Examination

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

Date of examination: 10 December 2018
Time of examination: 13.30 - 16.30

Instructions

- **This examination paper consists of 10 numbered pages and a separate 14-page appendix with data. Please check that you have both, and that they are complete!**
- Write your solutions and answers on the worksheets provided. You must hand in any unused worksheets at the end of the examination.
- Write **only your candidate number** on the worksheets (not your name and address).
- You may consult books, personal notes and other documentation when answering the questions.
- In answering the questions, you **must** provide the **calculations** and/or **reasoning** used to arrive at your solutions. If you are unable to reach a solution needed to answer subsequent parts of a question, you may assume a fictional one.
- The questions describe fictional situations, from which no rights may be derived. In some cases, not all the data provided are needed to answer the question.
- You can earn a total of 62 marks by answering all the questions correctly. The marks are distributed as follows.
  - Question 1: 13 marks
  - Question 2: 16 marks
  - Question 3: 17 marks
  - Question 4: 16 marks
- To pass this examination, you must obtain at least 55% of the available marks. That is, 34,1 marks or more.

Question 1: Fire service guidelines and the A_1 and A_2 transport threshold limits

The emergency services in the Netherlands have guidelines in place describing how to respond to incidents involving hazardous substances, including situations in which radioactive substances are present.

According to fire service guidelines:
In the event of an incident involving a radioactive substance, the fire service will establish a cordon upwind. This is positioned where a dose rate of 25 µSv/hour is measured. The service assesses the situation from this cordon.

The table below was taken from one of the General Radioactivity Action Cards (Aandachtskaarten RA Algemeen) included in the operational guide to radiation incidents for Safety Regions (*Stralingsincidenten veiligheidsregio's – Operationele handreiking*) published by the Netherlands Institute for Safety (Instituut Fysieke Veiligheid).

Distance from source at which 25 µSv/h is measured	Deployment time until a dose of 2mSv is reached at a distance to the source of		
	1 metre	5 metre	10 metre
10 metre	48 min	20 h	80 h
20 metre	12 min	5 h	20 h
30 metre	5 min	132 min	9 h
40 metre	3 min	75 min	5 h

Thus: if the measured dose rate is 25 µSv/h at 20 metres from the source, then the maximum deployment time is 12 minutes at 1 metre from the source.

Data

- **Appendix p. 3**: *Handboek Radionucliden*, A. S. Keverling Buisman (third edition, 2015), p. 13: Inleiding (Introduction).
- **Appendix pp. 4-5**: *Handboek Radionucliden*, A. S. Keverling Buisman (third edition, 2015), pp. 164-165, data ^{131}I.

Question 1.1 (2 marks)

Demonstrate, by means of a calculation, that the expected dose during a deployment lasting 3 minutes at a distance of 1 metre from the source is 2 mSv when the cordon is at a distance of 40 metres. You may, in this case, assume that the source is a point source.

To safeguard emergency responders during incidents in transit, the A_1 and A_2 values have been introduced for carrying radioactive substances. To better understand how the A_1 and A_2 values were arrived at, a radiation expert performs a number of calculations using them. These are done for the nuclide ^{131}I, because it is transported by road in large quantities on a daily basis.

Question 1.2 (3 marks)

Demonstrate, by means of a calculation and using the assumptions made in the introduction to the Radionuclides Handbook (*Handboek Radionucliden*), that the A_1 value for ^{131}I of 3 TBq is approximately correct.

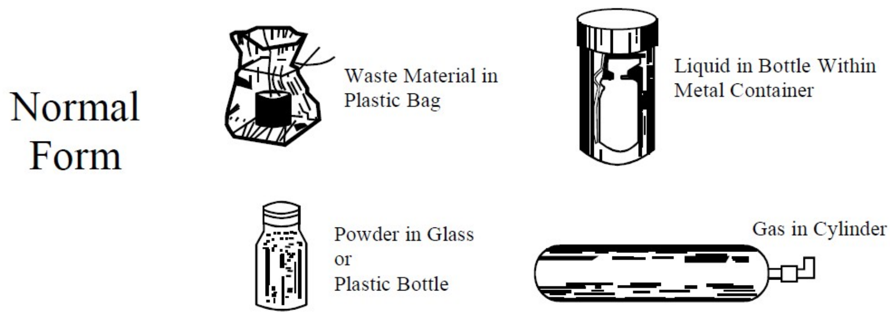

Fig 1.1 Examples of packaging for which the A_2 value is relevant since the contents may be dispersed in the event of an accident (illustration from www.nrc.gov)

Question 1.3 (4 marks)

Determine, by means of a calculation, whether a value of 0.7 TBq for A_2 in the case of ^{131}I corresponds with the assumptions made in the introduction to the Radionuclides Handbook.

