Versie met opmerkingen!

Embargo until 23 May 2016

Examination
Coordinating Expert Radiation Protection

Nuclear Research and Consultancy Group	NRG
Delft University of Technology	TUD
Boerhaave CME/LUMC	BN
University of Groningen	RUG
Radboud University/UMC St. Radboud	RU/UMC
TU Eindhoven	TUE

Examination date: 23 May 2016
Duration of examination: 13:30-16:30

Instructions:

- **This examination comprises 12 numbered pages and a separate 8-page appendix containing data. Please check whether it is complete!**
- Write your solutions and answers on the worksheets provided. You must return all worksheets, including any unused ones.
- Write **only your examination number** on the worksheets (not your name and address).
- You are allowed to consult books, personal notes and other documentation materials when answering the questions.
- *You are explicitly reminded that you must also indicate the **calculation method** and/or **reasoning** that you used in order to arrive at the solution.*
- If you cannot calculate part of a problem and the answer is needed to solve the rest of the problem, you may assume a fictitious answer.
- Some problems may not require you to use all of the data provided.
- You can earn a total of 63 points for solving the problems correctly. The points are distributed across the problems as follows:
  - Problem 1: 15 points
  - Problem 2: 17 points
  - Problem 3: 14 points
  - Problem 4: 17 points
- You passed this part of the exam if you scored more than 55% of the total number of points. This corresponds with a score of at least 34.65 points.

Problem 1 Measuring contamination

Sources are regularly made for a practical demonstration at a radionuclide laboratory. One day a contamination is discovered on the floor. The supervisory radiation expert is asked to investigate it. The log shows that only ^{60}Co and ^{35}S have been used since the last inspections. A wipe test is carried out on the contaminated part of the floor. The wipe sample is then measured with both a Geiger–Müller tube beta counter and a gamma spectrometer. The beta counter gives a reading of $4.20 \cdot 10^3$ cpm (counts per minute). The gamma spectrometer gives a reading of 480 cpm in the 1.3 MeV photo peak.

Data:

- ^{35}S $T_{1/2}$= 87.4 d $E_{\beta,max}$= 0.167 MeV (100%), no γ
- ^{60}Co $T_{1/2}$= 5.27 y $E_{\beta,max}$= 0.318 MeV (99.9%), $E\gamma$= 1.333 MeV (100%) and 1.173 MeV (99.9%)

  The percentage indicates the emission probability.
- Counting efficiencies in the test systems used:
  - Beta counter for $E_{\beta,max}$ between 100 and 400 keV: 45% (cps/Bq)
  - Gamma spectrometer photopeak efficiency at 1.3 MeV: 32% (cps/Bq)
- The counting efficiency of the beta counter for ^{60}Co photons may be taken as 0.
- Dead time of the beta counter: 200 µs
- Count time with both the beta counter and the gamma spectrometer is 2 minutes.
- The background count rate for both detectors may be ignored in this case.
- Wiped floor area: 120 cm^2
- Assumed wipe efficiency: 35%

Question 1
What is the beta count rate of the wipe sample corrected for dead time?

Question 2
What is the total beta activity of the wipe sample expressed in Bq?

Question 3
What is the measured ^{60}Co activity in the wipe sample expressed in Bq?

Question 4
Calculate the average surface contamination of the wiped area for both ^{35}S and ^{60}Co in $Bq \cdot cm^{-2}$.

The supervisory radiation expert wants to be absolutely certain that the total surface contamination does not exceed the surface contamination limit. A reliability limit a margin of 2x the standard deviation is used.

Question 5
Show by calculation, with the above reliability limit, that the total degree of contamination of the wiped surface does not exceed the legal permissible limit for surface contamination.

Problem 2 Brachytherapy emergency procedure

Patients with cancer of the oesophagus can be irradiated both externally and internally in a radiotherapy unit. Brachytherapy is a treatment that involves bringing a ^{192}Ir source close to the tumour to irradiate it at a short distance. The radioactive source is inserted in the patient remotely by means of a catheter.
One day a complication occurs during irradiation: the radioactive source is not removed from the patient automatically. The radiographer and the laboratory assistant now need to carry out the emergency procedure and get the ^{192}Ir out of the patient as quickly as possible. The radiographer and the assistant enter the brachytherapy room. The assistant first goes to the rack where the lead aprons are, takes one and puts it on. The radiographer goes straight to the patient, pulls the catheters, including the ^{192}Ir source, out of the patient and puts them in the emergency container beside the patient. Together they lead the patient out of the brachytherapy room, lock it and post warning signs.

