# ANSWERS

# Exam
# Radiation protection expert on the level of coordinating expert

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|---|---|
| Nuclear Research and consultancy Group | NRG |
| Delft University of Technology | TUD |
| Boerhaave Continuous Medical Education/LUMC | BN/LUMC |
| University of Groningen | RUG |
| Radboudumc | RUMC |

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Exam date: July 8th 2020

# Question 1: Iodine capsule

### Question 1.1 [2 points]

*If the dismissal rule is observed (recommendation 1), what is the activity of $^{131}I$ in the stomach that corresponds to the allowed dose rate?*

$\dot{H}^*(10) = h \times A / r^2$
20 [µSv/h] = 0.066 $[\mu Sv/h \cdot MBq^{-1} \cdot h^{-1}]$ × A [MBq] / $1^2$ [$m^2$] [1 point]
The patient is allowed to return home at an activity of 303 MBq in the stomach. [1 point]

### Question 1.2 [2 points]

*What is a reason that the activity determined in question 1.1 does not correspond to the maximum administrable activity of 400 MBq?*

The calculated activity is lower than the maximum administrable activity/dose. The capsule is located inside the stomach after ingestion, which makes the distance to the dose rate meter greater than 1 meter. In addition, there is self-absorption of the emitted radiation in the body.

### Question 1.3a [4 points]

*Suppose that after taking a $^{131}I$ capsule, a patient still decides to collect his urine during the first 24 hours at home. What will the activity in this patient's 24-hour urine be, i.e. one day after having taking the capsule?*

400 MBq × 0.3 = 120 MBq in the thyroid of a healthy person [1 point]
1.2 × 120 MBq = 144 MBq in the thyroid of this patient [1 point]

The remaining activity is immediately excreted and is therefore in the 24-hour urine ($f_1$ = 1). The urine therefore contains 400 MBq – 144 MBq = 256 MBq [1 point]

This activity still needs to be corrected for radioactive decay. With
$\lambda = \frac{\ln 2}{8.021\ \mathrm{d}}$ = 0.0864 $d^{-1}$ = 3.60×$10^{-3}$ $h^{-1}$ follows
$A = A_0 \cdot e^{-\lambda \cdot t} = 256 \cdot e^{-0.0864 \cdot 1} =$ 235 MBq [1 point]

### Question 1.3b [4 points]

*Calculate, based on your answer to question 1.3a, what the effective dose would be for a roommate that stays for a duration of 2 weeks at 1 meter distance from the collected urine.*

$\mathrm{H}^*(10) = \frac{h \cdot A_0}{r^2} \cdot \int_0^T e^{-\lambda \cdot t} dt = \frac{h \cdot A_0}{r^2} \cdot \left(\frac{1}{\lambda}\left(1 - e^{-\lambda \cdot T}\right)\right)$ [1 point]

$$H^*(10) = \frac{0.066\ \mu\frac{Sv}{h}\cdot MBq^{-1}\cdot h^{-1}\cdot 235\ \text{MBq}}{(1\ \text{m})^2} \times \left(\frac{1}{0.0036\ \text{h}^{-1}}\left(1 - e^{-0.086\ \text{d}^{-1} \times 14\ \text{d}}\right)\right) = 3.0\ \text{mSv}$$

And therefore E = 3.0 mSv [3 points]

**Question 1.4 [5 points]**
*Is this discharge formally allowed? Substantiate your answer with a calculation.*

Based on article 10.3 of the decree basic safety standards, an exemption on the prohibition of discharge into surface water (the ditch) without permit applies for discharges smaller than 0.1 $Re_{ing}$, corrected for physical half-life.

The discarded urine contains:

$A(t) = A(0) \cdot e^{-\lambda \cdot t} = 235\ \text{MBq} \times e^{-0.0864 \cdot 14} = 70\ \text{MBq}\ ^{131}\text{I}$ [1 point]

$0.1\ Re = 0.1 \times \frac{1\ \text{Sv}}{e(50)\text{ing}} = 0.1 \times (1\ \text{Sv}/\ 2.2 \cdot 10^{-8}) = 4.5\ \text{MBq}$ [2 points]

(conversely, you can also convert the discharged urine to Re)

