Exam
Radiation protection expert on the level of coordinating expert

Nuclear Research and consultancy Group	NRG
Delft University of Technology	TUD
Boerhaave Continuous Medical Education/LUMC	BN/LUMC
University of Groningen	RUG
Radboudumc	RUMC
Eindhoven University of Technology	TU/e

exam date: May 14th 2018
exam duration: 13.30 - 16.30 hours

Instruction:

- ☐ **This exam contains 9 numbered pages and a separate attachment containing 10 pages worth of data. Please check!**
- ☐ Write your solutions and answers on the worksheets provided. You will also need to hand in any unused worksheets at the end of the exam.
- ☐ Only state **your exam number** on the worksheets (so not your name and address).
- ☐ It is allowed to consult books, personal notes, and other documentation to answer the questions.
- ☐ When answering the questions, you have to state which **calculation** and/or which **reasoning** helped you reach the solution.
- ☐ If you are unable to calculate part of a question and you need that answer to be able to solve the other parts, you can assume a fictional answer.
- ☐ You do not necessarily need to use all of the data supplied to answer some of the questions.
- ☐ You can acquire a total of 58 points if you correctly answer all of the questions. The points are distributed between the questions as follows:

  Question 1: 16 points
  Question 2: 14 points
  Question 3: 15 points
  Question 4: 13 points
- ☐ You will have passed this exam if you have obtained at least 55% of the total amount of points. This corresponds to a score of at least 31.9 points.

Question 1: Shielding ^{166}Ho

There is a continuous search for new radionuclides for therapeutic applications. One of these isotopes is ^{166}Ho.
As producer, you are asked to pick a container and transportation package (Dutch:collo) in which the radionuclide, with an activity of 14 GBq per package, can be transported to hospitals. It concerns the transportation of a radioactive source above the exemption limit.

Once arrived at the hospital, the activity is placed in a delivery system. You place the source to be transported in a Perspex container to prevent the end-user from receiving a dose due to the beta radiation when transferring the source from the transport container to the delivery system.

Given:

- **Attachment, pg. 3**: Decay scheme ^{166}Ho
- Perspex: $Z_{eff} = 6.56$; $\rho = 1.19$ g/cm^3
- **Attachment, pg. 4**: Mass attenuation and energy absorption cross-sections in lead
- Use for the conversion of the air kerma rate to the ambient dose equivalent rate the conversion factor of 1.2
- Limiting transport values for the transportation of ^{166}Ho:
  A_1 = 0.4 TBq, A_2 = 0.4 TBq
- **Attachment, pg. 5**: Category classification of transport packaging

Question 1.1 (3 points)
What is the minimum thickness the wall of the Perspex container should have to shield all beta radiation?

For the next questions, assume that the attenuation of the gamma radiation through the Perspex and the potentially in the Perspex wall created bremsstrahlung can be neglected.

A simplified ^{166}Ho decay scheme of is supplied for the following questions. Here, three clusters of relevant photon components have been determined for you, see Table 1.1.

Cluster	Photon radiation	E_{avg} (MeV)	$\Sigma y \cdot E$ (MeV·(Bq·s)$^{-1}$)	$(\mu_{tr}/\rho)_{air}$ (m^2/kg)
1	$K_{alpha1} + K_{alpha2}$	0.050	$4.2 \cdot 10^{-3}$	0.00406
2	Gamma 1	0.081	$5.4 \cdot 10^{-3}$	0.00243
3	Gamma 8 + 12 + 13	1.5	$18 \cdot 10^{-3}$	0.00256

Table 1.1. Clusters of relevant photon components.

Question 1.2 (5 points)
Calculate the ambient dose equivalent rate for a 14 GBq ^{166}Ho source in the Perspex container at a distance of 15 cm. Because there are no source constants available, you will first need to calculate the air kerma rate constant for ^{166}Ho.

Initially you consider transporting the source with just the Perspex container in the package. The Perspex container containing the 14 GBq source is placed in a cube-shaped package with an edge of 30 cm for transportation. The source is located exactly in the centre of the package.

