HEALTH PHYSICS SIMPLE EXERCISES

for radiation protection officers

dispersible radioactive materials - level D
sealed radioactive sources

Frits Pleiter
Hielke Freerk Boersma

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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 - dispersible radioactive materials (level D) - measurement and control applications - sealed radioactive sources' by Frits Pleiter and Hielke Freerk Boersma (GARP, Groningen, 2024).

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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, 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 The atomic nucleus and the origin of alpha, beta and gamma 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* *because 1 day = 24 hours*
10	And what is the activity after 5 days? How many percent of the initial activity is this?	*100 / 32 = 3 MBq* *because $2^5 = 32$* *about 3%*
11	What is the half-life in the example shown in Figure 2.1 ?	*25 seconds*

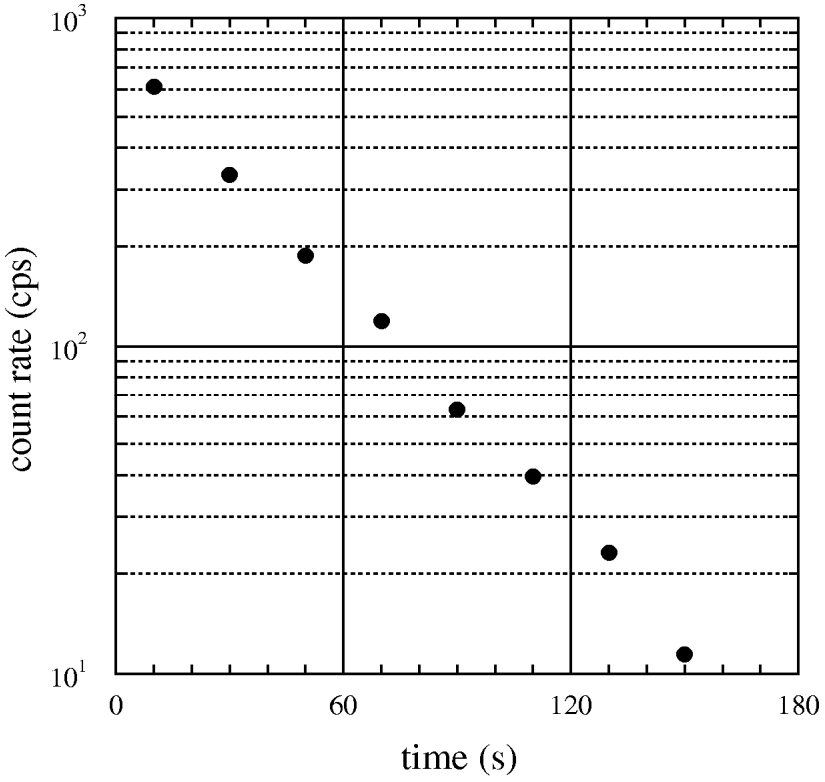

Figure 2.1

	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*

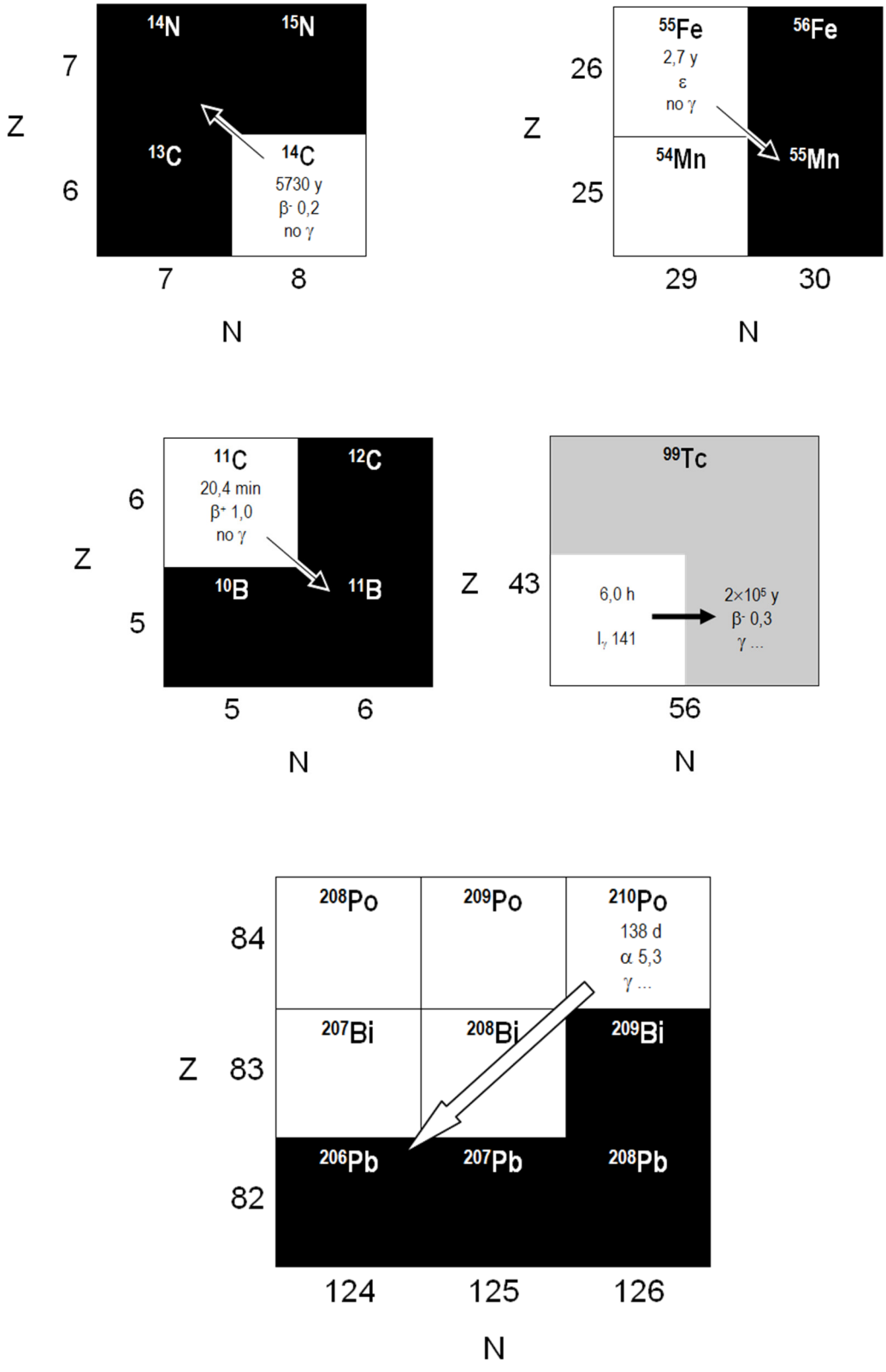
14N
15N
13C
14C
5730 y
β- 0,2
no γ
Z
7
6
7
8
N
55Fe
2,7 y
ε
no γ
56Fe
54Mn
55Mn
26
25
29
30
N
11C
20,4 min
β+ 1,0
no γ
12C
10B
11B
6
5
5
6
N
99Tc
6,0 h
I, 141
2×10⁵ y
β- 0,3
γ ...
Z
43
56
N
208Po
209Po
210Po
138 d
α 5,3
γ ...
207Bi
208Bi
209Bi
206Pb
207Pb
208Pb
84
83
82
Z
124
125
126
N

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 $^{218}_{84}Po$)*
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 = 26 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 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

