Radiation Protection Officer

measuring and control applications
&
dispersible radioactive materials
level D

Simple Exercises

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university of groningen / health, safety and sustainability / garp

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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*
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	The binding energy in a molecule is a few meV, or eV, or keV?	*a few eV*
9	The energy of X-radiation is is a few tens of an meV, or eV, or keV?	*a few tens of a keV*
10	X-rays do or do not have a harmful effect on the human body?	*they do*

2. Atomic nucleus and origin of α-, ß- and γ-radiation

	QUESTIONS	*ANSWERS*
1	What are isotopes?	*atoms with equal Z but different N*
2	What are isomers?	*atoms with equal Z and equal N*
3	What do you know about the Z-value of hydrogen (^{1}H), deuterium (^{2}H) and tritium (^{3}H)?	*all equal Z* *(Z = 1)*
4	What do you know about the N-value of hydrogen (^{1}H), deuterium (^{2}H) and tritium (^{3}H)?	*all different N* *(0, 1 and 2, respectively)*
5	What is the unit for activity? What is the symbol of this unit?	*bequerel* *Bq*
6	How many disintegrations per second (dps) is 1 Bq?	*1 dps*
7	Would you describe 1 kBq as a strong or a weak source in general?	*weak*
8	Would you describe 1 GBq as a strong or a weak source in general?	*strong*
9	The initial activity is 100 MBq. The half life is 24 hours. What is the activity after 1 day?	*100 / 2 = 50 MBq* *(1 day = 24 hours)*
10	And what is the activity after 5 days?	*100 / 32 = 3 MBq* *(2^5 = 32)*
	How many percent of the initial activity is this?	*about 3%*
11	What is the half-life in the example shown in Figure 2.1 ?	*25 seconds*

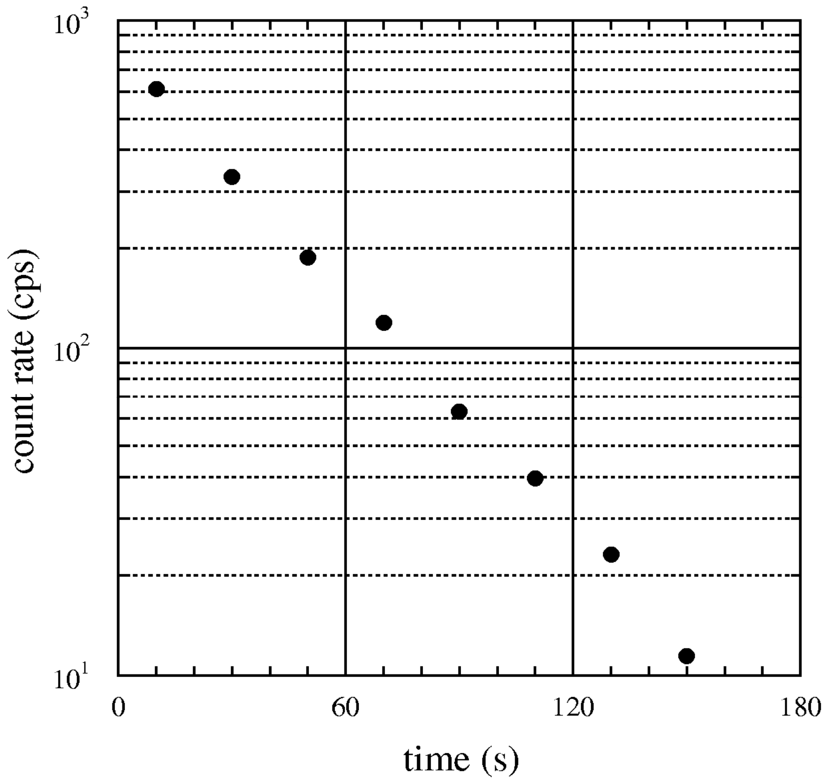


Figure 2.1

	QUESTIONS	*ANSWERS*
12	How change Z, N and mass number A during β^--decay?	*$\Delta Z = +1, \Delta N = -1, \Delta A = 0$*
13	How change Z, N and mass number A during β^+-decay?	*$\Delta Z = -1, \Delta N = +1, \Delta A = 0$*
14	How change Z, N and mass number A during electron capture?	*$\Delta Z = -1, \Delta N = +1, \Delta A = 0$*
15	How change Z, N and mass number A during α-decay?	*$\Delta Z = -2, \Delta N = -2, \Delta A = -4$*
16	How change Z, N and mass number A during γ-decay?	*$\Delta Z = 0, \Delta N = 0, \Delta A = 0$*
17	How change Z, N and mass number A during internal conversion?	*$\Delta Z = 0, \Delta N = 0, \Delta A = 0$*
18	Which secundary process takes place after electron capture?	*emission of X-ray photons*
19	Which secundary process takes place after internal conversion?	*emission of X-ray photons*
20	Which secundary process takes place after β^+-verval?	*emission of annihilation radiation ($E_{\pm}$ = 511 keV)*
21	The desintegration energy is 1000 keV. Can β^+-decay occur?	*no, for this the energy must be at least 2 × 511 keV*
22	Name the decay processes in Figure 2.2.	*from top-left: β^--decay, electron capture, β^+-decay, γ -decay and α -decay*
23	Can a nucleus show β^--decay as well as β^+-decay?	*yes, but not both during the same disintegration*
24	What is annihilation?	*$e^+ + e^- \rightarrow$ 2 photons, each with an energy of 511 keV*
25	Can the emission yield be larger than 100% ?	*yes, for example in case of X-ray or annihilation photons*

