A Table of Frequently Used Radioisotopes

Only decays with the largest branching fractions are listed. For β emitters the maximum energies of the continuous β-ray spectra are given. '$\rightarrow$' denotes the decay to the subsequent element in the table. EC stands for 'electron capture', a (= annus, Latin) for years, h for hours, d for days, min for minutes, s for seconds, and ms for milliseconds.

isotope $^{A}_{Z}$element	decay type	half-life	β resp. α energy (MeV)	γ energy (MeV)
$^{3}_{1}$H	β^-	12.3 a	0.0186	no γ
$^{7}_{4}$Be	EC, γ	53 d	–	0.48
$^{10}_{4}$Be	β^-	1.5×10^6 a	0.56	no γ
$^{14}_{6}$C	β^-	5730 a	0.156	no γ
$^{22}_{11}$Na	β^+, EC	2.6 a	0.54	1.28
$^{24}_{11}$Na	β^-, γ	15.0 h	1.39	1.37
$^{26}_{13}$Al	β^+, EC	7.17×10^5 a	1.16	1.84
$^{32}_{14}$Si	β^-	172 a	0.20	no γ
$^{32}_{15}$P	β^-	14.2 d	1.71	no γ
$^{37}_{18}$Ar	EC	35 d	–	no γ
$^{40}_{19}$K	β^-, EC	1.28×10^9 a	1.33	1.46
$^{51}_{24}$Cr	EC, γ	27.8 d	–	0.325
$^{54}_{25}$Mn	EC, γ	312 d	–	0.84
$^{55}_{26}$Fe	EC	2.73 a	–	0.006
$^{57}_{27}$Co	EC, γ	272 d	–	0.122
$^{60}_{27}$Co	β^-, γ	5.27 a	0.32	1.17 & 1.33
$^{66}_{31}$Ga	β^+, EC, γ	9.4 h	4.15	1.04
$^{68}_{31}$Ga	β^-, EC, γ	68 min	1.88	1.07
$^{85}_{36}$Kr	β^-, γ	10.8 a	0.67	0.52
$^{89}_{38}$Sr	β^-	51 d	1.49	no γ
$^{90}_{38}$Sr $\rightarrow$	β^-	28.7 a	0.55	no γ
$^{90}_{39}$Y	β^-	64 h	2.28	no γ
$^{99m}_{43}$Tc	γ	6 h	–	0.140

C. Grupen, *Introduction to Radiation Protection*,
Graduate Texts in Physics, DOI 10.1007/978-3-642-02586-0

isotope ^A_Z**element**	**decay type**	**half-life**	$\boldsymbol{\beta}$ **resp.** $\boldsymbol{\alpha}$ **energy (MeV)**	$\boldsymbol{\gamma}$ **energy (MeV)**
$^{106}_{44}$Ru →	β^-	1.0 a	0.04	no γ
$^{106}_{45}$Rh	β^-, γ	30 s	3.54	0.51
$^{112}_{47}$Ag	β^-, γ	3.13 h	3.90	0.62
$^{109}_{48}$Cd →	EC	1.27 a	–	no γ
$^{109m}_{47}$Ag	γ	40 s	–	0.088
$^{113}_{50}$Sn	EC, γ	115 d	–	0.392
$^{132}_{52}$Te	β^-, γ	77 h	0.22	0.23
$^{125}_{53}$I	EC, γ	60 d	–	0.035
$^{129}_{53}$I	β^-, γ	1.6×10^7 a	0.15	0.038
$^{131}_{53}$I	β^-, γ	8.05 d	0.61	0.36
$^{133}_{54}$Xe	β^-, γ	5.24 d	0.35	0.08
$^{134}_{55}$Cs	β^-, β^+, γ	2.06 a	0.65	0.61
$^{137}_{55}$Cs →	β^-	30 a	0.51 & 1.18	0.66
$^{137m}_{56}$Ba	γ	2.6 min	–	0.66
$^{133}_{56}$Ba	EC, γ	10.5 a	–	0.36
$^{140}_{57}$La	β^-, γ	40.2 h	1.34	1.60
$^{144}_{58}$Ce →	β^-, γ	285 d	0.32	0.13
$^{144}_{59}$Pr	β^-, γ	17.5 min	3.12	0.69
$^{144}_{60}$Nd	α	2.3×10^{15} a	1.80	no γ
$^{152}_{63}$Eu	EC, $\beta^\mp, \gamma$	13.5 a	0.68	0.122
$^{192}_{77}$Ir	EC, β^-, γ	74 d	0.67	0.32
$^{198}_{79}$Au	β^-, γ	2.7 d	0.96	0.41
$^{204}_{81}$Tl	β^-, EC	3.78 a	0.76	no γ
$^{207}_{83}$Bi	EC, γ	31.6 a	0.48	0.57
$^{222}_{86}$Rn →	α, γ	3.8 d	5.48	0.51
$^{218}_{84}$Po →	α, β^-	3.1 min	α: 6.00	no γ
$^{214}_{82}$Pb →	β^-, γ	26.8 min	0.73	0.35
$^{214}_{83}$Bi	β^-, γ	19.9 min	1.51	0.61
$^{226}_{88}$Ra	α, γ	1600 a	4.78	0.19
$^{228}_{90}$Th	α, γ	1.9 a	5.42	0.24
$^{234}_{92}$U	α, γ	2.5×10^5 a	4.77	0.05

isotope ^A_Zelement	**decay type**	**half-life**	**β resp. α energy (MeV)**	**γ energy (MeV)**
$^{235}_{92}$U	α, γ	7.1×10^8 a	4.40	0.19
$^{238}_{92}$U	α, γ	4.5×10^9 a	4.20	0.05
$^{239}_{94}$Pu	α, γ	24 110 a	5.15	0.05
$^{240}_{94}$Pu	α, γ	6564 a	5.16	0.05
$^{241}_{95}$Am	α, γ	432 a	5.49	0.06
$^{252}_{98}$Cf	α, γ	2.6 a	6.11	0.04
$^{252}_{100}$Fm	α, γ	25 h	7.05	0.096
$^{268}_{109}$Mt	α	70 ms	10.70	–

Explanatory note

The heavy α-ray-emitting radioisotopes can also decay by spontaneous fission. Half-lives for spontaneous fission are usually rather long. More detailed information about decay modes and level diagrams can be taken from nuclear data tables. Corresponding references are listed under ‘Further Reading’ in the section ‘Tables of Isotopes and Nuclear Data Sheets’. The most recent information on the table of isotopes can be found in the Internet under

`http://atom.kaeri.re.kr/`

and

`http://isotopes.lbl.gov/education` .

“We will be rich!
This isotope decays into gold!”

B Examples of Exemption Limits for Absolute and Specific Activities

There are no universal international values for exemption limits for radioactive sources and radioactive material. Different countries have defined limits based on the guidelines as recommended by the International Commission on Radiological Protection. The table below gives some examples which have been adopted by the new German radiation-protection ordinance in 2001. The corresponding limits in other countries are quite similar, although there are also some important differences in some national regulations.

If several sources each with activity A_i and corresponding exemption limit $A_i^{\max}$ are handled in a laboratory, the following condition must be fulfilled:

$$\sum_{i=1}^{N} \frac{A_i}{A_i^{\max}} \leq 1 \ .$$

This prevents the acquisition of several sources each with an activity below the exemption limit thereby possibly circumventing the idea of the exemption limit.

radioisotope	**exemption limit**	
	activity in Bq	**specific activity in Bq/g**
$^{3}_{1}$H	10^9	10^6
$^{7}_{4}$Be	10^7	10^3
$^{14}_{6}$C	10^7	10^4
$^{24}_{11}$Na	10^5	10
$^{32}_{15}$P	10^5	10^3
$^{40}_{19}$K*	10^6	10^2
$^{54}_{25}$Mn	10^6	10
$^{55}_{26}$Fe	10^6	10^4
$^{57}_{27}$Co	10^6	10^2
$^{60}_{27}$Co	10^5	10

radioisotope	exemption limit	
	activity in Bq	specific activity in Bq/g
$^{82}_{35}$Br	10^6	10
$^{89}_{38}$Sr	10^6	10^3
$^{90}_{38}$Sr†	10^4	10^2
$^{99m}_{43}$Tc	10^7	10^2
$^{106}_{44}$Ru†	10^5	10^2
$^{110m}_{47}$Ag	10^6	10
$^{109}_{48}$Cd†	10^6	10^4
$^{125}_{53}$I	10^6	10^3
$^{129}_{53}$I	10^5	10^2
$^{131}_{53}$I	10^6	10^2
$^{134}_{55}$Cs	10^4	10
$^{137}_{55}$Cs†	10^4	10
$^{133}_{56}$Ba	10^6	10^2
$^{152}_{63}$Eu	10^6	10
$^{197}_{80}$Hg	10^7	10^2
$^{204}_{81}$Tl	10^4	10^4
$^{214}_{82}$Pb	10^6	10^2
$^{207}_{83}$Bi	10^6	10
$^{210}_{84}$Po	10^4	10
$^{220}_{86}$Rn†	10^7	10^4
$^{222}_{86}$Rn†	10^8	10
$^{226}_{88}$Ra†	10^4	10
$^{227}_{89}$Ac†	10^3	0.1
$^{232}_{90}$Th†	10^4	10
$^{233}_{92}$U	10^4	10
$^{235}_{92}$U†	10^4	10
$^{238}_{92}$U†	10^4	10
$^{239}_{94}$Pu	10^4	1
$^{240}_{94}$Pu	10^3	1

radioisotope	**exemption limit**	
	activity in Bq	**specific activity in Bq/g**
$^{241}_{95}Am$	10^4	1
$^{244}_{96}Cm$	10^4	10
$^{252}_{98}Cf$	10^4	10

