Written Exam, Radiation Protection, Dosimetry, and Detectors (SH2603)
13.00-18.00, Oct 23, 2008, 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. In the fission process (e.g. in a nuclear reactor), a large number of radioactive *fission products* will be produced. In which part(s) of the nuclide chart can we find the fission products? What is the most common decay mode for these fission products? Motivate your answer. [1 p]

2. In light water (nuclear) reactors, a high flux of neutrons is present in the water close to the uranium fuel. Is it energetically possible for a thermal neutron to be absorbed by the protons of the water and form ^{2}H, e.g. deuterium? What is the Q-value for this reaction? [1 p]

3. A company producing radioactive sources (using a reactor) has prepared a ^{210}Po source. The activity of the source is measured to 63.42 mCi on the 3rd of March 2008. In late April, a customer contacts the company, requesting a ^{210}Po source of a lower activity, 40 mCi. The company decides to wait until the existing source has decayed to the lower activity. When should the source be delivered? [1 p]

4. In a lab of the nuclear physics department, we use a ^{133}Ba source. With a germanium gamma detector, we can clearly see a number of photo peaks of discrete energies emitted from the source. List six energies of gamma transitions that we should see clearly in the spectrum? [1 p]

5. Consider a high energy neutron approaching a nucleus. The probability for e.g. capture this is usually expressed in terms of the *microscopic cross section*. It is generally difficult to calculate the microscopic cross section for a certain nuclear reaction. But in the most naive approximation, we can see the cross section as the area we get if we project the volume of the nucleus to a plane. Using this simple definition, we can e.g. easily calculate the cross section of Ca-40 to be 0.53 [barn]. Here we use the unit *barn*. 1 [barn]=$1 \cdot 10^{-28}$ [m^2].
   Calculate the cross section in this way for ^{235}U. Express the area in units of *barn*. [1 p]

6. Explain the principle of the *fission ionisation chamber*, that we can use to detect neutrons. Use the example of a low energy (thermal) incoming neutron. Explain step-by-step how the neutron will be detected and how an electric pulse will be generated. You are encouraged to draw a picture to explain the principle. [1 p]

7. In a student lab exercise, the source is surrounded by lead for radiation protection. When a Co-60 source is placed in the lead cave, below the detector the students notice the 1173 keV and 1332 keV photo peaks from the decay of Co-60, but also peaks at lower energy (around 75-85 keV) in the gamma spectrum. When removing the Co-60 source, the low energy peaks are not visible. The students decide to investigate this and repeats the Co-60 measurement, this time without any lead protection, and now the low energy peaks are not visible. Explain what kind of radiation the low energy peaks correspond to. Explain why the low energy radiation is only present if the Co-60 source is there. [1 p]

8. The stopping power in air for an alpha particle at 5.5 MeV is about 0.8 MeV/cm. Using the theory of Bethe and Bloch, estimate the stopping power in air for the fission product ^{92}Kr, assuming that it has the same velocity as the alpha particle? [1 p]

9. What particles are emitted from a Cf-252 source? [1 p]

10. We know that photons of visible light (e.g. from stars, including the sun) can penetrate the Earth's atmosphere. But is gamma radiation able to penetrate the atmosphere?

    To find out, we consider a Co-60 source placed outdoor (at sea level), placed in a lead collimator, so that gamma photons are only emitted straight up (vertically) from the source. The intensity of gamma photons that escape the source and passes through the collimator is assumed to be equal to I_0. Estimate the intensity, I, (expressed as a fraction of I_0) that will be able to penetrate the atmosphere and escape into space? We can assume that the density of the air decreases exponentially with the altitude. The density at 5000 meters above sea level is approximately 50% of the density at sea level. [1 p]

Section B

1. In a hospital, a radioactive source is prepared for a PET investigation of a patient. The source (^{11}C, activity 1.5 Ci) is injected in the patient, and we can assume that it is distributed evenly over the whole body.

   Calculate the approximate total effective dose delivered to the patient as a consequence of the PET investigation. Also, calculate the effective dose delivered to a nurse sitting 2 m from the patient during the PET procedure (30 minutes). [2p]

   Make a radiation protection design (material, geometry) to decrease the dose to the nurse by a factor of 100. [1p]

2. The radio-luminescent paint was invented in 1902. Originally, this was a mixture of radium-226 and zinc sulfide. This paint glows in the dark and was used to paint watches and clock dials. Around 1920, the paint was applied using small brushes by hand, in factories, where (often female) workers was instructed to pointing the tip of the brush between their lips. In this way, considerable amounts of radium-226 was swallowed over time by the workers. Estimate the effective dose per year for one of the workers, from the decay of radium-226, assuming that her body have accumulated 1 μg of radium-226 (make your own assumptions regarding the diffusion rate for heavy inert gases in the body). [2p]

   Will a person *wearing* a watch containing a radium-226 painted dial receive any dose at all? (we assume that the dial is covered by 1 mm of glass on the front, and 1 mm of steel in the back) Motivate your answer well. [1p]

3. Two scientists (Dr. A, and Dr. B) work in a small laboratory where a Mössbauer experiment is prepared. Suddenly, Dr. A drops an open Co-57 source (200 mCi) on the table in front of her. It takes Dr. A 25 seconds before she is able to put the source back in the thick lead container. During the 25 seconds of exposure, Dr. B stands behind Dr. A (i.e. shielded by Dr. A's body), unaware of the incident. Calculate the effective dose received by Dr. A, and the effective dose received by Dr. B. Make your own (reasonable) estimations of the geometry of the problem. [3p]

4. In 1999, there was an accident in the nuclear fuel processing plant in Tokaimura, Japan. The accident occurred when workers of the plant was bringing too much liquid uranium solution together in a big tank. When the fuel in the tank reached the level of criticality, a very high neutron (and gamma) flux was suddenly emitted from the tank, where a number of employees were present.

   Neutron radiation can activate many different types of material. Since the natural sodium in the human body is activated when exposed to neutron flux, the dose that the employees received from the accident could be deduced by measuring (hours later) the radiation emitted from the body after the neutron exposure. Suggest (with a good motivation) a detector type, suitable to uniquely identify the specific radiation following neutron absorption in natural sodium. List two gamma energies, that we expect to see as photo peaks in our energy spectrum in the measurement. [2p]

Using this method, the effecitive doses to the three employees closest to the tank was deduced to be around 18 Sv, 10 Sv, and 2.5 Sv, respectively. One employee working on stopping the chain reaction after the accident received around 120 mSv. Around 100 people received between 1 and 10 mSv.

Do we expect anyone to die from this accident? If so, how many? Do we expect anyone to suffer from radiation sickness from the accident? If so, how many? [1p]