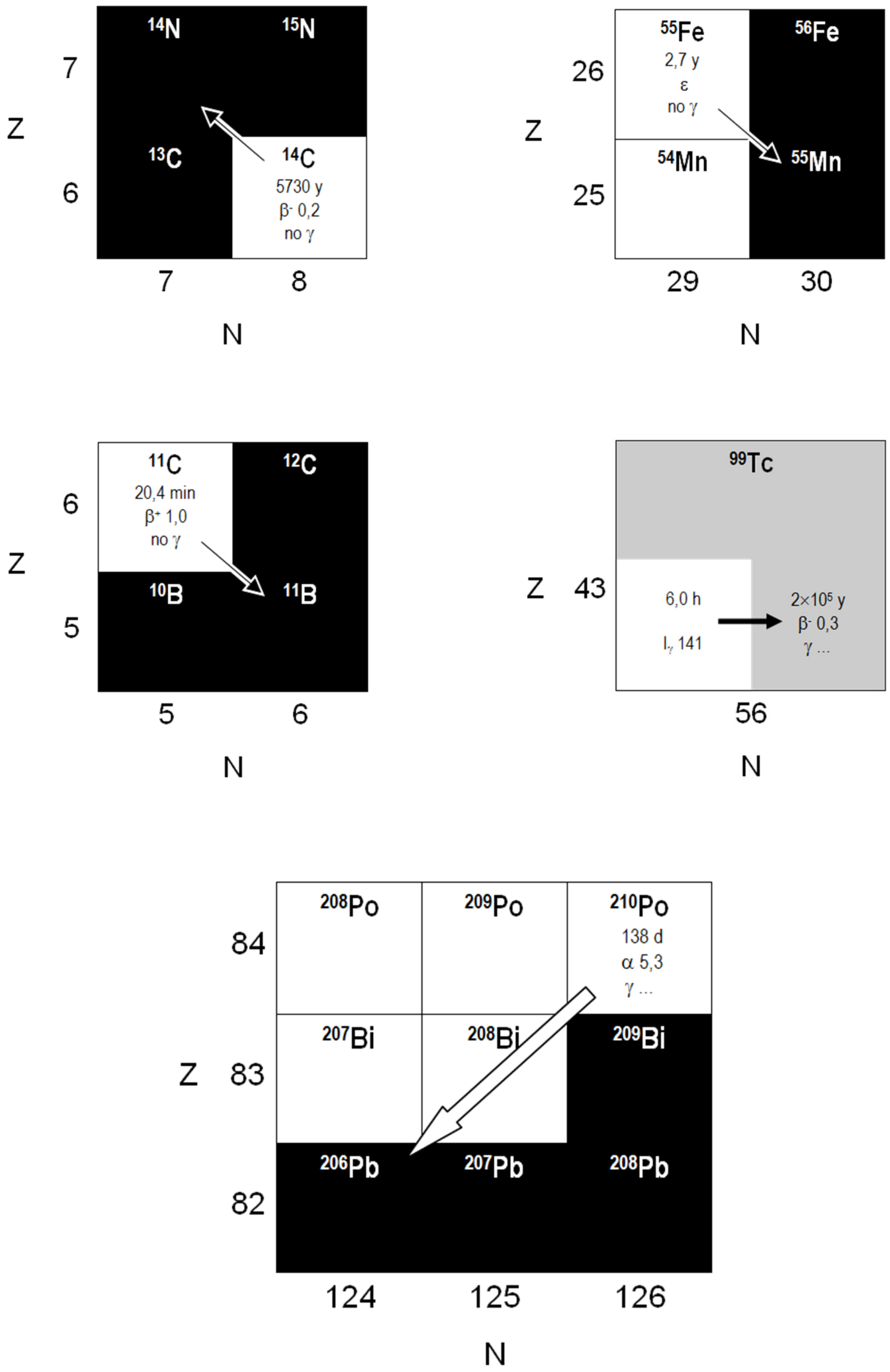

14N
15N
7
Z
13C
14C
5730 y
β- 0,2
no γ
6
7
8
N
55Fe
2,7 y
ε
no γ
56Fe
26
Z
54Mn
55Mn
25
29
30
N
11C
20,4 min
β+ 1,0
no γ
12C
6
Z
10B
11B
5
5
6
N
99Tc
Z
43
6,0 h
Iγ 141
2×10⁵ y
β- 0,3
γ ...
56
N
208Po
209Po
210Po
138 d
α 5,3
γ ...
84
207Bi
208Bi
209Bi
Z
83
206Pb
207Pb
208Pb
82
124
125
126
N

Figure 2.2

	QUESTIONS	*ANSWERS*
26	The nuclide ${}^{210}_{84}Po$ decays via α-decay. What is the mass number and the Z-value of the daughter nucleus?	*A = 206 and Z = 82 (thus ${}^{206}_{82}Pb$)*
27	The nuclide ${}^{214}_{82}Pb$ is formed via α-decay. What was the mass number and the Z-value of the mother nucleus?	*A = 218 and Z = 84 (thus ${}^{210}_{84}Po$)*
28	The nuclide ${}^{45}_{20}Ca$ decays via $ß^-$-decay. What is the mass number and the Z-value of the daughter nucleus?	*A = 45 and Z = 21 (thus ${}^{45}_{21}Sc$)*
29	The nuclide ${}^{26}_{12}Mg$ is formed via electron capture. What was the mass number and the Z-value of the mother nucleus?	*A = 20 and Z = 13 (thus ${}^{26}_{13}Al$)*
30	The nuclide ${}^{99m}Tc$ decays to ${}^{99}Tc$. How is this decay process commonly called?	*isomeric decay*

3. Logarithm

	QUESTIONS	*ANSWERS*
1	Consider the graph in Figure 3.1. 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 4 = 2 × 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*

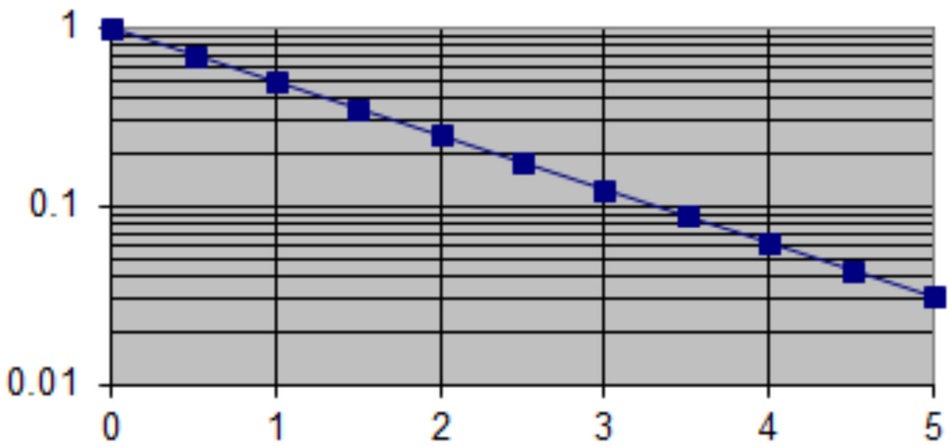


Figure 3.1

4. 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*
11	What is meant with half-value thickness $d_{½}$?	*absorber thickness required to reduce the radiation intensity by a factor of 2*

