HEALTH PHYSICS SIMPLE EXERCISES

for radiation protection officers

devices and accelerators

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This collection of exercises is designed to give the students the opportunity to test their own skills. The assignments are simple in nature and cover the material that the student is expected to have 'understood' during the exam.

The chapter numbers in this book of simple exercises refer to the chapters in the book 'HEALTH PHYSICS for radiation protection officers - control applications - devices and accelerators' by Frits Pleiter, Hielke Freerk Boersma and Age Froma (GARP, Groningen, 2024).

CONTENTS

1 The atom and the origin of X-radiation

	QUESTIONS	*ANSWERS*
1	A copper atom contains 29 protons. How many electrons are there in the electron cloud of a neutral copper atom?	*29*
2	Which particles are the building blocks of the atomic nucleus?	*protons and neutrons*
3	What is meant by excitation?	*promotion of an electron to a higher-energy level*
4	What is meant by ionization?	*removal of an electron from the electron cloud*
5	What is meant by characteristic radiation?	*radiation emitted if an electron moves from a higher-energy level to a lower-energy level, thus an electron shell closer to the atomic nucleus*
6	What is the difference between photons and electromagnetic radiation?	*there is no difference*
7	What is the energy gain of an electron that passes a potential difference of 1000 V ?	*1000 eV = 1 keV*
8	Is the binding energy in a molecule a few meV, or eV, or keV ?	*a few eV*
9	Is the energy of X-radiation a few tens of an meV, or eV, or keV ?	*a few tens of a keV*
10	Do X-rays have a harmful effect on the human body or not?	*they do*

2 Logarithm

	QUESTIONS	*ANSWERS*
1	Consider the graph in Figure 2.1. What is the function value (vertical axis) if x = 3 (horizontal axis)?	*≈ 0.12*
2	And if x = 5 ?	*≈ 0.03*
3	If log(2) = 0.3, what is the value of log(4)?	*0.3 + 0.3 = 0.6* *because log(4) = log(2 × 2)* *= log(2) + log(2)*
4	What is meant by the prefix m ?	*0.001*
5	What is meant by the prefix M ?	*1000 000*
6	What is meant by the prefix μ ?	*0.000 001*
7	What is meant by the prefix k ?	*1000*
8	What is meant by the prefix n ?	*0.000 000 001*
9	What is meant by the prefix G ?	*1000 000 000*
10	How is the product 1.0 × 234.56 written with only significant digits?	2.3×10^2