* as naturally occurring isotope unlimited

† in equilibrium with its daughter nuclei; the radiation exposure due to these daughter isotopes is taken account of in the exemption limits

C Maximum Permitted Activity Concentrations Discharged from Radiation Areas

There are no universal international values for the limits of radioactive material that may be released from radiation areas. Different countries have defined limits based on the guidelines as recommended by the International Commission on Radiological Protection. These limits generally refer to a maximum annual dose of 0.3 mSv that people from the general public may receive from such discharges. The table below gives some examples which have been adopted by the new German radiation protection ordinance in 2001. The corresponding limits in other countries are quite similar, but do vary in some national regulations.

radioisotope	**maximum permitted activity concentration**	
	in air in Bq/m^3	**in water in Bq/m^3**
${}^{3}_{1}H$	10^2	10^7
${}^{7}_{4}Be$	6×10^2	5×10^6
${}^{14}_{6}C$	6	6×10^5
${}^{24}_{11}Na$	90	3×10^5
${}^{32}_{15}P$	1	3×10^4
${}^{42}_{19}K$	2×10^2	2×10^5
${}^{54}_{25}Mn$	20	2×10^5
${}^{55}_{26}Fe$	20	10^5
${}^{57}_{27}Co$	30	3×10^5
${}^{60}_{27}Co$	1	2×10^4
${}^{82}_{35}Br$	50	10^5
${}^{89}_{38}Sr$	4	3×10^4
${}^{90}_{38}Sr$	0.1	4×10^3

radioisotope	**maximum permitted activity concentration** in air in Bq/m³	**maximum permitted activity concentration** in water in Bq/m³
$^{99m}_{43}Tc$	2×10^3	4×10^6
$^{106}_{44}Ru$	0.6	10^4
$^{110m}_{47}Ag$	1	4×10^4
$^{109}_{48}Cd$	4	4×10^4
$^{125}_{53}I$	0.5	2×10^4
$^{129}_{53}I$	0.03	4×10^3
$^{131}_{53}I$	0.5	5×10^3
$^{134}_{55}Cs$	2	2×10^4
$^{137}_{55}Cs$	0.9	3×10^4
$^{133}_{56}Ba$	4	4×10^4
$^{152}_{63}Eu$	0.9	5×10^4
$^{197}_{80}Hg$	10^2	4×10^5
$^{204}_{81}Tl$	10	7×10^4
$^{214}_{82}Pb$	2	3×10^5
$^{207}_{83}Bi$	1	9×10^4
$^{210}_{84}Po$	0.008	30
$^{226}_{88}Ra$	0.004	2×10^2
$^{227}_{89}Ac$	7×10^{-5}	30
$^{232}_{90}Th$	3×10^{-4}	2×10^2
$^{233}_{92}U$	0.004	2×10^3
$^{235}_{92}U$	0.004	3×10^3
$^{238}_{92}U$	0.005	3×10^3
$^{239}_{94}Pu$	3×10^{-4}	2×10^2
$^{240}_{94}Pu$	3×10^{-4}	2×10^2
$^{241}_{95}Am$	4×10^{-4}	2×10^2
$^{244}_{96}Cm$	6×10^{-4}	3×10^2
$^{252}_{98}Cf$	0.002	2×10^2
any unknown isotope mixture	10^{-5}	10

These limits describe maximum activity concentrations in air released from radiation areas with the danger of inhalation, and maximum permitted activity concentrations, which are allowed to be discharged as sewage water.

Correspondingly, the condition

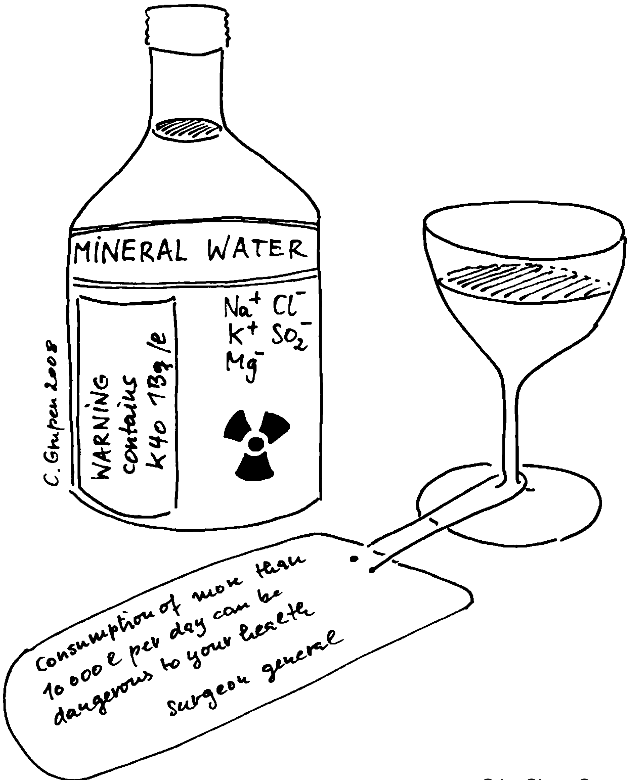
$$\sum_{i=1}^{N} \frac{\bar{C}_{i,\mathrm{a}}}{C_i} \leq 1$$

must be respected, where

C_i is the maximum permitted activity concentration

and

$\bar{C}_{i,\mathrm{a}}$ the actual released average annual activity concentration.



Examples of Clearance Levels

There are no universal international values for clearance levels for material containing residual radioactivity. After approved clearance the material is no longer considered as radioactive. Different countries have defined limits based on the guidelines as recommended by the International Commission on Radiological Protection. Clearance can only be approved if the residual activity causes insignificant exposure to the public ($\leq 10\,\mu\mathrm{Sv/yr}$). The table below gives some examples which have been adopted by the new German radiation-protection ordinance in 2001. The corresponding limits in other countries are quite similar.

radioisotope	**clearance of** solid material, liquids (Bq/g)	construction waste, excavation residues (Bq/g)	ground area (Bq/g)
^{3}H	1000	60	3
^{32}P	20	20	0.02
^{60}Co	0.1	0.09	0.03
^{90}Sr*	2	2	0.002
^{137}Cs*	0.5	0.4	0.06
^{226}Ra*	0.03	0.03	†
^{232}Th	0.03	0.03	†
^{235}U*	0.5	0.3	†
^{238}U*	0.6	0.4	†
^{239}Pu	0.04	0.08	0.04
^{240}Pu	0.04	0.08	0.04
^{241}Am	0.05	0.05	0.06

* in equilibrium with daughter isotopes; the radiation exposure due to these daughter isotopes is taken care of in the clearance levels

† naturally occurring radioisotopes in the ground with activities around 0.01 Bq/g

D Examples of Limits for Surface Contaminations

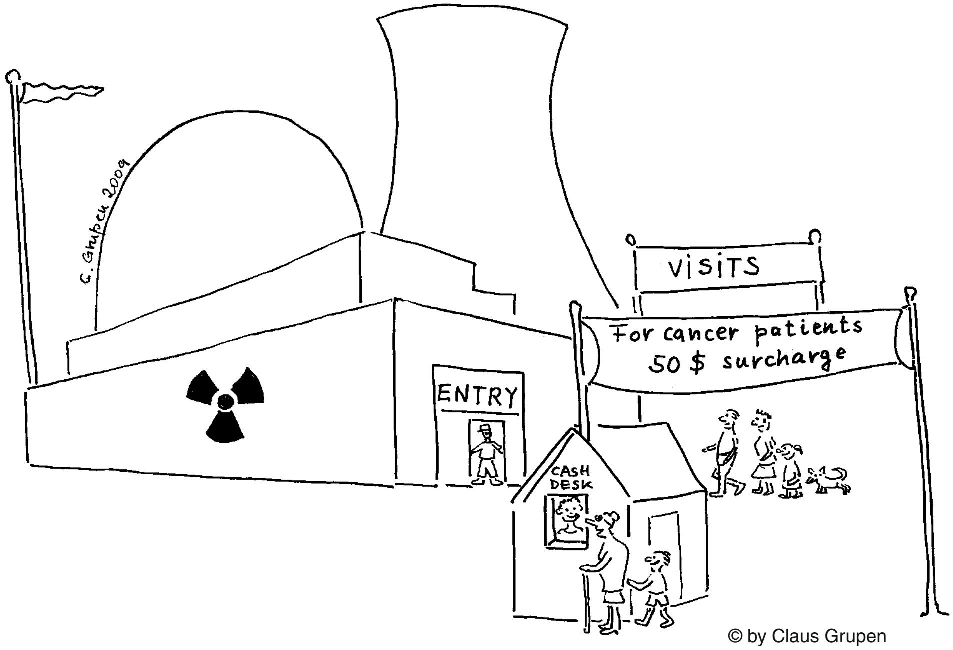
There are no universal international values for limits on surface contaminations in working areas. Because of the higher biological effectiveness the limits for α particles are more stringent compared to those of β- and γ-ray emitters, usually by a factor of 10. Different countries have defined limits based on the guidelines as recommended by the International Commission on Radiological Protection. The table below gives some examples which have been adopted by the new German radiation-protection ordinance in 2001. The corresponding limits in other countries are quite similar.