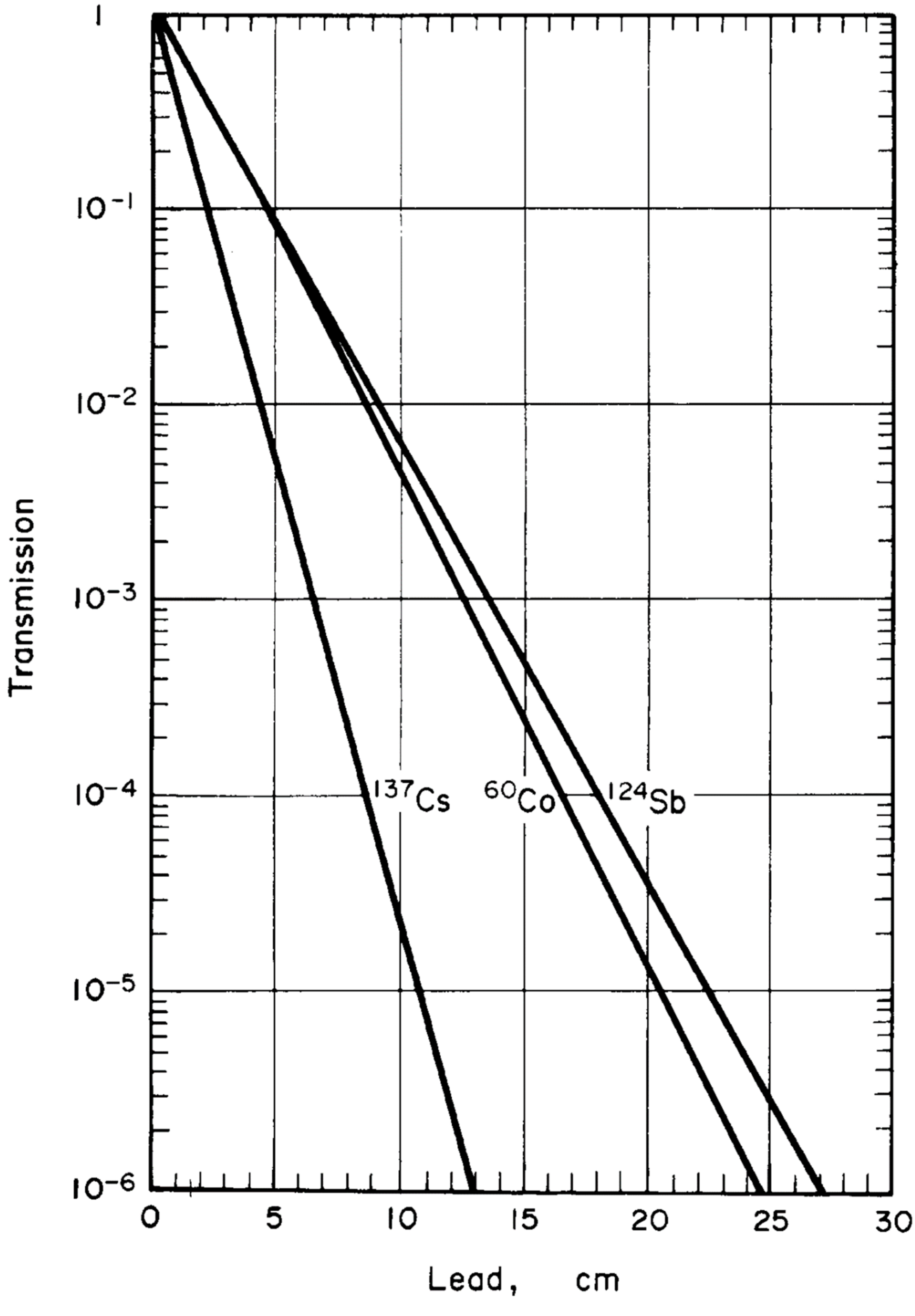
	QUESTIONS	*ANSWERS*
12	What is the linear attenuation coefficient μ if the half-value thickness is 3 mm ?	*$0.7 / 3 = 0.23\ mm^{-1} = 2.3\ cm^{-1}$*
13	What is the transmission through a layer of 5 half-value thicknesses?	*$1 / 2^5 = 1 / 32 \approx 0.03$*
14	What is the transmission through a layer of 10 half-value thicknesses?	*$1 / 2^{10} \approx 0.03 \times 0.03 \approx 0.001$*
15	What is the transmission through a layer of half a half-value thickness?	*$1 / \sqrt{2}$*
16	What is the main physical process by which α-particles lose energy in matter?	*collisions with electrons*
17	What is the main physical process by which β-particles lose energy in matter?	*collisions with electrons*
18	The range of 5 MeV α-particles in air is about 0.3 mm, or 3 mm, or 3 cm, or 3 m?	*about 3 cm*
19	The range of 1 MeV β-particles in air is about 0.4 mm, or 4 mm, or 4 cm, or 4 m?	*about 4 m*
20	The range of 5 MeV α-particles in tissue is about 3 µm, or 30 µm, or 0.3 mm, or 3 mm?	*about 3 cm / 1000 = 30 µm (the density of tissue is 1000 times larger than that of air)*
21	The range of 1 MeV β-particles in air is about 0.4 mm, or 4 mm, or 4 cm, or 4 m?	*about 4 m / 1000 = 4 mm (the density of tissue is 1000 times larger than that of air)*
22	The maximal range in water of β-radiation emitted by ^{32}P is 0.8 cm. What is the maximal range in air?	*about 1000 × 0.8 cm = 800 cm = 8 m (the density of air is 1000 times smaller than that of water)*

	QUESTIONS	*ANSWERS*
23	Electrons with an energy of 1 MeV produce more or less bremsstrahlung in water than in lead?	*less*
24	Electrons with an energy of 30 keV produce more or less bremsstrahlung in copper (Z=29) than in silver (Z=47) ?	*less*
25	Electrons in tungsten produce more or less bremsstrahlung at 1 MeV than at 3 MeV ?	*less*

5. Shielding of ionizing radiation

	QUESTIONS	*ANSWERS*
1	The half-value thickness for shielding γ-radiation is 1 cm. How much shielding material is needed to reduce the radiation level to 3% of the initial value?	*$5 \times 1 = 5$ cm* *($3\% \approx 1/2^5$)*
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?	*$5 \times (0.7 / 1) = 3.5$ cm* *($3\% \approx 1/2^5$ and $d_{½} = 0.7/\mu$)*
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 $\times$ 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*
6	Which material would you choose to shield α-radiation?	*no shielding needed* *(range is too small)*
7	Which material would you choose to shield β^--radiation?	*plastic* *(small Z-value to avoid bremsstrahlung)*
8	Which material would you choose to shield β^+-radiation?	*plastic + lead* *(to shield 511 keV annihilation photons)*

