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: Level measurement

Question 1.1 [4 points]

Calculate the current ambient dose equivalent rate at one meter distance (in point P, figure 1) from the surface of the source holder containing the ^{60}Co source. The shutter is closed.

$$\mathrm{A(t)} = \mathrm{A(t)} = \mathrm{A(0)} \times \left(\frac{1}{2}\right)^{\frac{t}{T_{1/2}}} = 4\,GBq \times \left(\frac{1}{2}\right)^{\frac{6[years]}{5.3\,[years]}} = 1.8\ \mathrm{GBq}$$ **[1 pt]**

The transmission is 0.004 (can be found in attachment 2) **[1 pt]**

$$\dot{\mathrm{H}}^*(10) = \frac{k \times A}{r^2} \cdot T = \frac{0.36\ [\ \mu Sv \cdot m^2 \cdot MBq^{-1} \cdot h^{-1}\ ] \times 1.8\ \cdot 10^3 [MBq]}{1.11\ [m^2]} \times\ 0.004$$

$$= 2.1\ \mu\mathrm{Sv/hour}$$

[2 pt]

Question 1.2 [5 points]

How many cps will the detector display when the storage tank is empty?

Geometric efficiency $= \frac{\text{detector surface}}{4\,\pi\,\mathrm{r}^2} = \frac{40\ [\mathrm{cm}^2]}{4\,\pi \cdot 210\ [cm^2]} = 7.2 \cdot 10^{-5}$ **[2 pt]**

Measured cps = A × yield × transmission × η_{geo} × detector efficiency

$= 1.8 \cdot 10^9$ [dps] × 2 [γ/dps] × 0.71 × $7.2 \cdot 10^{-5}$ × 0.01 [c/γ]

$= 1.8 \cdot 10^3$ cps **[3 pt]**

Question 1.3 [6 points]

There are advantages and disadvantages associated with replacing the ^{60}Co source with a ^{137}Cs source. Name four advantages and/or disadvantages and give an argument for each (dis)advantage. You score 1.5 point per correct combination of (dis)advantage and the argument. More than four correct answers do not yield additional points, incorrect answers result in points deducted.

[1½ pt per correct answer]

Advantage:
^{137}Cs photons have a lower energy compared to ^{60}Co photons, which results in a higher measurement efficiency. The detector efficiency is a factor 3 higher. This results in a more accurate measurement, and depending on the procedure could speed up the process.

Advantage:
The half-life of ^{137}Cs is considerably longer than that of ^{60}Co, which means that the source will not need to be replaced as often.

Advantage:
Because of its lower photon energy, it is much easier to shield ^{137}Cs than ^{60}Co. The ambient dose equivalent of the new shielded ^{137}Cs source is therefore lower than that of the (new) ^{60}Co source. This means that the distance to the new source does not need to be as large, which could be useful on the company premises.

Disadvantage:
It is not necessary to spend money on a new source, since the old source still sufficed.

Disadvantage:
Unnecessary expenditure on disposing of the old source, since it still sufficed.

Disadvantage:
^{137}Cs waste has a longer half-life compared to ^{60}Co waste, which means it will be more expensive to dispose of.

Advantage:
The argumentation that ^{137}Cs is easier to shield also has positive consequences for radiation protection (ALARA for the radiation dose of bystanders).

Advantage:
While the source does result in long-lived waste, this also means that you will not need to replace it as frequently, reducing all (potentially risky) actions that would need to be taken for this (ALARA for the exposed employees).

Disadvantage:
The old source is still sufficient. If the aim of the measurement is just to be able to see a difference between a full and empty tank, it is neither necessary nor justified to replace it for a more accurate measurement.

Point rating question 1

Question 1.1	4 points
Question 1.2	5 points
Question 1.3	6 points
Total	**15 points**

Question 2: Internal contamination

Question 2.1 [3 points]

Calculate using the liquid scintillation counts the tritium activity concentration (in Bq/mL) of the condensed water.

Net count rate is 7355 − 25 [cpm/mL] = 7330 [cpm/mL] = 122 cps/m **[1 pt]**

Activity concentration in the water: 122 [cps/mL] /0.31 = 394 Bq/mL **[2 pt]**

Question 2.2 [4 points]

Calculate the maximum activity concentration (in Bq/mL), assuming a statistical uncertainty of 3 sigma in the calculated activity.

$\sigma_A = \sigma_R/\varepsilon$

$\sigma_R = \sqrt{\frac{R_b}{t_b} + \frac{R_a}{t_a}} = \sqrt{\frac{7355}{10} + \frac{25}{60}} = 27$ cpm **[2 pt]**

σ_A = 27 [cpm] /(60 [s/min] x 0.31 [cps/Bq]) = 1.5 Bq **[1 pt]**

The measured volume is 1 mL.

The maximum activity concentration is: 394 [Bq]+ (3 x 1.5 [Bq])= 398 Bq/mL **[1 pt]**

Question 2.3a [2 points]

As radiation protection expert calculating the exposure of the employee, would you assume the activity concentration to be at equilibrium? Substantiate your answer.