radioisotope	**surface contamination in $\mathrm{Bq/cm^2}$**
${}^{3}_{1}\mathrm{H}$, ${}^{7}_{4}\mathrm{Be}$, ${}^{14}_{6}\mathrm{C}$	100
${}^{18}_{9}\mathrm{F}$, ${}^{24}_{11}\mathrm{Na}$, ${}^{38}_{17}\mathrm{Cl}$	1
${}^{54}_{25}\mathrm{Mn}$, ${}^{60}_{27}\mathrm{Co}$, ${}^{90}_{38}\mathrm{Sr}$	1
${}^{64}_{29}\mathrm{Cu}$, ${}^{76}_{33}\mathrm{As}$, ${}^{75}_{34}\mathrm{Se}$	10
${}^{99m}_{43}\mathrm{Tc}$, ${}^{105}_{45}\mathrm{Rh}$, ${}^{106}_{44}\mathrm{Ru}$	10
${}^{111}_{47}\mathrm{Ag}$, ${}^{109}_{48}\mathrm{Cd}$, ${}^{99}_{43}\mathrm{Tc}$	100
${}^{125}_{53}\mathrm{I}$, ${}^{131}_{53}\mathrm{I}$, ${}^{129}_{55}\mathrm{Cs}$	10
${}^{134}_{55}\mathrm{Cs}$, ${}^{137}_{55}\mathrm{Cs}$, ${}^{140}_{56}\mathrm{Ba}$	1
${}^{152}_{63}\mathrm{Eu}$, ${}^{154}_{63}\mathrm{Eu}$, ${}^{190}_{77}\mathrm{Ir}$	1
${}^{204}_{81}\mathrm{Tl}$, ${}^{197}_{78}\mathrm{Pt}$, ${}^{210}_{83}\mathrm{Bi}$	100
${}^{226}_{88}\mathrm{Ra}$, ${}^{227}_{89}\mathrm{Ac}$, ${}^{233}_{92}\mathrm{U}$	1
${}^{239}_{94}\mathrm{Pu}$, ${}^{240}_{94}\mathrm{Pu}$, ${}^{252}_{98}\mathrm{Cf}$	0.1
${}^{248}_{96}\mathrm{Cm}$	0.01
β emitter or EC emitter[1] with $E_e^{\max} < 0.2\,\mathrm{MeV}$	100
β or γ emitter in general	1
α emitter or radioisotopes from spontaneous fission	0.1

In case of surface contaminations by different isotopes the following condition must be fulfilled:

$$\sum_{i=1}^{N} \frac{A_i}{A_i^{\max}} \leq 1 \ ,$$

where A_i are the observed surface contaminations and $A_i^{\max}$ the corresponding limits as given in the table.



[1] EC = electron capture

E Definition of Radiation Areas

The definition of radiation areas varies somewhat in different countries, see Chap. 6 on 'International Safety Standards for Radiation Protection'. In the following table the radiation areas according to the ICRP recommendations, adopted by many countries, are given.

<table>
<tr><th colspan="2">controlled area</th><th>surveyed area</th></tr>
<tr><td rowspan="2">exclusion area
$> 3\,\mathrm{mSv/h}$</td><td>6–20 mSv/yr</td><td>1–6 mSv/yr</td></tr>
<tr><td colspan="2">radiation-exposed workers (2000 h/yr)
cat. A 6–20 mSv/yr
cat. B 1–6 mSv/yr</td></tr>
<tr><th colspan="3">neighborhood outside radiation areas</th></tr>
<tr><td colspan="3">$< 1\,\mathrm{mSv/yr}$ permanent residence</td></tr>
<tr><th colspan="3">limit for the general public
for discharges from nuclear facilities[1]</th></tr>
<tr><td colspan="3">$\leq 0.3\,\mathrm{mSv/yr}$</td></tr>
</table>

[1] This limit relates to maximum permitted releases of activity concentrations from radiation facilities (nuclear power plants, recycling facilities) via air and water, which are limited to 0.3 mSv/yr for the general public.

F Radiation Weighting Factors w_R

The following radiation weighting factors w_R are almost generally accepted in all countries, see also Chap. 6.[1] In the early days of radiation protection the biological effect of radiation was taken care of by the so-called quality factors q (see also Chap. 2).

type of radiation and energy range	**radiation weighting factor w_R**
photons, all energies	1
electrons and muons, all energies	1
neutrons $< 10\,\mathrm{keV}$	5
$10\,\mathrm{keV}$–$100\,\mathrm{keV}$	10
$> 100\,\mathrm{keV}$–$2\,\mathrm{MeV}$	20
$> 2\,\mathrm{MeV}$–$20\,\mathrm{MeV}$	10
$> 20\,\mathrm{MeV}$	5
protons, except recoil protons, energy $> 2\,\mathrm{MeV}$	5
α particles, fission fragments, heavy nuclei	20

[1] The radiation weighting factors as adopted in the United States, which are somewhat different, are given in Table 6.1 on page 94.

G Tissue Weighting Factors w_T

The following tissue weighting factors w_T are almost generally accepted in all countries, see also Chaps. 2 and 6.[1]

organs or tissue	tissue weighting factor w_T
gonads	0.20
red bone marrow	0.12
large intestine	0.12
lung	0.12
stomach	0.12
bladder	0.05
chest	0.05
liver	0.05
esophagus	0.05
thyroid gland	0.05
skin	0.01
periosteum (bone surface)	0.01
other organs or tissue	0.05

[1] The tissue weighting factors as adopted in the United States, which are somewhat different, are given in Table 6.2 on page 94.

H Physical Constants

Constants, which are exact, are given with their precise values, if possible. They are characterized with an $*$. For experimental values only the significant decimals are given, i.e., the measurement error is less than the last decimal place.

quantity	**symbol**	**value**	**unit**
velocity of light*	c	299 792 458	m/s
Planck constant	h	$6.626\,07 \times 10^{-34}$	J s
electron charge magnitude	e	$1.602\,177 \times 10^{-19}$	C
electron mass	m_e	$9.109\,38 \times 10^{-31}$	kg
proton mass	m_p	$1.672\,62 \times 10^{-27}$	kg
α-particle mass	m_α	$6.644\,661\,8 \times 10^{-27}$	kg
unified atomic mass unit	m_u	$1.660\,54 \times 10^{-27}$	kg
electron–proton mass ratio	m_e/m_p	$5.446\,170\,21 \times 10^{-4}$	
permittivity of free space*	$\varepsilon_0 = 1/(\mu_0\, c^2)$	$8.854\,187\ldots \times 10^{-12}$	F/m
permeability of free space*	μ_0	$4\,\pi \times 10^{-7}$	$\mathrm{N/A^2}$
fine-structure constant	$\alpha = e^2/(4\,\pi\,\varepsilon_0\,\hbar\,c)$	1/137.035 999	
classical electron radius	$r_e = e^2/(4\,\pi\,\varepsilon_0\,m_e\,c^2)$	$2.817\,940 \times 10^{-15}$	m
Compton wavelength	$\lambda_\mathrm{C} = h/(m_e c)$	$2.426\,310\,2 \cdot 10^{-12}$	m
gravitational constant	γ	6.674×10^{-11}	$\mathrm{m^3/(kg\,s^2)}$
standard gravitational acceleration*	g	9.806 65	$\mathrm{m/s^2}$
Avogadro constant	N_A	$6.022\,14 \times 10^{23}$	$\mathrm{mol^{-1}}$
Boltzmann constant	k	$1.380\,65 \times 10^{-23}$	J/K
molar gas constant	$R\ (= N_\mathrm{A}\,k)$	8.3144	J/(K mol)
molar volume[1]	V_mole	22.414×10^{-3}	$\mathrm{m^3/mol}$
Rydberg energy	$E_\mathrm{Ry} = m_e c^2 \alpha^2/2$	13.6057	eV
Stefan–Boltzmann constant	$\sigma = \pi^2 k^4/(60\,\hbar^3 c^2)$	5.6704×10^{-8}	$\mathrm{W\,m^{-2}\,K^{-4}}$
Bohr radius	$a_0 = 4\pi\varepsilon_0\hbar^2/(m_e c^2)$	$0.529\,177\,21 \times 10^{-10}$	m
Faraday constant	$F = eN_\mathrm{A}$	96 485.309	C/mol
electron charge-to-mass ratio	e/m_e	$1.758\,820 \times 10^{11}$	C/kg

[1] at standard temperature and pressure ($T = 273.15\,\mathrm{K}$, $p = 101\,325\,\mathrm{Pa}$)

