Coordinated examination in radiation protection Expertise Level 3

Nuclear Research and Consultancy Group

	NRG
Delft University of Technology	TUD
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Examination date: 14 December 2015
Duration of examination: 13:30-16:30

Instructions:

- **This examination comprises 10 numbered pages (1 page less than the Dutch version, due to translation) and a separate 21-page appendix containing data. Please check whether it is complete!**
- 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 allowed to consult books, personal notes and other documentation materials when answering the questions.
- *You are explicitly reminded that you must also indicate the **calculation method** and/or **reasoning** that you used in order to arrive at the solution*.
- If you cannot calculate part of a problem and the answer is needed to solve the rest of the problem, you may assume a fictitious answer.
- Some problems may not require you to use all of the data provided.
- You can earn a total of 67 points for solving the problems correctly. The points are distributed across the problems as follows:

  Problem 1: 16 points
  Problem 2: 17 points
  Problem 3: 17 points
  Problem 4: 17 points

Problem 1 Radiation protection measures when using ^{18}FDG

Patients are examined in a nuclear medicine department by administering a radiopharmaceutical. A radiopharmaceutical is a radioactive material that is selectively absorbed by a single organ or a limited number of organs. This question is about examinations using the radiopharmaceutical ^{18}F-fluorodeoxyglucose (^{18}F-FDG). The activity distribution can be seen on a PET (Positron Emission Tomogram) scan.

A department worker is about to use ^{18}F-FDG for the first time and wants to find out what his additional radiation exposure will be while working with the radionuclide ^{18}F. He carries out some calculations based on the procedure below.

The ^{18}F-FDG is contained in a syringe (made of polyethylene) encased in a 15 mm-thick lead shield. It is administered to the patient by means of an IV system that connects the syringe to the patient. Administering the ^{18}F-FDG takes 20 seconds. As well as administering the radiopharmaceutical the worker carries out various other actions, but these can be disregarded from the perspective of radiation protection.

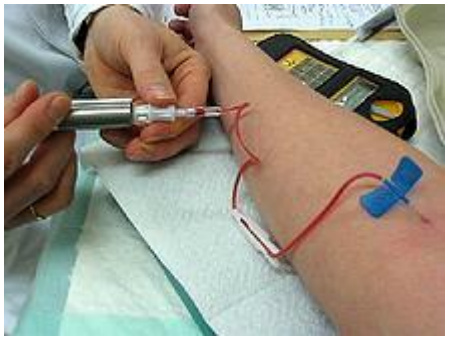

Figure 1 IV system in which only the syringe is shielded.

Data:

- **Appendix pg. 3-4** : Handboek Radionucliden [Radionuclides Handbook], A.S. Keverling Buisman (2nd edition 2007), pp. 26-27, data on ^{18}F;
- **Appendix pg. 5** : Figure 1: Half-value layer of various shielding materials for narrow beam photon radiation (Bos et al., p. 266);
- **Appendix pg. 6**: Figure 2: Build-up factors for an isotropic point source (Bos et al., p. 268);
- The activity at the time of administration is 400 MBq;
- The syringe – filled with ^{18}F-FDG – can be regarded as a point source in all situations;

- The attenuation of photon radiation by polyethylene can be disregarded;
- $\rho_{polyethylene} = 0.94\ g \cdot cm^{-3}$.

Question 1.1

Calculate the minimum thickness of the polyethylene wall of the syringe required to shield all β^+ particles.

During administration the radiopharmaceutical is in the unshielded IV system between the syringe and the patient for 20 seconds.

Question 1.2

Calculate the ambient dose equivalent ($H^*(10)$) at 50 cm from the IV system due to the 20 seconds of administration. At a distance of 50 cm the IV system can be regarded as a point source. Do not include the contribution due to the β^+ particles in the calculation.

The worker's hand is at a distance of 10 cm from the centre of the syringe shielded with 15 mm lead.

Question 1.3

Calculate the $H^*(10)$ at the worker's hand due to the 20 seconds of administration, taking the lead shielding of the IV system into account.

One hour after administration the PET examination begins, with imaging lasting 45 minutes. During the entire examination the worker keeps a distance of 2.5 metres from the patient.

- At this distance, the activity in the patient may be regarded as a point source.
- The attenuation of the photon radiation in the patient or by equipment can be disregarded.
- For the calculation below, the ambient dose equivalent rate half-way through the examination may be used to calculate the ambient dose equivalent rate for the worker during the entire examination.

Question 1.4

Calculate the ambient dose equivalent ($H^*(10)$) at the position of the exposed worker during the examination.

Problem 2 Exposure when calibrating radiation measuring equipment

The Radiation Protection Decree states that the proper operation and correct use of sources and equipment for measuring ionising radiation must be checked regularly, at least once a year. A licensee with a lot of measuring equipment has a number of sealed sources, including a ^{60}Co source with an activity of 22 GBq. This ^{60}Co source is used in a calibration room (see Fig. 1). While the source is in use, the operator is in the room at a distance of 2 metres from the source.

