Exam
Radiation protection expert on the level of coordinating expert

Nuclear Research and consultancy Group	NRG
Delft University of Technology	TUD
University of Groningen	RUG
Radboudumc	RUMC

exam date: May 9th 2022
exam duration: 13.30 - 16.30 hours

Instructions:

- **This exam contains 12 numbered pages, an attachment containing 15 pages of data and a separate attachment to fill in. Please check!**
- Write your solutions and answers on the worksheets provided. Use a separate, to that question corresponding worksheet for each question. 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 materials 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 may assume a fictional answer.
- For some of the questions you might not necessarily need to use all of the supplied data.
- Pay attention to stating and correctly applying quantities and units.
- The points are distributed between the questions as follows:

  Question 1: 17 points
  Question 2: 13 points
  Question 3: 15 points
  Question 4: 16 points
- You will have passed this exam if you have obtained at least 55% of the total amount of points (61). This corresponds to a score of at least 33.55 points.

Question 1: Transport of lutetium-177 [17 points]

Currently there is a lot of interest in the use of lutetium-177 for several therapeutic applications in nuclear medicine. A company wants to start supplying ready-to-use syringes containing labeled lutetium compounds to hospitals.
The company has access to a B-laboratory with a closed work cabinet (class-III cabinet) to prepare the syringes. The preparation consists of a few simple chemical steps followed by labeling with a non-volatile nuclide (inhalation class M).
As radiation protection expert, you are asked to investigate a few steps relating to legislation and regulations.

Given:

- **Attachment, pg. 3-4:** Handboek Radionucliden, A.S. Keverling Buisman (3rd edition 2015), pg. 204-205, ^{177}Lu data.
- **Attachment, pg. 5**: Parameters p, q and r from the Attachment radionuclide laboratory
- **Attachment, pg. 6:** Density and attenuation coefficients for lead
- **Attachment, pg. 7:** Build-up factors for lead
- **Attachment, pg. 8:** Labeling class 7
- ***Separate attachment*: Fill-in sheet with labels class 7**

Question 1.1 [4 points]

Calculate the maximum activity that may be prepared in this closed work cabinet at one time.

To be allowed to transport the syringes the maximum dose values measured on the surface of the collo as measured at a distance of 1 meter from the surface of the collo must be met.

You want to transport a syringe containing 7.4 GBq ^{177}Lu. As this activity is below the A1-value, you choose a type A packaging consisting of a cardboard box with outside dimensions of 24 cm by 24 cm by 24 cm. The activity is contained at the center of the box. Neglect the attenuation of photons by the syringe, the cardboard and the used filling materials.

Question 1.2 [4 points]

Calculate the dose rate at the surface of the collo if you would transport the syringe unshielded.

Question 1.3 [6 points]

Calculate the amount of lead required to be allowed to transport this syringe in the chosen collo. Take both dose requirements into consideration. Give your answer in whole millimeters. You may apply reasoned simplifications.

Question 1.4 [3 points]

Choose the correct label on the **separate attachment** and fill in the required information.

Points

Question 1	
Question	**Points**
1.1	4
1.2	4
1.3	6
1.4	3
Total	***17***

Question 2: Mobile X-ray system [13 points]

A horse clinic receives an emergency call because a horse has fallen and will no longer stand on its left front leg. The vet is still present in the clinic, takes the mobile X-ray system and drives together with an assistant to the place where the accident happened.
The clinic has a license to perform veterinary diagnostics with ionizing radiation emitting devices at constantly changing locations within the Netherlands.
The owner of the horse positioned the horse next to the stables, such that the vet will have sufficient space (see **Figure 2.1**). The shortest distance from the X-ray system to the terrain boundary is 3 meters. The stable wall at the boundary is made out of wood, with a thickness of 2 cm.