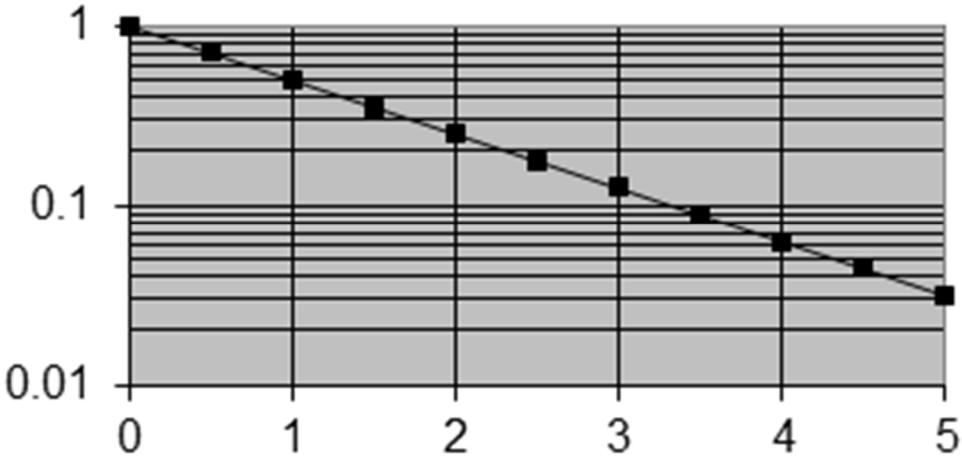

Figure 3.1

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, 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?	*$(½)^{½} = 1 / \sqrt{2} \approx 0.7$*
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	Is the range of 5 MeV α-particles in air about 0.3 mm, or 3 mm, or 3 cm, or 3 m ?	*about 3 cm*
19	Is the range of 1 MeV β-particles in air about 0.4 mm, or 4 mm, or 4 cm, or 4 m ?	*about 4 m*
20	Is the range of 5 MeV α-particles in tissue about 3 μm, or 30 μm, or 0.3 mm, or 3 mm ?	*about 3 cm / 1000 = 30 μm because the density of tissue is 1000 times larger than that of air*
21	Is the range of 1 MeV β-particles in air about 0.4 mm, or 4 mm, or 4 cm, or 4 m ?	*about 4 m / 1000 = 4 mm because 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 because the density of water is 1000 times larger than that of air*

	QUESTIONS	*ANSWERS*
23	Do electrons with an energy of 1 MeV produce more or less bremsstrahlung in water than in lead?	*less*
24	Do electrons with an energy of 30 keV produce more or less bremsstrahlung in copper (Z=29) than in silver (Z=47)?	*less*
25	Do 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 (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?	*$5 \times \ln(2) / \mu \approx 5 \times (0.7 / 1\ cm^{-1})$ = 3.5 cm* *$d_{½} = \ln(2) / \mu$* *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?	*$(11.3\ g/cm^3) \times 5\ cm = 57\ g/cm^2$*
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	Can neutrons be effectively shielded by water, or paraffin, or concrete, or any of these materials?	*any of these materials*
15	Can neutrons be effectively shielded by water, or iron, or lead, or any of these materials?	*water*