I Useful Conversions

quantity	conversion
force	$1\,\mathrm{N} = 1\,\mathrm{kg\,m/s^2}$
work, energy	$1\,\mathrm{eV} = 1.602\,177 \times 10^{-19}\,\mathrm{J}$
	$1\,\mathrm{cal} = 4.186\,\mathrm{J}$
	$1\,\mathrm{erg} = 10^{-7}\,\mathrm{J}$
	$1\,\mathrm{kWh} = 3.6 \times 10^{6}\,\mathrm{J}$
energy dose	$1\,\mathrm{Gy} = 100\,\mathrm{rad}$
	$1\,\mathrm{rad} = 10\,\mathrm{mGy}$
dose equivalent	$1\,\mathrm{Sv} = 100\,\mathrm{rem}$
	$1\,\mathrm{rem} = 10\,\mathrm{mSv}$
ion dose	$1\,\mathrm{R} = 258\,\mu\mathrm{C/kg}$
	$\widehat{=}\ 8.77 \times 10^{-3}\,\mathrm{Gy}$ (in air)
ion-dose rate	$1\,\mathrm{R/h} = 7.17 \times 10^{-8}\,\mathrm{A/kg}$
activity	$1\,\mathrm{Ci} = 3.7 \times 10^{10}\,\mathrm{Bq}$
	$1\,\mathrm{Bq} = 27.03\,\mathrm{pCi}$
pressure	$1\,\mathrm{bar} = 10^{5}\,\mathrm{Pa}$
	$1\,\mathrm{atm} = 1.013\,25 \times 10^{5}\,\mathrm{Pa}$
	$1\,\mathrm{Torr} = 1\,\mathrm{mm\,Hg}$
	$= 1.333\,224 \times 10^{2}\,\mathrm{Pa}$
	$1\,\mathrm{kp/m^2} = 9.806\,65\,\mathrm{Pa}$
charge	$1\,\mathrm{C} = 2.997\,924\,58 \times 10^{9}\,\mathrm{esu}$[1]
length	$1\,\mathrm{m} = 10^{10}\,\mathrm{Å}$
temperature	$\theta\ [^\circ\mathrm{C}] = T\ [\mathrm{K}] - 273.15$
	$T\ [^\circ\mathrm{Fahrenheit}] = 1.80\,\theta\ [^\circ\mathrm{C}] + 32$
	$= 1.80\,T\ [\mathrm{K}] - 459.67$
time	$1\,\mathrm{d} = 86\,400\,\mathrm{s}$
	$1\,\mathrm{yr} = 3.1536 \times 10^{7}\,\mathrm{s}$

[1] esu – electrostatic unit

J List of Abbreviations

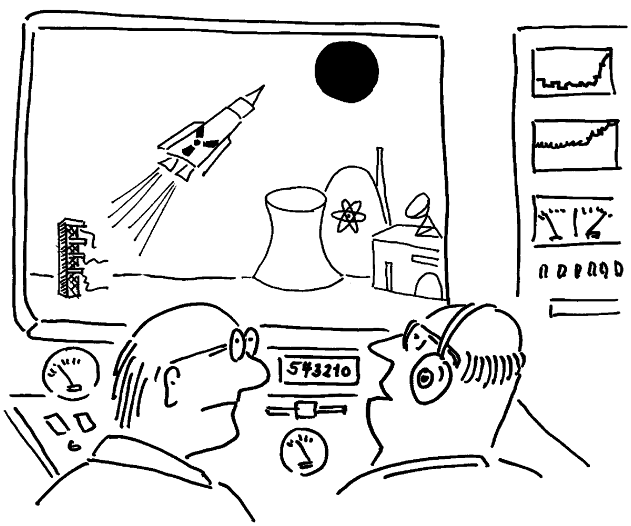
Å	–	angstrom (unit of length); 1 Å $= 10^{-10}$ m
a	–	year (from the Latin word ‘annus’)
A	–	ampere
ACS	–	American Chemical Society
ADR	–	Accord européen relatif au transport international des marchandises dangereuses par la route (European agreement about the transport of dangerous goods via roads)
AERB	–	Atomic Energy Regulatory Board of India
AIDS	–	Acquired Immune Deficiency Syndrome
ALARA	–	as low as reasonably achievable
arctan	–	arc tangent (Latin: arcus tangens): inverse function of tangent (on pocket calculators usually denoted by $\tan^{-1}$)
ALI	–	Annual Limit on Intake
ANSTO	–	Australian Nuclear Science and Technology Organisation
ARPANS	–	Australian Radiation Protection and Nuclear Safety
atm	–	atmosphere (unit of pressure)
bar	–	unit of pressure, from the Greek $\beta\alpha\rho o\varsigma$, ‘weight’
barn	–	unit of the (total) cross section ($= 10^{-24}$ cm^2)
BF_3	–	boron trifluoride
BMU	–	federal ministry for environment in Germany (Bundesministerium für Umwelt)
Bq	–	becquerel
C	–	coulomb (unit of the electric charge)
cal	–	calory (unit of energy)
CASTOR	–	cask for storage and transport of radioactive material
CEDE	–	Committed Effective Dose Equivalent
CERN	–	Conseil Européenne pour la Recherche Nucléaire (European Center for Particle Physics in Geneva)
Ci	–	curie
CW lasers	–	Continuous-Wave lasers
d	–	day (from the Latin word ‘dies’)
DARI	–	Dose Annuelle due aux Radiations Internes (annual dose due to internal radiation from the body)
DF	–	decontamination factor
DIN	–	German institute for engineering standards (Deutsches Institut für Normung)
DIS dosimeter	–	Direct Ion Storage dosimeter

DNA	–	deoxyribonucleic acid
DTPA	–	diethylenetriamine pentaacetate
e	–	Eulerian number ($e = 2.718\,281\ldots$)
EC	–	electron capture (mostly from the K shell)
EDTA	–	ethylenediamine tetraacetate
erg	–	unit of energy ($1\ \mathrm{g\,cm^2/s^2}$); from the Greek $\epsilon\rho\gamma o\nu$, 'work'
ERR	–	Excess Relative Risk
esu	–	unit of charge: electrostatic unit
EU	–	European Union
EURATOM	–	European Atomic Union
exp	–	short for the exponential function
eV	–	electron volt
F	–	farad (unit of capacitance)
FAO	–	Food and Agricultural Organization of the United Nations
FWHM	–	Full Width at Half Maximum
GBq	–	gigabecquerel
GeV	–	giga electron volt
GGVS	–	German ordinance for the transport of dangerous goods (Gefahrgut Verordnung Straße)
GM counter	–	Geiger–Müller counter
GSF	–	German research center for environment and health (Forschungszentrum für Umwelt und Gesundheit)
GSI	–	Gesellschaft für Schwerionenforschung, Darmstadt, Germany
Gy	–	gray
h	–	hour (from the Latin word 'hora')
hPa	–	hectopascal
HPGe detector	–	High Purity Germanium detector
HTR	–	high-temperature reactor
Hz	–	hertz (1/s)
IAD	–	inevitable annual dose
IAEA	–	International Atomic Energy Agency
IAEO	–	International Atomic Energy Organization
ICAO	–	International Civil Aviation Organization (Technical Instructions for Safe Transport of Dangerous Goods by Air)
ICNIRP	–	International Commission on Non-Ionizing Radiation Protection
ICRP	–	International Commission on Radiological Protection
ICRU	–	International Commission on Radiation Units and Measurements
ILO	–	International Labor Organization
IMDG	–	International Maritime Dangerous Goods code

ITER	–	International Thermonuclear Experimental Reactor
IUPAC	–	International Union for Pure and Applied Chemistry
IUPAP	–	International Union for Pure and Applied Physics
J	–	joule (unit of energy; 1 J = 10^7 erg)
JAZ	–	annual intake (from the German 'Jahresaktivitätszufuhr')
JET	–	Joint European Torus
K	–	kelvin (absolute temperature)
kBq	–	kilobecquerel
kerma	–	kinetic energy released per unit mass (also: kinetic energy released in matter (or material))
keV	–	kilo electron volt
kHz	–	kilohertz (or kilocycle)
kJ	–	kilojoule
kp	–	kilopond
kT	–	kiloton (explosive)
kV	–	kilovolt
LASER	–	Light Amplification by Stimulated Emission of Radiation
LD	–	lethal dose
LEP	–	Large Electron–Positron collider at CERN
LET	–	Linear Energy Transfer
LINAC	–	linear accelerator
ln	–	logarithmus naturalis (natural logarithm)
LNT	–	Linear No-Threshold hypothesis
mA	–	milliampere
MBq	–	megabecquerel
µC	–	microcoulomb
mCi	–	millicurie
µCi	–	microcurie
meV	–	milli electron volt
MeV	–	mega electron volt
mGy	–	milligray
µGy	–	microgray
mK	–	millikelvin
µK	–	microkelvin
mole	–	amount of material which contains 6.022×10^{23} molecules/atoms (= Avogadro number)
MOSFET	–	Metal Oxide Field Effect Transistor
MOX	–	Mixture of Oxides

