ANSWERS

Exam
Radiation protection expert on the level of coordinating expert

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Question 1: Incident with a source

Question 1.1a [5 points]

Calculate the ambient dose equivalent resulting from the external radiation received by the maintenance worker while cutting the weld seam. Assume that the distance from the worker to the source was 0.5 m, and that the total operation lasted for 45 minutes.

Without shielding
$H^*(10) = 0.072\ (\mu Sv/h\ per\ MBq/m^2) \cdot 1950 \cdot 10^3\ (MBq) \cdot (45/60)\ (h)\ /\ (0{,}5\ m)^2$
$= 421 \cdot 10^3\ \mu Sv = 421\ mSv$
[formula, correct time, distance and answer 2 points]

Half-value layer of iron for 215 keV is $d_{½} = 6$ mm **[1 point]**

Transmission pipe line is $T = B\ (0.5)^{d/d½} = 2 \cdot (0.5)^{7\ mm\ /\ 6\ mm} = 2 \cdot 0.5^{1,17} = 0.9$
[1 point]

With shielding by the pipe line
$H^*(10) = 421 \cdot 10^3\ (\mu Sv) \cdot 0.9 = 375\ mSv$ **[1 point]**

Question 1.1b [3 points]

Make an estimate of the effective dose incurred by the maintenance worker as a result of the external radiation.

Choice geometry AP **[1 point]**
For AP-geometry and 215 keV is $E\ /\ H^*(10) = 0.85$ **[1 point]**
$E = 0.85 \cdot 375\ (mSv) = 319\ mSv$ **[1 point]**

Question 1.2 [3 points]

Calculate the maximum equivalent skin dose assuming that the activity has been on the skin for a period of 8 hours.

$H_{skin} = 4 \cdot 10^{-11}\ (Sv/s\ per\ Bq/cm^2) \cdot 8\ (h) \cdot 3600\ (s/h) \cdot 30 \cdot 10^3\ (Bq/cm^2)$
$= 0.035\ Sv = 35\ mSv$ [1 point H_{skin}, 1 point time correction, 1 point answer]

Question 1.3 [3 points]

Calculate based on the above data the maximum possible committed effective dose caused by the internal contamination.

Assume lung purification class M (worst case scenario)
$e(50)_w = 1.7 \cdot 10^{-9}\ Sv/Bq$ **[1 punt]**

Total body count after 24 h = 1 d is $5.7 \cdot 10^{-1}$ Bq per Bq intake **[1punt]**

$E(50) = 1.7 \cdot 10^{-9}\ (Sv/Bq) \cdot 15 \cdot 10^3\ (Bq)\ /\ 5.7 \cdot 10^{-1}\ (Bq\ per\ Bq\ intake)$
$= 4.5 \cdot 10^{-5}\ Sv = 45\ \mu Sv$ **[1 punt]**

Question 1.4 [2 points]

Name two deficiencies in radiation protection which can be identified as a result of this incident.

Possible examples (sensible alternatives are also considered correct answers):
[1 point for each correct argument]

Note: each wrong argument, when more than 2 arguments are given, results in the deduction of one point. **[-1 point for each correct argument]**

- The radiography worker was apparently not wearing an electronic personnel dosimeter with alarming function, otherwise he would have heard an alarm while removing the pictures.
- The source was not placed in the (or a) container after the picture was taken.
- The contamination in the hall was cleaned improperly.
- Other work in the hall was not stopped during the cleaning activities.
- The radiation safety expert was not immediately notified.

Point rating:

Question 1	
Question	**Points**
1.1a	5
1.1b	3
1.2	3
1.3	3
1.4	2
Total	***16***

Question 2: Treatment of bone metastases

Question 2.1 [4 points]
How many mL of the radiopharmaceutical should be administered to the patient?

The patient should be administered 80 kg · 50 kBq/kg = 4.0 MBq. **[1 point]**

The activity concentration on the reference date is:
6.0 MBq/6.0 mL = 1.0 MBq/mL

The moment of administration is three days (72 hours) later. **[1 point]**

Therefore, a decay corrections should be applied:
Activity concentration: 1.0 MBq/mL · $2^{-3.0/11.4}$ = 0.83 MBq/mL **[1 point]**

A total of 4.0/0.83 = 4.8 mL of the radiopharmaceutical should be administered.
[1 point]

Question 2.2 [4 points]
Based on a calculation, conclude whether the pulling into the syringe in the situation described above is allowed according to the 'Attachment radionuclide laboratories' from the current license.

