Examination Co-ordinating Radiation Protection Expert

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Delft University of Technology	TU Delft
Boerhaave CME/LUMC	BN/LUMC
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Examination date: 12 December 2016

Duration of examination:
13:30 - 16:30

Instructions:

- **This examination comprises 11 numbered pages and a separate 14-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 permitted to consult books, personal notes and other relevant documentation 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 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 problems may not require you to use all of the data provided.
- You can earn a total of 63 points for solving the problems correctly. The points are distributed across the problems as follows:

  Problem 1: 17 points
  Problem 2: 15 points
  Problem 3: 17 points
  Problem 4: 14 points
- You will pass this examination if you obtain at least 55% of the total number of points. This corresponds to a minimum score of 34.65 points.

Problem 1 Shielding of a PET scanner

A hospital intends to purchase a PET scanner for examining patients injected with the radiopharmaceutical substance ^{18}F fluorodeoxyglucose (FDG). ^{18}F is a positron emitter that emits photons of 511 keV.
After the injection of the radiopharmaceutical substance, the patient must lie still for 60 minutes in a waiting area designated for that purpose until this radiopharmaceutical substance has been absorbed by the relevant organs. The patient must subsequently excrete the non-absorbed radioactivity, concentrated in the bladder, by means of urination. The PET scans are initiated immediately afterwards. The scans last 30 minutes per patient. A scanner room with a separate control room and two waiting areas is used in the department (see Figure 1).

You are asked to calculate how much shielding the rooms require. The starting point for this calculation is that the contribution to the effective dose in the hallway (reference point A, Fig.1) resulting from these examinations does not exceed 1 mSv/y.

Assumptions

- The patient can be considered a point source in all calculations.
- Every patient ('P') is located in the centre of one of the waiting areas. The scanner room distances are indicated by help lines (see Figure 1).
- The extra path length that the radiation traverses in the wall when it passes through it diagonally does not need to be taken into account.
- The ambient dose equivalent is a good approximation of the effective dose.
- The average transmission due to shielding by the PET scanner is 10%.

Supporting data

- **Appendix, pp. 3-4**: *Handboek Radionucliden*, [Radionuclides Handbook], A.S. Keverling Buisman (2nd edition 2007), pp. 26-27, ^{18}F data.
- The number of patients per year is 1500, equally distributed over both waiting areas.
- The injected activity per patient is 750 MBq.
- The self-absorption of 511 keV photons in the body of the patient amounts to 36% (AAPM Task Group 108 report).
- The excreted fraction after 60 minutes corresponds to 30% of the activity injected into the patient.

- For dose calculations during the decay of ^{18}F, a value corresponding to the correction factor (cf_{decay}) × the activity at t=0 may be chosen for an average activity over a certain period of time.
  - average over 30 minutes: cf_{decay} = 0.911
  - average over 60 minutes: cf_{decay} = 0.832
- Figure 1: Floor plan of the room
- **Appendix, p. 5**: Figure 2: Half-value layer of different shielding materials for narrow-beam photon radiation (p. 266, Bos et al.)
- **Appendix, p. 6**: Table 1: Broadbeam transmission factors at 511 keV (AAPM Task Group 108 report)
- **Appendix, p. 7**: Table 2: Build-up factors for an isotropic point source
- The occupancy rate at point A (hallway) is 0.2.
- The occupancy rate at point B (control room) is 1.0.