	QUESTIONS	*ANSWERS*
9	What is the half-value thickness of lead for γ-radiation emitted by the nuclide ^{137}Cs (see Figure 5.1)?	*0.6 cm*
10	What is the half-value thickness of lead for γ-radiation emitted by the nuclide ^{60}Co (see Figure 5.1)?	*1.3 cm*
11	What is the transmission of 10 cm lead for γ-radiation emitted by the nuclide ^{137}Cs (see Figure 5.1)?	2×10^{-5}
12	What is the transmission of 10 cm lead for γ-radiation emitted by the nuclide ^{60}Co (see Figure 5.1)?	5×10^{-3}
13	What is meant by build-up factor?	*this factor accounts for the contribution of scatter radiation to the dose*
14	Neutrons are effectively shielded by water, or paraffin, or concrete, or any of these materials?	*any of these materials*
15	Neutrons are effectively shielded by water, or iron, or lead, or any of these materials?	*water*



1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
Transmission
137Cs
60Co
124Sb
0
5
10
15
20
25
30
Lead, cm

Figure 5.1

6. X-ray tube

	QUESTIONS	*ANSWERS*
1	The maximum bremsstrahlung energy does or does not depend on the tube voltage?	*it does*
2	The maximum bremsstrahlung energy does or does not depend on the tube current?	*it does not*
3	The maximum bremsstrahlung energy does or does not depend on the anode material?	*it does not*
4	The energy of characteristic radiation does or does not depend on the tube voltage?	*it does not*
5	The energy of characteristic radiation does or does not depend on the tube current?	*it does not*
6	The energy of characteristic radiation does or does not depend on the anode material?	*it does*
7	The bremsstrahlung intensity does or does not depend on the tube voltage?	*it does*
8	The bremsstrahlung intensity does or does not depend on the tube current?	*it does*
9	The bremsstrahlung intensity does or does not depend on the anode material?	*it does*
10	The intensity of characteristic radiation does or does not depend on the tube voltage?	*it does*
11	The intensity of characteristic radiation does or does not depend on the tube current?	*it does*
12	The intensity of characteristic radiation does or does not depend on the anode material?	*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 skin-focus 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 6.1 show no intensity at low energy. Why is this?	*this is due to the 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	The radiation output of an X-ray tube is 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 mAs)*

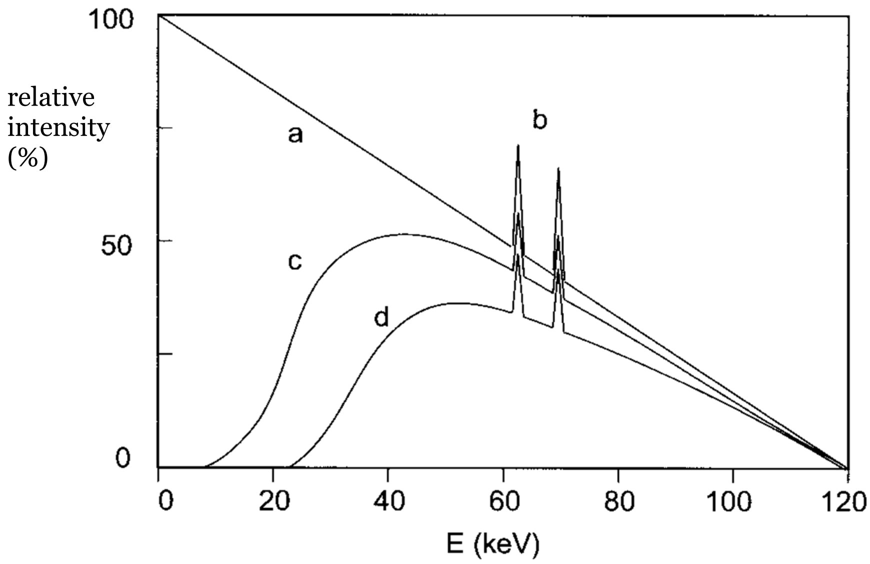


Figure 6.1

7. Applications of devices

8. Applications of sealed sources

9. Applications of open sources

10. 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	The radiation weighting factor w_R for X-radiation is 1, or 5, or 20, or 100 ?	*1*
9	The radiation weighting factor w_R for γ-radiation is 1, or 5, or 20, or 100 ?	*1*
10	The risk of death is 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 × 5 = 0.2 Sv*
14	Is 1 Sv a large or a small effective dose?	*a very large dose (50 times the annual limit)*
15	Is 0.1 μSv/h a large or a small equivalent dose rate?	*small equivalent dose rate (background is 1.6 mSv/y = 1600 μSv / (365 × 24) = 0.2 μSv/h)*
16	What is the unit for activity? What is the symbol of this unit?	*bequerel* *Bq*
17	What is the unit for committed effective dose? What is the symbol of this unit?	*sievert* *Sv*
18	The radiation weighting factor w_R for α-radiation is 1, or 5, or 20, or 100 ?	*20*
19	The radiation weighting factor w_R for β-radiation is 1, or 5, or 20, or 100 ?	*1*
20	A large value of e(50) means a large or a small radiotoxicity?	*large radiotoxicity*
21	The value of the effective dose coefficient does or does not depend on the radionuclide?	*it does*
22	The value of the effective dose coefficient does or does not depend on the chemical composition of the radioactive substance?	*it does*
23	The value of the effective dose coefficient does or does not depend on the contamination route?	*it does*

	QUESTIONS	*ANSWERS*
24	What is Re if e(50) = 1×10^{-9} Sv/Bq ?	*Re = 1 Sv / 1×10^{-9} Sv/Bq = 1×10^{9} Bq = 1 GBq*
25	What is e(50) if Re = 200 kBq ?	*e(50) = 1 Sv / 200×10^{3} Bq = 5×10^{-6} Sv/Bq*

Orders of magnitude of the radiation dose

1	The average annual effective dose due to natural radiation in the Netherlands is about 2 µSv, or 2 mSv, or 20 mSv ?	*2 mSv*
2	The average annual effective dose due to medical diagnostics in the Netherlands is about 1 µSv, or 1 mSv, or 10 mSv ?	*1 mSv*
3	A lethal dose is 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*