The source is contained in a source holder, which is shielded in such a way that there is no measurable increase in the ambient dose equivalent rate outside the source holder relative to the background. During calibration the source is raised until it is in front of the opened diaphragm in the source holder. The measuring instrument is positioned beforehand so as to be entirely in the collimated beam.

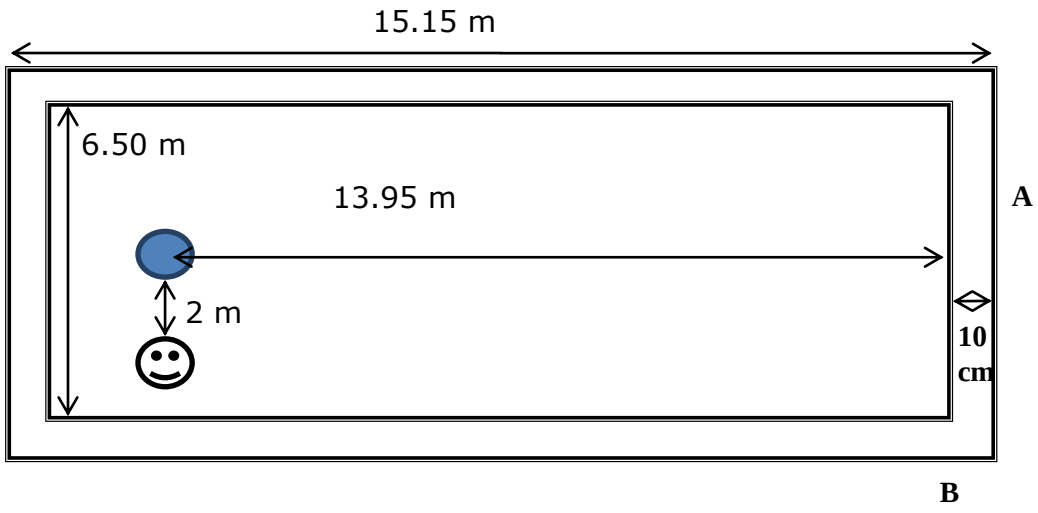

Fig. 1. Diagram of the calibration room as seen from above (not to scale)

Data

- **Appendix, pg. 7-8 :** Handboek Radionucliden [Radionuclides Handbook], A.S. Keverling Buisman (2nd edition 2007), pp. 74-75, data on ^{60}Co;
- **Appendix, pg. 9 :** Annex 1.3 to the Radiation Protection Implementing Regulation (Economic Affairs): Activity values above which a sealed source meets the definition of a high-activity source

Question 2.1

Calculate whether the calibration source described is a high-activity source.

Additional data

- **Appendix, pg. 10:** ICRP 33, pg. 49, figure 18, Broad-beam transmission of gamma rays from radionuclides through concrete;
- **Appendix, pg. 11:** ICRP 33, pg. 47, figure 16 Broad-beam transmission of gamma rays from radionuclides through lead;
- **Appendix, pg. 12:** ICRP 33, pg. 56, figure 22: Scatter fraction of incident kerma rate on concrete wall;
- Appendices pg. 10 and 11 may also be used for scattered radiation;
- The source is at a distance of 3.25 m from the inside of the long sides and 13.95 m from the opposite short side;
- The wall around the room is made of 10 cm-thick concrete;
- Point A is just on the outside of the room, in the primary beam;
- Point B is just on the outside of the room at the scatter point, at an angle of 90º to the point where the radiation beam hits the wall;
- The operator uses the source on average one hour a day, five days a week, 40 weeks a year, no other work is done in the room;
- The operator is at the same height as the diaphragm in the source holder;
- The source may be regarded as a point source;
- The scatter area on the opposite side of the calibration room is 3 m in diameter;
- The radiation scatter from the monitor being calibrated, ceiling and floor is negligible compared with the radiation scatter from the scatter area of the wall;
- The effective dose may be approximated with the ambient dose equivalent.

In order to comply with the internal limit of 1 mSv/j for the effective dose at point A, lead shielding is applied to the inside of the wall.

Question 2.2

Calculate the thickness of lead required to comply with the 1 mSv/j limit in the primary beam at point A. Round the answer to whole cm.

Question 2.3

Calculate whether the ambient dose equivalent ($H^*(10)$) at the outside of the long wall at point B complies with the 1 mSv/j limit.

Question 2.4

Calculate whether, based on these actions alone, the operator should be classified as a category A or category B exposed worker or does not need to be classified as an exposed worker.

Problem 3 Internal contamination with ^{210}Po

A couple of years ago, the Russian ex-spy and dissident Alexander Litvinenko was murdered by being served poisoned tea. The tea contained the radioactive isotope ^{210}Po. You wish to use your knowledge of radiation protection to determine the minimum amount of ^{210}Po that would have been used.

