Exam
Radiation protection expert on the level of coordinating expert

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

exam date: December 9th 2019
exam duration: 13.30 - 16.30 hours

Instructions:

- **This exam contains 9 numbered pages and a separate attachment containing 14 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.
- State **only 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, make sure you 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 are allowed to 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 68 points if you correctly answer all of the questions. The points are distributed between the questions as follows:

  Question 1: 16 points
  Question 2: 19 points
  Question 3: 17 points
  Question 4: 16 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 37.4 points.

Question 1: Incident with a source

A highly radioactive source with an activity of 1950 GBq ^{75}Se was used to inspect weld seams of pipelines during major maintenance in a factory. The work was done in shifts of 8 hours in order to finish as quickly as possible. At the end of a shift the source was left in one of the pipes while the radiographic recordings (pictures) were developed.

The radiography employee of the new shift noticed on the pictures that the last tested weld seam was defective. Immediately, he told the maintenance crew to cut the weld seam. However, the radiography employee of the new shift had not checked whether the source was located in its container. Because of this the maintenance crew could not know that the source was still located near the weld seam.

Given:

- **Attachment, pg. 3-4:** Handboek Radionucliden, A.S. Keverling Buisman (3rd edition 2015), pg. 90 and 91, data ^{75}Se
- For simplification purposes, you may assume that each photon in the decay scheme has an energy of 215 keV.
- The lung purification class of the source material is unknown.
- **Attachment, pg. 5:** Bos et al., figure 11-1; Half-value layer of some shielding materials for narrow beam photon radiation.
- **Attachment, pg. 6:** Bos *et al.*, figure 6-7; Ratio of the effective dose E and the ambient dose equivalent H*(10) as function of the photon energy for four different irradiation geometries.
- The pipelines have a thickness of 7 mm stainless steel.
- The density of stainless steel corresponds to the density of iron (Fe)
- The dose build-up factor can be set to B = 2.

Question 1.1a [5 points]

Calculate the ambient dose equivalent resulting from the external radiation received by the maintenance worker while cutting the weld seam. Assume that the distance from the worker to the source was 0.5 m, and that the total operation lasted for 45 minutes.

Question 1.1b [3 points]

Make an estimate of the effective dose incurred by the maintenance worker as a result of the external radiation.

Only after the weld had been cut did the radiography worker realize that the source was still located in the pipe. Because of the cutting work the source was severely damaged, resulting in the dispersal of a large amount of radioactivity. Countless hotspots were found through contamination measurements in the vicinity of the cut weld seam. The area was subsequently cleaned with an industrial vacuum cleaner, but this resulted in the activity spreading even further since the vacuum cleaner did not contain a dust bag. In the meantime, the work in the hall was not stopped.

At the end of the shift, the incident was reported to the radiation safety expert of the radiography company, who proceeded to immediately cease all operations. In the meantime, about 50 maintenance workers had been working for a shorter or longer period of time in the hall, and external contaminations were found on the skin and clothing of most of them. The highest measured value amounted to 30 $kBq\cdot cm^{-2}$.

Question 1.2 [3 points]

Calculate the maximum equivalent skin dose assuming that the activity has been on the skin for a period of 8 hours.

After all activity had been removed from the skin, a whole-body count (WBC) was performed for a number of maintenance workers. It was found that they were also internally contaminated. You may assume that was entirely caused by inhalation. The highest body activity was 15 kBq, measured 24 hours after exposure.

Question 1.3 [3 points]

Calculate based on the above data the maximum possible committed effective dose caused by the internal contamination.

Question 1.4 [2 points]

Name two deficiencies in radiation protection which can be identified as a result of this incident. Note: each valid argument yields 1 point to a maximum of 2 points. However, when more than 2 arguments are given, each wrong answer results in the deduction of a point.

Question 2: Treatment of bone metastases

The radionuclide ^{223}Ra is currently used in nuclear medicine to treat bone metastases of prostate cancer. The treatment is mainly aimed at pain relief and increasing the quality of the patient's remaining life span (a few months). The manufacturer provides the following information with the delivery of the radiopharmaceutical.