Correction factor CR for discharge: $T_{½}$ $^{131}$I: 8.021 d, CR is 0.1
Discharge allowed per year: 4.5 MBq / CR = 45 MBq $^{131}$I
The discharge is formally not allowed (we will disregard who is in violation).
[2 points]

**Proposed point rating**

| **Question 1** | |
|---|---|
| Question 1.1 | 2 points |
| Question 1.2 | 2 points |
| Question 1.3a | 4 points |
| Question 1.3b | 4 points |
| Question 1.4 | 5 points |
| **Total** | **17 points** |

# Question 2: Dental X-rays

### Question 2.1 [3 points]

*What is the absorbed dose received by the irradiated skin surface of a patient treatment per exposure, for each of the setups described above, with the given settings?*

Setup from figure 1:
From figure 1: entrance dose is 3000 μSv
From given: The ratio between the personal dose equivalent $H_p(10)$ and the absorbed dose in the skin for 50 keV photons is: $H_p(10)/D = 1.766$.
$D_{skin} = 3000 \cdot 10^{-6}$ [Sv] / 1.766 Sv/Gy = $1.699 \cdot 10^{-3}$ Gy = 1.7 mGy [1 point]

Setup dental practice:
The entrance skin dose is lower due to the longer spacer (the smaller irradiated skin surface does not influence the entrance skin dose):
For a focus to skin distance of 30 cm:
1.7 [mGy] × (20 [cm]/30 [cm])² = 0.76 mGy [2 points]

### Question 2.2 [4 points]

*Based on the doses calculated in Question 2.1, indicate for each of the above mentioned setups where the intra-oral radiographs are located with respect to these two DRL's.*

Setup from figure 1:
The skin dose can be equated to kerma in air. As a result, the calculated entrance skin dose of 1.7 mGy falls within the stated DRL values.

De DAP-value is 1.7 mGy x 30 $cm^2$ = 51 mGy·$cm^2$. This value falls within the DRL values. [2 points]

Setup dental practice:
The calculated entrance skin dose is 0.755 mGy. This value falls within the stated DRL values, because the skin dose can be equated with the kerma in air.

De DAP-value is 0.755 mGy x (3.5 x 4.5) $cm^2$ = 12 mGy·$cm^2$. This value is below the area in which the DRL values fall. [2 points]

**Question 2.3 [5 points]**

*To which personal dose equivalent $H_p(10)$ will the dentist be exposed in his clinic on a yearly basis when using the rectangular collimator and the settings and data mentioned above?*

Figure 1 shows a maximum personal dose equivalent of 0.5 µSv per exposure.
This scattered radiation dose can be scaled proportionally to the irradiated skin surface and the entrance skin dose:
0.5 [µSv] × (3.5 [cm] × 4.5 [cm])/30 [cm²] × (0.755 [mGy]/1.7 [mGy]) = 0.117 µSv at 1 meter distance.

At a distance of 50 cm this becomes: 0.117 [µSv] × (100 [cm]/50 [cm])² = 0.47 µSv

2000 images are taken annually. The received $H_p(10)$ per year therefore amounts to 0.47 x 2000 = 940 µSv/y = 0.94 mSv/y.

**Question 2.4a [4 points]**

*Based on a calculation, estimate the transmission of photons with an energy of 50 keV through the screen and lead glass.*

Transmission $T = B \cdot e^{-\mu d}$

$\mu/\rho$ in lead for 50 keV scattered radiation: 7.71 $cm^2 \cdot g^{-1}$ (Bos, pg.381)
$\mu = 7.71\ cm^2 \cdot g^{-1} \times 11.34\ g \cdot cm^{-3} = 87.4\ cm^{-1}$
d = 0.15 cm
$\mu d = 13.1$ [2 points]

De dose buildup factor B is based on table 11.1 (Bos) in any case less than about 2.5, but would in reality be closer to 1 (because the photo-effect is dominant for 50 keV). [1 point]

$T = B \cdot e^{-\mu d} = 1 \times e^{-87.4 \times 0.15} = 2 \times 10^{-6}$ [1 point]

**Question 2.4b [1 point]**

*Based on the calculation in question 2.4a, formulate your evaluation of the RI&E for this dentist.*

The yearly dose received by the dentist is acceptable when using the mobile screen (about 2 nSv/year). Further measures to comply with ALARA are not required. However, whether the dentist will actually always be using the screen in practice is very doubtful.