Data

- **Appendix, pg. 13-14 :** Handboek Radionucliden [Radionuclides Handbook], A.S. Keverling Buisman (2nd edition 2007), pp. 228-9, data on ^{210}Po;
- **Table 1:** Mass, tissue weighting factor and LD_{50} for α radiation in various organs;
- For the purposes of this problem, 'critical organ' means the organ for which the lowest administered activity is required to reach the LD_{50};
- The absorbed doses in the liver and red bone marrow after ingestion of 1 Bq ^{210}Po are $6.7 \cdot 10^{-8}$ Gy and $2.7 \cdot 10^{-8}$ Gy, respectively.

Table 1. Mass m_T, tissue weighting factor w_T (from ICRP 60) and LD_{50} for α radiation

Organ	m_T (g)	w_T (ICRP-60)	LD_{50} (Gy)
Liver	1800	0.05	8
Kidneys*	310	0.025	6
Red bone marrow	1500	0.12	3–4

* One of the other ten organs that together have a weighting factor of 0.05. If one of these organs is exposed to a higher equivalent dose than any other organ with its own tissue weighting factor, $w_T = 0.025$ will be used for that organ. In this case this would apply to the kidneys.

Question 3.1

Demonstrate that the effective half-life of ^{210}Po in the organs listed is 37 days.

Question 3.2

Verify through calculation that ingestion of 1 Bq ^{210}Po results in an absorbed dose of $1.3 \cdot 10^{-7}$ Gy in the kidneys.

Question 3.3

For each of the organs listed in Table 1 state what activity on ingestion results in an absorbed dose equal to the LD_{50}. Based on the results, determine which of the three organs listed should be regarded as the critical organ.

You assume that Litvinenko's murderers wanted to make sure he would not survive, and that he was therefore poisoned with *twice* the activity for the critical organ calculated in Question 3. After being poisoned, Litvinenko left behind a trail of ^{210}Po, which in turn contaminated third parties. You assume that the most highly contaminated person ingested 0.01% of the original activity.

Question 3.4

Calculate the committed effective dose due to ingestion for this person.

If you found no answer for question 3.3 you can use the value $1 \cdot 10^8$ Bq.

Problem 4 Determining zirconium silicate activity

Zirconium silicate is used in in the industrial manufacture of ceramics and as a sanding and polishing material. Zirconium is a mineral that is obtained from the earth's crust. Its structural formula is $ZrSiO_4$. When zirconium silicate is extracted, however, natural radionuclides of the uranium and thorium series are brought up with it, so the processing of zirconium silicate is regarded as a work activity as mentioned in the Dutch decree radiation protection.

200 kg of zirconium silicate remains as waste residue from a process. From this, a 2-kg sample is taken for gamma spectrometry analysis using an semi-conductor HPGe detector. The results for some characteristic peaks identified are shown in **Table 1**.

ROI No.	Nuclide	Photon energy [keV]	Gross count rate in ROI [cps]	Background count rate in ROI [cps]	Yield [photon/ disintegration]	Photo peak efficiency [counts/ photon]	Series (^{238}U or ^{232}Th)
1	^{234Th}	93	53.3	18.2	0.058		
2	^{214}Pb	352	159.2	22.4	0.376		
3	^{208}Tl	583	42.5	15.6	0.845		
4	^{228}Ac	911	30.0	10.6	0.258		

Table 1 Measurement data and nuclide information. The background count rate is in effect the count rate of the continuum in the relevant Region of Interest.

Data:

- **Appendix pg.15, Figure 3:** Efficiency calibration for the HPGe detector in the measuring conditions used (photo peak efficiency in counts per photon);
- **Appendix pg. 16-21:** Handboek Radionucliden [Radionuclides Handbook], A.S. Keverling Buisman (2nd edition 2007), pp. 230-235, data on ^{232}Th, ^{238}U and ^{226}Ra.

Question 4.1

Based on the data on the ^{238}U and ^{232}Th decay series and efficiency calibration in Fig. 1, determine what values should be entered in the empty cells in Table 1. Enter these values in your worksheet (the photo peak efficiency for each ROI and the series containing the nuclide).

Calculate Questions 4.2, 4.3a and 4.3b using only the nuclides in the thorium series.

Question 4.2

Calculate the activities of the nuclides identified of the thorium series.

The measuring time for both the zirconium and the background was one hour.

Question 4.3a

Calculate the 95% confidence interval in the activities identified for the nuclides of the thorium series.

Question 4.3b

Argue whether the ^{232}Th series is in secular equilibrium.

To determine whether the waste can be released, the values found are compared with the clearance limits in the Radionuclides Handbook.

If you did not find secular equilibrium in Question 3b, apply the (conservative) calculation rule using the highest activity identified in the thorium series as if the entire series was in equilibrium with it.

Additional data

- The ^{238}U concentration in the zirconium waste is 14 kBq/kg. The uranium series is in secular equilibrium.

Question 4.4

Does 200 kg of zirconium silicate exceed the exemption limits, or can it be released? Motivate your answer.