11. Measuring of ionizing radiation

	QUESTIONS	*ANSWERS*
1	The voltage over an ionization chamber is relatively low, or relatively high?	*relatively low*
2	The voltage over a proportional counter is relatively low, or relatively high?	*neither low nor high, but in the intermediate region*
3	The voltage over a Geiger-Müller counter is relatively low, or relatively high?	*relatively high*
4	A gas-filled ionization chamber can or can not measure radiation energies?	*it can not (signals are too small due to lack of gas amplification)*
5	A proportional counter can or can not measure radiation energies?	*it can*
6	A Geiger-Müller counter can or can not measure radiation energies?	*it can not (all signals are equal in size)*
7	A scintillation detector can or can not measure radiation energies?	*it can*
8	Which detector is commonly used as dose-rate monitor?	*Geiger-Müller counter*
9	TLD is a scintillation detector or an ionization chamber?	*scintillation detector*
10	For which type of measurement a TLD is commonly used?	*personal dosimetry*
11	For which type of detector does the dead time play a major role?	*Geiger-Müller counter*
12	Which type of detector would you use to identify 20 keV γ-radiation?	*proportional counter, Ge-detector or NaI(Tl) (with a thin window)*
13	Which type of detector would you use to identify 2 MeV γ-radiation?	*Ge-detector or NaI(Tl)*

	QUESTIONS	*ANSWERS*
14	Which type of detector would you use to identify 100 keV β-radiation?	*liquid scintillator, proportional counter, plastic scintillator, or Si-detector*
15	Which type of detector would you use to identify 2 MeV β-radiation?	*liquid scintillator, proportional counter, plastic scintillator, or Si-detector*
16	Which detector is suited to measure a contamination with a 20 keV γ-emitter?	*large-area proportional counter, or NaI(Tl) (with a thin window), combined with a smear test if necessary*
17	Which detector is suited to measure a contamination with a 2 MeV γ-emitter?	*Ge-detector or NaI(Tl), combined with a smear test if necessary*
18	Which detector is suited to measure a contamination with a 100 keV β-emitter?	*Geiger-Müller counter with a thin window (not for tritium), or liquid scintillator combined with a smear test*
19	Which detector is suited to measure a contamination with a 2 MeV β-emitter?	*Geiger-Müller counter, proportional counter with a window, or liquid scintillator combined with a smear test*
20	Which detector material is more suited to measure γ-radiation: Si (Z=14) or Ge (Z=32)?	*Ge*
	Why?	*larger photo-electric effect*
21	Which detector material is more suited to measure β-radiation: Si (Z=14), or Ge (Z=32)?	*Si*
	Why?	*small photo-electric effect, therefore less sensitive to background γ-radiation*
22	Which detector is suited to measure tritium?	*liquid scintillator*

	QUESTIONS	*ANSWERS*
23	What is a multichannel analyzer?	*an electronic device that digitizes the pulse heights and sorts them according to size*
	For which is it used?	*spectroscopy in order to identify radionuclides and measure activity*
24	A source with an activity of 1 kBq gives rise to 10 counts per second (cps). What is the counting efficiency?	*10 cps / 1×10^3 Bq = 0.01 = 1%*
25	One measures 100 counts. How big is the statistical uncertainty in this figure?	*$\pm\sqrt{100} = \pm 10$ counts*

12. Imaging

	QUESTIONS	*ANSWERS*
1	An underexposed X-ray photo is too light, or too dark?	*too light*
2	An overexposed X-ray photo is too light, or too dark?	*too dark*
3	The contrast of a uniform gray X-ray photo is too small, or too large?	*too small*
4	The contrast of an X-ray photo with only gray values of white and black is 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*

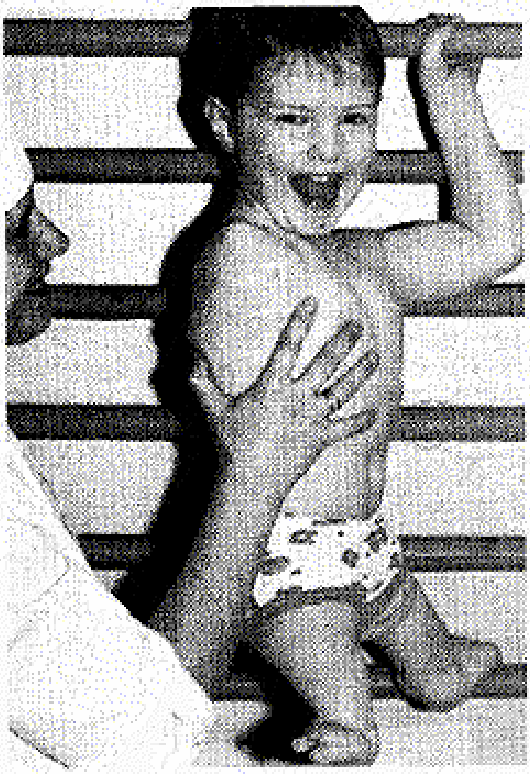
13. Biological effects of ionizing radiation

	QUESTIONS	*ANSWERS*
1	Damage produced by ionizing radiation is 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	The most radiation-sensitive tissue is 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	Leukemia is a stochastic effect, or a harmful tissue reaction?	*stochastic effect*
12	Cataract is a stochastic effect, or a harmful tissue reaction?	*harmful tissue reaction*

	QUESTIONS	*ANSWERS*
13	After a total-body irradiation to a dose of 1 Gy, people will proably die because of fatal damage to the bone marrow, or to the gastro-intestinal tract, or to the nervous system?	*bone marrow*
14	After a total-body irradiation to a dose of 10 Gy, people will proably die because of fatal damage to the bone marrow, or to the gastro-intestinal tract, or to the nervous system?	*gastro-intestinal tract or, at survival, bone marrow*
15	After a total-body irradiation to a dose of more than 50 Gy, people will die because of damage to the bone marrow, or to the gastro-intestinal tract, or to the nervous system?	*nervous system*
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 is irradiated during the second half of the pregnancy?	*no, organ formation is by then completed*
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	Regular exposure to the dose limit of 20 mSv per year is 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 17 million people live in the Netherlands. How many persons will die each year due to ionizing radiation?	*$0.05 \times 0.002 \times 17\,000\,000 = 1700$ (each year about 44 000 people die of cancer)*
23	The health risk of an effective dose of 10 μSv corresponds with the risk from smoking 1, or 100, or 10 000 cigarettes?	*1 cigarette*
24	A regular smoker will smoke around 5000 cigarettes a year. The risk of death for this smoker is comparable to the radiation risk of 0.5 mSv, or 5 mSv, or 50 mSv, or 500 mSv?	*5000×10 μSv = 50 000 μSv = 50 mSv (annual limit for the general public = 1 mSv)*
25	What is wrong with the caption of the newspaper clipping shown in Figure 13.1, 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



A victim of Chernobyl one year after the nuclear disaster.

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.

