Written Exam, Radiation Protection, Dosimetry, and Detectors (SH2603)
08.00-13.00, June 10, 2008

Allowed aids: pocket calculator.

The tables you need is handed out together with this exam
To pass the exam, you need at least 6 points from Section A, **and** at least 4 points from Section B (also for Fx).

Grading is determined by the total number of points:
A:20-22, B:18-19.5, C:15-17.5, D:13-14.5, E:11-12.5, Fx:10-10.5, F:0-9.5

Halv-points (0.5 etc) can be rewarded for partially correct answers

Motivate your answers by calculations and text. Write clearly.

Make your own, reasonable assumptions, when necessary. It should be clear from your text what assumptions you make.

Good Luck!

Section A

1. A rather common decay mode is *electron capture*. Explain in detail what happens in this decay. Give the origin of the involved particles. Especially for heavy elements, a secondary type of radiation is associated with electron capture. What is this radiation called, and what is its origin? (We assume here that the daughter nucleus is populated only in its ground state.) [1 p].

2. In Albanova, there is a laboratory for low-intensity measurements of ionising radiation. The inner walls of this room are coated with thick iron plates, in order to reduce the radiation emitted from the concrete walls themselves. One radioisotope in the concrete is ^{40}K. What thickness of the iron plates is needed to reduce the intensity of the gamma radiation from this isotope by a factor of 5 ? [1 p]

3. In a typical nuclear power reactor, uranium-238 is bombarded by thermal neutrons. Explain, step-by-step, how plutonium is created as a consequence of this. Include clear descriptions of all nuclides involved, types of radioactivity, and half-lives. [1 p]

4. In 1977, a well-preserved dead mammoth was found frozen in ice in Siberia, Russia. A sample of the mammoth was analysed using the carbon-14 dating method. A 1-gram sample of pure carbon (from the mammoth) contained $3.945 \cdot 10^8$ ^{14}C atoms. By making the simple assumption that the carbon-14 content in natural carbon was the same when the mammoth died, as it is today (1 C-14 atom for 10^{12} C-12 atoms), calculate the time (in years before today) when the mamooth died. [1 p]

5. High energy electrons that interact with bulk matter will loose their energy by two different processes. What are these processes? [1 p]

6. An employee working in a nuclear power plant, receives some dose every year, when inspecting nuclear fuel. The dose is monitored carefully with a personal dosimeter. He starts to work in the beginning of 1995, and receives the following effective doses per year:
   1995: 5 mSv
   1996: 29 mSv
   1997: 27 mSv
   1998: 19 mSv
   1999: 24 mSv
   2000: 5 mSv
   2001: 56 mSv
   2002: 11 mSv
   2003: 78 mSv
   2004: 14 mSv
   This sequence of yearly doses is not allowed. Which year is the dose limit (according to ICRP and the Swedish authorities (SSI)) broken for the first time? (i.e. when should the employee have been stopped from working in this intense radiation environment?) [1 p]

7. A small protective box is going to be designed for a ^{32}P source. The first attempt is to use a box made of rather thin walls made of tin (Sn). The

wall thickness is choosen (using the Katz and Penfold formula) so that no beta electrons escape the box. But when a Geiger detector is use to double-check the design, it gives a clear signal that ionising radiation still escapes the box. What kind of radiation is detected by the GM counter? What is the origin of this radiation? [1 p].

8. A university teacher works in the student laboratory 300 hours per year. We assume that the teacher (in the typical lab situation) stands 5 meters from a Cs-137 (closed) radioactive source with the activity 10 μCi. What is the effective dose (per year) that the teacher receives? [1 p]

9. Explain the principle of a gas-filled *ionising chamber* detector, used for detecting ionising radiation. Use the example of an incoming alpha particle (say, at 5 MeV), and explain step-by-step how an electric pulse can be generated by the detector. [1 p]

10. Bananas are radioactive. What is the activity of one single banana, assuming that it contains 451 mg of natural potassium(K)? [1 p]

Section B

1. A car accident exposes an open strong (100 Ci) Cs-137 source to the surrounding area early in the morning. The site is sealed-off, but people living nearby are not evacuated, and the source is not removed until the evening. Of special interest is a day-care centre (Kindergarten) with 30 children, situated 80 meters from the accident site. Calculate the effective dose for one of the children. The children is outside of the house playing for 3 hours, and inside the house (made of 10 cm thick concrete walls) for 5 hours. Do you expect the children to suffer from radiation sickness? Motivate your answer. [3 p]

2. A strong (1000 Ci) Co-60 gamma source is going to be installed in a hospital. It is decided that the radiation protection must be designed so that a person standing 3 meters from the source (in the same room) should receive an effective dose, no higher than 10μSv per hour. Also make sure that a person working in an office (8 hours per day, 200 days per year) in the floor below the source does not receive more than 0.1 mSv per year. The floor/ceiling is made of concrete and is 10 cm thick. Choose a suitable material and design the radiation protection so that it has a mass less than 1000 kg. In your answer, be clear about the geometry of your design (e.g. by drawing a picture). [3 p]

3. The Q_α-value and the energy of the alpha particle (for a specific alpha decay) are not the same. Explain why this is the case. Calculate Q_α for the alpha decay of ^{210}Po, using the alpha energy from the nuclide chart. [1 p]
   Use the Weizsäcker formula (see separate paper) to calculate the difference in *total* binding energy for the system before and after the alpha decay of the nuclide ^{210}Po. [1 p].
   Now do the same calculation (difference of total binding energy) without the Weizsäcker formula. Instead use experimental masses from the mass table to extract the binding energies. Compare the results. [1 p].

4. A holmium (Ho) sample is bombarded with thermal neutrons (neutron flux: 10^{10} n/s) for one hour. A few minutes after the irridiation, the sample is put in front of a germanium detector. At which energy do we expect to see the most intense gamma radiation? To which nuclide do this detected internal transition (gamma decay) belong? [1 p]

   The sample rests in the laboratory for one year. A second measurement is performed, again using the germanium detector. Are gamma photons with exactly the same energy as in the first measurement still emitted from the sample, or not? Explain. Give five gamma energies that are detected in the second measurement, (that was not detected in the first). [2 p]