ANSWERS

Exam
Radiation protection expert on the level of coordinating expert

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- The solutions below are meant as a guideline for correctors. The corrector can deviate from these with proper argumentation per sub question. The examination candidate cannot derive any rights from the proposed point distribution.

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

Question 1.1 [4 points]

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

$A_{max,j} = (0.02\ [Sv] / e_{50}) \times 10^{p+q+r}$

- inhalation class M: $e_{inh(50)} = 1.0{\cdot}10^{-9}$ Sv/Bq
- simple chemical steps, labeling: p=-2
- B-laboratory: q=3
- closed work cabinet (class-III cabinet): r=3

$A_{max,j} = 0.02\ [Sv] / (1.0{\cdot}10^{-9}\ [Sv /Bq]) \times 10^{-2+3+3} = 2.0 \times 10^{11}$ Bq (200 GBq)

Correct $e_{(50)}$ [1 point]

Correct parameters p, q and r [2 points]

Correct calculation [1 point]

Question 1.2 [4 points]

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

At the surface:

$\dot{H} = h \times A / r^2 = 0.0063\ [\mu Sv\ m^2\ MBq^{-1}\ h^{-1}] \times 7.4{\cdot}10^3\ [MBq] / (0.12\ [m])^2$

$\dot{H} = 3238\ \mu Sv/h$ or 3.2 mSv/h

Correct source constant [1 point]

Correct distance [2 points]

Correct calculation [1 point]

Question 1.3 [6 points]

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

Maximum values of the ambient dose equivalent rate
- at the surface of a parcel: 2 mSv/h
- at 1 m from the surface: 0.1 mSv/h

Transmission for surface requirement: T = 2 / 3.2 = 0.62
$\dot{H}$ at 1 meter = 3.2 [mSv/h] × (0.12 [m]/1.12 [m])^2 = 0.037 [mSv/h]
The ambient dose equivalent rate at 1 meter is thus already lower than the requirement. It follows that the surface requirement is the most restrictive.

Simplifications:
- The transmission is only calculated for the energy of 208 keV. The lower energetic photons will be absorbed more easily.
- μ/ρ for 208 keV equals μ/ρ for 200 keV

Lookup in attachment:
- μ/ρ at 200 keV in table "Mass attenuation coefficients for lead": μ/ρ (2.00E-01 [MeV]) = 9.985E-01 [cm^2/g] = $9.985 \cdot 10^{-1}$ [cm^2/g] = 0.9985 cm^2/g
- Lookup B at 200 keV in table "Exposure absorption build up factors": chosen initial value 1.2
- Density lead = 11.3 g/cm^3

$T = B \times e^{-\mu d} = B \times e^{-\mu/\rho \times d\rho}$
$0.62 = 1.2 \times e^{-0.9985\ [cm2/g] \times d \times 11.3\ [g/cm3]}$
$\ln (0.62/1.2) = \ln e^{-0.9985\ [cm2/g] \times d \times 11.3\ [g/cm3]}$
-0.66 = -0.9985 [cm^2/g]×d×11.3 [g/cm^3]
d = -0.66 / -0.9985 [cm^2/g]×11.3 [g/cm^3] = 0.058 cm = 0.58 mm
rounded up to whole mms: d = 1 mm

Check choice build up factor:
μd = 0.9985 [cm^2/g]×0.1 [cm]×11.3 [g/cm^3] = 1.12
Corresponding B: 1.19 (for R(mfp)=1.0 and E=0.2 MeV)
$\dot{H}$ = 3.2 [mSv/h] × 1.19 × $e^{-1.12}$ = 1.24 mSv/h, so well below the maximum value.

Calculation transmission	[1 point]
Correct distance	[1 point]
Naming simplifications	[1 point]
Calculating thickness and rounding up	[2 points]
Choice and check build-up-factor	[1 point]

Question 1.4 [3 points]

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

The dose rate at the surface for question 1.3 exceeds 0.5 mSv/h, so label III-yellow needs to be selected. On this label should be entered:

- CONTENTS: Lu-177
- ACTIVITY: 7.4 GBq
- TRANSPORT INDEX: 1.5

Calculation transport index:

$\dot{H}$ = 1.24 mSv/h at 12 cm from source, so at 112 cm this equals

1.24 [mSv/h] $\times$ $(12/112)^2$ = 0.0142 mSv/h

TI = 0.0142 [mSv/h] $\times$ 100 = 1.42 → TI = 1.5

(due to the mandatory rounding up)

Choice correct sticker	[1 point]
Calculating and correctly rounding up TI	[1 point]
Correctly labeling activity and nuclide	[1 point]

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

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

Question 2.1 [3 points]

Show through calculations that the air kerma in air at the location of the entrance surface (on the leg of the horse) indeed equals 0.69 mGy per image.

