Coordinated examination in radiation protection Expertise Level 3

Nuclear Research and Consultancy Group	NRG
Delft University of Technology	TUD
Boerhaave CME/LUMC	BN
University of Groningen	RUG
Radboud University/UMC St. Radboud	RU/UMC
TU Eindhoven	TUE

Examination date: 12 May 2014
Duration of examination: 13:30-16:30

Instructions:

- **This examination comprises 12 numbered pages and a separate 11-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: 18 points
  Problem 2: 16 points
  Problem 3: 17 points
  Problem 4: 16 points

Problem 1 Patient toilet

In the Nuclear Medicine department of a hospital, one of the toilets has recently been set aside for the exclusive use of patients coming in for a bone scan. They are administered, by injection, with activity of 600 MBq ^{99m}Tc HDP. HDP is a phosphate compound absorbed specifically by bone tissue.
Three hours after the injection, and immediately prior to gamma camera imaging, the patient is asked to go to the toilet and empty their bladder as much as possible. This aids image quality. The patient has not been allowed to use the toilet in the intervening period since the injection.
In emptying their bladder, the patient excretes 40 per cent of the radioactivity present in their body. The remaining 60 per cent has already been absorbed by bone and other tissues.

A new patient is scanned each hour on every weekday (five days a week). The first visits the toilet just before the scan at 11.00. The sixth and final patient of the day goes at 16.00.
The toilet is cleaned at 17.00. The cleaner is not designated as an "exposed worker", but has received instruction on how to clean the facility safely without prior decontamination by a radiological worker. The same person cleans the toilet daily throughout the year (50 working weeks), taking 10 minutes to do so. On average, he is 50 centimetres away from the contamination during this time.

Supporting data

- **Appendix, pp. 3-4**: Handboek Radionucliden, [Radionuclide Manual], A.S. Keverling Buisman (second edition, 2007), pp. 124-125: ^{99m}Tc.

Question 1.1

Assuming that each patient "spills" 0.1 per cent of their urine on the toilet floor, and also that no residual activity remains from the previous day, calculate the amount of activity the cleaner has to dispose of at the end of each day.

Question 1.2

Determine whether the cleaner's annual external dose limit is exceeded at the level of daily contamination described above. If you have been unable to answer Question 1, assume a level of daily contamination of 1 MBq.

The department's radiation expert wishes to verify the assumption that each patient "spills" 0.1 per cent of their urine on the toilet floor. To do this, she takes a sample of 1 ml of the detergent solution (total volume = 5 litres) used to clean the floor. The area cleaned measures 2 m^2 and "cleaning efficiency" is 100 per cent (that is, all the activity present is transferred to the solution). The net recorded activity is 5 cps (counts per second), with an efficiency of 0.20 counts per photon. Only the 141 keV photons are measured. The sample is taken and measured immediately after the toilet has been cleaned, so decay between sampling and measurement can be ignored.

Question 1.3
Determine whether the assumed spillage rate of 0.1 per cent is reasonable. Show your calculation.

One of the cleaner's latex gloves is sometimes contaminated whilst cleaning the toilet floor. On average, this occurs once a week at a level of 10 kBq over a surface area of 10 cm^2. After contamination, the glove is worn for another 15 minutes.

Question 1.4
Assuming that the contamination always affects the same part of the glove, what is the annual equivalent dose to the skin under the contaminated area?

