EMBARGO MAY 13th 2019

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

exam date: May 13th 2019
exam duration: 13.30 - 16.30 hours

Instruction:

- **This exam contains 11 numbered pages and a separate attachment containing 13 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 61 points if you correctly answer all of the questions. The points are distributed between the questions as follows:

  Question 1: 13 points
  Question 2: 15 points
  Question 3: 16 points
  Question 4: 17 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 33.55 points.

Question 1: Ingestion of uranium in drinking water

Researchers are taking various samples of the drinking water in Bangalore, India (12 million inhabitants) for a study on the chemical toxicity and radiotoxicity.
The uranium concentration in the drinking water varies from 0.136 μg/L to 2027.5 μg/L, with an average of 92.42 μg/L. A total of 96 samples have been collected, of which 20 samples exceed the limit of 100 μg/L (which is considered acceptable).

Given:

- **Table 1:** Natural uranium data
- The daily intake of drinking water is 2.0 L
- The effective dose conversion coefficient $e(50)_{ing}$ of U in its natural composition (without daughters) is $4.4 \cdot 10^{-8}$ Sv/Bq
- The potential daughters which have already been produced can be disregarded, since they are not present for the uranium analysis.
- Avogadro's constant is $6.022 \cdot 10^{23}$ mol^{-1}

Table 1. Data of uranium-isotopes in natural uranium

Isotope	**Molar mass (g/mol)**	**Natural occurrence**	**Half-life (year)**	**Percentage of total U activity**
^{234}U	234.04095	0.0054%	$2.4 \cdot 10^{5}$	49%
^{235}U	235.04393	0.7204%	$7.04 \cdot 10^{8}$	2%
^{238}U	238.05079	99.2742%	$4.47 \cdot 10^{9}$	49%

Question 1.1a (5 points)

Calculate the activity of ^{238}U in 1 μg natural uranium.

Question 1.1b (2 points)

Calculate the total activity of the three uranium isotopes in 1 μg natural uranium.

Question 1.2 (3 points)

Determine the committed effective dose caused by drinking water with an average uranium content of 92.42 μg/L for one year.

Question 1.3 (2 points)

Based on the linear no-threshold hypothesis (LNT-hypothesis), calculate the expected number of cancer-related deaths caused by the committed effective dose calculated in question 1.2.
If you were unable to answer question 1.2, use E(50) = 100 μSv.

Question 1.4 (1 point)

Is calculating the number of deaths in Bangalore based on the LNT-hypothesis in line with the recommendations of the ICRP?
Substantiate your answer.

Question 2: Checking the level of enrichment

Rubidium is an element which is found in nature as a combination of the stable isotope ^{85}Rb (72.17%) and the primordial radioactive isotope ^{87}Rb (27.83%). An institute orders 100 mg enriched rubidium chloride (RbCl), consisting for 99% of the isotope ^{87}Rb.

It is decided to check the level of enrichment of the supplied rubidium chloride. This is checked by comparing the count rates of the natural and enriched rubidium chloride.

Given:

- The specific activity of natural rubidium chloride is 653 Bq/g.
- **Attachment, pg. 3:** Handboek Radionucliden, A.S. Keverling Buisman (3rd edition 2015), top half of pg. 98, ^{87}Rb data

A total amount of 10.0 mg rubidium chloride is dissolved in distilled water in a scintillation vial, and supplemented with a liquid scintillation cocktail. This is done for both the natural as well as the enriched RbCl. The background and the RbCl counting samples are measured for 1000 seconds each in a liquid scintillation counter. The measured gross number of counts is per counting sample:

Counting sample	**Gross number of counts**	**Counting time**
natural RbCl	7520	1000 s
enriched RbCl	12110	1000 s
blank	1670	1000 s

Question 2.1 (4 points)
Calculate the counting efficiency based on the measurement of the natural RbCl. Give the answer in tps/Bq.

Question 2.2 (4 points)
Calculate the relative standard deviation of the counting efficiency (calculated for question 2.1).

Question 2.3 (4 points)
Does the level of enrichment of the supplied RbCl correspond to what was ordered? Support your answer with a calculation.

Question 2.4 (3 points)

Explain why in this case the liquid scintillation measurement is a better detection method than a contamination monitor.

Question 3: ^{99m}Tc-generators

Six ^{99m}Tc-generators containing 10 GBq each are collected from a French airport every Saturday morning. The driver delivers three generators to hospital A after a three hour trip, and after driving for another three hours he delivers the other three generators to hospital B. The driver wears a TLD personal radiation dosimeter during his work, which he hands in every four weeks.