**Proposed point rating**

| **Question 2** | |
|---|---|
| Question 2.1 | 3 points |
| Question 2.2 | 4 points |
| Question 2.3 | 5 points |
| Question 2.4a | 4 points |
| Question 2.4b | 1 point |
| **Total** | **17 points** |

# Question 3: Scientific experiment with iodine in an acidic environment

**Question 3.1 [4 points]**

*Check using calculations whether, and if so under which conditions, the described iodination is permitted according to the 'Attachment radionuclide laboratory'. Assume the most unfavorable lung purification class.*

Labeling volatile nuclide → p = –3 (see also the remark below).
The largest value of $e(50)_{w,inhalation} = 1.4 \cdot 10^{-8}$ Sv/Bq (for $I_2$).

$A_{max} = 0.02 \text{ (Sv)} \times 10^{p+q+r} / e(50)_{w,inhalation}$

$= 0.02 \text{ (Sv)} \times 10^{-3+q+r} / 1.4 \cdot 10^{-8} \text{ (Sv/Bq)} = 1.43 \times 10^{3+q+r}$ Bq [2 points]

He is working with 110 MBq = $1.1 \cdot 10^{8}$ Bq < $A_{max}$.

From this follows that q+r ≥ 5. Since r may never be larger than q, this means that q = 3 and r at least 2. The iodination should therefore take place in a B-laboratory (q = 3) in at least an approved fume hood (r = 2). A closed cabinet/glove box (r = 3) is of course also allowed. [2 points]

*Note*: a candidate who mentions this is a simple experiment / labeling in a closed system and therefore uses p = -1 can, if properly explained, also score all points for question 1 (and 2a and 2b).

**Question 3.2a [3 points]**

*Calculate the maximum possible committed effective dose for the researcher if the ampoule breaks during the experiment. Assume the fume hood functions properly (i.e. as referred to in the License attachment, pg. 12).*

The most unfavorable scenario is that upon breaking the ampoule all activity is converted to iodine vapor and 1% is released (corresponding to a DIN-approved fume hood, r = 2). [1 point]

Again the most unfavorable scenario is that the radiochemist inhales all released activity.

→ $A_{inhalation,max} = 1\% \times 110 \text{ MBq} = 1.1 \text{ MBq} = 1.1 \cdot 10^{6}$ Bq.

$E(50) = e(50)_{w,inhalation} \times A_{inhalation,max}$

$= 1.4 \cdot 10^{-8} \text{ (Sv/Bq)} \times 1.1 \cdot 10^{6} \text{ (Bq)} = 1.5 \cdot 10^{-2} \text{ Sv} = 15 \text{ mSv}$

[2 points]

A candidate who has used a closed cabinet in question 1 (r = 3) can assume that only 0.1% of the activity is released, or a fictional value smaller than or equal to 1%.

**Question 3.2b [2 points]**
*Indicate whether the researcher should be classified as exposed worker, solely based on your answer to question 3.2a, and if so, in which category he should be classified. Furthermore, name one radiation protection measure you could take for this particular experiment.*

The dose limit for an unexposed worker is 1 mSv. This will be exceeded (see question 2a), because of which the researcher should be classified as exposed worker.

Furthermore, because the calculated value exceeds 6 mSv, the researcher should be classified as category A-worker. [1 point]

The researcher can explicitly be instructed with regard to the dangers associated with handling volatile nuclides in advance. He can also be advised to use a closed work cabinet (r = 3) instead of a normal, licensed fume hood, if those are available. Monitoring the air quality or wearing a respirator are also options. Monitoring the thyroid dose of the researcher is also considered a correct answer, although this is in fact a control after the fact. Each good alternative will yield the point.
Note: Clearly wrong argumentation leads to point deduction! [1 point]

**Question 3.3 [5 points]**
*Calculate the $^{125}I$ activity in the thyroid of the researcher, and the standard deviation of this activity.*

$T_{net} = T_{gross} - T_{background} = (15 - 7)$ (cps) = 8.0 cps [1 point]

$\sigma_{Tnet}^2 = (T_{gross} + T_{background})/t$, in which t is the measurement time.
$\sigma_{Tnet}^2 = (15 + 7)$ (cps) / 2 (s) = 11.0 cps/s $\rightarrow$ $\sigma_{Tnet} = \sqrt{11.0}$ cps = 3.3 cps