Given:

- The radiopharmaceutical is supplied in single-use ampoules containing a total activity of 6.0 MBq in 6.0 mL on the reference date. The patient receives an activity of 50 kBq per kg of body weight.
- The half-life of the radionuclide ^{223}Ra is 11.4 days.
- The committed effective dose due to inhalation is for employees: $e(50)_{inh} = 6.9 \cdot 10^{-6}$ Sv/Bq (ICRP-119).
- The committed effective dose due to ingestion is for both employees and members of the public: $e(50)_{ing} = 1{,}0 \cdot 10^{-7}$ Sv/Bq (ICRP-119).
- The α-emitter ^{223}Ra is a surface locator according to the bone model of ICRP-30.
- **Attachment, pg. 7-9:** Attachment radionuclide laboratories of the KEW-license of the hospital.
- **Attachment, pg. 10:** Main contributors to the calculated absorbed organ dose through injection.
- **Attachment, pg. 10:** Tissue weighing factors according to ICRP-60.

On Monday morning the 13th of May 2019, an ampoule is delivered to the Nuclear Medicine department of a hospital with as reference date Friday the 10th of May 2019, 13.30 h. The radiopharmaceutical is drawn into a syringe in an (approved) fume hood in a C-laboratory and administered to a patient with a total body weight of 80 kg at 13.30 h.

Question 2.1 [4 points]

How many mL of the radiopharmaceutical should be administered to the patient?

Question 2.2 [4 points]

Based on a calculation, conclude whether the filling of the syringe in the situation described above is allowed according to the 'Attachment radionuclide laboratories' from the current license.

Question 2.3a [4 points]
Calculate the committed effective dose received by the patient as a result of the injection, according to the data of the manufacturer. Use the Attachment 'Most relevant dosimetric contributions to the dose for the patient after injection of the radiopharmaceutical'.

Question 2.3b [2 points]
Explain whether this committed effective dose if relevant for the patient.

A patient remains in the hospital for an additional two days after administration for observation. The hospital does not have a permit for the discharge of radioactive substances into the sewer.

Additional information:
- The decay of ^{223}Ra during the first two days after injection can be neglected.
- The total excretion during the first 48 hours after administration contains 15% of the injected activity.
- The average patient weighs 80 kg.
- **Attachment, pg. 11:** Art.10.3 Decree basic safety standards for radiation protection (Government gazette 2017, nr. 404).
- **Attachment, pg. 11:** Correction factors for discharge into water.
- As a result of other actions, the hospital discharges 4 Re_{ing} into the sewer each year.

Question 2.4 [5 points]
Calculate the maximum number of patients that can be treated with ^{223}Ra by the hospital without exceeding the exemption for discharge into the sewer.

Question 3: Irradiation of flower bulbs

An organization uses an X-ray machine to irradiate flower bulbs. This introduces mutations which result in new varieties of flowers. The machine is used in an irradiation room for 3 hours per working day for a total of 30 work weeks a year. The tube is continuously aimed at the ground. An office (point P) is located on the floor below. A laboratory (point Q) is located next to the irradiation room and there are always people present here. The door between the irradiation room and the workspace is equipped with an interlock system. The machine switches off as soon as the door is opened. The box with bulbs stops 42% of the radiation from the primary beam.