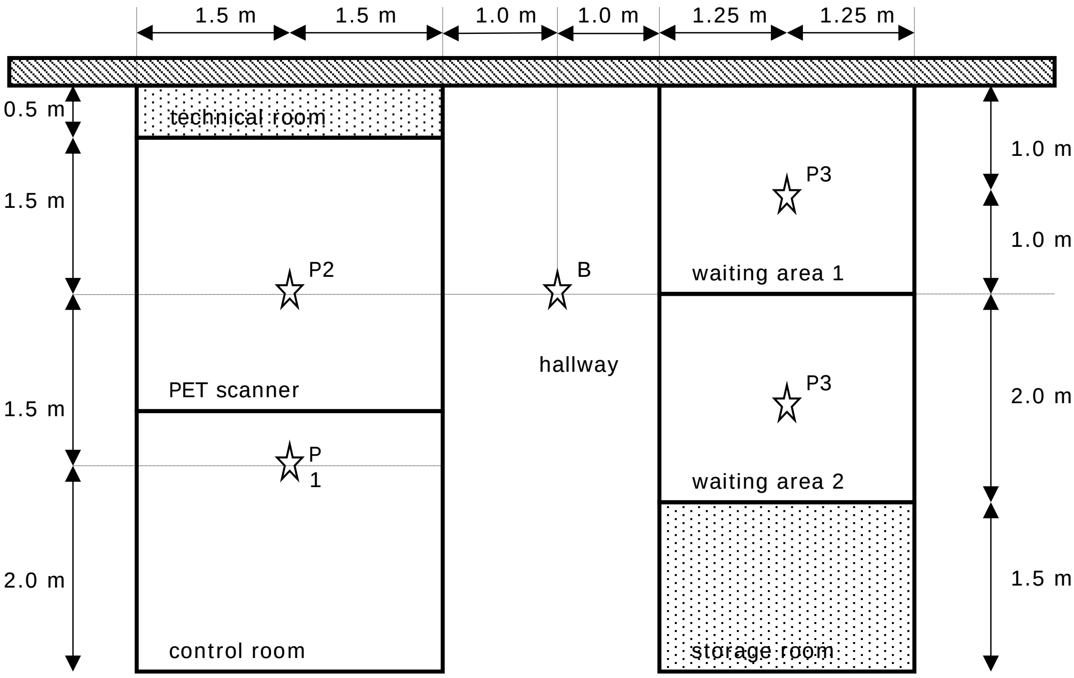

Figure 1: Floor plan of the room

Question 1.1a

Determine the contribution to the effective annual dose resulting from all patients (P2 and P3) in both waiting areas at point A in the hallway. Disregard the shielding effect of the walls.

Question 1.1b

Now determine the contribution to the effective annual dose at point A resulting from the patients who are scanned with the PET scanner under the same conditions as in question 1.1a.

Question 1.1c

Demonstrate that the total contribution to the effective dose for a person at point A – in the case of an occupancy rate of 0.2 – is equal to 4 mSv/y.

Question 1.2

Demonstrate that the amount of lead shielding (in whole mm) required in the walls on the hallway side to keep the contribution to the effective annual dose for a person at point A below 1 mSv is approximately 10 mm. Take the occupancy rate of this hallway into account. As a starting point, assume that the transmission from the scanner room is equal to the transmission from the waiting areas.
Use Table 1 (broad beam) for the transmission factors.

To be on the safe side, you wonder if the transmission label from the AAPM report (Table 1) is correct.
You therefore want to verify the values from Table 1 using Figure 2 (half-value layer of a narrow beam) and Table 2 (build-up factors).

Question 1.3

With the help of Figure 2 and Table 2, calculate the transmission for 10 mm of lead shielding and determine if this transmission deviates more or less than 10% from the value previously determined in Question 1.2.

Question 1.4

Argue that the total contribution to the effective annual dose at point B exceeds 1 mSv in the control room if the wall between the control room and the PET scanner room has the same transmission as the walls in the hallway.

Problem 2 Dietary salt

The following ingredients are listed on the label of a canister of low-sodium dietary salt:
97.3% potassium chloride (KCl), 0.2% magnesium chloride ($MgCl_2$),
14 different vegetables, herbs and seaweed. The stated percentages are percentages by mass.
A young radiation expert at a research institute reads this label and wonders if the activity of ^{40}K can be measured in this type of salt, since the salt mostly consists of potassium chloride. He therefore performs a number of measurements with detectors, using them in the manner in which they are used at his workplace.

Supporting data:

- The mass activity of ^{40}K in pure KCl is 16.2 Bq per gram of KCl. This 16.2 Bq may be regarded as a fixed figure, without a margin of error.
- **Appendix, pp. 8-9**: *Handboek Radionucliden*, [Radionuclides Handbook], A.S. Keverling Buisman (2nd edition 2007), pp. 42-43, ^{40}K data.

