Co-ordinated examination in Radiation Protection Expert level 3

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Examination time: 13.30 - 16.30

Instructions:

- **This examination comprises 11 numbered pages, plus a separate 16-page appendix containing supporting data. Please check that you have everything!**
- Write your solutions and answers on the worksheets provided. You must return all worksheets, including any unused ones.
- Write **only your examination number** on the worksheets (not your name and address).
- You are permitted to consult books, personal notes and other relevant documentation when answering the questions.
- *You are explicitly reminded that you must also show the* ***calculations*** *and/or* ***reasoning*** *you used to arrive at your solution.*
- If you are unable to calculate part of a question and the answer is needed to solve the rest of the question, you may assume a fictitious answer.
- Some questions might not require you to use all the data provided.
- You can earn a total of 67 points for answering all the questions correctly. The available points are divided between the questions as follows:

  Question 1: 16 points
  Question 2: 16 points
  Question 3: 18 points
  Question 4: 17 points

Question 1 Production of ^{11}C for PET

^{11}C is produced for Positron Emission Tomography (PET) using a cyclotron, an average of three times a week and a maximum of 3.5 TBq each time. The produced ^{11}C is coupled to choline (a non-volatile organic compound that is soluble in water and can form an aerosol) in the B Laboratory, in a closed work cabinet that meets NEN-EN-12649 regulations. The ^{11}C-choline is then used for research into prostate cancer.
It takes about one hour per batch to label the choline. Because ^{18}F and ^{13}N are also used in the same laboratory, it is important to know what the contribution of activities involving ^{11}C is to the loading factor B_w of the laboratory.

Given:

- **Appendix, pp. 3–4:** *Handboek Radionucliden* (Radionuclides Handbook), A.S. Keverling-Buisman (second edition, 2007) pp. 22–23: ^{11}C;
- A biological half-life of 40 days can be assumed for $^{11}CO_2$ following inhalation;
- **Appendix, p. 5:** Karlsruher Nuklidkarte, 7. Auflage 2006, detail;
- **Appendix, pp. 6–8:** q and r values and loading factor calculations from the Radionuclide Laboratory Appendix.

Question 1.1
The *Handboek Radionucliden* states that the radionuclide ^{11}C is produced using a cyclotron using the $^{11}B(p,n)$ or the $^{14}C(p,\alpha)$ reaction. Part of this statement is untrue. Which part is that? Provide the reasoning for your answer.

Question 1.2a
Show that the maximum amount of ^{11}C used is permissible in a B Laboratory. Show your calculation. Assume a value for the risk of dispersion of p = -2 for the series of calculations using the ^{11}C-choline.

Question 1.2b
Calculate the loading factor B_w for the room as a result of activities involving the use of the ^{11}C.

Ten minutes after production using the cyclotron, the ^{11}C is allowed to react with oxygen to produce gaseous $^{11}CO_2$. When recovering the gas, one of the valves sticks and some of the activity is released. The technician (exposed worker) closes the valve as quickly as possible and informs the company radiation expert. Six hours after exposure, a whole body count is carried out on the technician which then shows an activity of 572 Bq.

Question 1.3a
Calculate the effective half-life of $^{11}CO_2$ in the body. Explain your answer.

Question 1.3b
Show that the whole body activity is $4.8 \cdot 10^{-6}$ Bq, six hours after a single intake of 1 Bq $^{11}CO_2$. Show your calculation.

Question 1.4
Calculate the committed effective dose received by the technician as a result of this exposure.

Question 2 Radioactive contamination

Sentinel node procedures are to be carried out in the operating room in a hospital. This is a standard procedure if breast cancer is diagnosed, to see whether the tumour has spread. A ^{99m}Tc compound is injected that is taken up by the lymph nodes. The lymph nodes can then be identified on the operating table using a scintillation detector, and the tissue removed and tested for the presence of cancer cells. The operating room must be checked for contamination once the procedure is complete.

Contamination is defined as follows in the hospital complex license:

Radioactive contamination:

- Radioactive contamination is defined as alpha contamination of 0.4 Becquerel (Bq) or more per cm² or beta/gamma contamination of 4 Bq or more per cm². This concerns a wiped activity, therefor the following needs to be taken into account:
  - The wiped surface is about 5 cm²;
  - The detection limit is a maximum of 2 Bq for all nuclides. This applies both to alpha and beta/gamma sources.

The nuclear medicine departmental expert is responsible for the contamination check and uses the Berthold LB 122 A contamination monitor. This monitor has a thin-window detector filled with butane gas. The monitor can be set to measure alpha emitters or beta/gamma emitters. The beta/gamma setting is used for this contamination check.

Given:

- **Appendix, p. 9:** Berthold LB 122 A data;
- Background count rate of the Berthold LB 122 A is 10 cps;
- An increase in the count rate that is equal to or greater than the background count rate is considered to be significant.

