EMBARGO July 8th 2020

Exam
AP3371

Delft University of Technology TUD

exam date: July 8th 2020

exam duration: 14.30 - 16.00 hours

Instructions:

- **This exam contains 7 numbered pages and a separate attachment containing 9 pages worth of data. Please check!**
- Write down your solutions and answers op paper, scan these in the proper order!
- Write down **your student number** on each paper or set of scans (you may add your name if you wish).
- It is allowed to consult books, personal notes, and other documentation to answer the questions.
- When answering the questions, make sure you state which **calculation** and/or which **reasoning** helped you reach the solution.
- If you are unable to calculate part of a question and you need that answer to be able to solve the other parts, you are allowed to assume a fictional answer.
- You do not necessarily need to use all of the data supplied to answer some of the questions.
- You can acquire a total of 35 points if you correctly answer all of the questions. The points are distributed between the questions as follows:

  Question 1: 17 points

  Question 2: 18 points
- You will have passed this exam if you have obtained at least 55% of the total amount of points. This corresponds to a score of at least 19.25 points.

Question 1: Dental X-rays

A dentist is specialized in treating anxious patients. This dentist always remains standing next to the patients while making X-rays. The radiation protection expert searches for dose data in the context of a risk inventory and evaluation (RI&E). He finds a figure containing the personal dose equivalent resulting from the primary beam and scattered radiation. The personal dose equivalent values of the entrance and exit beam are also shown in the figure.

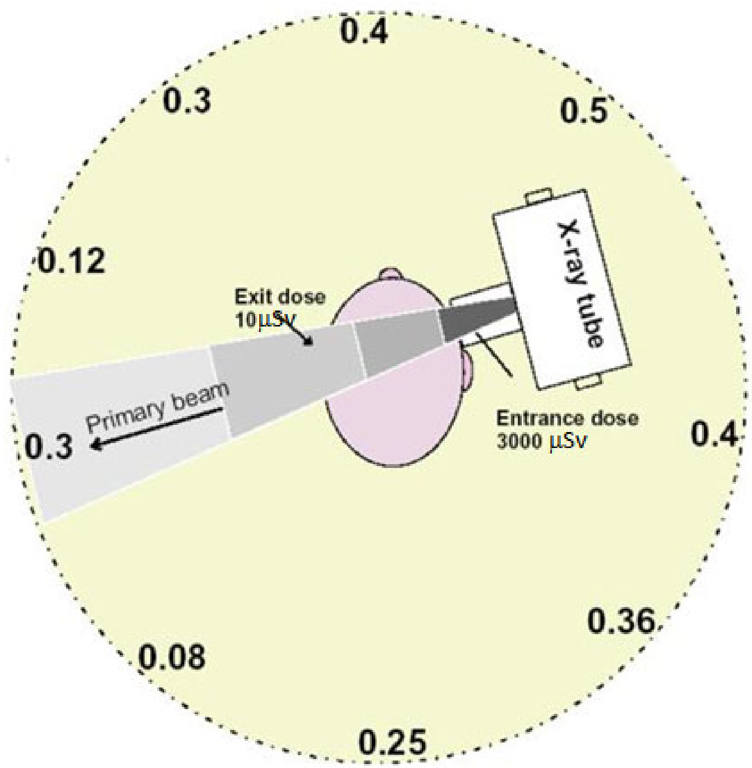

Figure 1: *Personal dose equivalent in µSv resulting from scattered radiation as well as the primary beam at 1 meter distance from the center of the head in a dental X-ray. The image is taken from Radiation Protection for Dentists and Assistants (Office of Radiation Safety, Ministry of Health, New-Zealand).*

Explanation of the data in figure 1:

- For simplicity's sake it may be assumed that the scattering radiation is produced in the center of the head.
- $H_p(10)$ at the entrance position of the beam (Entrance dose) is 3.0 mSv.
- $H_p(10)$ at the exit position of the beam (Exit dose) is 10 µSv.
- The dose values in the exiting beam ("Primary beam") are caused by both the attenuated primary beam as well as the scattered radiation.

The RI&E can be performed using the discovered information. In all situations, the tube current, kV, exposure time and filtering are the same as the situation outlined in figure 1. However, there is an important difference in the beam geometry between the set-up used by the dentist and the set-up in figure 1 as stated below:

<u>Setup dental practice:</u>
The device has a rectangular collimator and long spacer, which irradiates a skin surface of 35 mm x 45 mm with a focus to skin distance of 30 cm.

<u>Setup in figure 1:</u>
The device has a round collimator and a short wide spacer, with an irradiated skin surface of 30 cm^2 and a focus to skin distance of 20 cm.