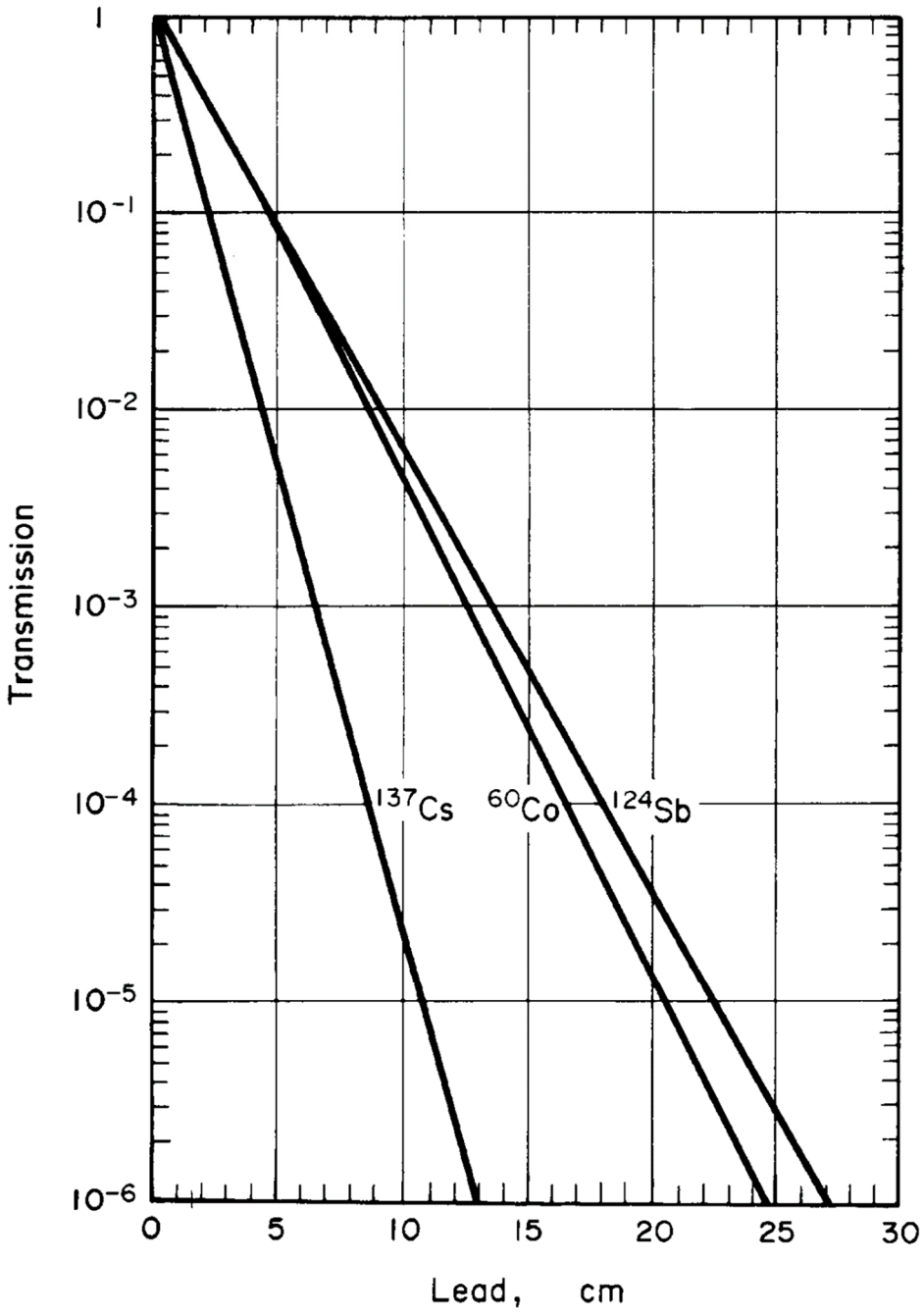

Figure 5.1

6 Applications of sealed sources
7 Applications of open sources

8 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)*
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	Is the radiation weighting factor w_R for α-radiation 1, or 5, or 20, or 100 ?	*20*
19	Is the radiation weighting factor w_R for β-radiation 1, or 5, or 20, or 100 ?	*1*
20	Does a large value of e(50) mean a large or a small radiotoxicity?	*large radiotoxicity*
21	Does the value of the effective dose coefficient depend on the radionuclide or not?	*it does*
22	Does the of the effective dose coefficient depend on the chemical composition of the radioactive substance or not?	*it does*
23	Does the value of the effective dose coefficient depend on the contamination route or not?	*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	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*

9 Measuring of ionizing radiation

	QUESTIONS	*ANSWERS*
1	Is the voltage over an ionization chamber relatively low, or relatively high?	*relatively low*
2	Is the voltage over a proportional counter relatively low, or relatively high?	*neither low nor high, but in the intermediate region*
3	Is the voltage over a Geiger-Müller counter relatively low, or relatively high?	*relatively high*
4	Canm a gas-filled ionization chamber measure radiation energies or not?	*it can not because signals are too small due to lack of gas amplification*
5	Can a proportional counter measure radiation energies or not?	*it can*
6	Can a Geiger-Müller counter measure radiation energies or not?	*it can not because all signals are equal in size*
7	Can a scintillation detector measure radiation energies or not?	*it can*
8	Which detector is commonly used as dose-rate monitor?	*Geiger-Müller counter*
9	Is a TLD a scintillation detector or an ionization chamber?	*scintillation detector*
10	For which type of measurement is a TLD 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)? Why?	*Ge* *larger photo-electric effect*
21	Which detector material is more suited to measure β-radiation: Si (Z=14), or Ge (Z=32)? Why?	*Si* *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? For which is it used?	*an electronic device that digitizes the pulse heights and sorts them according to size* *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?	*$\pm\sqrt{100} = \pm10$ counts*

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*
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	Is the transport index 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* *always round 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*