mrem	–	millirem
MRT	–	Microbeam Radiation Therapy
mSv	–	millisievert
μSv	–	microsievert
mV	–	millivolt
MW	–	megawatt
N	–	newton (unit of force)
NASA	–	National Aeronautics and Space Administration
NEA	–	Nuclear Energy Agency
NIR	–	Non-Ionizing Radiation
NPL	–	National Physical Laboratory
nSv	–	nanosievert
OECD	–	Organization for Economic Cooperation and Development
Ω	–	ohm
Pa	–	pascal (unit of pressure)
PBD	–	2-(4-tert.-butylene-phenyl)- 5-(4-biphenyl-1,3,4-oxadiazole)
pCi	–	picocurie
PET	–	Positron-Emission Tomography
pF	–	picofarad (10^{-12} F)
PIPS detector	–	Passive Implanted Planar Silicon detector
PM	–	photomultiplier
PMMA	–	polymethyl methacrylate
ppm	–	parts per million (10^{-6})
PTB	–	German national physical laboratory for weights and measures (Physikalisch–Technische Bundesanstalt in Braunschweig, equivalent to the British NPL)
R	–	roentgen
rad	–	radiation absorbed dose
rad	–	radian (unit of angle, the full radian is 2π)
Radar	–	Radio Detecting and Ranging
rem	–	roentgen equivalent man
RBE	–	relative biological effectiveness
RID	–	règlement international concernant le transport des marchandises dangereuses provision about the transport of dangerous goods
RNA	–	ribonucleic acid
RTG	–	Radioisotope Thermoelectric Generator
SAR	–	specific absorption rate

steradian	–	unit of solid angle; the full solid angle corresponds to the surface of the unit sphere: $4\,\pi$
StrlSchV	–	Strahlenschutzverordnung (German radiation-protection ordinance)
Sv	–	sievert
TeV	–	tera electron volt
TLD	–	thermoluminescence dosimeter
TNT	–	trinitrotoluol (explosive)
Torr	–	torricelli (unit of pressure, mm column of mercury)
UMTS	–	Universal Mobile Telecommunications System
UN	–	United Nations
UNSCEAR	–	United Nations Scientific Committee on the Effects of Atomic Radiation
UV	–	ultraviolet
UVA	–	ultraviolet type A radiation, wavelength 400–315 nm
UVB	–	ultraviolet type B radiation, wavelength 315–280 nm
UVC	–	ultraviolet type C radiation, wavelength 280–100 nm
V	–	volt
VDI	–	Verein Deutscher Ingenieure (association of German engineers)
WHO	–	World Health Organization
W W s	–	watt (unit of power), watt second (unit of energy)



"The perfect final deposit: A Black Hole!"

K List of Elements*

1 H hydrogen (Greek: $\upsilon\delta\omega\rho$, hydor, water + $\gamma\epsilon\iota\nu o\mu\alpha\iota$, geinomai, to engender; Latin: hydrogenium);
D = $^2_1$H deuterium (Greek: $\delta\epsilon\upsilon\tau\epsilon\rho o\varsigma$, deuteros, second) and T = $^3_1$H tritium (Greek: $\tau\rho\iota\tau o\varsigma$ tritos, third) are isotopes of hydrogen

2 He helium (Greek: $\eta\lambda\iota o\varsigma$, helios, sun)

3 Li lithium (Greek: $\lambda\iota\theta o\varsigma$, lithos, stone, rock)

4 Be beryllium (Greek: $\beta\eta\rho\upsilon\lambda\lambda o\varsigma$, beryllos, beryl)

5 B boron (Latin: boracium; Arabic: borax)

6 C carbon (Latin: carbo, coal; French: charbon, charcoal)

7 N nitrogen (Greek: $\nu\iota\tau\rho o\nu$, nitron + $\gamma\epsilon\iota\nu o\mu\alpha\iota$, geinomai, to engender, soda forming; Latin: nitrogenium)

8 O oxygen (Greek: $o\xi\upsilon\varsigma$, oxys, acid + $\gamma\epsilon\iota\nu o\mu\alpha\iota$, geinomai, to engender, acid forming; Latin: oxygenium)

9 F fluorine (Latin: fluere, to flow, to stream)

10 Ne neon (Greek: $\nu\epsilon o\varsigma$, neos, new, young)

11 Na sodium (Latin: sodanum; Hebrew: neter, soda; German: Natrium; from the Arabic word 'natrun' = soda)

12 Mg magnesium (Greek: $M\alpha\gamma\nu\eta\sigma\iota\alpha$, Magnesia (district in the Greek town Thessaly))

13 Al aluminum (Latin: alumen, a bitter salt)

14 Si silicon (Latin: silex, flint)

15 P phosphorus (Greek: $\phi\omega\sigma\phi o\rho o\varsigma$, phosphoros, light bearing, luminous)

16 S sulphur (Latin: sulfur)

17 Cl chlorine (Greek: $\chi\lambda\omega\rho o\varsigma$, chloros, light green, green-yellow)

18 Ar argon (Greek: $\alpha\rho\gamma o\nu$, argon, inactive, idle)

19 K potassium (German: Kalium from the Arabic word al-qali = ash or English: potash)

20 Ca calcium (Latin: calx, limestone)

21 Sc scandium (Latin: from Scandinavia)

22 Ti titanium (Greek: $\tau\iota\tau\alpha\nu o\varsigma$, Titans, children of the Earth)

23 V vanadium (Vanadis, Scandinavian goddess of beauty)

24 Cr chromium, (Greek: $\chi\rho\tilde{\omega}\mu\alpha$, chroma, color)

25 Mn manganese, (Greek: $M\alpha\gamma\nu\eta\sigma\iota\alpha$, Magnesia (district in the Greek town Thessaly); Latin: magnes, magnet)

26 Fe iron (Latin: ferrum)

27 Co cobalt (German: Kobold, goblin, evil spirit)

28 Ni nickel (German: Kupfernickel = devil's copper)

29 Cu copper (Greek: $\kappa\upsilon\pi\rho\iota o\varsigma$, kuprios; Latin: cuprum; metal from the island of Cyprus)

30 Zn zinc (German: Zink, sharp point)

31 Ga gallium (Latin: Gallia, France)

32 Ge germanium (Latin: Germania, Germany)

33 As arsenic (Arabic: al-zarnikh, gold-colored)

34 Se selenium (Greek: $\sigma\epsilon\lambda\eta\nu\eta$, selene, moon)

35 Br bromine (Greek: $\beta\rho o\mu o\varsigma$, bromos, stench)

36 Kr krypton (Greek: $\kappa\rho\upsilon\pi\tau o\varsigma$, kryptos, hidden)

37 Rb rubidium (Latin: rubidus, deep red)

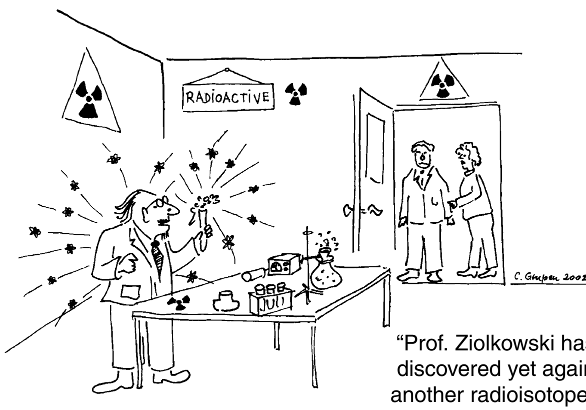
38 Sr strontium (Strontian, village in Scotland)

39 Y yttrium (after the Swedish village Ytterby)

* see also `www.periodensystem.info/periodensystem.htm`
resp. `www.webelements.com/`
or `http://elements.vanderkrogt.net/elem/`

