which factors in the six-factor formula for k-eff will change and why?
   (c.) What is the height to diameter ratio of the drum?

2. (20 min.) A cylindrical 10 MW reactor containing uranium fuel elements with an enrichment of 90% U-235 is cooled and moderated with light water. The purpose of the reactor is to produce medical isotopes. Depending on the isotope to be produced, the irradiation is done in a small water hole at the center of the core, or alternatively in a beam port coming off the core. It is proposed to convert the core to low enriched uranium (LEU), with an enrichment of 20%, to operate at the same fission power density.

   (a.) What effect does this have on the medical isotope production?
   (b.) What changes to the LEU reactor might increase the isotope production rate in the central location? In the beam port? (You can change geometry, reflector, moderator, etc.)

3. (30 min.)
   (a.) (15 min.) Starting from the point-reactor kinetics equations with one delayed neutron group, show how the "inhour" or "reactivity" equation is obtained.
   (b.) (10 min.) Derive the relationship for the prompt jump approximation for the "instantaneous" power increase following a positive reactivity insertion.
   (c.) (5 min.) Based on six delayed neutron groups, explain why the stable reactor period following a large negative reactivity insertion is ~ 80 seconds.

4. (20 min.) A sample is placed in a counter for exactly 15 minutes and 2128 counts are registered. The sample is then removed and 2561 background counts are observed in exactly 90 minutes. What is the net count rate and the standard deviation of the net count rate from the sample? How long should the sample be counted to be 95% certain that the measured count rate is within +/-5% of its true value? (Recall that the confidence range on the mean for the 95% confidence level is +/- 1.96 times the standard deviation.)

5. (10 min.) Calculate the Q-value for the following (decay) reaction:

$$^{226}Ra \rightarrow {}^{222}Rn + {}^{4}He$$

What is the kinetic energy in MeV of the alpha particle ($^{4}He$) that is produced?

Use the following atomic mass data:

Mass of one $^{226}$Ra atom is 226.025408 amu,
Mass of one $^{222}$Rn atom is 222.015760 amu,
Mass of one $^{4}$He atom is 4.0026032 amu.

6. (10 min.) There is a serious need for instruments that can measure the energy spectra of neutrons on spacecraft. However, this has proven to be a particularly difficult problem because the fluence of directly ionizing charged particles (protons, helium nuclei, etc.) is many times larger than the neutron fluence. Most detectors cannot distinguish between energy deposited by an incident proton and a recoil proton produced by a neutron, so the typical neutron spectrometer depends on an anticoincidence shield to identify the directly ionizing particle events. One alternative is to use a scintillator that detects the energy deposited as the neutron slows to thermal energy, and the energy deposited when the thermal neutron is captured by boron incorporated in the detector.

(a.) Describe the physical characteristics needed for the detector and electronics needed to make this system work. (You do not need to provide numerical values, just criteria that the system would have to meet.)

(b.) Describe the primary mechanism leading to misidentification of charged particles as neutrons, and identify the system parameter (one of the characteristics you listed in (a) that controls this error).