12 Specific regulations for sealed sources

	QUESTIONS	*QUESTIONS ANSWERS*
1	Is a sealed source always surrounded by a metal casing or not?	*not always*
2	Does a sealed source form a risk of internal contamination opr not?	*it does* *because the source may leak*
3	Does a sealed source form a risk of external irradiation or not?	*it does*
4	Is the application of a sealed source restricted to a radionuclide laboratory or not?	*not*
5	Does a smear test on a sealed source make sense or not?	*it does* *(the source may leak)*
6	Must the results of leak tests be kept in the nuclear energy act file or not?	*they must*
7	The ISO-classification consists of 5 digits, each running from 1 to 6. Does a high figure indicate 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. Does the figure 1 indicate that the source is not at all or only lightly tested?	*not at all 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. May this source be used or not?	*it may, but the source must be handled with care*

13 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	Are the design requirements for a C-type laboratory more or less strict than for a D-type laboratory?	*more strict*
4	Is the maximum allowed activity for a C-type laboratory larger or smaller than for a D-type laboratory?	*larger*
5	Is pipetting of 5 MBq on the table in a D-type laboratory allowed? (see Figure 13.1; $e(50)_{inhalation} \approx 3\times10^{-9}$ 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 13.1; $e(50)_{inhalation} = 3\times10^{-9}$ 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	Must the results of a contamination survey be kept in the nuclear energy act file or not?	*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 13.1

14 Practical radiation protection for sealed sources

	QUESTIONS	*ANSWERS*
1	Is it or is it not the task of the radiation protection officer to ensure that workers regularly receive training?	*it is*
2	Is it or is it 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	Is a leak test carried out with a dose-rate monitor, or a contamination monitor, or a smear test?	*smear test*
6	What is the best choice to reduce the received dose: to work twice as fast or to double the distance?	*double the distance* *(inverse square law)*
7	What is the best choice to reduce the received dose: 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* *to avoid bremsstrahlung*

15 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/cm^2 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 is 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	What is the best way to prevent dispersion of activity: using a splash tray or wearing a laboratory coat?	*using a splash tray*
11	May the window be completely closed while working in the fume hood?	*no* *because the air flow must not be obstructed*

	QUESTIONS	*ANSWERS*
12	May the window be completely opened while working in the fume hood?	*no* *because back-flow of air from the fume hood must be prevented*
13	Can aerosols arise when emptying a syringe?	*yes, likely*
14	Can aerosols occur during settling of a precipitate?	*no, unlikely*
15	Does a label with the text **radioactive substance** belong 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*

16 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 ?	*$(100\ cm / 10\ cm)^2 \times 1$ = 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 $\mu Sv \cdot m^2 \cdot MBq^{-1} \cdot h^{-1}$. 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 $\mu Sv \cdot m^2 \cdot MBq^{-1} \cdot h^{-1}$. What is the equivalent dose rate at a distance of 100 cm ?	*$H = h \times A$* *$= 0.4 \times 50 = 20\ \mu Sv$ per hour*
4	Does a β-source give 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?	*$E(50) = e(50) \times A$* *$= 2 \times 10^{-7} \times 100 \times 10^3$* *$= 0.02\ Sv = 20\ mSv$*
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 16.1)	*transmission = 2 mSv / 50 mSv* *$= 4 \times 10^{-2}$* *→ 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?	*$2000 \times 1 = 2000\ \mu Sv = 2\ mSv$*
8	Is this more or less than the annual limit for an exposed B-worker?	*less* *because annual limit = 6 mSv*