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 13.1

14. General laws and regulations

	QUESTIONS	*ANSWERS*
1	Radiological workers must comply with the Nuclear Energy Act, or with the Working Conditions Act, or with both?	*with both*
2	The Decree on Basic Safety Stanndards Radiation Protection is 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	The ICRP is 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	Radiological workers must comply with the dose limits, or with the ALARA principle, or with the principle of justification, or with all these principles?	*with all principles*
5	What is meant by ALARA principle?	*keep the dose as low as possible (as reasonably achievable)*
6	The annual effective-dose limit for the general public is 1 μSv, or 10 μSv, or 1 mSv, or 10 mSv ?	*1 mSv*
7	The annual effective-dose limit for a nonexposed worker is 1 μSv, or 10 μSv, or 1 mSv, or 10 mSv ?	*1 mSv*
8	The annual effective-dose limit for an exposed A-worker is 1 mSv, or 2 mSv, or 6 mSv, or 20 mSv.?	*20 mSv*
9	The annual effective-dose limit for an exposed B-worker is 1 mSv, or 2 mSv, or 6 mSv, or 20 mSv ?	*6 mSv*

	QUESTIONS	*ANSWERS*
10	The annual dose limit for the lens of the eye of an exposed A-worker is 2 mSv, or 20 mSv, or 150 mSv, or 500 mSv ?	*20 mSv*
11	The annual dose limit for hands, feet and skin of an exposed A-worker is 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	An area in which the annual effective dose can exceed 6 mSv, must 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*
21	Is radioactive material exempt if the activity is, but the activity concentration is not lower than the exemption values for moderate amounts?	*yes*
22	Is radioactive material exempt if the activity is not, but the activity concentration is lower than the exemption values for moderate amounts?	*yes*
23	Is radioactive material exempt if the activity and the activity concentration are both larger than the exemption values for moderate amounts?	*no*
24	The exemption values for tritium are 1 GBq and 1 MBq/g, respectively. Is 3 kBq tritium with an activity concentration of 10 MBq/g exempt?	*yes*
25	The exemption values for ^{131}I are 1 MBq and 100 Bq/g, respectively. Is 40 kBq of ^{131}I with an activity concentration of 40 MBq/g exempt?	*yes*
26	The transport index is calculated from the equivalent dose rate at the surface of the package, or at 1 m from the surface of the package	*at 1 m from the surface of the package*
27	The equivalent dose at 1 m from the surface of the package is 3.5 μSv per hour. How big is the transport index?	*TI = 3.5 / 10 = 0.4* *(must be rounded up)*
28	The label on a package states that TI = 2.1. What does this tell about the equivalent dose rate, and where has it been measured?	*2.1 × 10 μSv/h = 21 μSv/h* *at 1 m from the surface of the package*
29	Who may always collect radioactive substances?	*COVRA*

	QUESTIONS	*ANSWERS*
30	Is it allowed to store a radioactive substance to let the activity decay until it is below the clearance level?	*yes, but only if the half-life is not more than 100 days, the storage period is not longer than 2 years, and the purpose is re-use*

15. 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	A hand-baggage scanner at the airport is or is not an inherently safe device?	*it is*
3	A container scanner in the seaport is or is not an inherently safe device?	*it is not*
4	A transmission electron microscope is or is not an inherently safe device?	*it is*
5	A medical diagnostic X-ray device in the hospital is or is not an inherently safe device?	*it is not*
6	A hand-held X-ray device used for geofysical prospecting is or is not an inherently safe device?	*it is not*
7	An inherently safe device is exempted or subject to registration or subject to a license?	*subject to registration*
8	A transmission electron microscope is exempted or subject to registration or subject to a license?	*subject to registration*
9	A mobile container scanner in the seaport is exempted or subject to registration or subject to a license?	*subject to a license*
10	A radiation protection officer must or must not be appointed for an inherently safe device?	*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	An inherently safe device must or must not regularly checked for proper functioning?	*it must*
14	How often should an X-ray device be checked for proper functioning?	*at least once a year*

warning sign

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

16. Specific regulations for sealed sources

	QUESTIONS	*ANSWERS*
1	Sealed sources are or are not always surrounded by a metal casing?	*not always*
2	Sealed sources do or do not form a risk of internal contamination?	*they do* *(the source may leak)*
3	Sealed sources do or do not form a risk of external irradiation?	*they do*
4	Application of a sealed source is or is not restricted to a radionuclide laboratory?	*not*
5	A smear test on a sealed source does or does not make sense?	*it does* *(the source may leak)*
6	The results of leak tests must or must not be kept in the nuclear energy act file?	*they must*
7	The ISO-classification consists of 5 digits, each running from 1 to 6. A high figure indicates that the source is heavily or lightly tested?	*heavily tested*
8	The ISO-classification code consists of 5 digits, each running from 1 to 6. The figure 1 indicates that the source is not at all or only lightly tested?	<u>*not at all*</u> *tested*
9	The ISO-classification code of a sealed source is C43313. How many properties have been tested?	*4 properties*
10	The ISO-classification code of a sealed source is C11111. This source may or may not be used?	*it may, but the source must be handled with care*

17. Specific regulations for open sources

	QUESTIONS	*ANSWERS*
1	What is an open source?	*any radioactive substance that is not a sealed source*
2	What is considered to be the biggest risk when handling an open source?	*dispersion of activity*
3	The design requirements for a C-type laboratory are more or less strict than for a D-type laboratory?	*more strict*
4	The maximum allowed activity in a C-type laboratory is larger or smaller than that in a D-type laboratory?	*larger*
5	Is pipetting of 5 MBq on the table in a D-type laboratory allowed? (see Figure 17.1; $e(50)_{inhalation} \approx 3\times10^{-9}$ Sv/Bq)	$A_{max} = 0.02 / 3\times10^{-9} = 7$ *MBq* ($p = -1, q = 1, r = 0$) → *it is allowed*
6	The pipetting takes 1 morning = 4 hours. What is the contribution to the load factor?	$B = (4/40) \times (5/7) = 0.07$
7	Is boiling of 50 MBq until dryness allowed in a C-type laboratory, inside a fume hood that complies with NEN-EN 14175? (see Figure 17.1; $e(50)_{inhalation} = 3\times10^{-9}$ Sv/Bq)	$A_{max} = 0.02 / 3\times10^{-9} = 7$ *MBq* ($p = -4, q = 2, r = 2$) → *it is not allowed*
8	What is the maximum permissible wipeable surface contamination in case of α-activity?	*0.4 Bq/cm²*
9	What is the maximum permissible wipeable surface contamination in case of β- activity?	*4 Bq/cm²*
10	The results of a contamination survey must or must not be kept in the nuclear energy act file?	*they must*

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

p	procedure
-4	work with gass / powder in open system liquid close to boiling point highly splashing manipulation