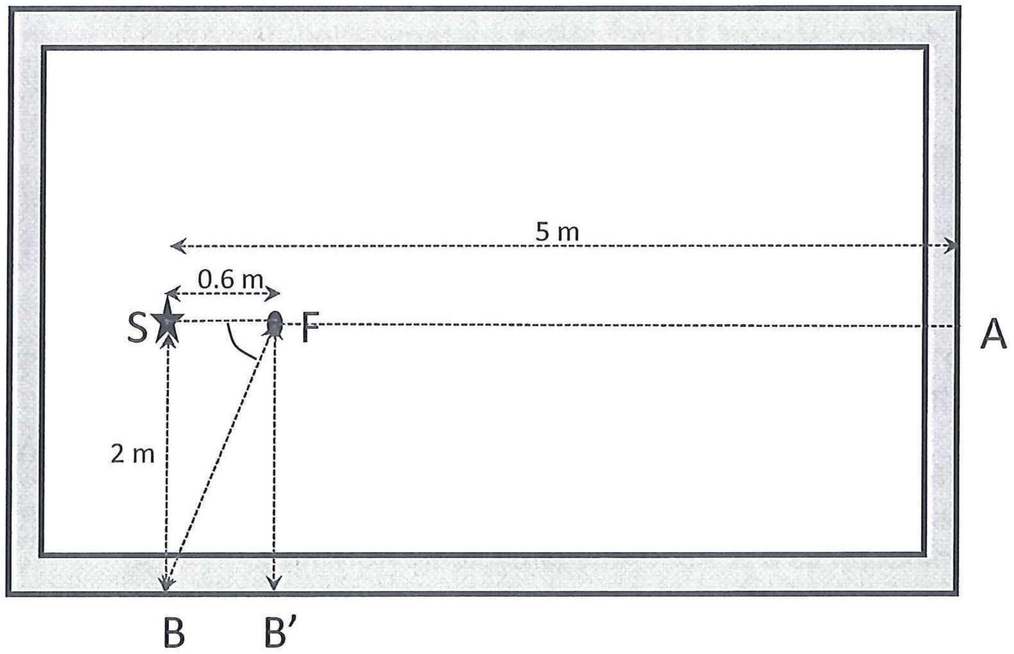
Due to unhygienic working practices, once a month the cleaner ingests the entire activity (10 kBq) from one of his contaminated gloves.

Question 1.5
What is the cleaner's annual committed effective dose from internal contamination as a result of his unhygienic working?

Problem 2 ^{60}Co source shielding

A research institute wants to set up a facility for the irradiation of phantoms using a ^{60}Co source. You are asked to calculate how much shielding the walls of the designated room require. The source's position is shown in the diagram below (view from above). During irradiation, it is located at point S and the primary beam is directed along line SA. The tissue-equivalent phantoms to be irradiated are positioned at point F.

The irradiation unit's control panel is situated at point B. Points B and B′ have been positioned so that lines SB and FB′ are at perfect right angles to line SA. Points A, B en B′ are all just outside the concrete walls of the irradiation area.



Irradiation area viewed from above (not to scale).
Other measurements:

- Distance FB is 2.09 m;
- Angle SFB is 73.3^0.

The source can be positioned at three points inside the irradiation area.

1. Close to the floor, fully shielded, no radiation leakage.
2. In the head of the unit at irradiation point S, 1.5 m above the floor, for 15 hours a week with the shutter closed.
3. In the head of the unit at irradiation point S, 1.5 m above the floor, for five hours a week with the shutter open.

Supporting data

- **Appendix, p. 5**: Broad beam transmission of gamma rays from various radionuclides through concrete. (based upon ICRP Publication 33, 1982, p. 47)
- **Appendix, p. 6**: Scattering percentages in concrete of various photon energies (based upon ICRP Publication 33, 1982, p. 56). For the purposes of this problem, this diagram can also be used for scattering to a tissue-equivalent phantom.
- **Appendix, p. 7**: Broad beam transmission of ^{60}Co gamma radiation scattered at various angles from a patient-simulating phantom through concrete (based upon ICRP Publication 33, 1982, p. 60)
- Unshielded, the ^{60}Co source produces an absorbed dose rate of 100 Gy/h in tissue at a distance of 1 metre.
- With the source positioned at point S, through leakage radiation the unit produces an absorbed dose rate of 2.0 mGy/h in tissue at a distance of 1 metre from point S.
- The source is in use 50 working weeks a year.
- The field size of the primary radiation at point F, the area of entry into the phantom, is 20 cm × 20 cm.
- Points A, B and B′ are all 1.5 m above the floor.
- For members of staff working at points A, B and B′, the maximum permitted weekly dose is 0.020 mSv. This corresponds with 1.0 mSv per annum, based upon a working year of 50 working weeks.
- A residence factor ("verblijffactor") of 1 is assumed for these members of staff.
- In your calculations, you may assume that the ratio of effective dose to absorbed dose is 1 Sv/Gy.

Question 2.1

Calculate the required thickness of the concrete wall between points S and A, taking into account the primary beam and radiation leakage. You do not need to consider any shielding by the phantom.

Question 2.2

Demonstrate that, taking into account only the radiation leakage, the required thickness of the concrete wall between points S and B is 63 cm.

In reality, however, you also need to consider the radiation scattered by the phantom.