Read the output, at 73 kV and 3 mm Al filter in figure Attachment pg. 9 “Output air kerma rate of X-ray systems with varying filters and tube currents” yields 3.7 mGy·mA^{-1}·min^{-1}.

$$K_{air} = 3.3\ [mGy \cdot mA^{-1} \cdot min^{-1}\ at\ 1\ meter] \cdot 12.5\ [mA \cdot s] \cdot \left(\frac{1}{60}[min \cdot s^{-1}\right) = 0.7708$$
$$= 0.77\ mGy$$

Read output between 3.5 and 3.9 $mGy \cdot mA^{-1} \cdot min^{-1}$ [1 point]

Application tube current and exposure time [1 point]

Correctly calculating the answer [1 point]

Question 2.2 [4 points]

Calculate the MID (multifunctional individual dose).

For this can be started with the output, or continuing calculations with 0.69 mGy.

$$MID = 0.69\ [mGy \cdot image^{-1}] \cdot \left(\frac{1\ [m]}{3\ [m]}\right)^2 \cdot 0.843\ [T_{wood}] \cdot 1.5[Sv \cdot Gy^{-1}]$$
$$\cdot 0.25\ [housing\ correction\ factor] = 0.024\ mSv \cdot year^{-1} = 24\ \mu Sv \cdot year^{-1}$$

Distance [1 point]

Transmission [1 point]

$H^*(10)/K_a$ [1 point]

Housing correction factor [1 point]

Question 2.3 – Permit [2 points]

Name one violation of the permit and provide one solution.

Examples of things that do not seem to go according to the permit:
- The wall is not made out of steel, stone, concrete or lead, but of wood, and the MID is exceeded.
- The terrain is not shielded, it is possible for people to enter or walk outside around the stables.

Examples how to solve for these in practice:
- Use additional shielding (for example a piece of lead behind the cassette).
- Blocking off the terrain using a sign / ribbon indicating that X-rays are present in the area in question.

[A violation including the associated solution is worth 2 points]
[Answers outside of the answers given here are also possible. When the answer given does not indicate a violation, but when the solution is an ALARA-measure coupled to a not-optimal situation a maximum of 1 point can be allocated.]

Question 2.4 [4 points]

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

For this can be started with the output, or continuing calculations with 0.69 mGy.

From the attachment pg. 10: for an angle of 90° and a tube current of 100 kV, 0.019% is scattered for a field of 100 cm^2 and a distance of 1 m.

[1 point]

$$Hp(10) = 0.69\ [mGy \cdot image^{-1}] \cdot 0.019\ \cdot 10^{-2}\ [\%]\ \cdot \left(\frac{200\ [cm^2]}{100\ [cm^2]}\right) \cdot \left(\frac{100\ cm}{50\ cm}\right)^2 \cdot 1.5\ [Sv \cdot Gy^{-1}]$$
$$= 1.57 \cdot 10^{-3}\ mSv = 1.6\ \mu Sv$$

Distance between the horse's leg and the assistant is 50 cm. [1 point]
Correction for field size is $10\ \times\ 20\ cm\ =\ 200\ cm^2$ [1 point]

Hp(10)/K_a [1 point]

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

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

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.*

The source constant of ^{137}Cs is h = 0.093 μSv/h per MBq/m^2 (Attachment pg 13).
The activity is therefore A = 1 [μSv/h] / 0.093 [μSv/h per MBq/m^2] = 10.8 MBq.

[2 points]

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.

$N_\gamma = A \times \varepsilon_{em} \times \varepsilon_{geo} \times \varepsilon_{abs}$

[1 point]

The emission probability (or rather the emission efficiency) is
$\varepsilon_{em} = 0.946 \times 0.898 = 0.85$.

[1 point]

The geometry factor is ε_{geo} = (effective surface of monitor) / (surface of sphere with diameter of 1 meter) = 15.55 [cm^2] / (4π ×[100 cm]^2) = $1.24 \cdot 10^{-4}$.

[2 points]

The absorption factor is $\varepsilon_{abs} = 1$ (omitting this data does not result in point deduction).

→ $N_\gamma = 10.8 \cdot 10^6$ [Bq] × 0.85 × $1.24 \cdot 10^{-4}$ × 1 = $1.14 \cdot 10^3\ s^{-1}$ [1 point]

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).

The response of the MiniTRACE for gammas emitted by ^{137}Cs equals 4.3 cps per μSv/h (see data).
In question 3.2 is calculated that $1.14 \cdot 10^3$ photons per second on the detector gives rise to an indication of 1 μSv/h.
The intrinsic detector efficiency is therefore 4.3 / $1.14 \cdot 10^3$ = 0.0038 pulses / photon. [2 points]

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.*

The sensitivity of the MiniTRACE S5 is 0.0038 pulses / photon.
The efficiency of the MiniTRACE CSDF is 0.006 cps/Bq for γ-photons, so with the cover closed. [1 point]

The efficiency of the MiniTRACE CSDF is determined by placing a point source at the location of the cover. In the 2π-geometry 1 Bq leads to:
$\varepsilon_{em} \times \varepsilon_{geo} = 0.85 \times 2\pi/4\pi = 0.425$ photons s^{-1} at the detector.