[2 points]

$A_{thyroid}$ = 100 (cm$^2$) × 8.0 (cps) / [0.3 (cps per Bq/cm$^2$)] = $2.4 \cdot 10^3$ Bq
$\sigma_{Athyroid}$ = 100 (cm$^2$) × 3.3 (cps) / [0.3 (cps per Bq/cm$^2$)] = $1.1 \cdot 10^3$ Bq

[2 points]

**Question 3.4 [4 points]**
*Calculate the committed effective dose for the researcher based on this conservative estimation. If you did not answer question 3.3, you will need to make plausible assumptions yourself.*

From the given for thyroid counting one day after intake (Handbook Radionuclides) follows for $I_2$ inhalation:

$A_{thyroid} = 0.24 \times A_{inhalation}$.

$A_{inhalation} < (A_{thyroid} + 2 \times \sigma_{thyroid}) / 0.24$
$= (2.4 \cdot 10^3 + 2.2 \cdot 10^3)$ (Bq) / 0.24 = $1.9 \cdot 10^4$ Bq [3 points]

$E(50) < e(50)_{w,inhalation} \times A_{inhalation}$
$= 1.4 \cdot 10^{-8}$ (Sv/Bq) × $1.9 \cdot 10^4$ (Bq) = $27 \cdot 10^{-5}$ Sv = 0.27 mSv
[1 point]

Plausible assumptions for the activity in the thyroid will be values smaller than a fraction of 1% of the used activity, or a fraction of 1.1 MBq. The standard deviation can be assumed to be in the same order of magnitude as the assumed activity, where the candidate is expected to know that when the background and net count rate are of the same order of magnitude, the standard deviation is relatively large.

**Proposed point rating**

| **Question 3** | |
|---|---|
| Question 3.1 | 4 points |
| Question 3.2a | 3 points |
| Question 3.2b | 2 points |
| Question 3.3 | 5 points |
| Question 3.4 | 4 points |
| **Total** | **18 points** |

# Question 4: Historical stone collection

### Question 4.1 [6 points]

*Calculate the total activity of all nuclides up to and including $^{226}$Ra in an average stone.*

Because $^{238}$U is in equilibrium with her daughters, the activity of $^{238}$U in the stone will need to be determined first:

m = 780 × 0.95 = 741 gram $UO_2$

$N = \frac{741}{238+32} \times N_A = 1{,}65 \cdot 10^{24}\ particles\ UO_2$ ($^{235}$U contribution may be neglected)

With the half life time from attachment 1 follows for the decay constant of $^{238}$U:

$$\lambda = \frac{ln\ 2}{T_{1/2}} = \frac{ln\ 2}{4.51 \cdot 10^9 year \times 365\ d/y \times 24\ h/d \times 3600\ s/h} = 4.87 \cdot 10^{-18}\ \text{s}^{-1}$$

As alternative, the half life time from the nuclide chart or the value of λ from the Handbook Radionuclides may also be used: $\lambda = 4.92 \cdot 10^{-18}$ s$^{-1}$.

$A = N \cdot \lambda$

$A = 4.87 \cdot 10^{-18} \times 1.65 \cdot 10^{24} = 8.04\ MBq$ [4 points]

From attachment 1 (or attachment 2) easily follows that there are in total 6 daughter nuclides in the uranium series up to and including $^{226}$Ra. Note that $^{234m}$Pa has two daughter nuclides ($^{234}$Pa and $^{234}$U), but that the activity of $^{234}$Pa is negligible (0.13% of the activity of each of the other daughters). This can also be observed from the Nuklidkarte (the white triangle for $^{234m}$Pa indicates that less than 5% of the decay $^{234m}$Pa happens via isomeric transition to $^{234}$Pa).