At the moment of arrival in the hospital, the activity is:
6.0 MBq · $2^{-2.75/11.4}$= 5.1 MBq.

$A_{max} = 0.02 \cdot 10^{p+q+r}$ and $X_{max} = \frac{A_{max}}{e(50),inh}$

Pulling up the syringe → p = -1
C-laboratory → q = 2
Maximum ventilation parameter → r = 2 **[finding 3 parameters = 1 point]**

Enter in formula:
$A_{max} = 0.02 \cdot 10^{-1+2+2} / 6.9 \cdot 10^{-6}$ Bq = $2.9 \cdot 10^{6}$ Bq = 2.9 MBq **[2 points]**

2.9 MBq < 5.1 MBq, it is not allowed according to current regulations. **[1 point]**

Whether or not the decay law is taken into account does not influence the conclusion.

Question 2.3a [4 points]

Calculate the committed effective dose received by the patient as a result of the injection, according to the data of the manufacturer. Use the Attachment 'Most relevant dosimetric contributions to the dose for the patient after injection of the radiopharmaceutical'.

The equivalent organ dose follows from the absorbed organ dose through multiplication with the radiation weighing factor (alpha particles: w_R=20)

[1 point]

The contribution to the committed effective dose is calculated through multiplication with the organ weighing factor w_T, where it is important to take into account that the organ weighing factor for the large intestine according to ICRP-30 should be divided into the upper and lower part of the large intestine.

Organ	D_{organ}	H_{organ}	$H_{organ, 4MBq}$	w_T	Contribution to e(50)	Contribution to e(50) 4 MBq
	Gy/MBq	Sv/MBq	Sv		Sv/MBq	Sv
Bone surface	1.15	23	92	0.01	0.23	0.92
Large intestine (lower part)	0.046	0.92	3.68	0.05	0.046	0.17
Large intestine (upper part)	0.032	0.64	2.56	0.07	0.045	0.18
Red bone marrow	0.14	2.8	11.2	0.12	0.33	1.34
Sum total		27.4	109.4		0.65	2.6

[Calculating with W_T = 1 point]

The $e(50)_{injection}$ can now be obtained by summing up the individual contributions:
$e(50)_{injection}$ = 0.65 Sv/MBq = $6.5 \cdot 10^{-7}$ Sv/Bq. **[1 point]**

4 MBq is administered to the patient.
$E(50)_{injection} = 4 \cdot 0.65 = 2.6$ Sv. **[1 point]**

Question 2.3b [2 points]

Substantiate whether this committed effective dose if relevant for the patient.

The calculated committed effective dose is of an order of magnitude which is not relevant for these patients. The treatment is mainly aimed at pain relief and increasing the quality of the patient's remaining life span by a few months. It is not expected that these patients will have stochastic effects due to this treatment.

NB. In addition, radiation weighing factors are determined for the highest RBE and they are valid in the low dose area. In the high dose area the RBE-values are lower so the calculation should have been done using the RBE weighted dose to determine the risk. The calculation method used here is therefore technically not correct, but this is only known after the calculation.

Question 2.4 [5 points]

Calculate the maximum number of patients that can be treated with ^{223}Ra by the hospital without exceeding the exemption for discharge into the sewer.

The discharged activity (W) is calculated with $W = A \cdot e_{(50),ing} \cdot CRw$

$A = 0.15 \cdot 4$ MBq $= 0.6 \cdot 10^{6}$ Bq, **[1 point]**
$e_{(50),ing} = 1 \cdot 10^{-7}$ Sv/Bq
$CR_w = 0.1$ (table 4, attachment 2 Bbs). **[1 point]**

$W = 6 \cdot 10^{-3}$ $Re_{ing.}$

$W_{max} = 10$ Re_{ing}, exempted discharge. (art. 10.3 Bbs) **[1 point]**

Already 4 Re_{ing} is being discharged. **[1 point]**
$(10 - 4)/6 \cdot 10^{-3} = 1000$ patients to reach W_{max}. **[1 point]**

Point rating:

Question 2	
Question	**Points**
2.1	4
2.2	4
2.3a	4
2.3b	2
2.4	5
Total	***19***

Question 3: Irradiation of flower bulbs

Question 3.1 [6 points]

Determine the shielding thickness of the concrete floor that is required to ensure that the maximum annual dose in point P (figure 1) will not be exceeded.