Figure 2: *left: an X-ray machine for dental applications, right: different spacer shapes, with a long and short spacer cone and round and square collimators. A spacer limits the beam size and ensures a constant focus to skin distance.*

Given:

- **Attachment, pg. 3:** Inleiding tot de stralingshygiëne, Bos *et al.* (2nd edition 2007), pg. 381, Table D; Interaction coefficients for photons.
- **Attachment, pg. 4:** Inleiding tot de Stralingshygiëne, Bos *et al.* (2nd edition 2007), pg. 268: Table 11.1; Exposure build-up factor for isotropic point source.
- Assume for this question that the effective energy of the emitted X-ray photons is 50 keV.
- Assume that the absorbed skin dose equals the kerma in air.
- The ratio between the personal dose equivalent $H_p(10)$ and the absorbed dose D in the skin for 50 keV photons is: $H_p(10)/D = 1.766$ Sv/Gy.
- The dentist takes 2000 images with this device each year.

Question 1.1 [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?

There are currently no diagnostic reference levels (DRL's) established in the Netherlands for intraoral radiographs. On the IAEA website, the following information is given under "Radiation doses in dental radiology, FAQs for health professionals":

- DRL values for adult exposures from various national surveys are in the following ranges: 0.65 to 3.7 mGy in terms of entrance surface kerma, and 26 to 87 mGy·cm² in terms of kerma-area product for intraoral radiography

Question 1.2 [4 points]

Based on the doses calculated in Question 1.1, indicate for *each* of the above mentioned setups if the dose levels for the intra-oral radiographs are within, above or below these two DRL's.

The dentist always stands where he is best able to reassure the patient. The radiation protection expert therefore assumes the highest given dose value (based on figure 1) for the RI&E, at a distance of 50 cm from the patient's head.

Question 1.3 [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?

A mobile screen for shielding is purchased within the framework of ALARA. The bottom half of the screen is completely made of lead , the top half contains a large window composed of lead glass. The (equivalent) lead thickness of the screen and lead glass is 1.5 mm.

Question 1.4a [4 points]

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

Question 1.4b [1 point]

Based on the calculation in question 1.4a, formulate your evaluation of the RI&E for this dentist.

Question 2: Scientific experiment with iodine in an acidic environment

One of the golden rules in radiochemistry is the following: never use an iodine compound in an acidic environment. However, of course there are exceptions: the iodination of TTD-PC (an organic molecule)[1] can only be performed successfully in an acetic acid solution. A special method has been developed to minimize the risk of internal contamination from released iodine vapor, where all chemical reactions take place in a closed ampoule.

Given:

- TTD-PC is iodinated with 110 MBq ^{125}I.
- The experiment is only performed once.
- **Attachment, pg. 5-6:** Handboek Radionucliden, A.S. Keverling Buisman (3rd edition 2015), pg. 160 and 161, ^{125}I data.
- **Attachment, pg. 7-9**: License attachment 'Attachment radionuclide laboratory', pg. 10, 11 and 12.

Question 2.1 [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.

In the context of the risk inventory and evaluation (RI&E), the accidental breaking of the ampoule during the experiment is regarded as the most important unintended event. Because of this scenario it was decided in advance to perform the experiment in a DIN-approved fume hood.

Question 2.2a [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 = p9 attachment).

The researcher does not perform any other actions with radioactive substances.

Question 2.2b [2 points]

Indicate whether the researcher should be classified as exposed worker,

[1] TTD-PC = 1-O-hexadecanoyl-2-O-[9-[[[2-(tributylstannyl)-4-(trifluoro-methyl-3Hdiazirin-3-yl)benzyl]oxy]carbonyl]nonanyl]-sn-glycero-3-phosphocholine, or a so-called photo-activatable phospholipid.

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solely based on your answer to question 2.2a, and if so, in which category he should be classified. Furthermore, name one radiation protection measure you could take for this particular experiment.

Unfortunately, the unintended event actually takes place during the experiment. One day after the experiment the activity in the researcher's thyroid is measured using a contamination monitor. This monitor contains a xenon-filled proportional counter with an effective detector surface of 100 cm^2. The measurement time of the monitor (in fact the integration time) is 2 seconds. The monitor displays a gross count rate of 15 cps. A background radiation measurement provides a count rate of 7 cps.

Additionally given:

- The manufacturer gives the following specifications for the monitor, calibrated with a homogenously contaminated surface of 100 cm^2:

Radionuclide	Net count rate (cps) per $Bq{\cdot}cm^{-2}$
^{14}C	0.2
^{60}Co	0.07
^{99m}Tc	0.3
^{125}I	0.3
^{131}I	0.04
^{241}Am	0.3

- You may assume that the manufacturer's specifications can be used to determine the activity in the thyroid without requiring additional corrections.

Question 2.3 [5 points]

Calculate the ^{125}I activity in the thyroid of the researcher, and the standard deviation of this activity.

To be able to make a conservative estimation of the committed effective dose, as a radiation expert you use the upper limit of the activity, determined with the 2σ uncertainty interval, where the unilateral probability of exceedance is 2.3%.

Question 2.4 [4 points]

Calculate the committed effective dose for the researcher based on this conservative estimation. If you did not answer question 2.3, you will need to make plausible assumptions yourself.