40 Zr zirconium (Persian: zargûn, gold color)
41 Nb niobium ($N\iota o\beta\eta$, Niobe, daughter of Tantalus)
42 Mo molybdenum (Greek: $\mu o\lambda\upsilon\beta\delta o\varsigma$, molybdos, lead ore)
43 Tc technetium (Greek: $\tau\epsilon\chi\nu\eta\tau o\varsigma$, technetos, artificial)
44 Ru ruthenium (Latin: Ruthenia = Ukraine, sometimes Russia is meant)
45 Rh rhodium (Greek: $\rho o\delta o\nu$, rodon, rose)
46 Pd palladium (Greek: named after Pallas Athene, the Greek goddess of wisdom) $\Pi\alpha\lambda\lambda\alpha\varsigma\ A\theta\eta\nu\eta$
47 Ag silver (Latin: argentum)
48 Cd cadmium (named after ‘Kadmos’, the founder of the Egyptian city of Thebes).
49 In indium (named after the indigo blue spectral color)
50 Sn tin (Latin: stannum or Indo-European: stag, dripping)
51 Sb antimonium (Latin: stibium or Greek: $\sigma\tau\iota\beta\iota$, stibi, cosmetic powder)
52 Te tellurium (Latin: tellus, earth, ground)
53 I iodine (Greek: $\iota o\epsilon\iota\delta\eta\varsigma$, ioeides, violet color)
54 Xe xenon (Greek: $\xi\epsilon\nu o\varsigma$, xenos, strange)
55 Cs cesium (Latin: caesius = bluish gray)
56 Ba barium (Greek: $\beta\alpha\rho\upsilon\varsigma$, barys, heavy)
57 La lanthanum (Greek: $\lambda\alpha\nu\theta\alpha\nu\omega$, lanthano, to lie hidden)
58 Ce cerium (Ceres, asteroid discovered in 1801)
59 Pr praseodymium (Greek: $\pi\rho\alpha\sigma\iota o\varsigma$ + $\delta\iota\delta\upsilon\mu o\varsigma$, prasios + didymos, green and twins)
60 Nd neodymium (Greek: $\nu\epsilon o\varsigma$ + $\delta\iota\delta\upsilon\mu o\varsigma$, neos + didymos, new and twins)
61 Pm promethium (Greek: $\Pi\rho o\mu\eta\theta\epsilon\upsilon\varsigma$, named after Prometheus)
62 Sm samarium (samarskite, mineral named after V.E. Samarskij-Byhovec)
63 Eu europium (Latin: Europa, Europe)
64 Gd gadolinium (gadolinite, mineral named after Johan Gadolin)
65 Tb terbium (named after the Swedish village Ytterby)
66 Dy dysprosium (Greek: $\delta\upsilon\sigma\pi\rho o\sigma\iota\tau o\varsigma$, dysprositos, hard to obtain)
67 Ho holmium (Latin: Holmia = Stockholm)
68 Er erbium (named after the Swedish village Ytterby)
69 Tm thulium (Latin: Thule in Scandinavia)
70 Yb ytterbium (named after the Swedish village Ytterby)
71 Lu lutetium (after the Roman name of Paris: Lutetia Parisorum)
72 Hf hafnium (Latin: Hafnia = København, Copenhagen)
73 Ta tantalum (Greek: $T\alpha\nu\tau\alpha\lambda o\varsigma$, Tantalos, figure in Greek mythology)
74 W tungsten (Swedish: Tung Sten, heavy stone; Wolfram: mineral wolframite, from ‘Wolf Rahm’ (German for wolf’s foam))
75 Re rhenium (Latin: Rhenus, Rhine)
76 Os osmium (Greek: $o\sigma\mu\eta$, osme, stench)
77 Ir iridium (Greek: $I\rho\iota\varsigma$, Greek goddess of the rainbow)
78 Pt platinum (Spanish: platina (del Pinto) = small silver (beads) of the river Pinto)
79 Au gold (Latin: aurum)
80 Hg mercury (Greek: $\upsilon\delta\rho\alpha\rho\gamma\upsilon\rho o\varsigma$, hydrargyros, liquid silver; Latin: hydrargyrum)
81 Tl thallium (Greek: $\theta\alpha\lambda\lambda o\varsigma$, thallos, green shot)
82 Pb lead (Latin: plumbum)
83 Bi bismuth (Latin: bisemutum; German: Weisse Masse, white substance)
84 Po polonium (Latin: Polonia = Polska, Poland)
85 At astatine (Greek: $\alpha\sigma\tau\alpha\tau o\varsigma$, astatos, unstable)
86 Rn radon (Latin: nitens, shining; named after the element radium, changed to radon to match the endings of most other noble gases)
87 Fr francium (Latin: named after France)
88 Ra radium (Latin: radius, ray)
89 Ac actinium (Greek: $\alpha\kappa\tau\iota\varsigma$, aktis, ray)

90 Th thorium (Thor, Scandinavian god of war)
91 Pa protactinium (Greek: $\pi\rho\omega\tau o\varsigma$ + actinium, first element after actinium in the uranium–actinium decay series)
92 U uranium (named after the planet Uranus)
93 Np neptunium (named after the planet Neptun)
94 Pu plutonium (named after the dwarf planet Pluto ($\Pi\lambda o\upsilon\tau\omega\nu$, Plouton), the Greek god of the underworld)
95 Am americium (Latin: America)
96 Cm curium (named after Marie Curie)
97 Bk berkelium (Berkeley, town in California)
98 Cf californium (California, state of the USA)
99 Es einsteinium (named after Albert Einstein)
100 Fm fermium (named after Enrico Fermi)
101 Md mendelevium (named after Dmitri I. Mendeleyev)
102 No nobelium (named after Alfred Nobel)
103 Lr lawrencium (named after Ernest O. Lawrence)
104 Rf rutherfordium (named after Ernest Rutherford)
105 Db dubnium (named after Dubna, a town in the Moscow region)
106 Sg seaborgium (named after Glenn T. Seaborg)
107 Bh bohrium (named after Niels Bohr)
108 Hs hassium (named after the German state Hassia, Hessen)
109 Mt meitnerium (named after Lise Meitner)
110 Ds darmstadtium (named after Darmstadt, a town in Germany)
111 Rg roentgenium (named after Wilhelm Conrad Röntgen)
112 Cn copernicium (named after Nicolaus Copernicus)
113 †
114 †
115 †
116 †
118 †



"Prof. Ziolkowski has discovered yet again another radioisotope!"

© by Claus Grupen

† $Z = 113, 114, 115, 116, 118$: Lawrence Livermore–Dubna Colaboration, Russia, and Berkeley, USA

L Decay Chains

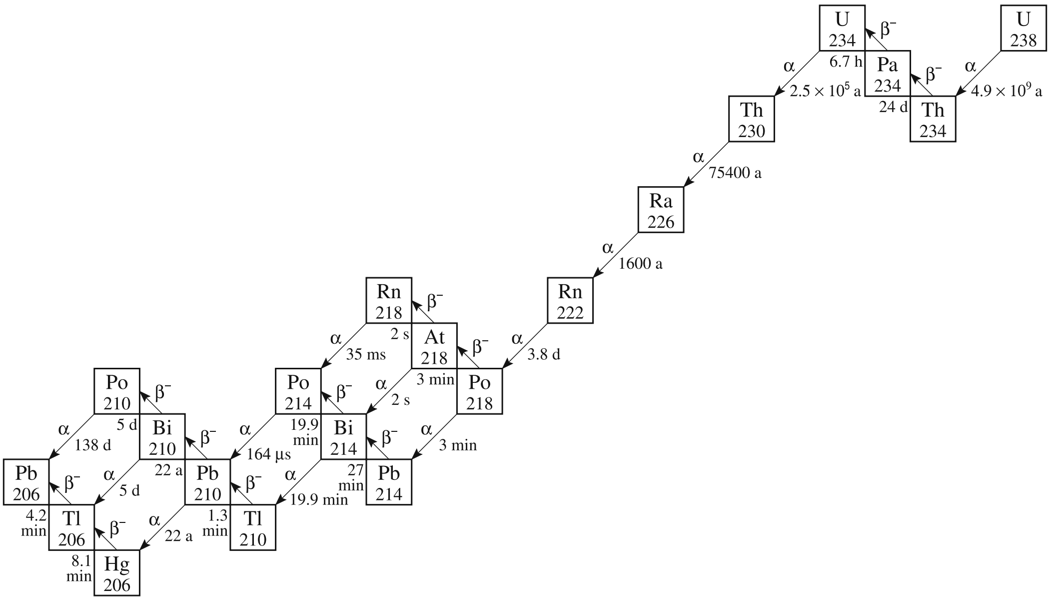


Figure L.1
Uranium (^{238}U) decay chain
(a = annus, year)

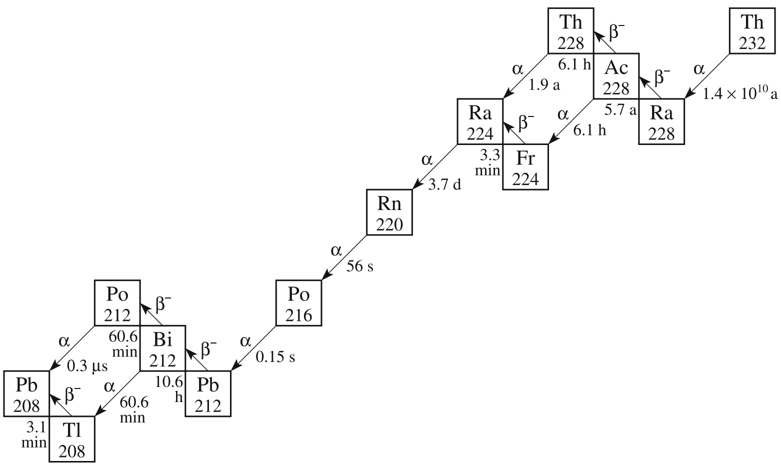


Figure L.2
Thorium (^{232}Th) decay chain
(a = annus, year)

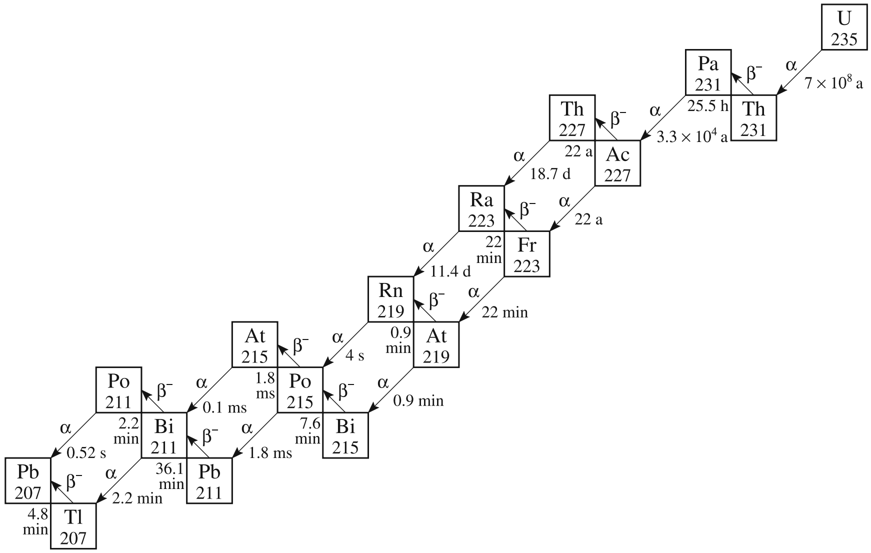


Figure L.3
Actinium (^{235}U) decay chain
(a = annus, year)