The Berthold LB 122 A detector is held 1 centimetre above a surface of which 5 cm² is contaminated with 40 Bq/cm² ^{99m}Tc.

Question 2.1
Calculate whether this contamination will cause a significant increase in the count rate.

Question 2.2
If the contamination is dispersed homogenously over a surface that is larger than the LB 122 A detector, what is the lowest contamination level of ^{99m}Tc (in Bq/cm²) that can be measured?

Another method for measuring contamination is to conduct wipe tests and measure the samples in a gamma counter. The nuclear medicine department has a 1470 Wizard, a counter in which gamma emitters are measured using a NaI well-type scintillation crystal.

Given:
- **Appendix, p. 10:** 1470 Wizard gamma counter data;
- During measurements in the gamma counter, the samples are placed in the well-type scintillation crystal and only count rates in the ^{99m}Tc 140 keV peak are determined;
- The wipe efficiency is 10%;
- The background count rate of the gamma counter in the ^{99m}Tc 140 keV peak is 17 cpm.

Question 2.3
Calculate the net count rate (in cpm) for a piece of paper in the 1470 Wizard if the paper has been used to wipe a surface of 5 cm² contaminated with ^{99m}Tc with a contamination level of 40 Bq per cm².

Question 2.4
Show that even for a count time of just 1 second, the 1470 Wizard will show the wiped ^{99m}Tc activity, whereby the net count rate must be at least 3 times the standard deviation of the background count rate.

Question 3 Accident during preparation of a ^{123}I radiopharmaceutical substance

A radiopharmaceutical company has various work cabinets in a B laboratory. After the preparation of a radiopharmaceutical substance with the radionuclide ^{123}I, this is transferred from one work cabinet to another in a flask in a tungsten jar. The operator drops the tungsten jar containing the flask with 25 GBq ^{123}I onto the floor. The flask falls out of the tungsten jar and breaks. In accordance with standard procedure, the contamination is cleaned up as quickly as possible using remote-controlled tools and absorbent material, after which it is deposited in a lead waste container. The operator spends one minute cleaning up the contamination. While doing so, his body is an average of 50 cm from the source of the contamination. At this distance, the contamination can be considered a point source.

Given:

- **Appendix, pp. 11–12:** *Handboek Radionucliden* (Radionuclides Handbook), A.S. Keverling-Buisman (second edition, 2007) pp. 156–157: ^{123}I;
- **Appendix, p. 13:** *Inleiding tot de Stralingshygiëne* (Introduction to Radiation Protection), A.J.J. Bos et al. (second edition, 2007), Appendix D Interaction coefficients for photons, p. 381;
- **Appendix, pp. 14–15:** ICRP 38, (1983), pp. 442–443, decay scheme of ^{123}I;
- **Appendix, p. 16:** SBD-TU/e, graph showing the transmission of photons from ^{123}I through lead;
- The waste container is cylindrical with the following external dimensions: diameter 40 cm and height 40 cm. The lead walls, base and lid are 2.5 cm thick. The container (approx. 190 kg) is always transported using a special trolley (see Figure 3.1).

Question 3.1

Calculate the effective dose to the operator whilst cleaning up the contamination. Show your calculation. Assume for the calculation that H*(10) is a good estimator for the effective dose.

Figure 3.1: The lead waste container

During the cleaning operation, 85% of the contamination is cleaned up using the absorbent material. As a worst-case scenario, assume that the radioactivity in the absorbent material can be considered a point source and that it is 1 cm away from the internal wall of the container.

Question 3.2
Calculate the transmission of gamma photons produced by the decay of the ^{123}I through the lead waste container and use this to calculate the ambient dose equivalent rate on the outside of the waste container. Use the information given on pages 11 to 13 in the Appendix. Take 100,000 as the build-up factor.

Question 3.3a
As well as the 159 keV gamma line (Appendix, p. 11), ^{123}I also emits other photons per decay. Explain, based on the data and the graph (Appendix, pp. 14–15 and p. 16), how the transmission calculated in Question 2 will change if these extra photons are also taken into account, and why the transmission curve (narrow beam) is not a straight line.

Question 3.3b
Taking build-up into account, recalculate the ambient dose equivalent rate on the outside of the waste container, using the graph in the Appendix (p. 16).

The container with the absorbent material is taken to a waste disposal area in another building. For the transport, labelling is applied in accordance with ADR/VLG.

Table 3.1: Table to determine transport index and category based on radiation level surrounding a package (NVS Publication 32).

Radiation conditions		
Transport index	Maximum radiation level $\dot{H}^*$ at any point on the surface of the package	Category
0†	$\dot{H}^* <= 5$ µSv/h	I-WHITE
0 < TI <= 1	5 µSv/h < $\dot{H}^*$ <= 500 µSv/h	II-YELLOW
1 < TI <= 10	500 µSv/h < $\dot{H}^*$ <= 2,000 µSv/h	III-YELLOW
10 < TI	2000 µSv/h < $\dot{H}^*$ < 10,000 µSv/h	III-YELLOW‡
† If the measured value for the *transport index* is no more than 0.05, the transport index is 0		
‡ Transport may only take place under '*exclusive use*'.		