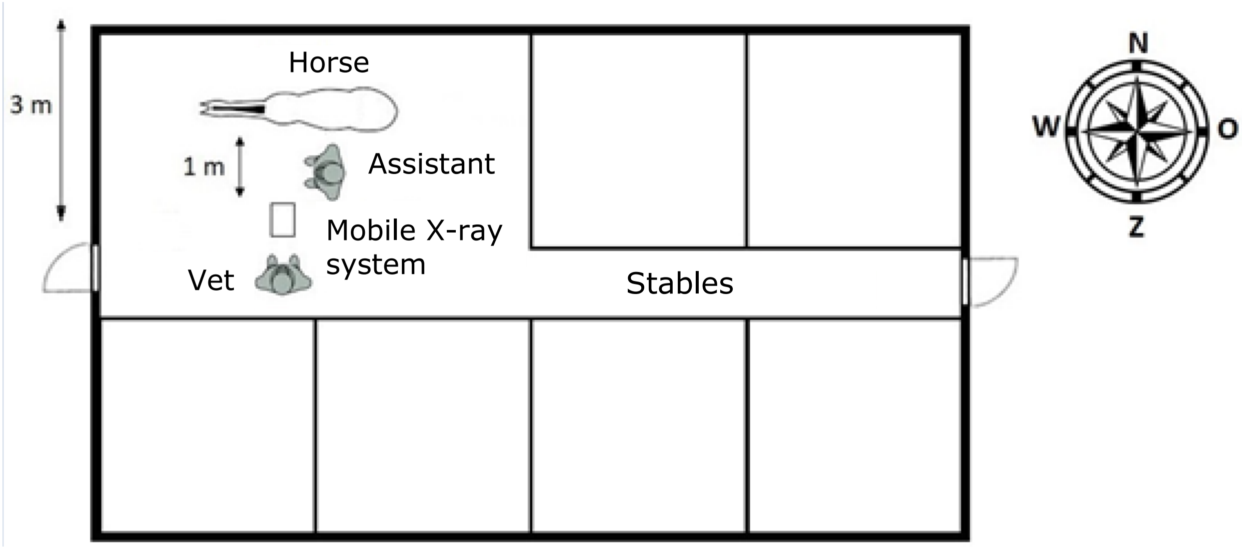

Figure 2.1 Situational sketch

Given:

- The exposure parameters for these images are:
    - a tube voltage of 73 kV
    - a filter of 3 mm aluminum
    - the tube current × exposure time equals 12.5 mA·s
- The distance between the X-ray tube and the entrance surface is 1 meter.
- The transmission of X-rays through 2 cm wood equals 84.3% (calculated using Archer parameters based on NCRP-147)
- The conversion coefficient of air kerma to personal dose equivalent for photons equals 1.5 Sv/Gy (both for primary as well as scatter radiation photons)

- **Attachment, pg. 9:** Output air kerma rate of X-ray systems with varying filters and tube currents
- The air kerma free in air at the location of the entrance surface (on the leg of the horse) equals 0.69 mGy per image

Question 2.1 [3 points]
Show through calculations that the air kerma free in air at the location of the entrance surface (on the leg of the horse) indeed equals 0.69 mGy per image.

For the next two sub questions, read the texts from the license of the vet in **Attachment, pg 10**. The correction factor for indoor living ("the housing correction factor") equals 0.25. You may assume that the vet will take an X-ray no more than once a year at this location.

Question 2.2 [4 points]
Calculate the MID (multifunctional individual dose).

Question 2.3 [2 points]
Name one violation of the permit and provide one solution.

The assistant holds a cassette behind the horse's leg to take the X-rays. She wears the following personal protective equipment: lead gloves, a lead apron and thyroid protection (see **Figure 2.2** for an example). After attenuation and scattering of the primary beam by an object (in this case the horse's leg), scatter radiation is created to which the assistant is exposed.

Figure 2.2 The assistant holds the cassette behind the horse's leg and wears personal protective equipment while doing so (Source: X-Ray - Field Equine Vets).