With formula 11.4 from Bos et al.: β = Pd²/WUT
Max effective dose for unexposed employees = 0.3 mSv/y →

$\frac{0.3[mSv \cdot y^{-1}]}{1.35[Sv \cdot Gy^{-1}]} = 0.22\, mGy \cdot y^{-1}$ **[1 point]**

$$P = \frac{0.22[mGy \cdot y^{-1}]}{30[wk \cdot y^{-1}]} = 0.0074 mGy \cdot wk^{-1}$$

$$W = 10[mA] \cdot 5[d \cdot wk^{-1}] \cdot 3[h \cdot d^{-1}] \cdot 60[min \cdot h^{-1}] = 9000\, mA \cdot min \cdot wk^{-1}$$

$$\beta = \frac{Pd^2}{WUT} = \frac{0.0074\, [\frac{mGy}{wk}] \cdot 5^2[m^2]}{9000\, [mA \cdot \frac{min}{wk}] \cdot 1 \cdot 1} = 2.1 \cdot 10^{-5} mGy \cdot (mA \cdot min)^{-1} at\ 1\ meter$$

The box stops 42% of the radiation:

$\beta = \frac{2.1 \cdot 10^{-5}}{(1-0.42)} = 3.5 \cdot 10^{-5} mGy \cdot (mA \cdot min)^{-1} at\ 1\ meter$ = limit **[3 points]**

Reading from attachment 1, the curve for 250 kV gives for $1 \cdot 10^{-4}$: 45 cm concrete. About 3.5 10^{-1} is then still missing, this can be read for example between $1 \cdot 10^{-4}$ and $3{,}5 \cdot 10^{-4}$, this is 5 cm. A total of 50 cm concrete is required.
[2 points]

Alternative:

$$13.9[mGy \cdot mA^{-1} \cdot min^{-1} \cdot m^2] \cdot \frac{1}{5^2[m^2]} \cdot 10[mA] \cdot 30[wk] \cdot 5[d \cdot wk^{-1}] \cdot 3[h \cdot d^{-1}]$$
$$\cdot\, 60[min \cdot h^{-1}] \cdot 1.35[Sv \cdot Gy^{-1}] \cdot 1[U] \cdot 1[T] \cdot (1 - 0.42)[T_{box}] \cdot T_{required} = 0.3\ [mSv]$$

To use this alternative method it is not required to mention U and T.

$T_{required} = \frac{0.3}{117544} = 2.55 \cdot 10^{-6}$
→ Standard reading at $2.55 \cdot 10^{-6} \cdot 13.9 = 3.5 \cdot 10^{-5}$

Reading yields: 50 cm concrete, see above for reading outside the graph.
(2x leaving 13.9 out yields the standard value immediately and is correct)

Question 3.2a [6 points]

Calculate the yearly ambient dose equivalent in point Q (from figure 1) assuming the door does not provide any shielding. For the sake of simplicity, assume that there is no weakening and hence no scattering in the box with flower bulbs. Scattering only takes place on the floor.

Reading 0 cm shielding at 250 kV yields:
13.9 mGy/mA·min at 1 meter. **[1 point]**

At 2.5 meter this is $13.9 \cdot 1^2/2{,}5^2 = 2.22$ mGy/mA·min **[1 point]**

2.22 [mGy/mA·min] ·10 [mA] · 60 [min/h · 5 h/d · 3d/wk · 30 wk/y =
$6 \cdot 10^5$ mGy/y at the concrete floor. **[1 point]**

Reading of the 90 degree scattered radiation for 250 kV gives that 0.018% of the dose rate at the irradiated surface is scattered in that direction per 100 cm^2.
[1 point]

Irradiated surface = $0.3\ m^2 \cdot 10^4\ cm^2/m^2 = 3000\ cm^2$ **[1 point]**

$6 \cdot 10^5$ mGy/y $\cdot\ 1.8 \cdot 10^{-4} \cdot (3000 / 100) \cdot 1/3^2 = 360.3$ mGy/year
→ 1.35 [$Sv \cdot Gy^{-1}$]· 360.3 mGy/y = 486 mSv/y **[1 point]**

Question 3.2b [3 points]

How thick should the shielding material be that has to be placed on the door? Round to whole mms.