Data:

General:

- **Appendix, p. 3:** *Handboek Radionucliden* [Radionuclides Handbook], A.S. Keverling Buisman (2nd edition 2007), p. 214, data on ^{192}Ir
- **Appendix, p. 4:** Detailed curve of broad beam transmission of photons from ^{192}Ir through lead (SBD-TU/e)
- The ambient dose equivalent may be used as an estimator of the effective dose.

Procedure:

- During the emergency procedure, the radiographer and the laboratory assistant are exposed to the ^{192}Ir source for 30 seconds.
- The radiographer and the assistant may be assumed to be at a fixed distance from the ^{192}Ir source during the emergency procedure, 20 cm and 2 m respectively. 2,0 m !
- Thickness of lead apron 0.50 mm Pb
- The laboratory assistant may be assumed to have been wearing the lead apron for the full 30 seconds.
- The attenuation by the patient may be ignored.

Source data:

- The activity of the ^{192}Ir source was 12 Ci on the calibration day.
- The patient's treatment took place 30 days after the calibration.
- The ^{192}Ir source may be regarded as a point source.

- The casing of the radioactive material is 0.33 mm thick stainless steel (density = 7.8 g/cm^3)

Emergency container:

- The emergency container, a cylindrical lead container, has an external diameter of 25 cm and a height including base and lid of 25 cm.
- All the walls, including the base and lid, are 3 cm thick.

The ^{192}Ir source may be assumed to be at the centre of the container, both horizontally and vertically.

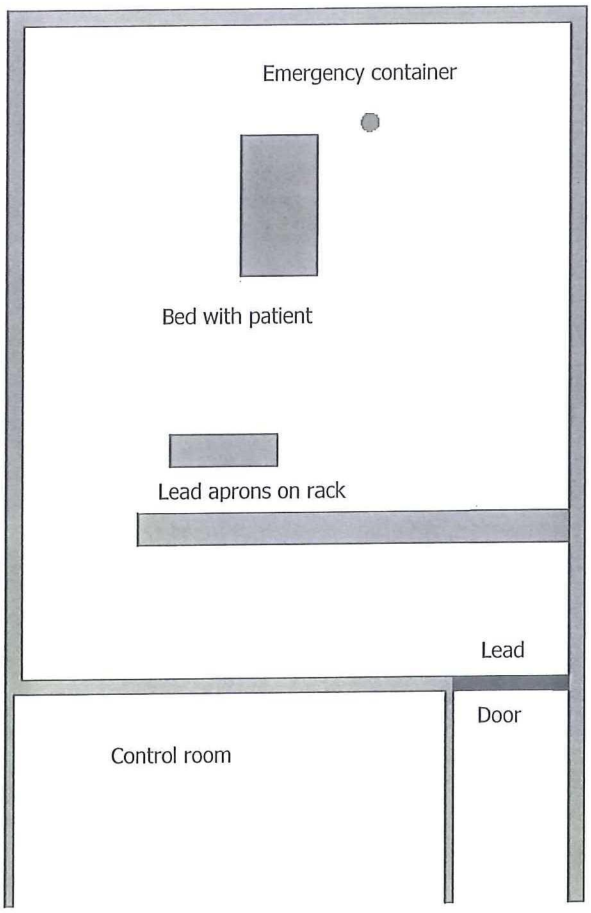

Fig. 1: Bird's eye view of brachytherapy room with bed and patient

Question 1

Show by calculation that the casing of ^{192}Ir source is thick enough to absorb the β^- radiation emitted completely.

Question 2a

What effective dose do the radiographer and the laboratory assistant receive as a result of the emergency procedure, ignoring the effect of the lead apron?

Question 2b

Does the lead apron provide any added value in terms of protection in this emergency procedure? What should the advice on wearing lead aprons in this emergency procedure be? Explain your answer.

Question 3

Based on the exposure risks from his other work, the radiographer (regular dose 5 mSv per year) is classified as a Category B exposed worker. Is Category B the correct classification if the probability of the above scenario occurring is taken to be once a year? Explain your answer.

Under the Transport Decree the limits for the transport of a package are:
1) 2 mSv/h at the surface of the package and
2) 0.1 mSv/h at a distance of 1 m from the surface of the package.

Question 4

Does the closed emergency container – immediately after the incident – comply with the Transport Decree limits?

Problem 3 Effectiveness of a lead apron

An interventional radiologist has been working in interventional radiology for 14 years and has a badge reading (deep dose, $H_p(10)$) averaging 4.7 mSv per year. He wears a 0.25 mm lead-equivalent apron and a 0.50 mm lead-equivalent thyroid collar. The lead apron is a wrap-around apron with a wide overlap at the front, resulting in 0.50 mm lead equivalent at the front. The TLD badge is worn on the chest outside the lead apron. During irradiation the radiologist stands facing the patient.
To ascertain how much effect wearing the lead apron has on the effective dose an experiment is carried out to measure the transmission. This involves simulating the scattered radiation that occurs in a patient by producing scattered radiation in a perspex phantom. A detector is placed inside the lead apron. Transmission is determined by comparing the measured intensity with and without the lead apron. This is carried out using various phantoms, geometries and tube voltages. The results of these measurements are set out in the Appendix.