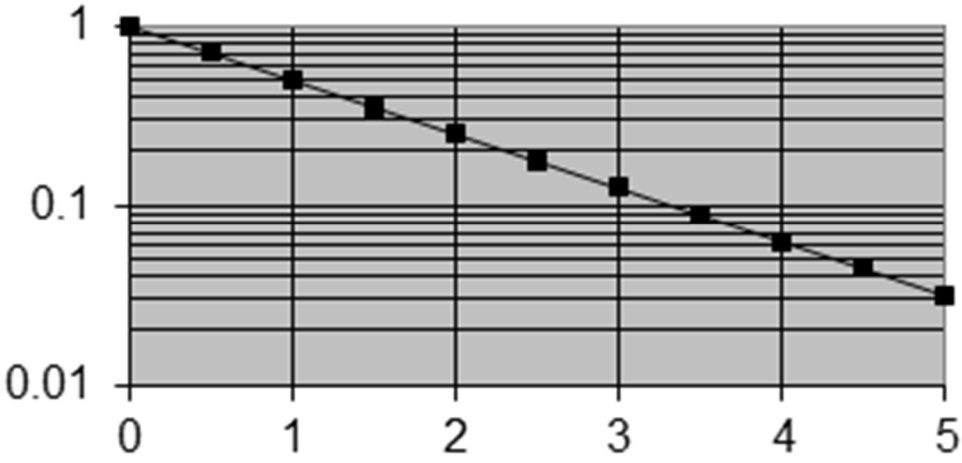

Figure 2.1

3 Interaction of ionizing radiation with matter

	QUESTIONS	*ANSWERS*
1	Name a few examples of electromagnetic radiation	*radio waves, radar waves, light, X-radiation, γ-radiation*
2	What is the photo-electric effect?	*ionization due to absorption of a photon*
3	What is the Compton-effect?	*scattering of a photon by an electron*
4	What is meant with scattering of radiation?	*new photons are emitted under varying angles with the initial radiation direction, and with a photon energy that is smaller than the primary energy*
5	Does scattering occur with photo-electric effect, or with Compton-effect?	*with Compton-effect*
6	Does photo-electric effect become more or less dominant with respect to Compton-effect if the photon energy increases?	*less dominant*
7	Is photo-electric effect more dominant in tissue (Z=8), or in lead (Z=82)?	*in lead*
8	Is Compton-effect more dominant in tissue (Z=8), or in lead (Z=82)?	*in tissue*
9	What is the ratio between scattered dose and entrance dose at 1 m from an irradiated area of 10 cm × 10 cm ?	*about 0.001*
10	What is the change of the scattered dose if the size of the irradiated area increases from 10 cm × 10 cm to 20 cm × 20 cm ?	*the scattered dose increases by a factor of 2 × 2 = 4, because scattering increases linearly with the size of the area*
11	What is meant with half-value thickness $d_{½}$?	*absorber thickness required to reduce the radiation intensity by a factor of 2*

	QUESTIONS	*ANSWERS*
12	What is the linear attenuation coefficient μ if the half-value thickness is 3 mm ?	$\mu = \ln(2) / d_{½} \approx 0.7 / 3\ mm$ $= 0.23\ mm^{-1} = 2.3\ cm^{-1}$
13	What is the transmission through a layer of 5 half-value thicknesses?	$(½)^5 = 1 / 32 \approx 0.03$
14	What is the transmission through a layer of 10 half-value thicknesses?	$(½)^{10} = (½)^5 \times (½)^5$ $\approx 0.03 \times 0.03 \approx 0.001$
15	What is the transmission through a layer of half a half-value thickness?	$(½)^{½} = 1 / \sqrt{2} \approx 0.7$

4 Shielding of ionizing radiation

	QUESTIONS	*ANSWERS*
1	The half-value thickness (HVT) for shielding γ-radiation is 1 cm. How much shielding material is needed to reduce the radiation level to 3% of the initial value?	*5 HVT × 1 cm/HVT = 5 cm* *transmission = (½)* $^{d/HVT}$ *3% = 0.03 ≈ (½)*^{5}
2	The linear attenuation coefficient for shielding γ-straling is 1 cm^{-1}. How much shielding material is needed to reduce the radiation level to 3% of the initial value?	*5 × ln(2) / μ ≈ 5 × (0.7 / 1* cm^{-1}*)* *= 3.5 cm* $d_{½}$ *= ln(2) / μ* *3% = 0.03 ≈ (½)*^{5}
3	The specific mass of lead is 11.3 g/cm^3. What is the mass thickness of a 5 cm thick leadbrick?	*(11.3* g/cm^3*) × 5 cm = 57* g/cm^2
4	A concrete wall has a mass thickness of 50 g/cm^2. The specific mass of concrete is 2.4 g/cm^3. How thick is the wall in cm ?	*(50* g/cm^2*) / (2.4* g/cm^3*)* *= 21 cm*
5	The waiting room at the dentist must be shielded. What is the best shielding material?	*lead*