-3	work with volatile nuclide:
	    ^{3}H as vapour
	    iodine
	work with powder in closed system
	boiling of liquid in closed system
	shaking, mixing on a vortex, centrifugation
	storage of gass in closed system

-2	simple chemical procedure (RIA) labeling with a nonvolatile nuclide

-1	brief very simple work:
	    pipeting of nonvolatile nuclide
	procedure in closed system:
	    eluting technetium generator
	    pulling up syringe
	    labeling in closed system
	    measurement on closed ampoule
	storage of radioactive waste in working area

q	laboratory type
0	working area outside radionuclide laboratory
1	D-laboratory
2	C-laboratory
3	B-laboratory

r	workplace
0	table without local ventilation
1	table with local ventilation fume hood not complying with NEN-EN 14175
2	fume hood complying with NEN-EN 14175 biohazard cabinet (class II)
3	biohazard cabinet (class III) glove box

Figure 17.1

18. Practical radiation protection for devices

	QUESTIONS	*ANSWERS*
1	It is or is not the task of the radiation protection officer to introduce new employees into house rules and protocols?	*it is*
2	It is or is 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	The radiation protection officer may or may not carry out a risk analysis?	*he may*
6	The radiation protection officer may or may not approve a risk analysis?	*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)*

19. Practical radiation protection for sealed sources

	QUESTIONS	*ANSWERS*
1	It is or is not the task of the radiation protection officer to ensure that workers regularly receive training?	*it is*
2	It is or is not the task of the radiation protection officer to carry out leak tests?	*it is*
3	The source-oriented strategy dictates that personal protection is used, activity is reduced, and distance is increased. In which order is this done?	*1. reduce activity* *2. increase distance* *3. use protection*
4	How often should a sealed source be tested for leakage?	*at least once a year*
5	A leak test is carried out with a dose-rate monitor, or a contamination monitor, or a smear test?	*smear test*
6	The best choice to reduce the received dose is to work twice as fast, or to double the distance?	*double the distance* *(inverse square law)*
7	The best choice to reduce the received dose is to work four times as fast, or to double the distance?	*double the distance* *(more haste less speed)*
8	Does the dose rate decrease if one works faster?	*no*
9	Does the dose rate decrease if the distance is increased?	*yes*
10	What is the best shield for the positron emitter ^{11}C: 1 cm plexiglass surrounded by 1 cm lead, or 1 cm lead surrounded by 1 cm plexiglass?	*1 cm plexiglass surrounded by 1 cm lead* *(avoid bremsstrahlung)*

20. Practical radiation protection for open sources

	QUESTIONS	*ANSWERS*
1	Who may cary out a risk analysis?	*(in principle) anyone*
2	Who may approve a risk analysis?	*only a registered radiation protection expert*
3	Who is responsible that the operation of the fume hood is checked regularly?	*radiation protection officer*
4	What is the reason that the pH value is kept below 4 when handling iodine compounds?	*to avoid formation of volatile iodine*
5	May or may not objects with a surface contamination of less than 4 Bq/cm² be disposed of as industrial waste?	*they may*
6	May or may not the contents of a counting vial in general be discharged via the sewer?	*they may not* *(no chemical waste in the sewer)*
7	May or may not the contents of a counting vial in general be disposed of as chemical waste?	*they may not* *(disposal via COVRA is compulsary if the activity concentration exceeds the clearance value for unlimited amounts)*
8	Which the first thing to do if a serious contamination is discovered in the radionuclide laboratory?	*close the laboratory and check the workers for possible external contamination*
9	What is the preferred spot to wear a TLD badge?	*on the chest, outside the laboratory coat*
10	To avoid dispersion of activity, one uses a splash tray, or one wears a laboratory coat?	*use a splash tray*
11	May the window be completely closed while working in the fume hood?	*no* *(the air flow must not be obstructed)*

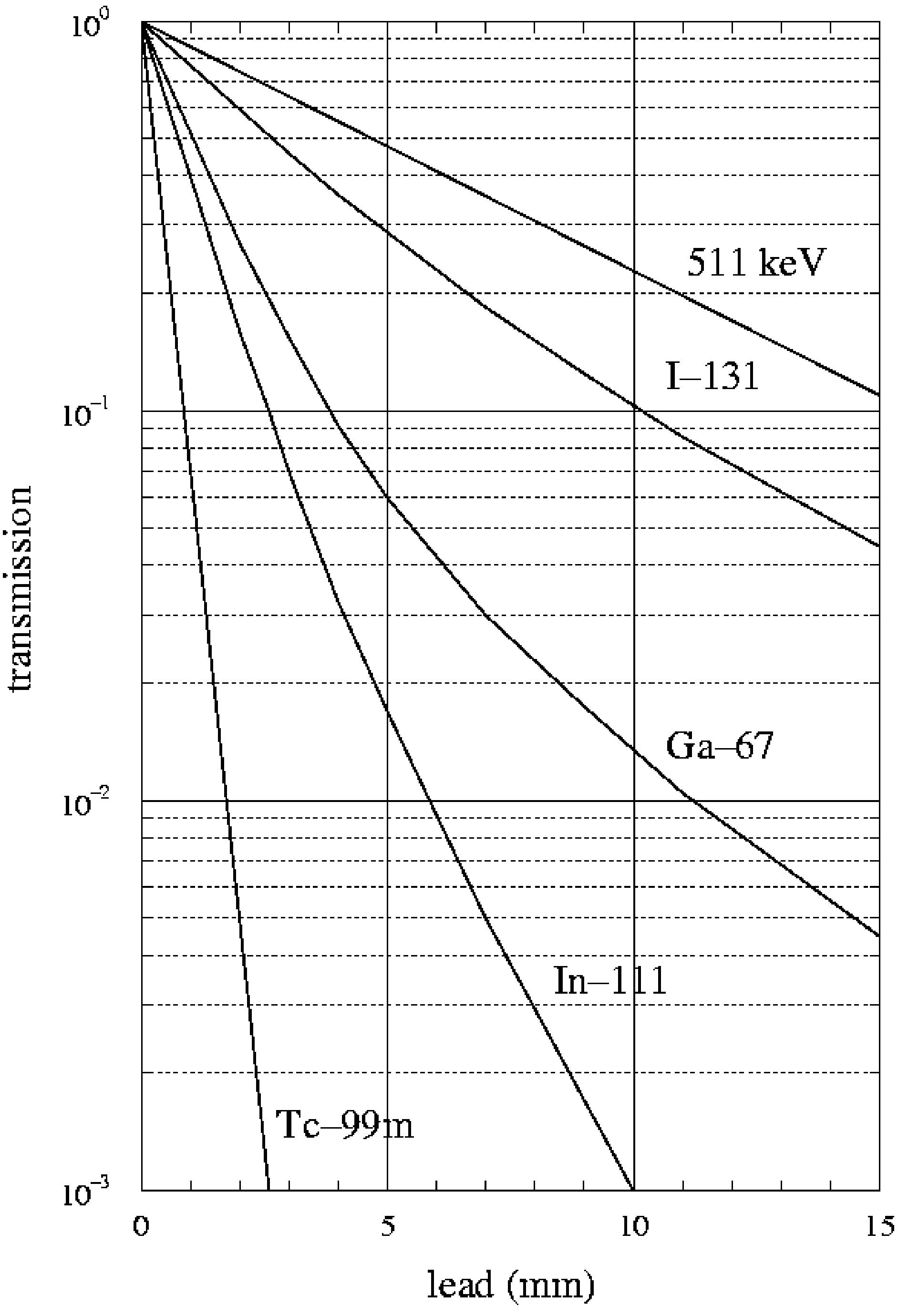
	QUESTIONS	*ANSWERS*
12	May the window be completely opened while working in the fume hood?	*no* *(the air flow must not be obstructed)*
13	Can aerosols arise when emptying a syringe?	*yes, likely*
14	Can aerosols occur during settling of a precipitate?	*no, unlikely*
15	A label with the inscription radioactive substance belongs in the trash bin, or in the box for environmental waste, or in the container for hazardous industrial waste, or in the container for radioactive waste?	*container for radioactive waste*