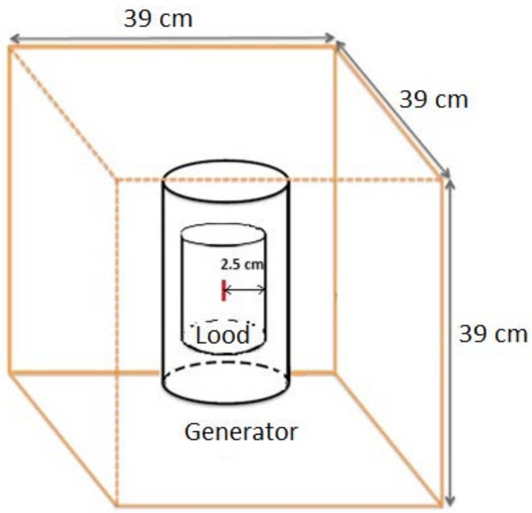
The employer receives a TLD readout with an unusually high dose for one of the drivers. Research is done to discover the cause.

Given:

- **Attachment, pg. 4:** Decay scheme of ^{99}Mo from Nucleonica.com
- **Attachment, pg. 5:** Dosimetric quantities as function of the photon energy
- **Attachment, pg. 6:** Conversion coefficients as function of the photon energy
- **Attachment, pg. 7:** Attenuation constants for different photon energies in lead (appendix D of Inleiding tot de Stralingshygiëne)
- **Attachment, pg. 8:** Labeling class 7
- The Build-up through 2.5 cm lead of 740 keV photons of ^{99}Mo is 1.7
- The Build-up through 2.5 cm lead of 778 keV photons of ^{99}Mo is 1.7
- The Build-up through 2.5 cm lead of 181 keV photons of ^{99}Mo is 2.0
- The ambient dose equivalent can be equated to the effective dose: H*(10) = E

Information about the package:

- Each generator is packed in its own transportation packaging (package).
- The activity is placed in the center of the package and can be regarded as a point source.
- 2.5 cm lead is placed around the activity in the generator.
- Only the lead shielding needs to be taken into account for the transmission calculations, any shielding by other materials can be ignored.
- The package of the ^{99m}Tc-generator is a standard type A package, a cardboard box of 39 cm × 39 cm × 39 cm.



Question 3.1 (4 points)
Show through a calculation that the dose at the surface of the package is practically exclusively caused by the 740 keV and 778 keV photons of ^{99}Mo. Do this by calculating the transmission of the 181 keV and 740 keV photons through the lead shielding.

Question 3.2 (5 points)
Calculate the ambient dose equivalent rate (caused by the 740 keV and 778 keV photons of ^{99}Mo) at the surface of a package when leaving the airport.

Question 3.3 (3 points)
Calculate the transportation index and indicate which danger label should be attached to each package (see attachment, pg. 8). Motivate your answer.
If you were unable to find the answer to question 3.2 you can assume 600 μSv/h.

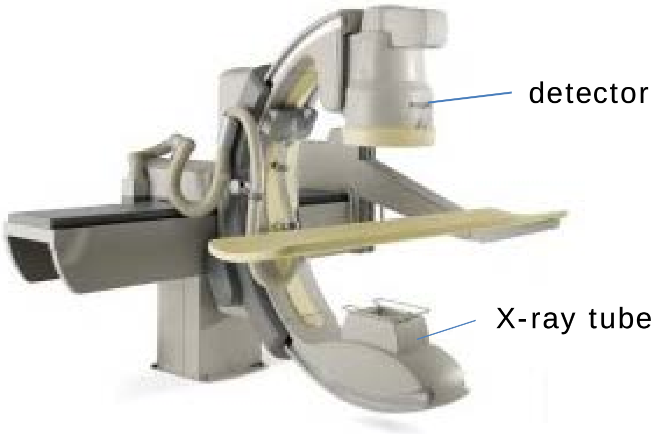
A risk analysis has been made in advance. The expected effective dose for the driver during a transport at which six packages have been placed as far away from the driver as possible in the cargo area of the van is 0.5 mSv per month.
However, the incident report shows that the six packages had been placed in the cargo area just behind the chair of the driver instead of in the back.
During a reconstruction of the incident, one package with 10 GBq ^{99}Mo was placed at the location behind the chair of the driver, to measure the ambient dose equivalent rate at the location of the driver. This turned out to be 68.5 μSv/h.