The expert first performs measurements with two contamination monitors: one with a Geiger-Müller tube (GM tube) and another with a sodium iodide crystal (NaI crystal). See the photo below, which shows, from left to right: The canister containing 125 g of dietary salt, the contamination monitor with GM tube (diameter = 3.8 cm) and the contamination monitor with NaI crystal (diameter = 4.0 cm). A marker in the foreground of the photo serves as a reference for the dimensions.

His first action is to sprinkle a 5-mm thick layer of the dietary salt in a petri dish. This petri dish has a diameter of 6.0 cm. He then performs a measurement with both monitors in the centre of the dish at 0.5 cm above the layer of salt, obtaining the following result:

Monitor with:	Background	Dietary salt measurement
GM tube	0.5 cps	4.0 cps
NaI crystal	4 to 5 cps	4 to 5 cps

Question 2.1

Based on the most important emitted radiation types of ^{40}K, provide a possible reason for why the measurement with the GM tube shows a clear increase.
In addition, provide a possible reason for why the measurement with the NaI crystal does not show an increase.

The measurements are now repeated with fixed set-ups.

GM measurement in a fixed set-up:
A very thin layer of 535 mg of dietary salt is spread out in a small container. This container is placed in a central position underneath a GM tube window. The window of the GM tube is somewhat larger than the container with salt and is located 1.0 cm above the salt layer.

Supporting data:

- The dead time of the GM tube in the fixed set-up is $3.2 \cdot 10^{-4}$ s.

The results of the measurement of 535 mg of dietary salt:

	Counts	Time (s)
Dietary salt measurement	994	999
Background measurement	499	999

Question 2.2

Calculate the counting efficiency of this measurement in cps/Bq. In addition, calculate the standard deviation in this counting efficiency.

NaI measurement in a fixed set-up:
The NaI measurement is also performed again in a fixed set-up. Dietary salt weighing 3.08 grams is measured in a plastic tube and counted in an NaI crystal well with a Multi Channel Analyzer, MCA. The photopeak is selected as a Region Of Interest, ROI. A measurement time of 20 hours (= 72,000 s) is set.

The results of the 20-hour measurement of 3.08 grams of dietary salt:

	Counts in the photopeak	Time (s)
Dietary salt measurement	121,526	72,000 s
Background measurement	104,589	72,000 s

Question 2.3

Demonstrate with a calculation that the NaI measurement with the dietary salt in the fixed set-up is now significantly higher than the background measurement (with a confidence interval of 99.7%).

Question 2.4

Determine the counting efficiency with this fixed NaI set-up in counts per second/photons per second (cps/pps).

Problem 3 Unanticipated consequence of iodine therapy

Early 2005, a 46-year-old tourist from Birmingham unintentionally triggered the alarm of a dose rate monitor in operation at the airport of Orlando. He was immediately detained by security, sniffer dogs were deployed and a long interrogation followed. Apparently, the man had been treated for hyperthyroidism six weeks earlier in England and had undergone iodine therapy. These types of incidents are said to be occurring with increasing frequency. [British Medical Journal 333 (2006) 293]

You want to determine the dose consequences of this therapy for the man and his environment, and determine when he will be able to pass through airport security without problems.

Supporting data:

- At the start of the iodine therapy, 400 MBq of ^{131}I was administered orally to the man.
- **Appendix, pp. 10-11**: *Handboek Radionucliden*, [Radionuclides Handbook], A.S. Keverling Buisman (2nd edition 2007), pp. 164-165, ^{131}I data
- **Appendix, p. 12**: Table: Tissue weighting factors, derived from ICRP-60
- You can assume that the information from the *Handboek Radionucliden* [Radionuclides Handbook] can also be used for this patient.
- The distance between the tourist and the detector was 0.5 metres.
- The threshold value that triggers an alarm is 5 nSv/h, which is a net count rate.
- The contribution of the γ photons and conversion electrons to the thyroid gland dose may be disregarded.
- The mass of the thyroid gland ($m_{thyroid}$) is 20 g.
- The conversion factor 1 eV = $1.60 \cdot 10^{-19}$ J.