21. 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 erxposure 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*

22. Risk analysis for sealed sources

	QUESTIONS	*ANSWERS*
1	The dose rate at 1 m is 1 mGy per hour. What is the dose rate at 10 cm ?	*(100 cm / 10 cm)^2 × 1* *= 100 mGy per hour*
2	At 1 m from a radioactive source is the equivalente dose rate 10 μSv per hour. The source constant is 0.1 μSv m^2 MBq^{-1} h^{-1}. What is the activity of the source?	*$H = h \times A$* *$A = H / h = 10 / 0.1 = 100$ MBq*
3	The activity of a source is 50 MBq. The source constant is 0.4 μSv m^2 MBq^{-1} h^{-1}. What is the equivalent dose rate at a distance of 100 cm ?	*$H = h \times A$* *$= 0.4 \times 50 = 20$ μSv per hour*
4	A β-source gives rise to a much higher or much lower skin dose than a γ-source with the same activity at the same distance and in the same time?	*much higher skin dose*
5	A worker gets contaminated by ingestion of 100 kBq ^{241}Am. The effective dose coefficient is 2×10^{-7} Sv/Bq. What is the committed effective dose?	*$E(50) = e(50) \times A$* *$= 2\times10^{-7} \times 100\times10^3$* *= 0.02 Sv = 20 mSv*
6	On the outside of a package containing a sealed source of ^{111}In, the equivalent dose rate amounts to 50 mSv per hour. How much lead is needed to reduce this value to 2 mSv per hour? (see Figure 22.1)	*transmission = 2 mSv / 50 mSv* *$= 4\times10^{-2}$* *→ about 3.5 mm lead*
7	An accelerator is automatically switched off if the equivalent dose rate at 1 m from the outside is more than 1 μSv per hour. What is the maximal effective dose that a worker in the hall can receive when he works 2000 hours per year?	*2000 × 1 = 2000 μSv = 2 mSv*
8	Is this more or less than the annual limit for an exposed B-worker?	*less* *(annual limit = 6 mSv)*



10^0
10^-1
10^-2
10^-3
transmission
511 keV
I–131
Ga–67
In–111
Tc–99m
0
5
10
15
lead (mm)

Figure 22.1

	QUESTIONS	*ANSWERS*
9	The car driver sits at 1 m from the outside of a radioactivity containing package. The label states a transport index TI = 2.5. What is the maximal effective dose that the driver may receive per hour?	*TI = 2.5* *→ 2.5 × 10 μSv/h* *= 25 μSv/h at 1 m*
10	Is this more or less than the annual limit for a nonexposed worker?	*less* *(annual limit = 1 mSv)*

23. Risk analysis for open sources

	QUESTIONS	*ANSWERS*
1	After decontamination of a surface area of 10 cm × 10 cm, it turns out to be still contaminated with 40 Bq of a pure β-emitter. What is the remaining surface contamination (in Bq/cm^2)?	*activity = 40 Bq* *area = 10 cm × 10 cm* *= 100 cm^2* *→ 40 / 100 = 0.4 Bq/cm^2*
2	Is this more or less than the limit for surface contamination?	*limit = 4 Bq/cm^2* *→ less than the limit*
3	What measure(s) should the radiation protection officer take?	*1. cover the contaminated area with plastic* *2. mark with sticker stating date, nuclide and activity*
4	A measurement shows that the thyroid contains 60 kBq ^{131}I. According to ICRP, 30% of the taken-in iodine is transferred to the thyroid. The effective dose coefficient is 1×10^{-8} Sv/Bq. What is the committed effective dose?	*intake = 60 kBq / 30%* *= 200 kBq* *E(50) = e(50) × A* *= $1 \times 10^{-8} \times 200 \times 10^3$* *= 0.002 Sv = 2 mSv*
5	Is this more or less than the annual limit for a nonexposed worker?	*annual limit = 1 mSv* *→ more than the limit*
6	An accident causes 10 cm^2 of the skin of a worker to get contaminated with 50 kB of the pure β-emitter ^{32}P. How big is the equivalent dose rate on the skin?	*skin contamination = 50 / 10* *= 5 kBq/cm^2* *rule of thumb:* *2 mSv/h per kBq/cm^2* *→ 5 × 2 = 10 mSv/h*
7	After how many hours will the annual limit for the skin of an exposed A-worker be exceeded?	*annual limit = 500 mSv* *after 500 / 10 = 50 hours*
8	A worker inhales 20 MBq ^{36}Cl. The effective dose coefficient is 5×10^{-10} Sv/Bq. What is the commited effective dose?	*E(50) = e(50) × A* *= $5 \times 10^{-10} \times 20 \times 10^6$* *= 0.01 Sv = 10 mSv*
9	Is this more or less than the annual limit for an exposed B-worker?	*annual limit = 6 mSv* *→ more than the limit*

	QUESTIONS	*ANSWERS*
10	The average retention time of chlorine in the body is about 2 weeks. What is the estimated activity excretion via the urine per day?	*2 weeks = 14 days* *excretion ≈* *10 / 14 = 0.7 MBq per day*