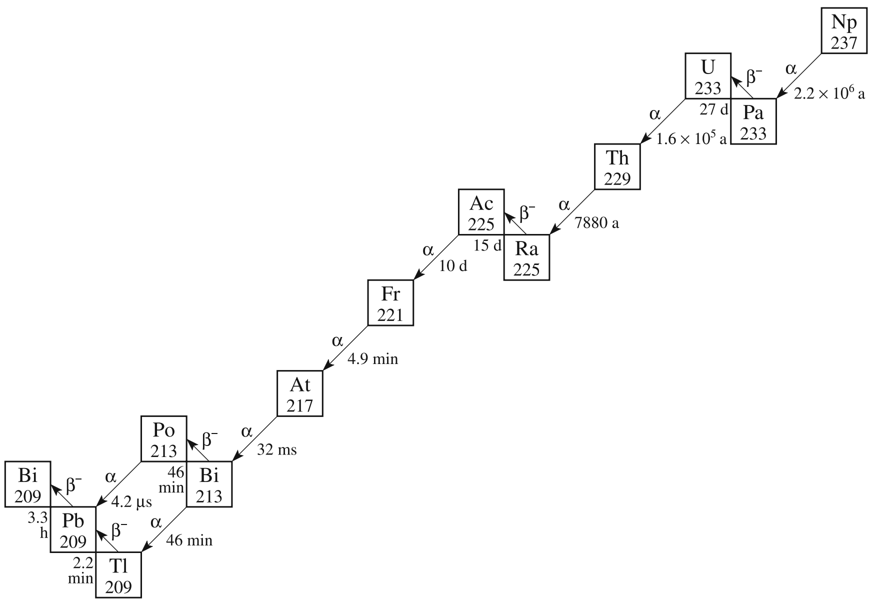


Figure L.4
Neptunium (^{237}Np) decay chain
(a = annus, year)

M List of Isotopes Frequently Used in Nuclear Medicine and Radiology

isotope	half-life	decay	main energy	application
protons	stable		$\approx 200\,\text{MeV}$	particle therapy
^{3}H	12.3 yrs	β^-, no γ	0.02 MeV	total body water content determination
^{11}B	stable			melanoma and brain tumor treatment
^{11}C	20.4 min	β^+, no γ	1.0 MeV	Positron-Emission Tomography; PET scans
^{12}C	stable		$\approx 300\,\text{MeV}$ per nucleon	particle therapy
^{14}C	5730 yrs	β^-, no γ	0.2 MeV	e.g. pancreatic studies
^{13}N	10 min	β^+, no γ	1.2 MeV	Positron-Emission Tomography; PET scans
^{15}O	2 min	β^+, no γ	1.7 MeV	Positron-Emission Tomography; PET scans
^{18}F	110 min	β^+, no γ	0.6 MeV	Positron-Emission Tomography; PET scans
^{22}Na	2.6 yrs	β^+ γ	0.5 MeV ... 1275 keV	electrolyte studies
^{24}Na	15 h	β^- γ	1.4 MeV ... 2754 keV ...	studies of electrolytes within the body
^{32}P	14.3 d	β^-, no γ	1.7 MeV	treatment against excess of red blood cells
^{42}K	12.4 h	β^- γ	3.5 MeV 1525 keV ...	for measurement of coronary blood flow
^{47}Ca	4.5 d	β^- γ	0.7 MeV... 1297 keV ...	bone metabolism
^{51}Cr	27.7 d	γ EC	320 keV	labeling of red blood cells
^{59}Fe	44.5 d	β^- γ	0.5 MeV ... 1099 keV ...	metabolism in the spleen
^{57}Co	272 d	γ EC	122 keV...	marker to estimate organ size

isotope	**half-life**	**decay**	**main energy**	**application**
^{58}Co	71 d	β^+ γ EC	0.5 MeV ... 811 keV	gastrointestinal absorption
^{60m}Co	10.5 min	γ	59 keV	external beam radiotherapy
^{60}Co	5.3 yrs	β^- γ γ	0.3 MeV ... 1173 keV 1332 keV	tumor treatment
^{62}Cu	9.7 min	β^+ γ	2.9 MeV ... 1173 keV ...	positron-emitting radionuclide for PET
^{64}Cu	12.7 h	β^- β^+ γ EC	0.6 MeV 0.7 MeV 1346 keV	study of genetic of diseases
^{67}Cu	61.9 h	β^- γ	0.4 MeV ... 185 keV ...	radioimmunotherapy
^{64}Ga	2.6 min	β^+ γ	2.9 MeV ... 992 keV ...	treatment of pulmonary diseases
^{67}Ga	78.3 h	γ EC, no β^+	93 keV ...	tumor imaging
^{68}Ga	67.6 min	β^+ γ	1.9 MeV ... 1077 keV ...	study thrombosis and atherosclerosis detection of pancreatic cancer
^{68}Ge	271 d	no β^+, no γ, EC		PET imaging
^{72}As	26 h	β^+ γ	2.5 MeV ... 834 keV ...	planar imaging, SPECT, or PET
^{75}Se	120 d	γ EC	265 keV ...	radiotracer used in brain studies scintigraphy scanning study of the production of digestive enzymes
^{81m}Kr from ^{81}Rb	13 s	γ EC	190 keV	pulmonary ventilation
^{82}Rb from ^{82}Sr	6.3 h	β^+ γ	0.8 MeV ... 776 keV ...	PET agent in myocardial perfusion imaging
^{89}Sr	50.5 d	β^- γ	1.5 MeV ... 909 keV	reducing the pain due to prostate and bone cancer
^{90}Y	64.1 h	β^- γ	2.3 MeV ... 2186 keV ...	cancer brachytherapy

isotope	**half-life**	**decay**	**main energy**	**application**
^{99}Mo	66 h	β^- γ	1.2 MeV ... 740 keV ...	parent of ^{99m}Tc
^{99m}Tc	6 h	γ	141 keV ...	skeleton, heart muscle, brain, thyroid, lungs, liver, spleen, kidney, gall bladder, bone marrow, salivary, and lacrimal glands
^{103}Ru	39.4 d	β^- γ	0.2 MeV ... 497 keV ...	myocardial blood flow
^{103}Pd	17 d	γ EC	357 keV ...	brachytherapy for early prostate cancer
^{109}Cd	463 d	no γ, EC		cancer detection, pediatric imaging
^{111}In	2.8 d	γ EC, no β^+	245 keV ...	brain studies
^{117m}Sn	13.6 d	γ	159 keV ...	bone cancer pain relief
^{122}I	3.6 min	β^+ γ	3.1 MeV ... 564 keV ...	brain blood flow studies
^{123}I	13.2 h	γ EC, no β^+	159 keV ...	diagnosis of the thyroid function
^{125}I	59.4 d	γ EC	35 keV	cancer brachytherapy (prostate and brain) filtration rate of kidneys
^{131}I	8.0 d	β^- γ	0.6 MeV ... 364 keV ...	treatment of thyroid cancer with beta therapy
^{132}I	2.3 h	β^- γ	2.1 MeV ... 668 keV ...	marking of red blood cells
^{130}Cs	29.2 min	β^+ β^- γ EC	2.0 MeV ... 0.4 MeV 536 keV	myocardial localizing agent
^{127}Xe	36.4 d	γ EC	203 keV ...	neuroimaging for brain disorders
^{133}Xe	5.3 d	β^- γ	0.3 MeV ... 81 keV ...	lung ventilation studies
^{137}Cs	30.2 yrs	β^- γ	0.5 MeV ... 662 keV ...	brachytherapy
^{141}Ce	32.5 d	β^- γ	0.4 MeV ... 145 keV	gastrointestinal tract diagnosis

isotope	half-life	decay	main energy	application
^{153}Sm	46.3 h	β^- γ	0.7 MeV ... 103 keV ...	prostate and breast cancer relieving pain of secondary cancers
^{155}Eu	4.8 yrs	β^- γ	0.17 MeV ... 87 keV ...	osteoporosis detection
^{165}Dy	2.4 h	β^- γ	1.3 MeV ... 95 keV ...	treatment of arthritis
^{166}Ho	26.8 h	β^- γ	1.9 MeV ... 81 keV ...	treatment of liver tumors
^{169}Er	9.4 d	β^- γ	0.3 MeV ... 110 keV ...	for relieving arthritis
^{170}Tm	129 d	β^- γ	1.0 MeV ... 84 keV ...	portable blood irradiations for leukemia
^{169}Yb	32 d	γ EC	63 keV ...	cerebrospinal fluid studies in the brain
^{177}Lu	6.7 d	β^- γ	0.5 MeV ... 208 keV ...	β radiation for small tumors γ rays for imaging
^{178}Ta	9.3 min	β^+ γ EC	0.9 MeV 93 keV ...	viewing of heart and blood vessels
^{182}Ta	115 d	β^- γ	0.5 MeV ... 68 keV ...	bladder cancer treatment
^{186}Re	3.7 d	β^- γ EC	1.1 MeV ... 137 keV ...	for pain relief in bone cancer for imaging
^{188}Re	17 h	β^- γ	2.1 MeV ... 155 keV ...	β irradiation of coronary arteries
^{191m}Ir	5 s	γ	129 keV ...	cardiovascular angiography
^{192}Ir	74 d	β^- γ EC	0.7 MeV ... 317 keV ...	cancer brachytherapy source supplied in wire form
^{198}Au	2.7 d	β^- γ	1.0 MeV ... 412 keV ...	brachytherapy and liver treatment
^{201}Tl	73.1 h	γ EC	167 keV ...	diagnosis of coronary artery disease
^{213}Bi	45.6 min	α β^- γ	5.87 MeV ... 1.4 MeV ... 440 keV ...	Targeted Alpha Therapy (TAT)

isotope	half-life	decay	main energy	application
^{226}Ra	1600 yrs	α γ	4.78 MeV ... 186 keV ...	brachytherapy
^{238}Pu	87.7 yrs	α γ sf	5.50 MeV ... 43 keV ...	pacemaker (no ^{236}Pu contaminants)
^{241}Am	432 yrs	α γ sf	5.49 MeV ... 60 keV ...	osteoporosis detection, heart imaging
^{252}Cf	2.6 yrs	α γ sf	6.12 MeV ... 43 keV ...	brain cancer treatment

