Homework #8 (group) – Thursday, April 12 by 4:00 pm

5290 exercises (individual) – Thursday, April 12 by 4:00 pm

extra credit (individual) – Tuesday, April 17 by 4:00 pm

Readings for this homework assignment and upcoming lectures

- Review lecture notes:
  - Part 10a. Nuclear Energy
  - Part 10b. Nuclear Fission
  - Part 10c. Nuclear Reactors
- DOE Fundamentals Handbook: Nuclear Physics and Reactor Theory, Volume 1
- Appendix K. Partial List of Isotopes
- Appendix L. Radioisotope Fuels

Homework Submission

- For this assignment, the 4200-portion of the homework is to be worked as a group assignment and submitted as a group in class or by dropping off at my office (room 905). If you use EES for this assignment, then print a copy of the code and solution and include with the homework.
- MEEM 5290 problems are always to be worked and submitted individually.
- Extra credit exercises are always to be worked and submitted individually.
- **At the end of each problem, rank your confidence in the answer from 1 to 5; 5 being very confident and 1 being 'a guess'.**
- Include the course number (MEEM4200, MEEM5290) in the subject line of any email correspondence.

Homework Exercises

Homework #8 - due Thursday, April 12 by 4:00 pm

1. Radioactive carbon-14 is used to estimate the age of materials composed of organic carbon. It is formed by a reaction between CO_2 atoms in the upper atmosphere and high energy neutrons (part of cosmic radiation) that bombards the earth. Living organic material absorbs and uses carbon dioxide from the atmosphere which contains about 1 percent $^{14}CO_2$. When the organism dies, the ratio of C-14 to C-12 decrease with time as the radiocarbon decays. If the proportion of C-14 to stable carbon in an old manuscript is found to be 0.70%, determine the age of the manuscript assuming the atmospheric bombardment of high-energy neutrons is constant.

2. When pure ordinary water passed through a reactor as a coolant-moderator, it becomes slightly radioactive. The most important of the radioactivities is due to the absorption of a neutron by an oxygen-16 nucleus. This reaction results in emission of a proton and a radioactive product nucleus that has a 7.2 second half-life.
   (a) Identify the product nucleus.
   (b) Calculate the percent radioactivity remaining in the water 28.8 seconds after this reaction.

3. In fast-breeder reactors, plutonium-239 is the primary fuel. A relatively stationary ^{239}Pu nucleus is fissioned by a 1.0 MeV neutron resulting in two fission fragments: krypton-93 and cerium-144.
   (a) Identify all decay products of these two fragments until stable isotopes are obtained.
   (b) Calculate the total energy released in MeV per ^{239}Pu nucleus and kWh per gram of ^{239}Pu.

4. SNAP (systems for nuclear auxiliary power) are devices that generate electric power directly from the heat generated by radioisotopic "fuels", in which case the are given odd numbers; or fissuon nuclear reactors, in which case they are given even numbers. Direct generation is usually accomplished by thermoelectric energy conversion. An example is the Apollo lunar surface experiment package (ALSEP), called SNAP-27, which was placed on the lunar surface by the Apollo astronauts during their lunar landings in the late 1960s and early 1970s. SNAP-27 used plutonium-238 in the form of plutonium carbide PuC as 'fuel'. If the fuel deployed has a mass of 1 kg and the thermoelectric conversion efficiency is 8%, calculate
   (a) determine the number of Pu-238 nuclei present and the rate of reaction at the beginning,
   (b) the power generated, in Watts, upon deployment, and
   (c) the power generated, in Watts, 5 years after deployment

5. A pressurized water reactor operating at 2000 psia has primary water entering at 550 °F and leaving at 610 °F. A 1000-ft^3 pressurizer is normally half-full of water. During a transient the pressure rose to 2100 psia, 200 lbm of spray water entered the pressurizer, and the pressurizer became 60% full of water. Ignoring heat losses to the environment, calculate the amount of heat in kW addded by the electric heaters.

6. A boiling-water reactor operating at a pressure of 70 bar produces 1200 kg/s of saturated steam from 200 °C feedwater. The average core exit quality is 0.10. Calculate
   (a) the recirculation ratio,
   (b) the core inlet enthalpy, in kJ/kg, and temperature, in °C,
   (c) the degree of subcooling, in °C, and
   (d) the heat generated in the reactor, in MW_{th}.

Homework #8 – 5290 only

7. Calculate the power generated per unit volume, in MeV/cm^3 and kW/m^3, of a 3.5% enriched uranium dioxide fuel element in a thermal reactor with an effective cross section of 350 barns and a neutron flux of 10^{14} neutrons/s-cm^2. The density of UO_2 is 10.5 g/cm^3. The mean energy released per fission of uranium-235 is approximately 200 MeV.

8. A PWR primary loop with 8000 ft^3 volume operates at an average temperature of 580 °F. The reactor has a 1000-ft^3 vapor pressurizer that normally contains 60% water by volume at 2200 psia. An accident occurs in which the relief valve becomes stuck in an open position and fluid is discharged to the relief tank. The system pressure steadily drops to 1600 psia, during which time the electric heaters were fully activated to help slow down the pressure drop. At 1600 psia, the primary loop average temperature is 550 °F, the pressurizer is 95% full of steam, the heaters were turned off to keep them from overheating, and the emergency core cooling system (ECCS) was activated. The ECCS replenished the primary loop with water to prevent uncovering and damaging the fuel elements. The relief tank is assumed to remain at nearly atmospheric pressure, but there is a 15.3 psi pressure drop in the line connecting the relief tank to the stuck pressurizer relief valve. Ignoring the effect of spray and heat losses to ambient, calculate:
   (a) the initial mass composition of the water-steam in the pressurizer, in lbm,
   (b) the condition of the fluid at the exit of the relief valve, before passing flowing to the relief tank, at the instant it opened (pressure, temperature, quality or degree of superheat),
   (c) the total loss of fluid, in lbm, from the primary loop (before ECCS) assuming for simplicity that the temperature remained constant, and
   (d) the condition of the fluid at the exit of the relief valve at the instant the ECCS came on line.

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9. For 1-g of Radium-226 calculate the percent loss of radium nuclei after 100 years. How long until the activity reaches 1 millicurie (mCi)?

10. When a spent fuel rod is removed from a reactor core, it is placed in an on-site storage pool of water so that the most intense, short-lived radioactive fission products decay and the road is safe for further handling. Consider one of the fission isotopes xenon-133, which is a beta-emitter with a half-life of 5.27 days, that decays into a stable isotope. A 30-kg fuel rod removed from the reactor core contains 0.1% by mass of xenon-133. What is the minimum time that this fuel rod should be stored in the water pool so that the activity due to the xenon is less than 300 mci?

11. A 1000-MW boiling water reactor powerplant with 33% efficiency is operating at 75% of rated load with a steam mass flow rate of 1150 kg/s, reactor core pressure of 70 bar, and an average exit quality from the core of 0.136. The reactor utilizes recirculation control. Find
    (a) the feedwater temperature, in °C,
    (b) the core degree of subcooling, in °C,
    (c) the downcomer flow at 75% load,
    (d) the average exit quality immediately after initiation of a load change to 80%, as well as at a steady load of 80%, and
    (e) the steam and downcomer flows, in kg/s, at a steady load of 80%.