Question 3.1

How many days after the application of the iodine therapy will the monitor still trigger an alarm at the airport? Shielding by the body tissue of the man can be considered negligible and therefore disregarded.

Question 3.2 a

Calculate the total number of disintegrations $U_{thyroid}$ (in Bq·s) in the thyroid gland.

Question 3.2b

Using the answer to Question 3.2a, calculate the dose $D_{thyroid}$ absorbed by the thyroid gland. If you were unable to obtain the answer to Question 3.2a, use

10^{14} disintegrations.

Question 3.3

Determine the committed effective dose for the man. In addition, demonstrate with a calculation that most of this committed effective dose is determined by the dose absorbed in the thyroid gland (also use the answer to Question 3.2b in your calculation).

The Englishman and his wife were accustomed to sleeping together every night in their double bed. Against the explicit advice of the hospital, they continued to do so after the iodine therapy.

Additional information:

- The Englishman left the hospital after the quick excretion phase – the direct excretion therefore occurred in the hospital.

Question 3.4

Estimate the effective dose that the woman receives in the nights following the iodine therapy as a result of the ^{131}I activity. State the assumptions required to make this estimation.

Problem 4 Veterinary practice

At a veterinary practice, veterinary diagnostic procedures are performed on pets and small farm animals. The practice therefore has an X-ray device with a maximum tube voltage of 100 kV at its disposal. In accordance with Article 10 of the Radiation Protection Decree, a risk analysis has been performed for the use of this device.
The procedure for which the risk analysis was performed is the taking of X-ray photographs of a pet. The regular procedure can be clearly described without dividing it into subprocedures. The technician operates the X-ray device at a distance of at least 0.25 metres from the primary beam. The veterinarian holds the animal and stands at a distance of at least 0.20 metres from the scattering surface of the primary beam. The X-ray tube is located above the table and the detector is located under the table.
Both employees wear a lead apron and a thyroid gland protector. The veterinarian also wears lead gloves, because he is holding the animal and wants to be protected in case his hands enter the primary beam.

Supporting data:

- **Appendix, p. 13**: Figure 3: Kerma rate free in air of X-ray radiation through lead
- **Appendix, p. 14**: Figure 4: Scattering fraction of kerma free in air
- Page 13 and 14 in the Appendix may be used for both the primary beam and the scattered radiation.
- It is assumed that 1000 X-ray photographs are taken each year.
- The device is used with a tube voltage of 75 kV.
- The tube current × time setting is 10 mAs.
- The entry dose rate may be approximated by the kerma rate free in air.
- The quantities absorbed dose (*D*) and effective dose may be approximated by the kerma rate free in air.
- The distance from the focus of the X-ray tube to the entry surface is 60 cm; the hands of the veterinarian are located at the same distance.
- The size of the entry field on the animal is 500 cm^2.
- The veterinarian is standing next to the animal; the scattering angle may be approximated to 90º.
- The lead aprons, thyroid gland protectors and gloves have a lead-equivalent thickness of 0.5 mm.
- A third person is never present in the room during the scans.
- In his specifications, the supplier of the lead gloves indicates a dose reduction of 40% for primary radiation and 80% for scattered radiation.

Question 4.1

Demonstrate that the entry dose of a single scan at the level of the scattering surface is equal to 2.8 mGy.

Question 4.2

Determine the maximum effective dose per year behind the lead apron at the level of the veterinarian.

According to the radiation risk analysis, the following event is considered the most probable expected unintended event:

> The hands come into contact with the primary beam, because the pet is held with two hands (and has not been sedated [=anesthetized]). The hands are normally placed next to the primary beam, but during one in ten scans the hands enter the primary beam when the non-sedated animal attempts to escape. In that case, you can assume that both hands are in the primary beam for the entire duration of the scan.

Question 4.3

Determine the equivalent annual dose resulting from this anticipated unintended event for both of the veterinarian's hands when the mentioned lead gloves are used, and indicate whether or not the legal limit for the hands of an exposed employee is exceeded.

Question 4.4

Explain why the protection factor of the lead gloves is lower in the case of exposure to the primary beam (40%) than in the case of exposure to scattered radiation (80%).