Question 2.3
Calculate the dose rates, in Gy/week, of the radiation scattered by the phantom at both point B and point B′ without the wall in place between points S and B/B′.

Question 2.4
Determine the thickness of wall needed for points B and B′ to satisfy the defined requirements, taking into account only the scattered radiation.

Problem 3 ^{207}Bi source leakage test

The holder of a ^{207}Bi source bears a label reading "^{207}Bi 100 μCi 12 May 1966". During a regular leakage test on 12 May 2014, the holder is wiped by the supervising radiation expert (level 3). A check with a Ge detector reveals that the wipe is radioactive. The expert has to decide what action to take.

Data:

- **Appendix, p. 8**: MIRD data for ^{207}Bi (http://www.nndc.bnl.gov/mird/).
- **Appendix, p. 9**: Table and excerpt from the draft Directive on Sealed Radioactive Sources.
- Table 1: Net content of the most important photopeaks in the gamma spectrum, measured over 10,000 seconds.
- Figure 1: Measured counting efficiency (defined as the number of recorded pulses per emitted photon).
- The ambient dose equivalent rate constant for ^{207}Bi is defined as $h = 0{,}2\ \mu Sv \cdot h^{-1} \cdot m^2 \cdot MBq^{-1}$.
- It may be assumed that only photons are emitted from the source holder and that photon absorption by the holder is negligible.
- It may be assumed that H*(10) is a good estimator for the effective dose.
- The dose conversion coefficient for ingestion ^{207}Bi is $e_{ing}(50) = 1{,}3 \cdot 10^{-9}\ Sv \cdot Bq^{-1}$.

Table 1 Net content of the most important photopeaks in the gamma spectrum, measured over 10,000 seconds.

Photopeak energy (in keV)	Net photopeak content (pulses per 10^4 s)
570	1778
1064	941
1770	73

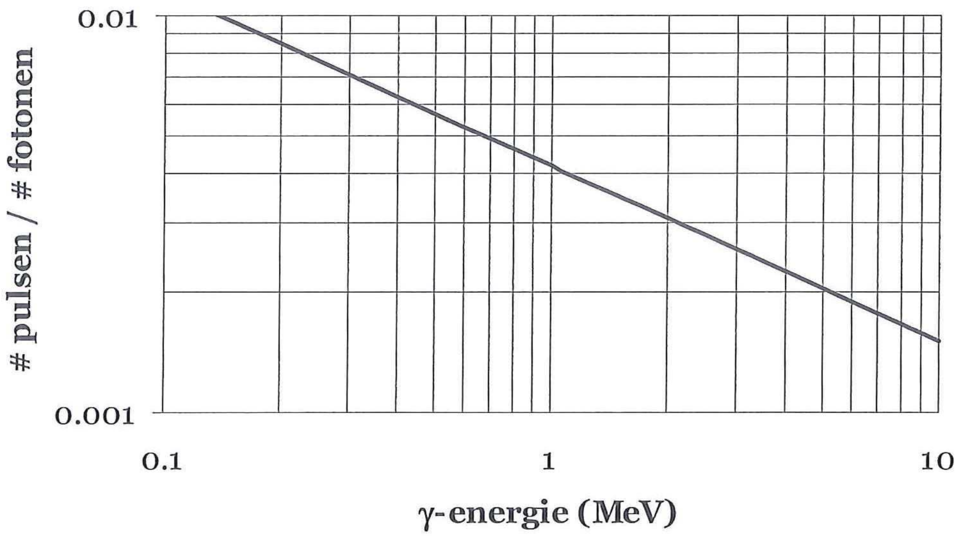


Figure 1: Measured counting efficiency (defined as the number of recorded pulses per emitted photon).

Question 3.1
Determine whether the draft Directive on Sealed Radioactive Sources requires that the source itself be wipe tested. Base your answer upon the source's activity on 12 May 2014, assuming that the details on the label are correct.

Question 3.2a
Calculate the wiped activity, based upon the net content of the photopeak measured with the smallest relative error. Explain your choice of photopeak.

Question 3.2b
Calculate the standard deviation for the wiped activity calculated in question 3.2a. You need only take into account the net number of pulses; the contribution of the standard deviation of the background measurement can be ignored.

Question 3.3
Describe what should be done, given the level of contamination identified. If you have been unable to answer question 3.2b, then for this question you may assume a measured wiped activity level of 100 Bq.