Question 3.4 (4 points)
What is the effective dose the driver received in the first four weeks? The decay of ^{99}Mo can be neglected for this calculation.

Question 4: Positioning a CT scanner

You have been hired as radiation protection expert for a private clinic. The clinic already has a C-arm, and is currently installing a CT scanner (including the associated control room) in the space next to the C-arm. As radiation protection expert you are asked to calculate the exposure to the existing staff and to take care of the licensing.

CT-scanner



C-arm

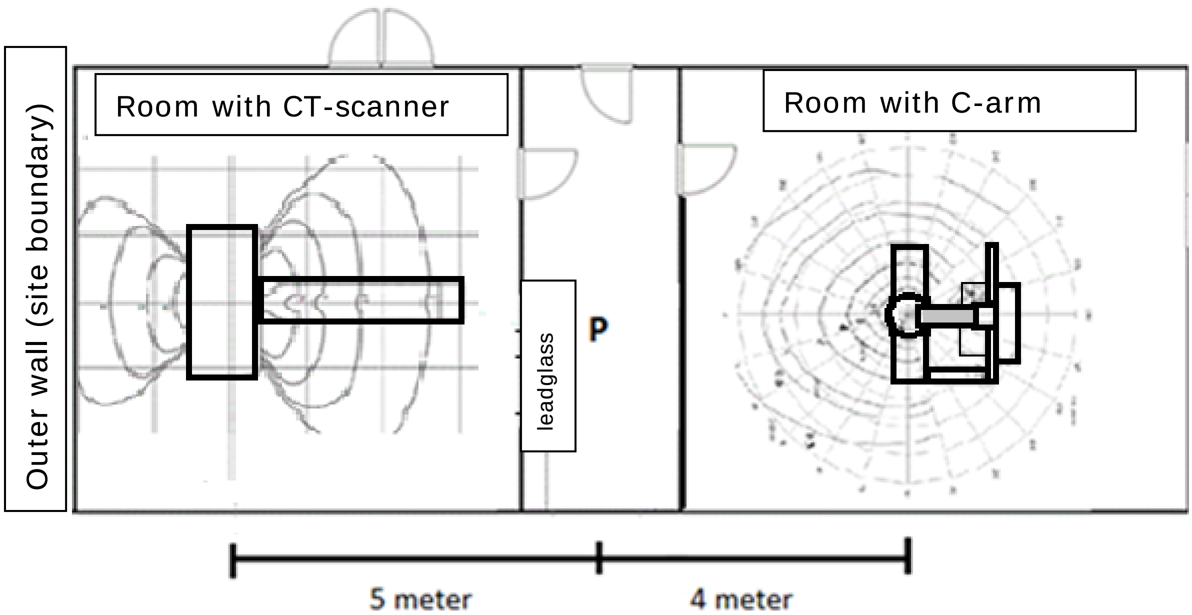


Figure 4.1: Situation sketch showing the layout of both rooms containing the devices as well as the control room in between.

Figure 4.1 shows the CT scanner and C-arm with the associated kerma distribution in the rooms (see also attachment pg. 12 and 13). P is the position of an employee in the control room. The wall between the C-arm and the control room contains 1.0 mm lead, any shielding caused by the other material in the wall can be neglected. The distances indicated in figure 4.1 are the distances between P and an imaginary point from where the scattered radiation originates.

General information:

- Conversion factor $E(AP)/K_a$ = 1.4 Sv/Gy
- **Attachment, pg. 9**: Transmission graph of X-rays through lead
- For the transmission calculations you can equate the spectra of the scattered radiation of the C-arm and CT scanner to 90-kV X-rays
- **Attachment, pg. 10:** Conversion of lead equivalent to lead glass thickness
- **Attachment, pg. 11**: Transmission graph of X-rays through concrete

Information C-arm:

- 800 examinations are performed on the C-arm each year
- The C-arm gives for each examination an average DAP-value of 20 $Gy \cdot cm^2$. The DAP value (Dose Area Product) is the product of the absorbed dose (Gy) and the irradiated area (cm^2)
- **Attachment, pg. 12:** Iso kerma map of the C-arm

Question 4.1 (4 points)

Calculate the effective yearly dose behind the lead containing wall at position P generated only by the C-arm. The kerma due to scattered radiation at 3 meters distance amounts to K_a = 0.6 µGy per $Gy \cdot cm^2$ (read from attachment, pg. 12).