Further study of the literature tells us that an increasingly wider range of basic factors are used in determining the A_2 value, and also that more causes than just inhalation risk are involved. In Appendix I of its *Safety Guide No. TS-G-1.1* (2002), the IAEA explains the system for calculating the A_1 and A_2 values. In determining the A_2 value, factors considered include possible skin contamination.

Freely adapted from IAEA *Safety Guide No. TS-G-1.1*

Assumptions concerning skin contamination risk when determining the limiting activity A_2 include:

- *the equivalent dose to the skin for an emergency responder must not exceed 500 mSv;*
- *a maximum of 1% of the activity being transported is dispersed homogenously over a surface area of 1 m^2;*
- *of this, a maximum of 10% is transferred to the hands through direct contact; and,*
- *no gloves are worn and the hands are washed after no more than five hours.*

Explanation of the assumption that 10% of the activity is transferred to the hands: the degree of contamination (the activity per surface unit) of the hands is no more than 10% of that of the contaminated surface. So if the homogenous surface contamination is 2000 Bq/m^2, for example, then the maximum contamination of the hands will be 200 Bq/m^2.

Question 1.4 (4 marks)

Demonstrate, by means of a calculation, that the transport threshold limit value of 0.7 TBq for A_2 in the case of ^{131}I corresponds with the scenario for skin contamination in *Safety Guide No. TS-G-1.1*.

Question 2: Contamination checks

In a radionuclides laboratory work is done with ^{3}H en ^{14}C. To check for contamination, wipe tests are carried out and the results measured by a liquid scintillation counter. A contamination monitor is also used. The relevant regulations are as follows.

Authority for Nuclear Safety and Radiation Protection (ANVS)

Basic Safety Standards for Radiation Protection (Bbs)

Article 1.1 (definition of terms)

In these regulations, the following is meant by the term *radioactive contamination*: a non-fixed (=removable) alpha contamination of 0.4 becquerel or more per cm² or a non-fixed beta/gamma contamination of 4 becquerel or more per cm².

Article 4.21 (instruction contamination checks)

In performing a contamination check as referred to in Article 4.11, clause 1, the following standards apply:

a) the surface wiped has an area of approximately 5 cm²; and,
b) for all nuclides, the lower limit of detection is 2 becquerels.

For the measurements taken in the liquid scintillation counter, the following details are known.

- The measurement time for the wipe samples is 1 minute.
- The counting efficiency of the wipe samples is assumed to be equal to that of two calibration standards:
    - measuring 10,000 dpm of ^{3}H results in 6,053 counts in 1 minute; and,
    - measuring 10,000 dpm of ^{14}C results in 9,420 counts in 1 minute.
- An extended measurement of a blank sample results in 908 counts in 1 hour.

Question 2.1 (4 marks)

Calculate the counting efficiency for the measurement of ^{3}H in cpm/dpm, and the standard deviation in this counting efficiency.

In this question, the MDA (Minimum Detectable Activity) for measurement time t refers to the level of activity producing a count rate equal to three times the standard deviation in the background count rate.

Question 2.2 (4 marks)
Verify, using the liquid scintillation counter's MDA, whether it complies with the lower limit of detection as defined in Article 4.21 for both nuclides with the measurement time given for the wiped samples.

During a contamination check (conducted as per instructions), a gross figure of 753 counts is measured in one of the wipe samples. Further analysis reveals that this is ^{14}C contamination only.

Question 2.3 (4 marks)
Calculate the wiped-off ^{14}C activity in Bq/cm² of this contamination.

The laboratory's contamination monitor is not used to determine non-fixed activity, but rather to detect the activity present in the event of a surface being contaminated. Assuming that 50% of the activity is non-fixed, an activity of 8 Bq/cm² present over a contaminated area of 5 cm² should then be measurable.
Under normal circumstances, the contamination monitor measures a background count rate of 5 cps with a fluctuation of 2 cps. All available details about the sensitivity of this device can be found in figure 2.1. The dimensions of the detector are 11 × 11 cm². Consider a surface to be contaminated if the gross count rate is 10 cps or more.