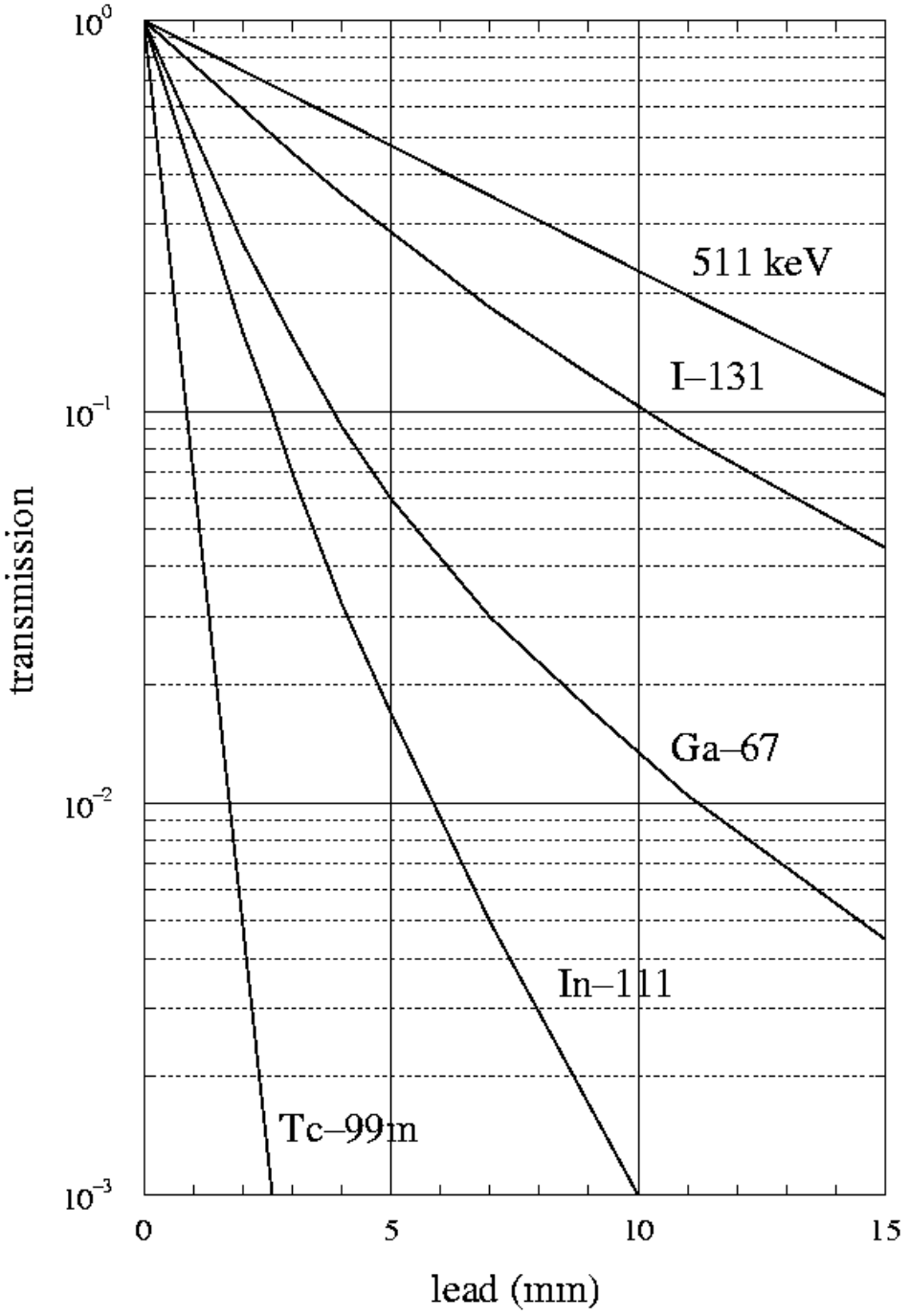
10^0
10^-1
10^-2
10^-3
transmission
511 keV
I–131
Ga–67
In–111
Tc–99m
0
5
10
15
lead (mm)

Figure 16.1

	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* *because annual limit = 1 mSv*

17 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/cm²)?	*activity = 40 Bq* *area = 10 cm × 10 cm* *= 100 cm²* *→ 40 / 100 = 0.4 Bq/cm²*
2	Is this more or less than the limit for surface contamination?	*less than the limit* *because limit = 4 Bq/cm²*
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* *= 1×10^{-8} × 200×10^{3}* *= 0.002 Sv = 2 mSv*
5	Is this more or less than the annual limit for a nonexposed worker?	*more than the limit* *because annual limit = 1 mSv*
6	An accident causes 10 cm² 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/cm²* *rule of thumb:* *2 mSv/h per kBq/cm²* *→ 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* *= 5×10^{-10} × 20×10^{6}* *= 0.01 Sv = 10 mSv*
9	Is this more or less than the annual limit for an exposed B-worker?	*more than the limit* *because annual limit = 6 mSv*

	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 ≈* *20 / 14 = 1.4 MBq per day*