5 X-ray tube

	QUESTIONS	*ANSWERS*
1	Does the maximum bremsstrahlung energy depend on the tube voltage or not?	*it does*
2	Does the maximum bremsstrahlung energy depend on the tube current or not?	*it does not*
3	Does the maximum bremsstrahlung energy depend on the anode material or not?	*it does not*
4	Does the energy of characteristic radiation depend on the tube voltage or not?	*it does not*
5	Does the energy of characteristic radiation depend on the tube current or not?	*it does not*
6	Does the energy of characteristic radiation depend on the anode material or not?	*it does*
7	Does the bremsstrahlung intensity depend on the tube voltage or not?	*it does*
8	Does the bremsstrahlung intensity depend on the tube current or not?	*it does*
9	Does the bremsstrahlung intensity depend on the anode material or not?	*it does*
10	Does the intensity of characteristic radiation depend on the tube voltage or not?	*it does*
11	Does the intensity of characteristic radiation depend on the tube current or not?	*it does*
12	Does the intensity of characteristic radiation depend on the anode material or not?	*it does*

	QUESTIONS	*ANSWERS*
13	Why is an X-ray device equipped with a filter?	*to reduce the skin dose of the patient*
14	Why is an X-ray device equipped with a position indicating device (PID)?	*to limit beam size and focus-skin distance*
15	Why is an X-ray device equipped with a light visor?	*to check beam size and beam position*
16	In contrast to curve (a), the curves (c) and (d) in Figure 5.1 show no intensity at low energy. Why is this?	*curve c: only internal filter* *curve d: internal + extra filter*
17	What is the homogeniety of the X-ray beam?	*a measure of the width of the distribution of X-ray energies*
18	What is the hardness of the X-ray beam?	*a measure of the average X-ray energy*
19	What is meant by mAs value?	*product of tube current (in mA) and exposure time (in s)*
20	Is the radiation output of an X-ray tube greatest at 1 mA for 5 s, or 2 mA for 4 s, or 3 mA for 3 s, or 2 mA for 4 s ?	*3 mA for 3 s* *(mAs value = 3 × 3 = 9 mA·s)*