Additional given:

- **Attachment, pg. 11:** Scattering angle and dose(kerma)rate of divergent beams of X-ray and gamma radiation incident perpendicular to a flat concrete wall. For this question, these data may be used for scatter radiation on a horse's leg.
- You may assume that the scattering angle equals 90°.
- The distance between the assistant and the horse's leg equals 50 cm.
- The dimensions of the entrance surface (on the horse's leg) are 10 x 20 cm^2.

Question 2.4 [4 points]

Calculate the personal dose equivalent Hp(10) at the location of the assistant following one X-ray.

Points:

Question 2	
Question	**Points**
2.1	3
2.2	4
2.3	2
2.4	4
Total	***13***

Question 3: The efficiency of the MiniTRACE monitor [15 points]

A radiation protection expert frequently uses a MiniTRACE type S5 monitor in his practice, and has therefore determined the intrinsic detector efficiency for photons emitted by ^{137}Cs. He has recently found more comprehensive data for the newer model, the MiniTRACE type CSDF, than he has for his own monitor. He assumes that the actual detector of the two monitors is the same. He wants to verify the result of his calculations with the given efficiency of the Minitrace CSDF.

The detector of both MiniTRACE monitors is located at the back of the monitor and is equipped with a protective grid and a cover that can be used to cover the detector window (see **Figure 3.1**).

Figure 3.1 The top and bottom of the MiniTRACE CSDF monitor.

Given:

- The response of the MiniTRACE, types S5 and CSDF, for gamma photons emitted by ^{137}Cs amounts to 4.3 cps per μSv/h for a distance of 1 meter between the source and detector
- **Attachment, pg. 12**: Efficiency (in cps/Bq) of the MiniTRACE, type CSDF
- **Attachment, pg. 13**: Handboek Radionucliden, A.S. Keverling Buisman (3rd edition 2015), pg. 172, ^{137}Cs data
- The MiniTRACE has an effective detector surface of 15.55 cm^2. This applies for both type CSDF as well as type S5

- According to the supplier, when the cover is closed the monitor is only sensitive to γ-radiation. The monitor is sensitive α-, β- and γ-radiation when the cover is open.
- The cover is composed of aluminum (density 2.7 g/cm^3) and has a thickness of 1 mm

Question 3.1 [2 points]
Calculate the activity of a ^{137}Cs-source which, at a distance of 1 meter, gives rise to an ambient dose equivalent rate H*(10) of 1 μSv/h.

For the next question assume that the detector is placed at a distance of 1 meter from the source, and that there is no absorption of gamma photons in the material between the source and the fill gas in the detector. If you did not find an answer to question 3.1, you may use an activity of 10 MBq for your calculations.

Question 3.2 [5 points]
Calculate the number of γ-photons emitted from the in question 3.1 indicated source which reach the fill gas of the detector per second.

If you did not find the answer to question 3.2 you may assume 10^3 photons per second for the subsequent questions.

Question 3.3a [2 points]
Calculate from the previous data (detector alignment and the response of the MiniTRACE S5 for gamma photons emitted by ^{137}Cs) the detector efficiency of the MiniTRACE S5 (in pulses per incident photon).

Question 3.3b [4 points]
Check whether the detector efficiency of the MiniTRACE S5 corresponds to the detector efficiency of the MiniTRACE CSDF, as given in **Attachment, pg. 12**. Explain your answer.

Question 3.4 [2 points]
The supplier claims that the monitor is only sensitive to γ-radiation when the cover is closed. Do you expect this to be true for the betas emitted by ^{137}Cs?

Points:

Question 3	
Question	**Points**
3.1	2
3.2	5
3.3a	2
3.3b	4
3.4b	2
Total	***15***

Question 4: Administration with carbon-11 [16 points]

A patient may have Alzheimer's disease. To confirm this diagnosis, a PET-scan is made of the brain. ^{11}C-methionine is used for this nuclear medicine procedure. This radiopharmaceutical is administered through an injection in a vein on the inside of the elbow.