Question 1.3 (3 points)
Verify that the 14 GBq ^{166}Ho source can be transported in a type A collo. Subsequently determine using the category classification of transport packages whether, and if so in which category, the source with only the Perspex container in the package can be transported.

To take the optimization principle (ALARA) into account, the Perspex container is shielded by lead. The build-up factor for the emitted photon radiation in lead is 1.6.

Question 1.4 (5 points)
What is the minimally required thickness (in full mm) of the lead shielding if you want the transportation to take place in category II-YELLOW? And in that case, what will the transportation index be?

Question 2: Scattered radiation via the ceiling

Nuclear medicine departments oftentimes work with PET-nuclides. Shielding is required to limit the dose in the adjacent rooms. To reduce the costs, shielding is usually not applied to the full height of the walls. Because of this, the radiation scattered via the ceiling can pass through the unshielded upper part of the wall into the adjacent room.

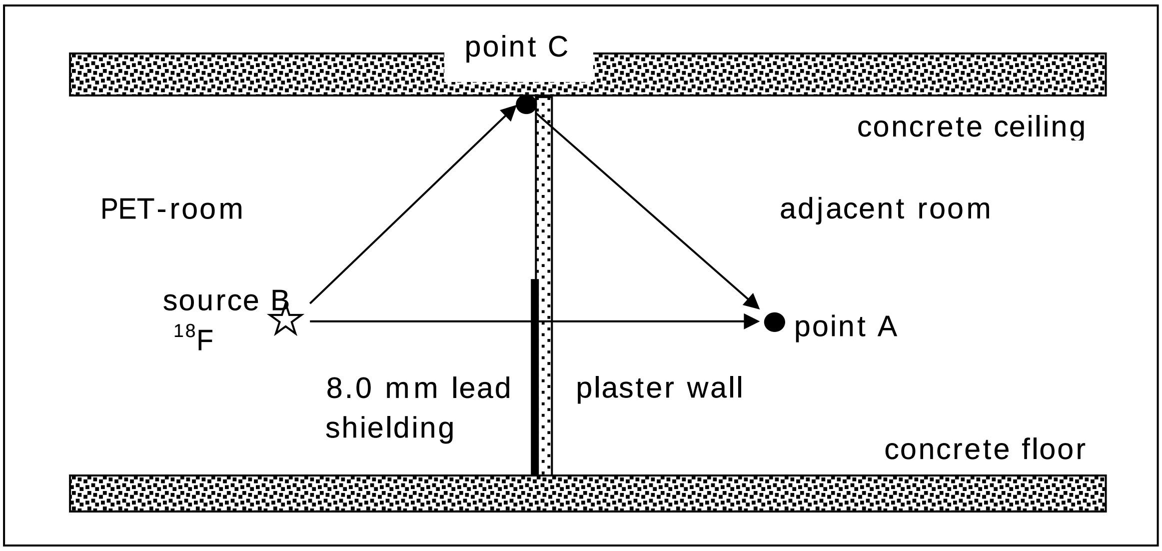

Figure 2.1. Situation sketch of the PET-room. The distance between B and A is 4.0 meters, the distance between B and C and between C and A is 2.8 meters.

Given:

- **Attachment, pg. 6:** Handboek Radionucliden, A.S. Keverling-Buisman (3rd edition 2015), pg. 26, ^{18}F data
- **Attachment, pg. 7:** Broad beam transmission factors at 511 keV in lead, concrete, iron, Madsen et al.: AAPM Task Group 108: PET and PET/CT Shielding
- **Attachment, pg. 8:** Scattering fraction of kerma
- Source B contains 200 MBq ^{18}F
- The height of the ceiling in the rooms is 3.6 meters
- The lead in the plaster wall has been applied to a height of 1.8 meters
- The shielding due to the plaster wall may be neglected
- The line of 100-300 kV from the figure “Scattering fraction of kerma” may be used to determine the scattering fraction of 511-keV photons
- Assume a scattering angle of 90 degrees for the scattering due to the ceiling
- Assume an irradiated ceiling surface of 10 m²
- The ceiling surface may be considered a “point” to apply the inverse-square law, situated in point C

Question 2.1 (3 points)
Calculate the kerma rate in point A as a result of the direct 511-keV photons from source B.