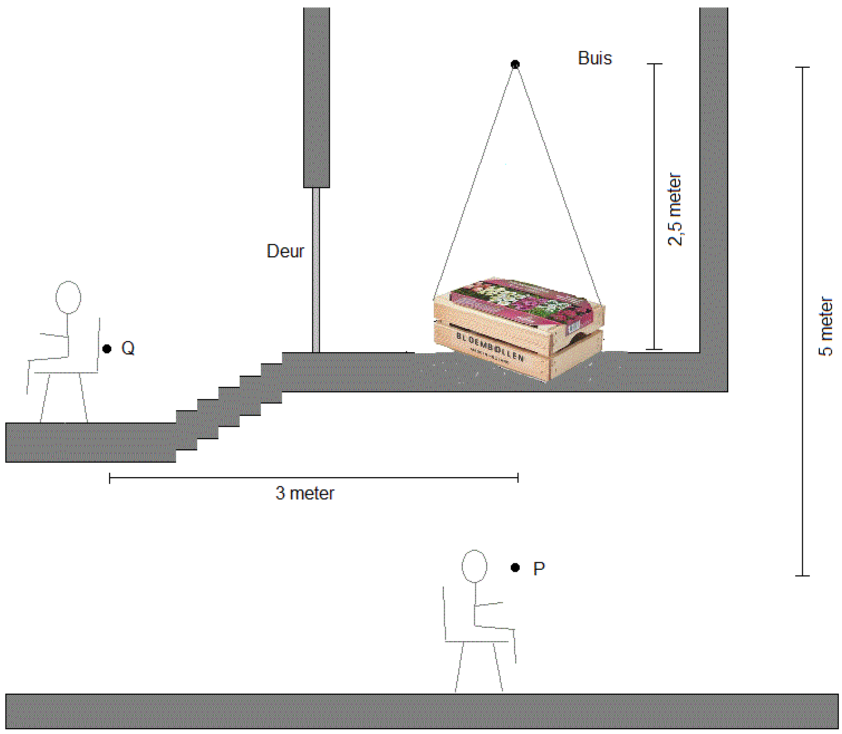

Figure 1. Situation sketch of the set-up and the adjacent rooms

Given:

- Tube voltage 250 kV
- Tube current 10 mA
- **Attachment, pg. 12:** ICRP-33 fig. 11, Broad-beam transmission of X-rays through concrete
- **Attachment, pg. 13:** ICRP-33 fig. 22, Scattering patterns of divergent X-ray and gamma ray beams normally incident on a flat concrete wall.
- **Attachment, pg. 14:** Mass attenuation, energy transfer and energy absorption cross-sections in lead.

- Assume a conversion coefficient of 1.35 Sv/Gy for the conversion of kerma in air to an effective dose for X-rays generated with a tube voltage of 250 kV.
- The density of lead is 11.34 g/cm^3.
- A floor area of 0.3 m^2 is hit by the primary beam.
- For optimization purposes, the organization decided that it is not allowed to incur a annual dose higher than 0.3 mSv in any work space.

Question 3.1 [6 points]

Determine the shielding thickness of the concrete floor that is required to ensure that the maximum annual dose in point P (figure 1) will not be exceeded.

Question 3.2a [6 points]

Calculate the yearly ambient dose equivalent in point Q (from figure 1) assuming the door does not provide any shielding. For the sake of simplicity, assume that there is no attenuation and hence no scattering in the box with flower bulbs. Scattering only takes place on the floor.

The radiation protection expert uses lead to shield the door with the interlock system to meet the requirements of the organization for the employee in point Q. For the shielding calculations you can assume scattered photons with an energy of 150 keV. Neglect the build-up though the lead-shielded door. Assume, if you did not find the answer to question 3.2a, that the yearly ambient dose equivalent in point Q equals 0.5 Sv without any additional measures.

Question 3.2b [3 points]

How thick should the shielding material be that has to be applied to the door? Round to whole mms

Question 3.3 [2 points]

Why may the build-up through the lead-shielded door be neglected?

Question 4: Radioactive hospital waste

To prevent radioactive material from leaving the hospital unnoticed, a detector gate consisting of two plate detectors is placed at the central waste collection point of a hospital. The radiation safety expert of this hospital performs calculations to determine whether the new plate detectors are suitable for measuring ^{99m}Tc-containing waste.

The two plate detectors are located on either side of a corridor. All waste containers, containing all possible types of waste, are transported through this corridor, see also figure 4.1. A motion sensor is used to monitor the speed.