Calibration data of LB 1210 B

Isotope	$1\ s^{-1}$*) per Bq · cm^{-2}	$1\ s^{-1}$*) per $10^{-4}\ \mu Ci/cm^2$	Thresold setting*) 3,7 Bq · cm^{-2} ($10^{-4}\ \mu Ci/cm^2$)
^{14}C	0.2	0.05	$20\ s^{-1}$
^{60}Co	0.07	0.02	$50\ s^{-1}$
^{99m}Tc	0.3	0.08	$13\ s^{-1}$
^{125}I	0.3	0.08	$13\ s^{-1}$
^{131}I	0.04	0.01	$100\ s^{-1}$
^{241}Am	0.3	0.08	$13\ s^{-1}$

*) Countrate above background

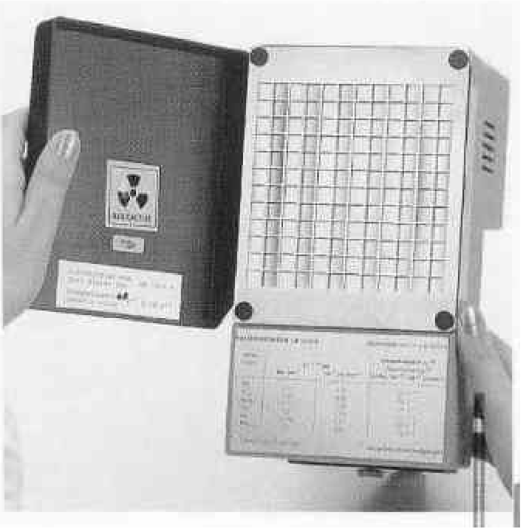

Figure 2.1: Contamination monitor sensitivity.

Question 2.4 (4 marks)
Would a contamination of 8 Bq/cm² over an area of 5 cm² be detected as contaminated if this monitor is used? You may assume that the rest of the surface is completely uncontaminated.

Question 3: Screening during sterilisation

A company uses gamma radiation from a sealed cobalt-60 source to sterilise medical equipment. The source has an activity of 185000 TBq. For active use, the source is lifted to a position just above the water level, where it can freely irradiate the equipment being sterilised. Under the company's internal protocols, the ambient dose equivalent rate in the working space directly above the irradiation chamber must not exceed 1.0 µSv/h. The irradiation chamber is 10 metres high and the floor separating the irradiation chamber from the working area is made of concrete and is 2 metres thick (Figure 3.1).

Once a day, a staff member enters the chamber, during 2.5 minutes, to place materials on the table for sterilisation. The irradiation table is positioned 1 metre above the water level. The positioning occurs with the source still being submerged in 3.5 metres of water. Other than this the worker is not occupationally exposed to ionising radiation.

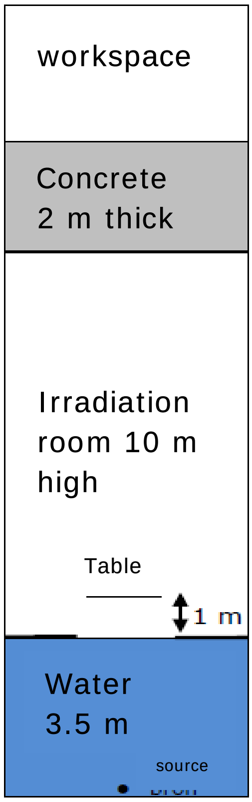

Figure 3.1

Data

- The ambient dose equivalent rate constant for ^{60}Co is h=0,36 µSv/h per MBq/m^2
- As a result of the decay of ^{60}Co decays two photons are emitted with energies of 1173 and 1332 keV respectively and y = 1(Bq·s^{-1}) for both photons; any other emitted radiation is negligible.
- **Appendix p. 6, Figure 1:** Broad-beam transmission of gamma rays from various radionuclides through concrete, density 2.350 g/cm^3.
- **Appendix p. 7, Table 1:** Exposure build-up factor for an isotropic point source. For the purposes of this question, when determining the build-up factor you may use the column in the table with the value in µd closest to the calculated value.
- **Appendix p. 8, Figure 2.** Mass half-value thicknesses of various materials for narrow-beam gamma radiation.
- Atmospheric absorption may be disregarded.
- A working week consists of five days. There are 40 working weeks in a calendar year.
- The effective dose may be taken as being equal to the ambient dose equivalent.
- You may assume that the source is a point source.

Question 3.1 (4 marks)

Using Figure 3.2, demonstrate that the transmission of photons emitted by ^{60}Co through 2 metres of concrete is in the order 10^{-10}.

Question 3.2 (3 marks)

Verify if the ambient dose equivalent rate in the workspace above the irradiation chamber is compliant with the in-house rules when the source in its active position.