Yes, if we assume continuous release of activity and continuous activity removal through ventilation, you will reach an equilibrium concentration.

Question 2.3b [3 points]

What is the maximum activity concentration in the air (in Bq/m^3) of the contaminated laboratory?

398 Bq/mL = 398 Bq/g **[1 pt]**
The air contains 15 g/m^3 water, the activity concentration in the air is therefore 398 [Bq/g] × 15 [g/m^3] = 5970 Bq/m^3 **[2 pt]**

Question 2.4 [4 points]

Calculate the effective dose received by the employee through inhalation, using the activity concentration in the air calculated in question 2.3b.

The inhaled activity: 5970 [Bq/m^3] × 1.2 [m^3/h] × 8 [hours]= 57 kBq **[2 pt]**
The effective dose through inhalation = $5.7 \cdot 10^4$ [Bq] × $1.8 \cdot 10^{-11}$ [Sv/Bq] = 1.0 μSv

[2 pt]

Point rating question 2

Question 2.1	3 points
Question 2.2	4 points
Question 2.3a	2 points
Question 2.3b	3 points
Question 2.4	4 points
Total	**16 points**

Question 3: Needle accident

Question 3.1 [2 points]

Calculate the activity in the thyroid at the time of measurement.

Net count rate: 95 [cpm] – 45 [cpm] = 50 cpm **[1 pt]**
Activity: $R/\varepsilon = A$
50 [cpm] / 60 [cpm/kBq] = 0.83 kBq **[1 pt]**

Question 3.2 [4 points]

Calculate the amount of activity which has ended up in the body of the technician during this incident.

From the table "Percentage radioactivity distribution over the organs after ^{123}I-IBZM administration" follows that approximately 0.6% of the total activity is located in the thyroid between 15 – 95 minutes after administration. **[1 pt]**

The total activity is at that moment: **[2 pt]**

$$\frac{0.83\ [kBq]}{\frac{0.6\%}{100\%}} = 139\ kBq$$

The activity was injected approximately 1 hour earlier

$\frac{139\ [kBq]}{½^{1/13.22}}$= 139 [kBq]/0.95 = 146 kBq

Or state: decay may be assumed to be negligible **[1 pt]**

Question 3.3 [2 points]

Calculate the committed effective dose for the technician due to this incident.

The committed effective dose coefficient for ^{123}I is 0.034 mSv/MBq. The committed effective dose for 139 kBq is therefore: 0.139 [MBq] × 0.034 [mSv/MBq] = 0.0047 mSv
= (5 μSv) **[2 pt]**

Question 3.4 [6 points]

Calculate the count rate in cpm per injected kBq of this urine sample.

From "Handboek Radionucliden, A. Keverling Buisman (3rd edition 2015), pg. 156, ^{123}I data" you can determine the total emitted electrons:
113.4 electrons per 100 disintegrations.
Per kBq these are 1134 electrons per second.
These electrons are detected with a detector efficiency of 0.9 counts per emitted electron. **[2 pt]**

From “Percentage radioactivity distribution over the organs after ^{123}I-IBZM administration”: 13.3% of the activity is located in the 300 mL urine 3 hours after the incident. **[1 pt]**
10 mL urine then contains 10/300 × 13.3% = 0.443% **[1 pt]**
0.443%/100% × 1134 [electrons/s] = 5.02 electrons per second
The count rate is 5.02 [electrons per second] × 0.6 = 3.01 cps, this equals 181 cpm. **[3 pt]**
3 hours have passed since the incident. The count rate is therefore:
$181\ [cpm] \times \tfrac{1}{2}^{3/13.22}$ = 181 [cpm] × 0.854 = 154 cpm per injected kBq.

[1 pt]

Point rating question 3

Question 3.1	2 points
Question 3.2	4 points
Question 3.3	2 points
Question 3.4	6 points
Total	**14 points**

Question 4: Lutetium-177

Question 4.1 [3 points]

Calculate the number of ^{176}Lu atoms in the supplied 2 mg lutetium nitrate.

$N = \frac{0.85\,[f]\times 2\cdot 10^{-3}\,[g]\times 6.022\cdot 10^{23}[mol^{-1}]}{(175.85+3\times 62.03)\,[g\cdot mol^{-1}]} = 2.83\cdot 10^{18}\text{ lutetium atoms}$ **[3 pt]**

Points subdivision:
Molecular weight $Lu(NO_3)_3$ is 175.85 + (3 x 62.03) = 361.94 g·mol^{-1} **[1 pt]**
Applying degree of enrichment **[1 pt]**
Applying 2 mg (and calculate N) **[1 pt]**

Question 4.2 [5 points]

Calculate what the irradiation time (in hours) should be to meet the customer's request.

The activity should be 500 GBq upon arrival, so:

$A(5h) = A(0) \cdot e^{-\ln(2) \times t/(T1/2)}$

$A(0) = 500\ [GBq] / e^{-\ln(2) \times 5\ [h]\ /(6.71[days] \times 24[h/day])}$ = 511 GBq should be produced.

