Written Exam, Radiation Protection, Dosimetry, and Detectors (SH2603)
13.00-18.00, Feb. 10, 2009, KTH, Stockholm

Allowed aids: pocket calculator.

All tables etc that you need are 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

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

Motivate your answers by calculations and text (and pictures, if you want). 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. The nuclide ^{210}Po decays by alpha emission. What is the kinetic energy of the *daughter* nucleus, immediately after the alpha decay? [1 p]

2. During an archaeological excavation, a tool handle of wood is found. When investigating the material in a laboratory, it is found that it had 43 ^{14}C atoms per 10^{14} ^{12}C atoms. In fresh wood, this ratio is 100 ^{14}C atoms per 10^{14} ^{12}C atoms. How old is the sample? [1 p]

3. Explain how a scintillator detector works. Use the example of a 1 MeV gamma photon that is detected by a NaI scintillator. Explain also how an electric pulse can be produced from the scintillator signal. [1 p]

4. In a type of cancer treatment called BNCT, the patient's brain is irradiated, using a high flux source of neutrons, for example from a small nuclear reactor. We assume here that no other body parts are affected. If the deposited energy in the brain is 2.5 Joule, and assuming that the neutrons have only energies in the range from 1 eV to 10 keV, what is the effective dose received by the patient? [1 p]

5. According to the Swedish radiation protection authority, what is the highest allowed effective dose per year, for an employee working with ionising radiation? [1 p]

6. A germanium detector is used in the student lab at KTH. A ^{137}Cs source of 10 mCi is placed 40 cm from the detector. The active part of the detector is a single crystal of pure germanium. It has a cylindrical shape with a radius of 3 cm and a height of 6 cm. Estimate the number of detected gamma photons per second (including both photoelectric effect and Compton scattering) in the detector. [1 p]

7. One of the plutonium isotopes created (as a consequence of the neutron flux) in nuclear reactors is ^{244}Pu. This nuclide is unstable to alpha decay, but the half-life is rather long ($8 \cdot 10^7$ years). In the intense neutron flux of the reactor, starting from ^{244}Pu, another nuclide is eventually formed, also unstable to alpha decay. Which nuclide is this? Describe the different steps, decay modes, and half-lives involved. [1 p]

8. The light nucleus ^{16}O has a density of approximately $0.2 \cdot 10^{18}$ kg/m^3. What is the approximate density of the heavy nucleus ^{235}U? [1 p]

9. A researcher is using the 60 keV gamma line from a ^{241}Am source for imaging purposes, (similar to X-ray imaging). What thickness should the film (photographic emulsion, Standard Nuclear) have if 50% of the gamma photons should be stopped by the film? [1 p]

10. Make the (simplified) assumptions that ^{235}U and ^{238}U was created in equal amounts when the Earth was formed, and estimate the age of the Earth, considering only the radioactive decay of the two uranium isotopes. [1 p]

Section B

1. Atomic bomb tests have, over several decades, increased the amounts of radioisotopes in the atmosphere. As a consequence, small amounts of radioactive nuclides have been absorbed by animals and humans, world-wide. One study, in the USA, found an average ^{239}Pu-concentration of 0.22 pCi/kg in the human skeleton, and 0.55 pCi/kg in the human liver. Assume that the plutonium is only present in the skeleton and in the liver. Calculate the number of ^{239}Pu atoms in the body [1p]. Calculate the effective dose received per year, as a consequence of the plutonium content [2p].

2. A child (25 kg) finds a closed ^{241}Am source (about 1 mm of plastic surrounds the (closed) source) and swallows it. The source stays in the body for 24 hours, but it is intact when it leaves the body. The child suffers from acute radiation sickness (nausea, vomiting), but recovers fully within about a week, and is not sick again. Estimate the effective dose received by the child [1p]. What is the approximate activity of the source [2p]?

3. In March 1979, a serious accident occurred at the nuclear power plant at Three Mile Island, Harrisburg, USA. The reactor was stopped, but the core was destroyed. More than a year after the accident, in June 1980, a decision was made to release a volume of radioactive gas (a total of about 45000 Ci) from the reactor vessel to the surrounding environment. A main concern was the release of a krypton (Kr) isotope. Which radioactive krypton isotope would have been the most abundant, at the time of the gas release [1p]? Explain the types of decay involved, and the decay energies involved, in the decay of the krypton isotope of interest. Which type/mode of decay would be of most concern, e.g. the potentially most harmful to people living near the power plant? Motivate your answer [1p]. Assume that the activity was evenly distributed in an air volume of one cubic kilometre (1 km^3). Estimate the dose per day received by a person exposed to that concentration of the radioactivity. For simplicity, we can make the assumption that only the gas present in the lungs will contribute to the dose [1p].

4. A box with radioactive sources is kept in a student lab. All sources are marked with a date at which they had the specified activity:

Nuclide	Activity	Date	note
^{60}Co	10 mCi	Feb. 3, 1963	closed source
^{137}Cs	10 mCi	Feb. 3, 1982	closed source
^{57}Co	100 mCi	Feb. 3, 2001	closed source
^{241}Am	1 mCi	Feb. 3, 1982	closed source
^{90}Sr	10 mCi	Feb. 3, 1982	open source
^{88}Y	10 mCi	Feb. 3, 2002	closed source

The room has a rectangular shape (8 times 5 metres). The box is situated in one corner, and a lab assistant works in the (diagonally) opposite corner. The box is made of 2 mm thick iron. Calculate the effective dose received by the lab assistant during 8 hours [2p]. Design a radiation protection that reduces the dose by a factor of 10 [1p].