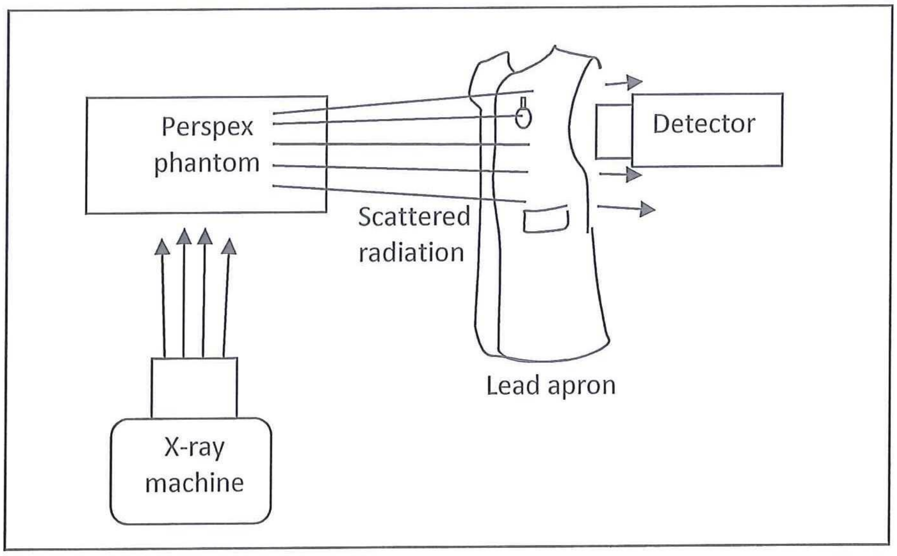

Fig. 1: Experimental determination of transmission of the scattered radiation

Data:

- The dose received by the radiologist is caused solely by radiation scattered at 90°.
- The radiation scattered by the patient can be simulated effectively using a perspex phantom.
- During irradiation the X-ray device is set at 80 kV.
- Density of lead: 11.34 g/cm³

- **Appendix, p. 5:** Fig. 6-2: Experimentally determined transmission of direct and scattered X-rays through a 0.50 mm lead-equivalent apron as a function of tube voltage (from Report 17 of the Netherlands Commission on Radiation Dosimetry, *Dosimetrie in de Radiologie: Stralingsbelasting van de Patiënt en Werknemers* [Dosimetry in Radiology: Radiation Exposure of Patients and Workers] (2007))
- **Appendix, p. 6:** Graph of interaction coefficients for photons, lead 0.0010 MeV – 0.2 MeV (based on Table D in *Inleiding tot de Stralingshygiëne* [Introduction to Radiation Protection], Bos et al. (2nd edition 2007))
- **Appendix, p. 7:** Fig. 6.9 in *Inleiding tot de Stralingshygiëne*, Bos et al. (2nd edition 2007): Ratio between effective dose E and personal dose equivalent H_p, slab(10. 0°) as a function of photon energy in the AP radiation geometry (from ICRP-74)
- **Appendix, p. 8:** Tissue weighting factors according to ICRP-60

Question 1

With shielding of monoenergetic photons μ/ρ can be determined from the transmission. Although an X-ray machine does not emit monoenergetic photons, this is a method of determining a photon energy that can be referred to as the effective photon energy.
Determine the effective photon energy of photons scattered in perspex at an angle of 90º to the place where the radiologist stands, assuming that:

- the tube voltage is 80 kV
- the equivalent lead thickness of the lead apron is 0.50 mm
- the build-up factor may be taken as 1.

Question 2

The scattered radiation irradiates the radiologist in an AP geometry. From the average badge reading ($H_p(10)$), determine the interventional radiologist's average annual effective dose if he wears a lead apron and a thyroid collar, assuming that all the organs that contribute to the effective dose are shielded with 0.50 mm lead. 0.060 MeV
(If you have not found the answer to Question 1, you may take 0.06 MeV as the average energy of the scattered radiation.)

Question 3

Say a thyroid collar is not worn, what would the annual effective dose be, assuming in this case that among the organs that contribute to the effective dose only the entire thyroid gland is unprotected?

Question 4

The interventional radiologist does not wear eye protection. If you were the radiation expert, would you advise him to do so? Explain your answer based on the current legal dose limit for the eye lens of 150 mSv/year and the limit for the eye lens of 20 mSv/year under the new European Basic Standards. The badge reading $H_p(10)$ may be taken as a good estimator of the eye lens dose.