[1 pt]

Which yields:

$$5.1\cdot 10^{11}\ Bq =$$
$$2.83\cdot 10^{18}\ [N]\times 5\cdot 10^{19}\ [m^{-2}\cdot s^{-1}]\times 2100\cdot 10^{-28}\ [m^{2}]\times (1-e^{-1.2\cdot 10^{-6}[s^{-1}]\times t})$$

Inserting flux, cross section and decay **[2 pt]**

$$1.7\cdot 10^{-2} = 1 - e^{-1.2\cdot 10^{-6}[s^{-1}]\times t}$$

$$-e^{-1.2\cdot 10^{-6}[s^{-1}]\times t} = 1.7\cdot 10^{-2} - 1$$

$$e^{-1.2\cdot 10^{-6}[s^{-1}]\times t} = 1 - 1.7\cdot 10^{-2}$$

$$t = \frac{\ln\left(1-1.7\cdot 10^{-2}\right)}{-1.2\cdot 10^{-6}[s^{-1}]} = 1.44\cdot 10^{4}\ sec$$

$\frac{1.44\cdot 10^{4}\ [s]}{3600\ [s\cdot h^{-1}]} = 4\ hours$ **[2 pt]**

Assuming decay to be negligible is also acceptable when supported with correct argumentation.

Question 4.3a [6 points]

Calculate the maximum air kerma rate ($\dot{K}$) on the surface of the collo. Assume all the β-radiation is absorbed by the lead, and that only a negligible amount of bremsstrahlung is formed.

Activity = 511 GBq (see question 4.2)
The transmission per photon energy will be determined.

Transmission= $B \cdot e^{-\mu d} = B \cdot e^{-((\mu/\rho)\cdot\rho)\cdot d}$

Finding (μ/ρ) in the attachment, pg 2: 208 keV = 1 $cm^2 \cdot g^{-1}$ and 113 keV = 5 $cm^2 \cdot g^{-1}$ **[1 pt]**

$T_{208keV} = 1 \cdot e^{-(1\cdot 11.34)\cdot 0.7} = 3.57 \cdot 10^{-4}$ **[1 pt]**

$T_{113keV} = 1 \cdot e^{-(5\cdot 11.34)\cdot 0{,}7} = 5.8 \cdot 10^{-18}$ → and therefore negligible **[1 pt]**

Points subdivision:
Finding the mass attenuation coefficient is worth *1 point*.
The transmission needs to be calculated and is worth *1 point.*
Reasoning that the 113 keV photon is not relevant based on a lower yield and energy is equivalent to the conclusion T_{113keV} = nil and is worth *1 point.*

The kerma rate is therefore only determined by the 208 keV gamma radiation.

$$\dot{K} = \frac{\Gamma \times A}{r^2} \times T$$

$$\Gamma = \frac{1}{8} \times E_{208} \times yield = \frac{1}{8} \times 0.208 \times 0.11 = 2.86 \cdot 10^{-3} \mu Gy \cdot m^2 \cdot MBq^{-1} \cdot h^{-1}$$ **[2 pt]**

Any other appropriate rule of thumb is also approved.

A = 511 GBq
r = 0.21 meters
T= $3.54 \cdot 10^{-4}$

$$\dot{K} = \frac{2.86 \cdot 10^{-3} [\mu Gy \cdot m^2 \cdot MBq^{-1} \cdot h^{-1}] \times 511 \cdot 10^3 [MBq]}{0.21\ [m]^2} \cdot 3.57 \cdot 10^{-4} = 11.8 \cdot \mu Gy \cdot h^{-1}$$ [**1 pt]**

Question 4.3b [4 points]

Calculate the transport index of this collo.

Reading the conversion factor of 208 keV γ-radiation = 1.4 (attachment 3)[**1 pt]**

$$11.8\ [\mu Gy \cdot h^{-1}] \cdot 1.4 \cdot \left(\frac{0.21[m]^2}{1.21[m]^2}\right) = 0.5\ \mu Sv \cdot h^{-1}$$ [**2 pt]**

Without interim rounding, $H^*(10) < 0.5$ μSv·h^{-1}. The TI = 0.0.

If calculation yields $H^*(10) \geq 0{,}5$ μSv·h^{-1} then TI = 0.1.
(Correct TI including rounding up to 1 decimal). **[1 pt]**

Question 4.4 [2 points]
Which label should be attached to the collo? Give all the data which should be added on the label.

Activity A is below the A1 and A2 values. The activity can therefore be transported in a type A collo. Given the dose rate on the surface 11.8 μGy x 1.4 Sv/Gy =16.5 μSv a type A collo should be chosen with label II-Yellow

Entered contents: 177 Lu
Activity: 511 GBq
TI: 0.1

Point rating question 4

Question 4.1	3 points
Question 4.2	5 points
Question 4.3a	6 points
Question 4.3b	4 points
Question 4.4	2 points
Total	**20 points**