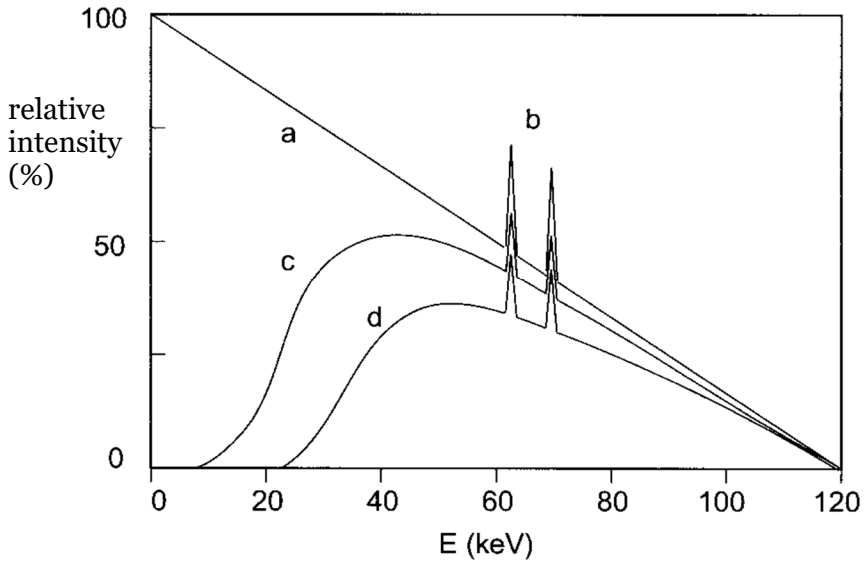

Figure 5.1

6 Applications of devices

7 Quantities and units in radiation protection

	QUESTIONS	*ANSWERS*
1	What is the unit for exposure? What is the symbol of this unit?	*röntgen* *R*
2	What is the unit for absorbed dose? What is the symbol of this unit?	*gray* *Gy*
3	What is the unit for equivalent dose? What is the symbol of this unit?	*sievert* *Sv*
4	What is the unit for effective dose? What is the symbol of this unit?	*sievert* *Sv*
5	Which quantity is expressed in röntgen? What is the symbol of this quantity?	*exposure* *X*
6	Which quantity is expressed in gray? What is the symbol of this quantity?	*absorbed dose* *D*
7	Which quantity is expressed in sievert? What is the symbol of this quantity?	*equivalent dose and effective dose* *H and E, respectively*
8	Is the radiation weighting factor w_R for X-radiation 1, or 5, or 20, or 100 ?	*1*
9	Is the radiation weighting factor w_R for γ-radiation 1, or 5, or 20, or 100 ?	*1*
10	Is the risk of death determined by the absorbed dose, or the equivalent dose, or the effective dose?	*effective dose*
11	An energy of 3 joules is deposited in an organ with a mass of 30 grams. What is the absorbed dose?	*3 joule / 0.03 kg = 100 Gy*
12	What is the equivalent dose, if the absorbed dose is 1 mGy and the radiation weighting factor is $w_R = 1$?	*$H = 1 \times 1 = 1$ mSv*

	QUESTIONS	*ANSWERS*
13	The tissue weighting factor for the thyroid is $w_{thyroid} = 0.04$ and the equivalent dose on the thyroid is $H_{thyroid} = 5$ Sv. What is the effective dose?	*$E = 0.04 \times 5 = 0.2$ Sv*
14	Is 1 Sv a high or a low effective dose?	*a very high dose* *it is 50 times the annual limit*
15	Is 0.1 μSv/h a high or a low equivalent dose rate?	*small equivalent dose rate* *background is 1.6 mSv/y* *= 1600 μSv / (365 × 24)* *= 0.2 μSv/h)*

Orders of magnitude of the radiation dose

1	Is the average annual effective dose due to natural radiation in the Netherlands about 2 μSv, or 2 mSv, or 20 mSv ?	*2 mSv*
2	Is the average annual effective dose due to medical diagnostics in the Netherlands about 1 μSv, or 1 mSv, or 10 mSv ?	*1 mSv*
3	Is a lethal effective dose 0.1 Gy, or 1 Gy, or 100 Gy ?	*100 Gy*
4	What makes the largest contribution to natural radiation in the Nederlands?	*radon*
5	What makes the largest contribution to man-made radiation in the Nederlands?	*medical diagnostics*

8 Measuring of ionizing radiation

	QUESTIONS	*ANSWERS*
1	Does the working of the ionisation detector depend on the counting gas or not?	*it does not*
2	Does the working of the ionisation detector depend on the gas pressure or not?	*it does not*
3	Does the working of the ionisation detector depend on the dimensions of the detector or not?	*it does not*
4	Does the working of the ionisation detector depend on the anode voltage or not?	*it does*
5	Is a Geiger-Müller counter useful as a dose monitor or not?	*it is*
6	Is a scintillation detector useful as a dose monitor or not?	*it is*
7	Which detector is (relatively) cheap: a Geiger-Müller counter, or a scintillation detector?	*Geiger-Müller counter*
8	Which unit is indicated on the scale of a dose monitor?	*gray, röntgen, or sievert*
9	Which unit is indicated on the scale of a dose-rate monitor?	*for example gray per hour*
10	Is the thermoluminescence detector (TLD) an ionisation detector, or a scintillation detector?	*scintillation detector (scintillates after heating)*

9 Imaging

	QUESTIONS	*ANSWERS*
1	Is an underexposed X-ray photo too light or too dark?	*too light*
2	Is an overexposed X-ray photo too light or too dark?	*too dark*
3	Is the contrast of a uniform gray X-ray photo too small or too large?	*too small*
4	Is the contrast of an X-ray photo with only gray values of white and black too small or too large?	*too large*
5	What is better: a small or a large contrast?	*the contrast must be optimal to be able to answer the question*