Problem 4 Exposure in a cyclotron room

When a cyclotron is operating, activation of the air causes some relatively short-lived radionuclides to be formed, which are then discharged into the atmosphere via the ventilation system. This problem involves examining the radiation protection effects on workers in the cyclotron room or one of the irradiation rooms.

Data

- **Table 1:** Overview of annual discharge of activity
- Assume that the activity concentration in the discharged air is constant during the hours when the cyclotron is operating.
- The average activity concentration in the cyclotron room during the hours when the cyclotron is operating may be taken to be the same as that in the discharged air.
- Assume that the activity concentration of ^{15}O determines the total activity concentration.
- The ventilation flow rate in the cyclotron room is 24,000 $m^3 \cdot h^{-1}$.
- The cyclotron operates 24 hours a day, 5 days a week and 50 weeks a year.
- A worker's full working hours are 2,000 h per year.
- According to the submersion model the absorbed dose D_T (in Gy) in organ T is given by the expression

$$D_T = 2.5 \cdot 10^{-10} (\mathrm{J \cdot MeV^{-1} \cdot m^3 \cdot kg^{-1} \cdot s \cdot h^{-1}}) \sum_i g_{T,i} \times C_i \times E_i \times t \ \ (\mathrm{Gy})$$

  where g_T is the protection factor for organ T, C is the activity concentration (in $Bq \cdot m^{-3}$) in the air, E the energy (in MeV per Bq·s) released per disintegration, and t the residence time (in h). Summation takes place over all nuclides (*i*).
- The contribution to the radiation exposure due to inhalation by workers during submersion may be ignored in Questions 2 and 3.

Table 1: Annual activity discharge per nuclide, where $T_{½}$ is the half-life, $<E_\beta>$ the average beta energy, E_γ the energy of gamma or annihilation radiation per disintegration, and A the annual discharged activity of the particular nuclide.

Nuclide	$T_{½}$ (min.)	$<E_\beta>$ (MeV/(Bq·s))	E_γ (MeV/(Bq·s))	A (GBq·y^{-1})
^{11}C	20	0.39	1.02*	180
^{15}O	2	0.74	1.02*	1600
^{13}N	10	0.49	1.02*	160
^{41}Ar	110	0.46	1.28	50

* Assuming *two* annihilation photons of 0.511 MeV each

Question 1

Determine the activity concentration (in kBq·m^{-3}) of ^{15}O.

Question 2

Calculate the annual effective dose due to submersion in air with ^{15}O for a worker who spends all his working hours in the cyclotron room while the cyclotron is operating. Assume that photon radiation is the only contributor to the effective dose and that shielding of deeper organs in the body may be ignored (i.e. the value of g_T for all organs may therefore be taken as 1). If you have failed to answer Question 1 you may assume an activity concentration of ^{15}O of 10 kBq·m^{-3}.

Repeating Question 2 for other nuclides shows that the dose effects are almost entirely determined by ^{15}O, so the other nuclides need not be considered.

Adjacent to the cyclotron room are a number of irradiation rooms, where the ventilation is not as good as in the cyclotron room and the activity concentration in the air is therefore substantially higher. Measurements show that the ambient dose equivalent rate caused by ^{15}O immediately after switching off the beam in the irradiation rooms can reach a maximum of 100 µSv·h^{-1}.

Question 3

Calculate the maximum ^{15}O activity concentration in the air in the irradiation rooms, assuming that the ambient dose equivalent is a good estimator of the effective dose (due to submersion).

In contravention of the rules a worker enters an irradiation room immediately after the cyclotron beam is switched off.

Additional data

- When the worker enters the irradiation room $\dot{H}^{*}(10) = 100\ \mu Sv \cdot h^{-1}$.
- According to ICRP-80 ^{15}O *injections* have a dose conversion coefficient of $e(50)_{injection} = 9.3 \cdot 10^{-13}$ Sv Bq^{-1}.
- Approximately 20% of the oxygen inhaled is absorbed in the transfer compartment via the lungs and may be regarded as injected activity for the purpose of this question.
- The worker's average breathing rate is 1.4 $m^3 \cdot h^{-1}$.
- The removal of activity from the irradiation room by ventilation may be ignored for the purpose of this question.

You now want to estimate both the committed effective dose of ^{15}O due to inhalation and the effective dose due to external irradiation by ^{15}O.

Question 4

Show by calculation that the *maximum* committed effective dose due to inhalation of ^{15}O as a result of entering the irradiation room too early is negligible compared with the effective dose due to external irradiation by this nuclide. If you have failed to answer Question 3 you may assume a maximum activity concentration of ^{15}O of 500 $kBq \cdot m^{-3}$.