Question 2.2 (4 points)
Calculate the kerma rate in point A as a result of the radiation scattered by the ceiling.

A recent publication[1] gives the following rule of thumb to estimate the dose contribution due to scattered radiation from the ceiling for a wall not completely shielded up to the ceiling:

When, for 511-keV photons of PET-nuclides, the wall contains 8 mm lead, the scattered radiation causes less than 15% of the total dose in the adjacent room.

Question 2.3 (3 points)
Check, though a calculation, whether this rule of thumb is useful for this situation and argue whether it gives an under- or overestimation of the risk.

There are two possible options to further reduce the dose, both requiring the applied amount of lead to be doubled:

1. make the shielding 2× as thick;
2. make the shielding 2× as high

Question 2.4 (4 points)
Argue which of the two options allows for the greatest reduction of the kerma rate in the adjacent room.

---

[1] Monte Carlo simulations of ceiling scatter in nuclear medicine: ^{99m}Tc, ^{131}I and ^{18}F. (Roald S. Scherr e.a., Med. Phys. 44, March 2017)

Question 3: Iodine prophylaxis

The following is written about the dosage of iodine tablets in a report from the RIVM ‘Iodine prophylaxis following nuclear accidents’: a single dose of 170 mg potassium iodate, which corresponds to 100 mg iodine, yields sufficient protection against the potential uptake of radioactive iodine when exposed through inhalation during the passing of the radioactive cloud.

A radiation protection expert wonders how much (activity) ^{131}I needs to be inhaled to exceed the intervention level of a committed equivalent dose of 100 mSv on the thyroid.

Given:

- **Attachment, pg. 9-10:** Handboek Radionucliden, A.S. Keverling Buisman (3rd edition 2015), pg. 164-165, data ^{131}I
- Avogadro’s constant is $6.02 \cdot 10^{23}$ molecules/mol
- The molar mass of ^{131}I is 130.9 gram/mol
- The iodine present in a passing radioactive cloud is in the form of iodine vapour (I_2)
- The contribution of photon radiation can be neglected in the determination of the thyroid dose
- The mass of the thyroid amounts to 20 grams for adults (ICRP-123)
- The tissue weighing factor of the thyroid is 0.05 (ICRP-60)

Question 3.1 (2 points)
Determine the effective half-life of ^{131}I in the thyroid.

Question 3.2 (6 points)
Determine the activity in the thyroid which leads to the intervention level of a committed equivalent dose of 100 mSv for the thyroid. You will need to use the SEE and the required number of disintegrations U_s.

Question 3.3 (3 points)
Determine the inhaled activity which leads to the intervention level of a committed equivalent dose of 100 mSv for the thyroid and calculate the committed effective dose due to this inhalation. If you did not manage to answer question 3.2, assume an activity of 100 kBq in the thyroid.

Question 3.4 (4 points)
Show that an iodine tablet contains enough iodine to saturate the thyroid by calculating the ratio of the mass of the activity calculated in question 3.2, and the mass of the iodine ingested as iodine prophylaxis. If you did not manage to answer question 3.2, assume an activity of 100 kBq in the thyroid.

Question 4: Water sample

A water sample is being measured in a laboratory. It is known which nuclides could be present in the water. A calibration measurement of a mix of the relevant radionuclides has been performed earlier (table 4.1).

The γ-spectrum is measured to determine which radionuclides are present in the water sample, as well as their activities (figure 4.3).

Due to the low activity of the water, the water sample is transferred to a Marinelli beaker and subsequently measured for 24 hours using a Ge-detector. See also figures 4.1 and 4.2.