The sensitivity of the MiniTRACE CSDF is therefore:
$\varepsilon_{det,\gamma} = 0.006$ [cps/Bq] / 0.425 [photons s^{-1} / Bq] = 0.014 pulses / photon. [2 points]
Both values differ by more than a factor of 3 and therefore do not correspond. [1 point]

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?

The maximum energies of the emitted betas are according to the Handboek Radionucliden respectively 0.5 and 1.2 MeV.

$0.5 \times E = R \cdot \rho$, so $R = (0.5\ E)/\rho$
R = (0.5 × 0.5 [MeV]) / 2.7 [g/cm^3] = 0.093 cm = 0.93 mm
R = (0.5 × 1.2 [MeV]) / 2.7 [g/cm^3] = 0.22 cm = 2.2 mm [1 point]

Conclusion: the betas with a maximum energy of 0.5 MeV are stopped completely by 1 mm aluminum, but those with a maximum energy of 1.2 MeV are not all stopped. [1 point]

Explanation:
The gas filled detector will be more sensitive to beta radiation than to γ-radiation. A small number of betas can therefore have a large effect on the measurement result. The higher sensitivity of the type CSDF could be partially or completely explained by this.

Points:

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

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

Question 4.1 [4 points]

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

The net count rate of the syringe is equals 33500 – 45 = 33455 cps (the contribution of the relatively low value of the count rate in the background can be neglected).

The standard deviation in the net count rate equals:

$$s_{R_{net}} = \sqrt{\frac{R_{gross}}{t_{gross}} + \frac{R_{background}}{t_{background}}} = \sqrt{\frac{33500[cps]}{15[s]} + \frac{45[cps]}{15[s]}} = 47 \text{ cps}$$ [2 points]

The net count rate with a 95%-confidence interval (2s) is therefore:

33455 ± 95 cps [1 point]

When the count rate efficiency is seen as an error-free value, the activity with the 95% confidence interval can be found by dividing the values for the net count rate, including the margins of the 95% confidence interval, by the count rate efficiency ($9.0 \cdot 10^{-5}$ cps/Bq).

The activity with a 95%-confidence interval (2s) is therefore:
372 MBq ± 1 MBq. [1 point]

Question 4.2 [3 points]

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

Given the short half live, the effective half-life is completely determined by the physical half-life. [1 point]

$$A = \lambda \cdot N$$

$$T_{½} = 20.39 \text{ min} = 20.39 \cdot 60 \frac{[sec]}{[min]} = 1223 \, sec$$ [1 point]

$$\lambda = \frac{ln2}{T_{½}} = 5.666 \cdot 10^{-4} \, s^{-1}$$

$$U_s = N = \frac{A}{\lambda} = \frac{372 \cdot 10^6 [Bq]}{5.666 \cdot 10^{-4} \, [s^{-1}]} = 6.56 \cdot 10^{11} \text{ disintegrations } ^{11}\text{C}$$ [1 point]

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 dominated the delivered dose in the muscle tissue.*

Positrons are positively charged particles and have a range, while annihilation photons can theoretically continue on forever. [1 point]

The slowed down positrons are locally stopped and are therefore responsible for a total energy delivery close to the injected area. [1 point]

The contribution of the annihilation photons is much smaller, as these will mainly leave the body and therefore cause a significantly lower energy delivery in the muscle tissue. [1 point]

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.

$Energy\ deposition = \frac{Y \cdot E_{avg}}{m_T}\ (MeV \cdot g^{-1})\ per\ desintegration$ [1 point]

β^+:

- Emission probability Y = 1.000
- E_{avg} = 385 keV
- mass m_T = 5 [cm^3] x 1.05 [g/cm^3] = 5.25 g

$\frac{1.000 \cdot 0.385[MeV]}{5.25[g]} = 0.0733\ (MeV \cdot g^{-1})\ per\ desintegration$

[2 points]

$average\ absorbed\ dose = 0.0733\ [MeV \cdot g^{-1}] \cdot 6.56 \cdot 10^{11} [disintegrations] \cdot 1.602 \cdot 10^{-13} [J \cdot MeV^{-1}] \cdot 1000\ [g \cdot kg^{-1}] = 7.7\ [J \cdot kg^{-1}] = 7.7\ Gy\ by\ positrons$ [1 point]

Question 4.4 [2 points]

Calculate the committed effective dose E(50) when the injection would have been administered in the vein.

If the activity would have correctly spread through the body, the E(50) can be calculated using the injected activity (A_{in}) and the value of e(50) associated with an injection.

$e(50)_{injection} = 2.4 \cdot 10^{-11}$ Sv/Bq [1 point]
A_{in} = 372 MBq
$E(50) = A_{in} \cdot e(50)_{injection} = 372 \cdot 10^{6}$ Bq x $2.4 \cdot 10^{-11}$ Sv/Bq = $8.9 \cdot 10^{-3}$ Sv = 8.9 mSv [1 point]

Points:

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