10 Biological effects of ionizing radiation

	QUESTIONS	*ANSWERS*
1	Is damage produced by ionizing radiation mainly due to direct breaks of bio-molecules or to ionization of water molecules?	*ionization of water molecules*
2	Which cells are most sensitive to radiation?	*quickly dividing cells*
3	Which cells are least sensitive to radiation?	*cells that do not divide anymore*
4	Which tissue is most radiation-sensitive: bone marrow, or bone, or red blood corpuscles, or brain tissue?	*bone marrow*
5	Is there a threshhold dose for stochastic effects?	*no*
6	Is the severity of a stochastic effect dose dependend?	*no*
7	How great is the risk of death due to a stochastic effect after exposure to ionizing radiation?	*5% per sievert*
8	What is meant by: The risk factor for ionizing radiation is 0.05 per Sv?	*if 1 million people are exposed to 1 Sv, about 0.05 × 1 000 000 = 50 000 people will die*
9	Is there a threshhold dose for harmful tissue reactions?	*yes*
10	Is the severity of harmful tissue reactions dose dependend?	*yes*
11	Is leukemia a stochastic effect or a harmful tissue reaction?	*stochastic effect*
12	Is cataract a stochastic effect or a harmful tissue reaction?	*harmful tissue reaction*

	QUESTIONS	*ANSWERS*
13	What is the most likely cause of death after whole-body irradiation with a dose of 1 Gy: bone marrow syndrome, bowel syndrome, or brain syndrome?	*bone marrow syndrome*
14	What is the most likely cause of death after whole-body irradiation with a dose of 10 Gy: bone marrow syndrome, bowel syndrome, or brain syndrome?	*bowel syndrome or, at survival, bone marrow syndrom*
15	What is the most likely cause of death after whole-body irradiation with a dose of 50 Gy: bone marrow syndrome, bowel syndrome, or brain syndrome?	*brain syndrome*
16	What happens if the unborn embryo is irradiated during the first week of the pregnancy?	*either nothing or the embryo dies*
17	Is it possible that malformed organs develop if the unborn embryo is irradiated during the first week of the pregnancy?	*no*
18	Is it possible that malformed organs develop if the unborn embryo is irradiated during the second month of the pregnancy?	*yes, during this period the organs are formed*
19	Is it possible that malformed organs develop if the unborn foetus receives a dose of 1 mGy during the second half of the pregnancy?	*no, because this dose is far below the threshold dose of 100 mGy*
20	What might happen if the unborn foetus is irradiated during the second half of the pregnancy?	*growth retardation and/or lowering of IQ*
21	Is regular exposure to the dose limit of 20 mSv per year a relatively small or a relatively high occupational hazard?	*relatively (very) high occupational hazard*

	QUESTIONS	*ANSWERS*
22	The risk factor for ionizing radiation is 0.05 per Sv. The average annual dose is about 2 mSv. Nearly 18 million people live in the Netherlands. How many persons will die each year due to ionizing radiation?	*0.05 × 0.002 × 18 000 000 = 1800* *(each year about 44 000 people die of cancer)*
23	When comparing the health risks of ionizing radiation and smoking, how many cigarettes correspond to an effective dose of 10 μSv: 1, 100, or 10 000?	*1 cigarette*
24	Regular smokers will smoke around 5000 cigarettes a year, putting them at an increased risk of death. Which effective dose poses a comparable risk: 0.5 mSv, 5 mSv, 50 mSv, or 500 mSv ?	*5000 × 10 μSv = 50 000 μSv = 50 mSv* *because 1 sigaret corresponds to 10 μSv* *(annual limit public = 1 mSv)*
25	What is wrong with the caption of the newspaper clipping shown in Figure 10.1, and why is it wrong?	*the little boy is at least 4 years old and was born long before the Chernobyl disaster; the malformations must, therefore, be caused by something else*

Wit-Rusland blijft lang radioactief besmet

Wit-Rusland heeft nog steeds te maken met een ernstige besmetting door het ongeluk met de kerncentrale in Tsjernobyl in 1986. En de gevolgen zullen de komende twintig jaar nauwelijks minder worden. Dat blijkt uit gegevens van Alexi Okeanog, directeur van het instituut voor medische technologie in Minsk. Hij presenteerde cijfers en kaarten over de besmetting door de gevaarlijk radioactieve stof cesium op de conferentie van de Wereldgezondheidsorganisatie (WHO) in Genève.