Question 3.4
Based on the radiation level calculated in Question 3b, determine which label must be attached to the container and what the transport index is. If you were unable to obtain an answer for Question 3b you may use the value of 1 mSv/h.

Question 4 Demonstration using a uranium source

An employee at a training institute has seen a description of a demonstration experiment about half-lives on the internet. Using a mixture containing uranyl nitrate ($UO_2(NO_3)_2$), he can produce a source with which he can demonstrate the half-life of one of the short-lived daughters of ^{238}U.

The description states that uranyl nitrate should be used, which contains uranium with its natural isotopic composition (natural uranium). Because uranyl nitrate is obtained by a chemical process, both ^{238}U and ^{235}U are only in equilibrium with the short-lived daughters. For ^{238}U these are the short-lived daughters ^{234}Th and ^{234m}Pa and for ^{235}U the short-lived daughter ^{231}Th.

Given:

- In the Nuclear Energy Act, fissionable materials are defined as: materials which contain a percentage of uranium, plutonium, thorium or other element, to be determined by a general administrative regulation;
- In the general administrative regulation referred to (Nuclear installations, fissionable materials and ores Decree), the percentage of uranium, plutonium or thorium in fissionable materials is set at 0.1%, 0.1% and 3% respectively, calculated by weight;
- The atomic mass of (natural) U, O and N is 238, 16 and 14 u respectively;
- The Avogadro constant is $6.02 \cdot 10^{23}$ atoms/mol;
- 1 u is equal to $1.66 \cdot 10^{-27}$ kg;
- Natural uranium consists of 99.3% ^{238}U atoms and 0.7% ^{235}U atoms;
- The total activity is defined as the activity of the uranium isotopes named above combined;
- This uranium also contains a very small amount of ^{234}U, but this is not important for the purpose of radiation protection and may therefore be ignored here;
- The decay constants of ^{238}U and ^{235}U are $4.92 \cdot 10^{-18}$ s^{-1} and $3.12 \cdot 10^{-17}$ s^{-1} respectively;
- The ambient dose equivalent rate constant *h* of ^{238}U+ (including short-lived daughters ^{234}Th and ^{234m}Pa)[1] is 0.041 μSv/h MBq^{-1} m^2 and that of ^{235}U+ (including short-lived daughter ^{231}Th) is 0.239 μSv/h MBq^{-1} m^2;

[1] from ORNL/RSIC-45, "Specific Gamma-Ray Dose Constants for Nuclides Important to Dosimetry and Radiological Assessment", May 1982.

- In the demonstration source too, ^{238}U and ^{235}U are in equilibrium with their short-lived daughters. Other radionuclides from the ^{238}U and ^{235}U series respectively may be neglected (therefore also ^{234}U);
- It is not necessary to take into account the alpha and beta particles emitted by the mixture in this question.

Question 4.1
Show that uranyl nitrate is a fissionable material according to the definitions given in the Nuclear Energy Act and the Nuclear installations, fissionable materials and ores Decree.

The training institute license states that a maximum of 15 grams of natural uranium may be used in the institute. The employee also wants to use the source outside the institute, which means it needs to be transported by road.

Additional information:

- The following activities are exempt from the Transport of fissionable materials, ores, and radioactive substances Decree:
  - The maximum activity of ^{238}U is less than 10 kBq;
  - The maximum activity of ^{235}U is less than 10 kBq;
- A package is exempt if:
  - The ambient dose equivalent rate on the package surface is less than 5 μSv/h.

Question 4.2
Show by a calculation that 15 grams of natural uranium is not exempt under the Transport of fissionable materials, ores, and radioactive substances Decree. If you are unable to calculate the activity, use the values $A_{U\text{-}238}$ = 190 kBq and $A_{U\text{-}235}$ = 10 kBq for the rest of this question.

The employee wants to use an exempted package to transport the demonstration source so that the package is not subject to regulations. It is assumed that the source material and exempted; package do not offer any radiation protection.

Question 4.3

Determine whether the demonstration source with 15 grams of natural uranium in solution as uranyl nitrate may be transported as an exempted package. The package has the form of a cube and measures 30 x 30 x 30 cm^3. The source may be assumed to be a point source in the centre of the package.

The training institute also wants to use the demonstration source outside the institute. A dose calculation is made to apply for the license. It is assumed that the training institute employee will be in contact with the demonstration source at a distance of 30 cm from the point source for 30 minutes. The employee will give the demonstration ten times a year.

Question 4.4

Calculate the ambient dose equivalent per year for the training institute employee as a result of giving the demonstrations.