Question 3.4

Calculate the effective dose from external exposure whilst carrying out the leakage test. Assume that the test took 1 minute to complete and that the average distance between the source and the tester's body during this time was 50 cm.

Problem 4 Contaminated pigeons

Pigeons at reprocessing plant found to be highly radioactive
Pigeons living close to the Sellafield nuclear waste reprocessing plant in the UK are highly radioactive, according to tests carried out for Greenpeace. The environmental organisation claims that, under European standards, the birds should be treated as radioactive waste. Substantial quantities of ^{137}Cs have been found in their plumage, flesh and droppings. The feathers of some birds are so contaminated, says Greenpeace, that skin contact with just 0.3 per cent of their caesium content would deliver the maximum permitted human dose for an entire year.

De Volkskrant, 12/03/1998

A radiation expert saw this newspaper report after taking a holiday near Sellafield. Curious as to whether it was accurate, he decided to make some calculations based upon the details provided.

Supporting data

- **Appendix, pp. 10-11**: Handboek Radionucliden, [Radionuclide Manual], A.S. Keverling Buisman (second edition, 2007), pp. 172-173: ^{137}Cs.
- ^{137}Cs is in equilibrium with its daughter isotope, ^{137m}Ba.
- In the event of skin contact between a human and a pigeon, 30 cm^2 of the person's skin is contaminated with the 0.3 per cent of plumage caesium activity mentioned in the article.
- Brief contact with a pigeon results in contamination that remains on the skin of the hands for a period of one hour.
- The mass of a pigeon is 800 grams.
- The average total skin area of a typical human being is 17,000 cm^2.

Question 4.1

Determine the activity in the pigeon's plumage, based upon the one-hour period of skin contamination. Assume that the dose to the skin corresponds with the annual equivalent skin dose limit for a member of the public, and that this contact is the only source of such a dose during the year.

If you have been unable to answer question 4.1, then for the remainder of this question you may assume that the activity in the pigeon's plumage is 300 MBq.

Question 4.2
Determine whether, based upon the activity in their plumage, these pigeons should indeed be disposed of as radioactive waste after death.

The radiation expert was quite shocked by the amount of activity found in answering question 1 and wondered what effect the contamination would have if the person affected did NOT wash their hands. He therefore calculated the effective dose resulting from one-time contamination of the hands, using as a worst-case scenario the assumption that the hands are not washed at all and that the activity finally disappears after five days through linear wear.

Question 4.3
Following one-time contamination of the skin, what contribution does the equivalent skin dose make to the effective dose in the above worst-case scenario? Assume that the equivalent dose may be interpreted as a stochastic dose.

The kind of contamination described above may be caused by holding the pigeon. In that case, as well as skin contamination there will also be exposure of the body to external radiation emanating from the bird when in close proximity to the subject.
In this situation, the centre of the pigeon is 30 cm from the person's body. Since a pigeon has a wing span (maximum dimension) of some 40 cm, the point source method cannot be applied.
According to DOVIS-B,[1] the bird can be treated as "extended" if its breadth is no more than 8 cm (1/5 × 40 cm). The radiation expert assumes that this is the case and so uses the following formula:[2]

$$\dot{H}^*(10,g) = \frac{2A}{L_{max}}\frac{h(10)}{g}\tan^{-1}\left(\frac{L_{max}}{2g}\right)$$

where L_{max} is the pigeon's maximum dimension (in metres) and g is the distance to its centre (in metres). A is the activity (in MBq), $\dot{H}^*(10,g)$ is the ambient dose equivalent rate (in μSv/h) at distance g and h(10) is the ambient dose equivalent rate constant (in μSv/h per MBq at 1 m).

1 Dosisberekening voor de Omgeving bij Vergunningverlening Ioniserende Straling – DOVIS Deel B: Externe Straling [Ambient Dose Calculation for Use in Ionising Radiation Licensing – DOVIS Part B: External Radiation], J. F. A. van Hienen et al. (2002).

2 $tan(\alpha) = \frac{L_{max}}{2g}$; $\alpha = \arctan\left(\frac{L_{max}}{2g}\right)$ of $\alpha = \tan^{-1}\left(\frac{L_{max}}{2g}\right)$; α in radians,

Question 4.4

Using the extended source method, determine the ambient dose equivalent from the external radiation if the pigeon is held for 10 seconds. Assume that the activity calculated in question 4.1 is distributed evenly over the bird.