Figure 4.1. Cross-section Marinelli beaker

Figure 4.2. Marinelli beaker is placed on the Ge-detector in the lead castle

Table 4.1. Results of the calibration measurement (with a solution of the radionuclides which might be present in the water sample)

Nuclide	gamma energy (keV)	activity (Bq)	emitted gamma/s	background (counts)	net measurement (counts)	net count rate (cps)	efficiency (counts/ gamma)
^{133}Ba	80.98	399.738	131.1143	65506	127812	1.479	0.011280
	276.39	399.738	29.14095	23920	27593	0.319	0.010947
	302.92	399.738	74.35141	32934	66324	0.768	0.010329
	356.01	399.738	249.0372	33538	185221	2.144	0.008609
	383.91	399.738	35.3369	18305	25919	0.300	0.008490
^{134}Cs	604.72	68.893	67.24008	11310	24544	0.284	0.004224
	795.86	68.893	58.83507	6257	15961	0.185	0.003144
^{137}Cs	661.58	541.589	460.8927	10985	195215	2.259	0.004901
^{60}Co	1173.18	242.139	242.1392	4945	53259	0.616	0.002544
	1332.5	242.139	242.1392	938	47297	0.547	0.002259

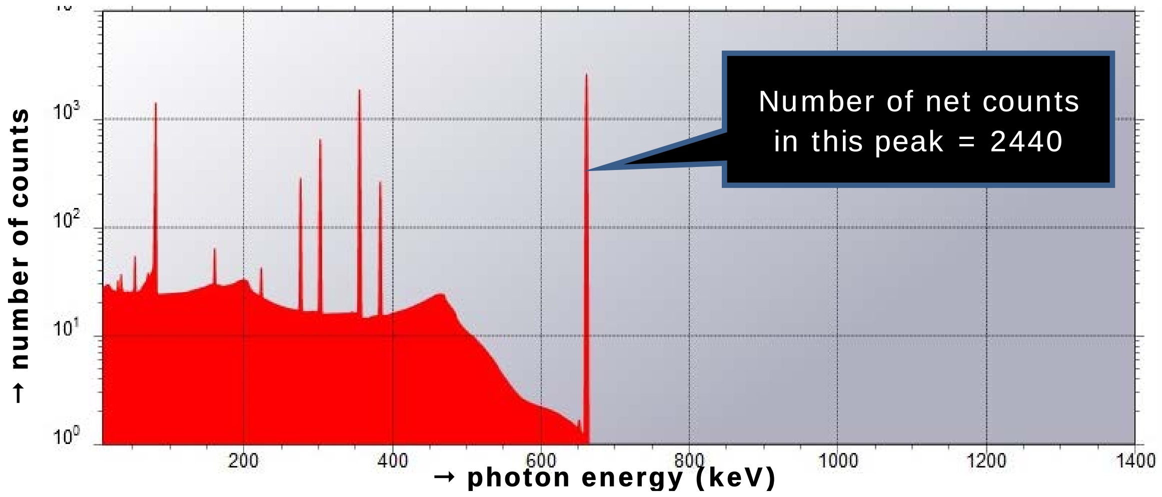

Figure 4.3. Result of the net measurement of the unknown water sample.

Given:

- Measurement time of both the calibration measurement and the background in the calibration measurement = 86400 s
- In table 4.1: the background also contains possible compton photons of the other radionuclides present
- Volume of the water sample in the Marinelli beaker = 500 mL
- Measurement time of both the water sample measurement and its background = 86400 s
- Measurement value of the background in the 662 keV peak in the unknown sample = 3200 counts

Question 4.1 (2 points)
Which radionuclides are visible in the gamma spectrum? Justify your answer.

Question 4.2 (4 points)
What is the activity concentration (Bq/mL) in the sample of the radionuclide which causes the right hand peak? The net number of counts in this photopeak is 2440.

Question 4.3 (4 points)
What is the activity (in Bq) and corresponding standard deviation of the water sample for the nuclide of question 4.2?

In this question, the MDA (minimal detectable activity) at a measurement time t signifies the activity which gives rise to a count rate equal to three times the standarddeviation of the background count rate.

Question 4.4 (3 points)
Calculate the MDA of the nuclide in question 4.2 at a measurement time of 86400 s.