Question 3.3 (6 marks)

Using Table 1 and Figure 3.3, calculate the transmission through 3.5 metres of water.

If you are unable to answer the question above, you may assume that the transmission through water is $2 \cdot 10^{-8}$ for the next question.

Question 3.4 (4 marks)

Calculate the effective annual dose and, based upon this, determine in which category the worker would fall. Foreseeable, unintended events may be disregarded.

Question 4: Incident with ^{177}Lu

The nuclide ^{177}Lu is now widely used in radionuclide therapy. What is less well-known is that it has also been used in applied nuclear physics for over 50 years, for research into various properties of solid substances. In 1974, to this purpose, a capsule containing 370 MBq of ^{177}Lu was produced by irradiating 10 mg of ^{176}Lu-enriched Lu_2O_3, in powdered form, with thermal neutrons.

Data

- **Appendix pp. 9-10**: *Handboek Radionucliden*, A. S. Keverling Buisman (third impression,2015), pp. 204-205: ^{177}Lu
- **Appendix pp. 11-13**: Appendix to Nuclear Energy Act Licence for Radionuclide Laboratories (*Bijlage radionuclidenlaboratoria*), pp. 10, 11, 12.
- The cross-section for thermal neutrons of $^{176}Lu(n,\gamma)^{177}Lu$ is σ_{th} = 2000 barn.
- The enrichment level of the isotope ^{176}Lu is 72% (atomic percent).
- The flux density of the thermal neutrons at the location of the irradiated specimen was $3.0 \cdot 10^{16}$ m^{-2} s^{-1}.
- The atomic weight of oxygen is 16 g mol^{-1}.
- The atomic weight of ^{176}Lu-enriched lutetium may be taken as 176 g mol^{-1}.
- The Avogadro constant is $N_A = 6.022 \cdot 10^{23}$ mol^{-1}
- You may use the following formula for activation:

$$A = \sigma_{th} \cdot n \cdot \varphi_{th} \cdot (1 - e^{-\lambda t}) \approx \sigma_{th} \cdot n \cdot \varphi_{th} \cdot \lambda \cdot t$$

where

A	=	activity produced (in Bq)
σ_{th}	=	cross-section for thermal neutrons (in m^2)
n	=	number of atoms irradiated
φ_{th}	=	flux density of the thermal neutrons (in $m^{-2} \cdot s^{-1}$)
λ	=	decay constant of the reaction product (in s^{-1})
t	=	irradiation time (in s)

Question 4.1 (5 marks)

For how many minutes must the specimen be irradiated to achieve the desired activity?

When processing the ^{177}Lu capsule, things went very wrong. The irradiated capsule was opened by a radiochemist on a lab table (!) in the Category B Laboratory. Just when he had transferred the powder onto a balance to weigh it, the telephone rang in the adjacent anteroom. While he was answering this call, another member of staff entered the laboratory. Finding the powder on the balance, he assumed it was waste and threw it into the waste bin, causing considerable contamination. He subsequently performed his own tasks on the lab table. When the radiochemist returned, he discovered what had happened and immediately took action.

Question 4.2 (3 marks)

Under the provisions of the Appendix ‘Radionuclide Laboratories’ to the Nuclear Energy Act Licence as they currently apply, should the radiochemist have handled 370 MBq $^{176}Lu_2O_3$ powder in the manner described?

As the second member of staff threw away the powder, a proportion of the total activity it contained was dispersed and may well have been inhaled by him. The radiochemist asks him to blow his nose forcefully into a tissue to determine whether he has suffered any internal contamination and, if so, to what extent. Measurement of the tissue using a contamination monitor detects a net count rate of 120 cps.

Additional data

- The contamination monitor has a surface detection area of 218 cm^2.
- **Appendix p. 14**: Figure 1, counting efficiency (in cps per Bq cm^{-2}) of the contamination monitor (Berthold LB 122A) as a function of the average β energy (in keV), <u>assuming a yield of 1.</u>
- The detector is insensitive for γ radiation.
- **Appendix p. 14**: *Inleiding tot de stralingshygiëne*, A. J. J. Bos et al., Table 9-6.
- Assume that half of the activity deposited in the nose is expelled again when he forcefully blows his nose.
- The activity in the tissue from the noseblow falls entirely within the surface detection area of the contamination monitor.

Question 4.3 (4 marks)

Determine by calculation that the counting efficiency of the contamination monitor for ^{177}Lu is approximately 0.23 *<u>cps per Bq</u>*.

Question 4.4 (4 marks)

Determine the inhaled activity and, from this, the committed effective dose received by the member of staff.