The wall between the control room and the CT scanner contains lead, with a window fitted with lead glass. From an ALARA point of view, it has been decided that the total effective dose in the control room should not exceed 50 µSv per year.

Information CT-scanner:

- **Attachment, pg. 13:** Iso kerma map of the CT scanner
- The tube voltage of the CT-scanner is 120 kV
- The mAs value of the CT-scanner is 51,850,000 mAs per year, for all conducted examinations

Question 4.2 (5 points)
Calculate the required thickness of the lead glass in mms if the total effective dose in P is not allowed to exceed 50 µSv/year.

The backside of the CT scanner is placed in the direction of the outside facade. The outer wall consists of 20 cm concrete and 10 cm aerated concrete, and is also the site boundary. The distance between the imaginary point from where the scattered radiation originates at the CT scanner and the outside of the outer wall is 2.3 meters.
Aerated concrete consists of the same raw materials as ordinary concrete, but due to the presence of small gas bubbles its density is much lower. The specific weight of ordinary concrete is 2400 kg/m^3. The specific weight of aerated concrete is 600 kg/m^3.

Question 4.3 (4 points)
Determine whether the contribution of the CT scanner to the effective dose on the site boundary is lower than the secondary level.

Eye lens dose at the C-arm
Several radiologists work at the clinic, and they divide the number of interventions at the C-arm amongst themselves in such a way that each radiologist performs a maximum of 200 procedures per year. The X-ray tube is located under the table during the screening with the C-arm. Viewed from above, each radiologist always stands at an angle of 15 degrees with the C-arm (see figure 4.2). The radiologists wear a lead apron, but do not use any eye protection.

Given:
- The distance at the C-arm between the eyes of the radiologist and the imaginary point in the patient from where the scattered radiation originates is on average 80 cm.
- The conversion factor $D_{eye\ lens}/K_a$ = 1.9 Gy/Gy.
- You can equate the equivalent dose of the eye lens to the eye lens dose: $H_{eye\ lens}$ (Sv) = $D_{eye\ lens}$ (Gy) × 1 (Sv/Gy)
- **Attachment, pg. 12:** Iso kerma map of the C-arm at a height of 150 cm above the floor. This iso kerma map can be used for the kerma at eye level.

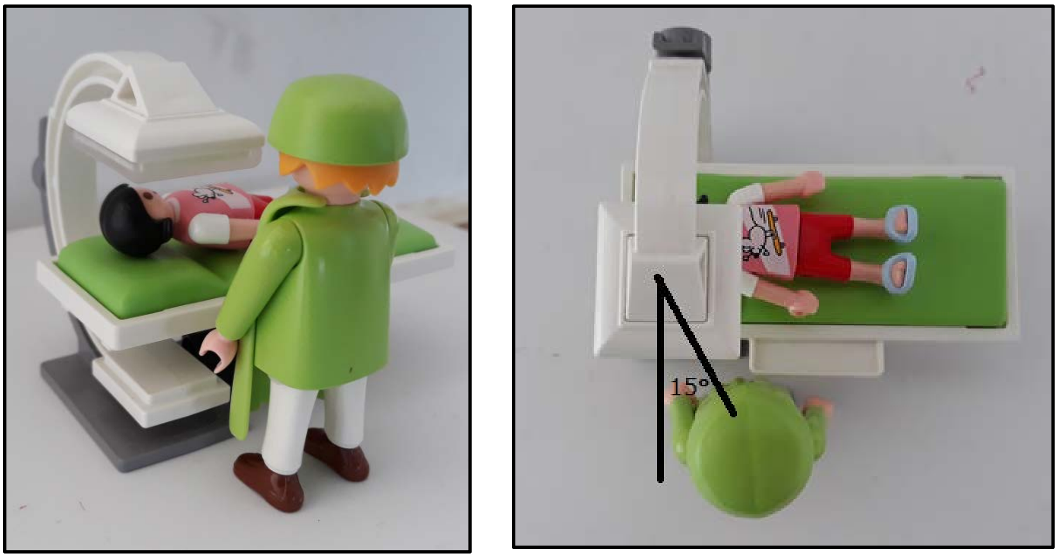


Figure 4.2: Operations with the C-arm

Question 4.4 (4 points)

Calculate, using the iso kerma map of the C-arm (attachment, pg. 12), whether the equivalent dose limit of the eye lens of the radiologist is exceeded.