$A_{total} = 6 \times A_{U238} = 6 \times 8.04\ MBq = 48.2\ MBq$ [2 points]

### Question 4.2 [3 points]

*At which rate (in Bq·s$^{-1}$) is the $^{222}$Rn-activiteit formed?*

From the decay of $^{226}$Ra, 8.04·10$^6$ $^{222}$Rn-atoms are formed per second.

$$\lambda_{\text{Rn}-222} = \frac{\ln 2}{3.823 \times 24 \times 3600} = 2.10 \cdot 10^{-6}\ \text{s}^{-1}$$

$\dot{\text{A}} = \dot{\text{N}} \cdot \lambda$

$\dot{\text{A}} = 8.04 \cdot 10^6 \times 2.10 \cdot 10^{-6} = 16.9\ \text{Bq} \cdot \text{s}^{-1}$

**Question 4.3 [4 points]**

*What is the equilibrium activity concentration (in Bq·m$^{-3}$) of the $^{222}$Rn in the exhibition room caused by an average stone?*

1% of the formed radon escapes into the air of the museum = 0.169 Bq·s$^{-1}$

$$\lambda_{ventilation} = \frac{50[m^3 \cdot h^{-1}]}{150[m^3]} \times \frac{1}{3600}[h \cdot s^{-1}] = 9.26 \cdot 10^{-5}\ s^{-1}$$

$$A_{equilibrium} = \frac{\dot{P}}{\lambda_{eff}}$$

$\lambda_{eff} = \lambda_{phys} + \lambda_{vent}$ (the reasoning that $\lambda_{vent}$ is approximately equal to $\lambda_{eff}$ is also correct)

Calculation $\lambda_{eff}$: [2 points]

$$A_{equilibrium} = \frac{0.169}{(2.10 \cdot 10^{-6} + 9.26 \cdot 10^{-5})} = 1.78\ kBq$$

The equilibrium activity concentration is therefore:

$$\frac{1.78 \cdot 10^3\ Bq}{150\ m^3} = 11.9\ Bq \cdot m^{-3} = 0.0119\ kBq \cdot m^{-3}.$$

Calculation $C_{equilibrium}$: [2 points]

Alternative:
Each hour 0.169 x 3600 = 608 Bq is produced. If this is also discharged in 50 m$^3$(/h) then – neglecting the physical decay – the situation is in equilibrium: 608/50 = 12.2 Bq/m$^3$ = 0.0122 kBq/m$^3$

**Question 4.4a [3 points]**

*Calculate the committed effective dose for a visitor who visits the exhibition room once. Come up with a realistic exposure time yourself.*

The collection contains 20 stones uraninite.
The equilibrium concentration would be 20 × 0.0119 kBq/m$^3$ = 0.238 kBq/m$^3$.
The respiratory rate of visitors is = 1.2 m$^3$·h$^{-1}$
A realistic exposure time will approximately be between 15 minutes and 1 hour.
In principle all exposure times between 5 minutes and 8 hours (maximum opening time in a day) would be acceptable.

$V_{max} = 1.2\ m^3 \cdot h^{-1} \times 8\ h = 9.6\ m^3$

$A_{inh} = 9.6\ m^3 \times 0.238 \frac{kBq}{m^3} = 2.3\ kBq$ [2 points]

$E(50) = A_{inh} \cdot e(50)$

$E(50) = 2.3 \cdot 10^3 \times 1.3 \cdot 10^{-8} = 3.0 \cdot 10^{-5}\ Sv = 30\ \mu Sv$ [1 point]

An exposure time of 15 minutes leads to an exposure of 1 μSv.

Note: The e(50) used in this assignment is for the sake of simplicity taken from the most conservative value from table A.11 (ICRP-137) for the effective dose as a result of exposure to the daughters of $^{222}Rn$: $1.5 \cdot 10^{-5}$ mSv per Bq·h·m$^{-3}$.

**Question 4.4b [1 point]**
*Provide a measure with which the exposure of visitors (and employees) can be decreased.*

A common measure is to ensure that emanated radon cannot or hardly enter the room. This could be done by storing the stones ‘airtight’ or ensuring that there is direct ventilation on the showcase which would prevent most of the radon from entering the room.
Each useful measure will be rewarded a point, to a maximum of 1 point. Mention of ‘limiting the exposure time’ is theoretically speaking a suitable measure, but not realistic in practice, and will therefore only be rewarded 0.5 point. Nonsense measures can lead to point deduction.

**Proposed point rating**

| **Question 4** | |
|---|---|
| Question 4.1 | 6 points |
| Question 4.2 | 3 points |
| Question 4.3 | 4 points |
| Question 4.4a | 3 points |
| Question 4.4b | 1 points |
| **Total** | **17 points** |