Homework #7 - due Friday, November 20 by 3:00 pm

Readings for this homework assignment and upcoming lectures

- Chapter 10. Nuclear Power Plants, Weston
- Review lecture notes:
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    * 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
  - Chart of Nuclides

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 831). 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.
- Bonus problems 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’.
- PLEASE include the course number (MEEM4200, MEEM5290) in the subject line of any email correspondence.
1. State the name of the element, the number of protons and neutrons, the half-life and decay reaction, and the daughter nuclide. If the daughter nuclide is radioactive, continue until the decay reactions produce a stable nuclide.

Example: \( ^{60}_{27}\text{Co} \rightarrow ^{60}_{28}\text{Ni} + \beta^- + \gamma_d \)

- Parent: cobalt-60, beta decay, \( t_{1/2} = 5.62 \text{ y} \)
- Daughter: nickel-60, stable

(a) \( ^{15}_{8}\text{O} \)  (b) \( ^{24}_{11}\text{Na} \)  (c) \( ^{107}_{48}\text{Cd} \)  (d) \( ^{131}_{53}\text{I} \)  (e) \( ^{222}_{86}\text{Rn} \)

2. 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 \(^{14}\text{CO}_2\). 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.

3. Find the maximum kinetic energy, in MeV, of the emitted particle and that of the residual nucleus from the radioactive decay of the following radioisotopes. The energy quantities in parenthesis are the amount of gamma radiation energy (\( \gamma_d \)) emitted in each decay process.

(a) uranium-234 (0.053 MeV)
(b) uranium-235 (0.186 MeV)
(c) uranium-236 (0.049 MeV)
(d) plutonium-239 (0.052 MeV)

4. Write the complete decay reactions, determine the activity, and calculate the energy generated, in MeV/reaction and J/reaction, of the following radioisotopes:

(a) \( ^{211}_{84}\text{Po} \)  (b) \( ^{95}_{40}\text{Zr} \)  (c) \( ^{30}_{15}\text{P} \)  (d) \( ^{64}_{29}\text{Cu} \) (K-capture reaction)  (e) \( ^{87}_{36}\text{Kr} \)

5. 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.
6. SNAP (systems for nuclear auxiliary power) are devices that generate electric power directly from the heat generated by radioisotopic “fuels”, in which case they 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) the power generated, in Watts, upon deployment, and
(b) the power generated, in Watts, 5 years after deployment

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7. A sample of radioactive material is composed of two independent radioisotopes – a long-lived radioisotope and a short-lived radioisotope. A geiger counter, from which the output is directly proportional to the total activity of the sample, gave the following results:

<table>
<thead>
<tr>
<th>time, h:</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>60</th>
<th>90</th>
<th>120</th>
<th>180</th>
<th>240</th>
<th>360</th>
</tr>
</thead>
<tbody>
<tr>
<td>activity, Bq:</td>
<td>9000</td>
<td>3818</td>
<td>1703</td>
<td>837</td>
<td>472</td>
<td>231</td>
<td>139</td>
<td>95</td>
<td>47</td>
<td>23</td>
<td>5</td>
</tr>
</tbody>
</table>

Determine the half-life for the two radioisotopes. (Hint: Use a semilog plot and assume the half-life of one isotope is much longer than the second.) If the total initial activity of the mixture is 1 Ci, calculate the number of radioactive nuclei of each isotope at time 0 and 120 hours.

8. Tritium decays by emitting low-energy $\beta$ particles. This radiation acts on a phosphor producing illumination. Illumination can thus be made by adding tritium to a phosphor in the form of paint which are sealed in a plastic container that is transparent to illumination but that blocks the $\beta$ particles so that no hazard is encountered. The illuminators are used for such devices as locks, timepieces, aircraft safety markers, exit signs, etc. Regulations limit the amount of original radioactivity in such devices, depending upon service. Assuming that 4 mCi are permitted for an aircraft safety device, calculate

(a) the maximum mass of tritium that can be used, in grams, and
(b) the percent decrease in luminosity (which is proportional to radioactivity) after 10 years of service.

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)?