A victim of Chernobyl one year after the nuclear disaster.

Uit de gegevens blijkt dat de radioactieve besmetting tot 2016 nauwelijks zal afnemen. Drieëntwintig procent van Wit-Rusland zal in de visie van Okeanog een ecologisch rampgebied blijven.

Volgens Ivan Kenik, de Tsjernobyl-minister van Wit-Rusland, geeft dit land veertien procent van zijn begroting uit aan de bestrijding van de gevolgen van de Tsjernobyl-ramp. Daarbij gaat het om de bouw van nieuwe woningen, om gezondheidszorg voor duizenden mensen en om de aankoop van onbesmet voedsel. Kenik schat de kosten over de periode 1986 tot 2015 op 86 miljard dollar, zo'n 140 miljard gulden.

HERMAN DAMVELD

Figure 10.1

11 General laws and regulations

	QUESTIONS	*ANSWERS*
1	What must be taken into account when performing radiological work: Nuclear Energy Act, or Working Conditions Act, or both?	*both*
2	Is the Decree on Basic Safety Standards Radiation Protection a recommendation of the ICRP, or a Decree under the Nuclear Energy Act, or a Decree under the Working Conditions Act, or none of these?	*Decree under the Nuclear Energy Act*
3	Is the ICRP an independent committee of experts, or an advisory board of the Dutch government, or an advisory board of the European Community?	*an independent committee of experts*
4	What must be taken into account when performing radiological work: dose limits, or ALARA, or justification, or all of these?	*all of these*
5	What is meant by ALARA principle?	*keep the dose as low as possible (as reasonably achievable)*
6	Is the annual effective-dose limit for the general public 1 µSv, or 10 µSv, or 1 mSv, or 10 mSv ?	*1 mSv*
7	Is the annual effective-dose limit for a nonexposed worker 1 µSv, or 10 µSv, or 1 mSv, or 10 mSv ?	*1 mSv*
8	Is the annual effective-dose limit for an exposed A-worker 1 mSv, or 2 mSv, or 6 mSv, or 20 mSv.?	*20 mSv*
9	Is the annual effective-dose limit for an exposed B-worker 1 mSv, or 2 mSv, or 6 mSv, or 20 mSv ?	*6 mSv*

	QUESTIONS	*ANSWERS*
10	Is the annual dose limit for the lens of the eye of an exposed A-worker 2 mSv, or 20 mSv, or 150 mSv, or 500 mSv ?	*20 mSv*
11	Is the annual dose limit for hands, feet and skin of an exposed A-worker 2 mSv, or 20 mSv, or 150 mSv, or 500 mSv ?	*500 mSv*
12	What is the dose limit for the unborn child?	*1 mSv (from the moment the pregnancy has been reported to the employer)*
13	Must an area in which the annual effective dose can exceed 6 mSv, be qualified as controlled area ("gecontroleerde zone") or as supervised area ("bewaakte zone")?	*controlled area*
14	Which is the largest annual dose that can possibly be received in a supervised area ("bewaakte zone")?	*6 mSv*
15	Is it allowed for a nonexposed worker to work inside a supervised area ("bewaakte zone")?	*yes, provided he can not receive more than 1 mSv per year*
16	The radiation protection officer must ensure that the annual effective dose on the public road does not exceed a certain value. What is that value in the case of an application that requires a permit?	*0.1 mSv = 100 μSv*
17	The radiation protection officer must ensure that the annual effective dose on the public road does not exceed a certain value. What is that value in the case of an application that requires registration?	*0.01 mSv = 10 μSv*
18	In radiation protection, how many hours are you assumed to work per day?	*8*
19	In radiation protection, how many hours are you assumed to work per week?	*40*