Transmission = $0.3/486.4 = 6.2 \cdot 10^{-4}$ ($6 \cdot 10^{-4}$ for 0,5 Sv) **[1 point]**

μ/ρ for 150 keV 0.207 m^2/kg (·10) = 2.07 cm^2/g **[1 point]**
$e^{-\mu d} = 6.2 \cdot 10^{-4}$ → $\ln(6.2 \cdot 10^{-4}) = -\mu d$
$d = \ln(6.2 \cdot 10^{-4}) / -(2.07 \cdot 11.34) = 0.31$ cm = 4 mm lead
[rounded up = **1 point]**

Question 3.3 [2 points]

Why may the build-up through the lead-shielded door be neglected?

Correct answers are:

- The photo effect is dominant due to lead having a high Z combined with a low acceleration voltage. The photons are stopped before they can contribute to the build-up.
- To calculate the transmission Compton photons of 150 keV are used, while on average the beam has a lower energy, which results in an overestimation and would lower the build-up to 1.

Point rating:

Question 3	
Question	**Points**
3.1	6
3.2a	6
3.2b	3
3.3	2
Total	***17***

Question 4. Radioactive hospital waste

Question 4.1 [4 points]

Determine the total detection efficiency of the plate detectors in cps/Bq. Assume the source is located exactly in the center of both plate detectors. You may assume that the plate detectors are part of a sphere surface.

$\varepsilon_{tot} = \varepsilon_{geo} \cdot \varepsilon_{intr} \cdot$ yield **[1 point]**

$$\varepsilon_{geo} = \frac{\text{surface of the detector}}{4\pi\,(r)^2} = \frac{2 \cdot (24.6\text{ cm} \cdot 48.4\text{ cm})}{4\pi\,(75\text{ cm})^2} = 0.034$$ **[2 points]**

$\varepsilon_{tot} = 0.034 \cdot 0.17$[count/photon] $\cdot$ 0.889 [photon per disintegration] = $5.1 \cdot 10^{-3}$ cps/Bq. **[1 point]**

Question 4.2 [3 points]

Calculate the minimum detectable activity (MDA) if the plate detectors have to emit a signal when the background is exceeded, with a reliability of 99.9% (3σ)

The background is 3.55 cps

$$\text{MDA} = \frac{3\sqrt{\frac{R_a}{t_b}}}{\varepsilon_{tot}} = \frac{3\sqrt{\frac{3.55\ cps}{0.2\ s}}}{5.1 \cdot 10^{-3}} = 2.5\text{ kBq}$$

Question 4.3 [5 points]

Conclude based on a calculation whether this band aid can be measured using the new plate detectors, taking a confidence interval of 95% (2σ) into account for the measurement with the GM tube.

$$A = \frac{R_{netto}}{\varepsilon} = \frac{\left(\frac{1240\text{ counts}}{60\text{ s/min}} - \frac{532\text{ counts}}{300\text{ s/min}}\right)}{0.0027\text{ cps/Bq}} = 7.0\text{ kBq}$$ **[1 point]**

95% confidence is 2σ

$$\sigma_{Rnetto} = \sqrt{\frac{R_b}{t_b} + \frac{R_a}{t_a}} = \sqrt{\frac{\frac{1240\text{ counts}}{60\text{ s}}}{60\text{ s}} + \frac{\frac{532\text{ counts}}{300\text{ s}}}{300\text{ s}}} = 0.59\text{ cps}$$ **[2 points]**

2σ = 2 $\cdot$ 0.59 counts = 1.18 counts

$$A_{2\sigma} = \frac{\sigma_{Rnetto}}{\varepsilon} = \frac{1.18}{2.7 \cdot 10^{-3}\ \text{cps/Bq}} = 437\ \text{Bq} = 0.4\ \text{kBq}$$ **[1 point]**

The band aid contains 7 kBq ± 0.4 kBq > MDA (2.5 kBq), so detectable.
[1 point]

Question 4.4 [4 points]

Make a few assumptions and argue whether the hospital could potentially exceed the release limits if the band aids described in this question end up with the regular waste.

Assumptions: a band aid weighs a maximum of 1 gram, and yearly about 250 work days · 8 band aids a day = 2000 band aids disappear into the regular disposal.
Assumption working days [1] and band aids per day [1]. **[2 points]**

The activity concentration is for a 1 gram band aid
(7 kBq / $1 \cdot 10^{-3}$=) 7 MBq/kg and thus exceeding 100 kBq/kg **[1 point]**

and the activity exceeds the release limits of 10 MBq per year
(10 MBq / 7 kBq is approximately 1400 band aids) **[1 point]**

Point rating:

Question 4	
Question	**Points**
4.1	4
4.2	3
4.3	5
4.4	4
Total	***16***