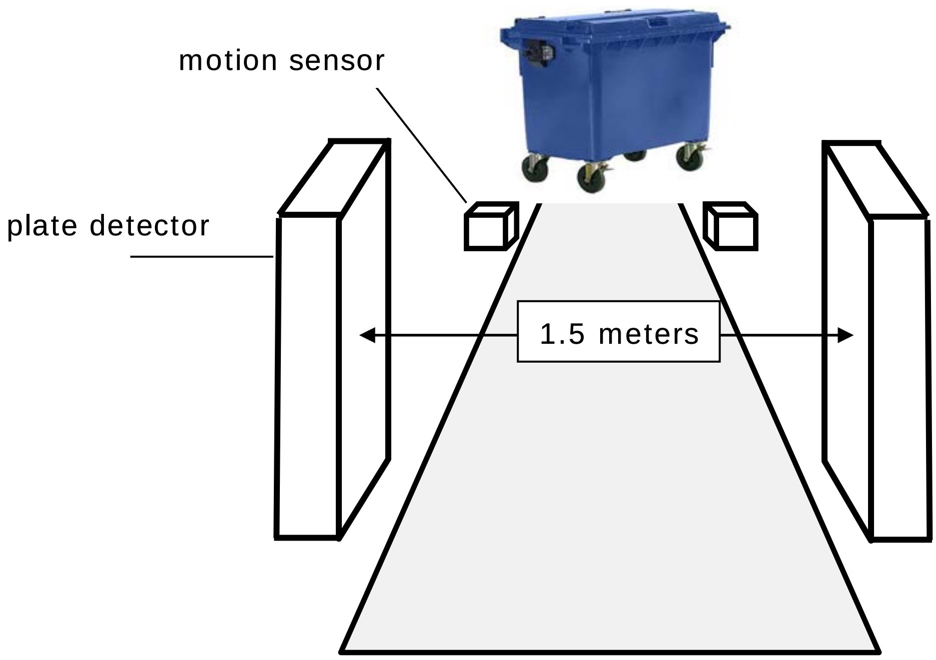

Figure 4.1: Situation sketch, each waste container moves between the two plate detectors.

Given:

- The distance between the two plate detectors is 1.5 meter
- Each plate detector is 246 mm wide and 484 mm high.
- Consider the radioactive waste as a point source.
- Neglect the attenuation by the container wall and the rest of the waste.
- ^{99m}Tc emits a 141 keV gamma photon with an emission probability of 0.889.
- The background count rate measured by the plate detectors is 3.55 cps, determined with a very long measuring time.
- The total counting time per container is at least 0.2 seconds.

- The efficiency of the plate detectors is 0.17 counts per incident photon for ^{99m}Tc.
- The release limits for moderate quantities (< 1000 kg) of ^{99m}Tc are: 100 kBq/kg and 10 MBq.

Question 4.1 [4 points]
Determine the total detection efficiency of the plate detectors in cps/Bq. Assume the source is located exactly in the center of both plate detectors. You may assume that the plate detectors are part of a sphere surface.

Question 4.2 [3 points]
Calculate the minimum detectable activity (MDA) if the plate detectors have to emit a signal when the background is exceeded, with a reliability of 99.9% (3σ)

Patients are injected with ^{99m}Tc for a large number of studies in the Nuclear Medicine department of this hospital. These patients receive a band aid because of possible bleeding. These radioactively contaminated band aids often unintentionally end up in regular trash cans in the hospital after use. A contaminated band aid weights a maximum of 1 gram.

The radiation safety expert wants to determine whether a contaminated band aid can be detected by the plate detectors 1 day after being thrown away. A Geiger-Müller counter with a total measurement efficiency of $2.7 \cdot 10^{-3}$ cps/Bq gives for the measurement of a 1 day old band aid 1240 counts in one minute. The background measurement gives 532 counts in 5 minutes.

Question 4.3 [5 points]
Conclude based on a calculation whether this band aid can be measured using the new plate detectors, taking a confidence interval of 95% (2σ) into account for the measurement with the GM tube

Question 4.4 [4 points]
Make a few assumptions and argue whether the hospital could potentially exceed the release limits if the band aids described in this question end up with the regular waste.