	QUESTIONS	*ANSWERS*
20	In radiation protection, how many hours are you assumed to work per year?	*2000*

12 Specific regulations for devices

	QUESTIONS	*ANSWERS*
1	At 10 cm from (an accessible point of) an inherently safe device, the radiation level must not exceed a certain value. Is that value 0.1 µSv, or 1 µSv, or 10 µSv per hour?	*1 µSv per hour*
2	Is a hand-baggage scanner at the airport an inherently safe device or not?	*it is*
3	Is a container scanner in the seaport an inherently safe device or not?	*it is not*
4	Is a transmission electron microscope an inherently safe device or not?	*it is*
5	Is a medical diagnostic X-ray device in the hospital an inherently safe device opr not?	*it is not*
6	Is a hand-held X-ray device used for geofysical prospecting an inherently safe device or not?	*it is not*
7	Is an inherently safe device exempted, or subject to registration, or subject to a license?	*subject to registration*
8	Is a transmission electron microscope exempted, or subject to registration, or subject to a license?	*subject to registration*
9	Is a mobile container scanner in the seaport exempted, or subject to registration, or subject to a license?	*subject to a license*
10	Must a radiation protection officer be appointed for an inherently safe device or not?	*an RPO must be appointed*

	QUESTIONS	*ANSWERS*
11	The radiation protection officer must ensure that the annual effective dose on the public road does not exceed a certain value. Is that value 0.1 µSv, or 1 µSv, or 10 µSv, or 100 µSv per year?	*100 µSv per year for devices requiring a license* *10 µSv per year for devices requiring registration*
12	The radiation protection officer must ensure that the effective annual dose inside the location does not exceed a certain value. Is that value 1 µSv, or 1 mSv, or 20 mSv per year?	*1 mSv per year*
13	Must an inherently safe device be regularly checked for proper functioning or not?	*it must*
14	How often should an X-ray device be checked for proper functioning?	*at least once a year*

warning sign

15	Must a warning sign be attached to an inherently safe device or not?	*it must*

13 Practical radiation protection for devices

	QUESTIONS	*ANSWERS*
1	Is it or is it not the task of the radiation protection officer to introduce new employees into house rules and protocols?	*it is*
2	Is it or is it not the task of the radiation protection officer to supervise the use of adequate personal protection?	*it is*
3	Who is in charge of the nuclear energy act file?	*radiation protection officer*
4	Is the radiation protection officer allowed to have the nuclear energy act file managed by the secretariat?	*no*
5	May the radiation protection officer carry out a risk analysis or not?	*he may*
6	May the radiation protection officer approve a risk analysis or not?	*he may not*
7	What is an inherently safe device?	*device for which the equivalent dose rate at 10 cm from any accessible part of the outside does not exceed 1 µSv/h*
8	The source-oriented strategy dictates that personal protective equipment is used, the tube output is reduced and the distance is increased. What is the first step to take?	*reduce the tube output*
9	The source-oriented strategy dictates that personal protective equipment is used, the tube output is reduced and the distance is increased. What is the last step to take?	*use personal protective equipment*
10	The distance to the focus is doubled. What happens to the entrance dose?	*entrance dose four times lower (inverse square law)*

14 Risk analysis for devices

	QUESTIONS	*ANSWERS*
1	The filter thickness is increased from 1 to 2 mm. Will the entrance dose increase or decrease?	*decrease*
2	The tube voltage is increased from 70 to 110 kV. Will the entrance dose increase or decrease?	*increase*
3	The mAs value is increased from 5 to 10 mA·s. Will the entrance dose increase or decrease?	*increase*
4	The exposure time is increased from 0.1 to 0.2 s. Will the entrance dose increase or decrease?	*increase*
5	The distance to the focus is increased from 25 to 30 cm. Will the entrance dose increase or decrease?	*decrease*