Given:

- **Attachment, pg. 14-15:** Handboek Radionucliden, A.S. Keverling Buisman (3rd edition 2015) pg. 22-23, ^{11}C data
- Spherical volume of injected muscle tissue = 5 cm^3
- Muscle tissue has a density of 1.05 $g \cdot cm^{-3}$
- The injected activity is located in the muscle close to the skin
- The injected muscle tissue is both source as well as target organ
- The β^+-particles are completely absorbed in the muscle tissue
- 1 MeV = $1.602 \cdot 10^{-13}$ J

To monitor the administration of ^{11}C-methionine a scintillation detector is used. This detector registers the count rate (in cps) during a 15 second measurement. Prior to administration, a 15 second background measurement is performed at the site where the activity will be injected. This background measurement shows a count rate of 45 cps. The measurement immediately following ^{11}C-methionine administration yields 33500 cps.

Unfortunately the administration does not go well in this patient, as directly after emptying the syringe a superficial bump appears in the elbow cavity. The blood vessel appears not to have been punctured properly, and it is possible that the activity has completely entered the directly surrounding muscle tissue.

The net count rate efficiency for the measurement in the used measurement setup equals $9.0 \cdot 10^{-5}$ cps/Bq. For convenience it may be assumed that this net count rate efficiency is an error-free value.

Question 4.1 [4 points]

Calculate the administered ^{11}C-activity including the corresponding 95% confidence interval.

The bump has stayed for a couple of hours, and the patient indicates that he feels pain at the location where the activity was injected.
The pain could be caused by the stretching of the muscle due to the injected volume, but could also be partially caused by the locally absorbed dose. An entry-level radiation protection expert is asked how he would calculate this dose. In the following questions we will follow his calculation steps.

If you were unable to find the answer to question 4.1, you may assume an administered ^{11}C-activity of 350 MBq from this moment on.

Question 4.2 [3 points]

Calculate the total number of disintegrations U_s of the ^{11}C which has been injected into the muscle tissue.

See **Figure 4.1** for a schematic overview of the elbow with the injection location.

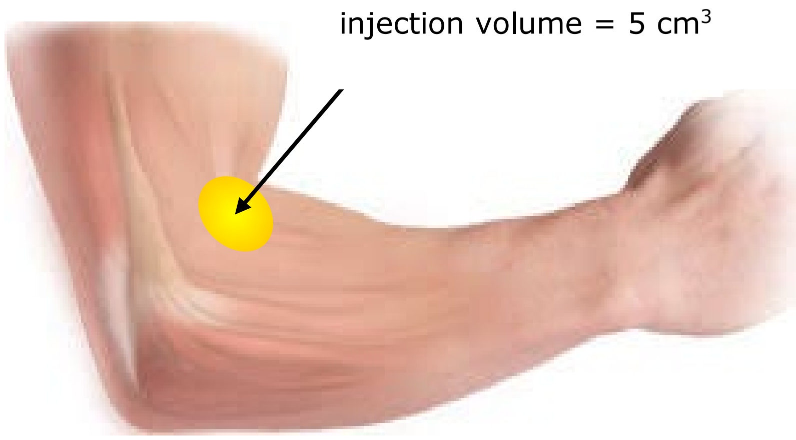

Figure 4.1 Schematic overview of an elbow with injected ^{11}C-methionine.

Question 4.3a [3 points]

Attachment, pg. 14-15 shows an overview of the main radiation emitted. Explain based on this data which type of radiation mainly dominates the delivered dose in the muscle tissue.

Question 4.3b [4 points]

Calculate the average absorbed dose in the injection volume (5 cm^3) caused by the type of radiation as argued in question 4.3a.

Finally, the radiation protection officer is interested in what the committed effective dose caused by the treatment would have been following successful administration.

Question 4.4 [2 points]
Calculate the committed effective dose E(50) when the injection would have been administered into the vein.

Points:

Question 4	
Question	**Points**
4.1	4
4.2	3
4.3a	3
4.3b	4
4.4	2
Total	***16***