Abbreviations

PET – Positron-Emission Tomography
SPECT – Single Photon Emission Computed Tomography
TAT – Targeted Alpha Therapy
EC – electron capture
sf – spontaneous fission

all γ energies are given in keV
for β decays the endpoint energies (i.e. the maximum energies) are given
for α decays the discrete energies are given

References:

Radioisotopes in Medicine: `www.world-nuclear.org/info/inf55.htm`,
`www.expresspharmaonline.com/20050331/radiopharmaceuticals01.shtml`,
`www.radiochemistry.org/nuclearmedicine/frames/medical_radioisotopes/index.html`

N Critical Organs for Various Radioisotopes

isotope	physical half-life	effective half-life	emitter	critical organ
^{3}H	12.3 yrs	10 d	β^-	whole body
^{7}Be	53.3 d	53.3 d	γ, EC	whole body, bones
^{10}Be	1.6×10^6 yrs	4 yrs	β^-	whole body
^{14}C	5730 yrs	40 d	β^-	whole body
^{16}N	7.1 s	7.1 s	β^-, γ	lung
^{18}F	110 min	110 min	β^+	skeleton
^{22}Na	2.6 yrs	11 d	β^+, γ	whole body
^{24}Na	15 h	14 h	β^-, γ	gastrointestinal tract
^{32}Si	172 yrs	100 d	β^-	whole body
^{32}P	14.3 d	14.1 d	β^-	bones
^{33}P	25.3 d	25.3 d	β^-	bones
^{35}S	87.5 d	44 d	β^-	whole body
^{36}Cl	3×10^5 yrs	30 d	β^-	whole body
^{39}Ar	269 yrs	5 min	β^-	lung
^{40}K	1.28×10^9 yrs	30 d	β^+, β^-, γ	whole body
^{45}Ca	163 d	163 d	β^-, γ	bones
^{47}Ca	4.5 d	4.5 d	β^-, γ	bones
^{51}Cr	27.7 d	22.8 d	γ, EC	lung, gastrointestinal tract
^{54}Mn	312 d	88.5 d 23 d	γ, EC	lung liver
^{55}Fe	2.7 yrs	1.1 yrs	EC	spleen
^{59}Fe	44.5 d	41.9 d	β^-, γ	spleen
^{60}Co	5.3 yrs	117 d	β^-, γ	lung

isotope	physical half-life	effective half-life	emitter	critical organ
^{63}Ni	100 yrs	variable	β^-	whole body
^{64}Cu	12.7 h	12 h	β^+, β^-, γ, EC	whole body
^{65}Zn	245 d	194 d 81 d	β^+, γ, EC	whole body lung
^{75}Se	120 d	61 d 10 d	γ, EC	lung kidney
^{82}Br	35.3 h	30.5 h	β^-, γ	whole body
^{81m}Kr	13.1 s	13 s	γ, EC	lung
^{85}Kr	10.7 yrs	5 min	β^-, γ	whole body
^{86}Rb	18.7 d	13 d	β^-, γ, EC	whole body, pancreas, liver
^{87}Rb	4.8×10^{10} yrs	44 d	β^-, γ, EC	whole body, pancreas, liver
^{85}Sr	65 d	65 d	γ, EC	bones
^{89}Sr	50.5 d	50.5 d	β^-, γ	bones
^{90}Sr	28.6 yrs	18 yrs	β^-	bones
^{90}Y	64.1 h	30 h	β^-, γ	gastrointestinal tract
^{91}Y	58.5 d	58 h	β^-, γ	bones, liver
^{95}Zr	64.0 d	64 d	β^-, γ	bones
^{99}Mo	66.0 h	65 h	β^-, γ	bones, liver
^{99m}Tc	6 h	4 h	γ	thyroid, gastrointestinal tract
^{103}Ru	39.4 d	35 d	β^-, γ	lung, whole body
^{105}Ru	4.4 d	4 d	β^-, γ	lung, whole body
^{106}Ru	373.6 d	35 d	β^-	lung, whole body
^{110m}Ag	250 d	50 d	β^-, γ	liver
^{109}Cd	463 d	463 d	EC	kidney
^{111}In	2.8 d	2.8 d	γ, EC	bone marrow, liver
^{113m}In	99.5 min	96.6 min	γ	kidney, gastrointestinal tract
^{125}Sb	2.8 yrs	5 d	β^-, γ	bones, liver
^{129m}Te	33.6 d	20 d	β^-, γ	bones, kidney
^{132}Te	76.3 h	24 h	β^-, γ	bones, kidney
^{123}I	13.2 h	13 h	γ, EC	thyroid
^{125}I	59.4 d	41.8 d	γ, EC	thyroid

isotope	physical half-life	effective half-life	emitter	critical organ
^{129}I	1.6×10^{7} yrs	80 d	β^-, γ	thyroid
^{131}I	8.0 d	7.6 d	β^-, γ	thyroid
^{132}I	2.3 h	2 h	β^-, γ	thyroid
^{133}I	20.8 h	20 h	β^-, γ	thyroid
^{134}I	52 min	52 min	β^-, γ	thyroid
^{135}I	6.6 h	6 h	β^-, γ	thyroid
^{133}Xe	5.3 d	5 min	β^-, γ	whole body
^{134}Cs	2.1 yrs	120 d	β^+, β^-, γ	muscles, whole body
^{136}Cs	13.2 d	13 d	β^-, γ	muscles, whole body
^{137}Cs	30.2 yrs	110 d	β^-, γ	muscles, whole body
^{140}Ba	12.8 d	10.7 d	β^-, γ	gastrointestinal tract
^{138}La	1.1×10^{11} yrs	10 yrs	β^-, γ, EC	liver, bones
^{141}Ce	32.5 d	32 d	β^-, γ	bones, liver
^{144}Ce	284.8 d	280 d	β^-, γ	bones, liver
^{147}Pm	2.6 yrs	2.4 yrs	β^-, γ	bones, liver
^{147}Sm	1.1×10^{11} yrs	10 yrs	α	liver, bones
^{176}Lu	3.8×10^{10} yrs	10 yrs	β^-, γ	bones
^{186}Re	89.3 h	48 h	β^-, γ, EC	muscle tissue
^{187}Re	5×10^{10} yrs	2 d	β^-	muscle tissue
^{198}Au	2.7 d	1 d	β^-, γ	kidney, gastrointestinal tract
^{203}Hg	46.6 d	11 d	β^-, γ	kidney
^{201}Tl	73.1 h	72 h	γ, EC	whole body
^{202}Tl	12.2 d	10 d	γ, EC	whole body
^{208}Tl	3.1 min	3 min	β^-, γ	whole body
^{210}Pb	22.3 yrs	1.2 yrs 6.8 yrs	β^-, γ	kidney bones
^{212}Pb	10.6 h	10 h	β^-, γ	bones, liver
^{212}Bi	60.6 min	60 min	α, β^-, γ	kidney
^{214}Bi	19.9 min	19 min	α, β^-, γ	kidney
^{210}Po	138.4 d	31.7 d 66.7 d	α, γ	kidney lung

isotope	physical half-life	effective half-life	emitter	critical organ
^{220}Rn	55.6 s	55 s	α, γ	lung
^{222}Rn	3.8 d	5 min	α, γ	lung
^{224}Ra	3.7 d	3.7 d	α, γ	bones, bone marrow, lung
^{226}Ra	1600 yrs	41 yrs	α, γ	bones, bone marrow, lung
^{228}Ra	5.8 yrs	5.7 yrs	β^-, γ	bones, bone marrow, lung
^{227}Ac	21.8 yrs	21 yrs	α, β^-, γ	bones, liver
^{228}Ac	6.1 h	6 h	α, β^-, γ	bones, liver
^{228}Th	1.9 yrs	1.9 yrs	α, γ	lung, periosteum (bone surface)
^{230}Th	7.5×10^4 yrs	25 yrs	α, γ	lung, periosteum (bone surface)
^{232}Th	1.4×10^{10} yrs	25 yrs	α, γ	lung, bones
^{234}Th	24.1 d	24 d	β^-, γ	lung, periosteum (bone surface)
^{231}Pa	3.3×10^4 yrs	10 yrs	α, γ	bones
^{233}U	1.6×10^5 yrs	variable, $\leq$ 14 yrs	α, γ	bones, lung, kidney
^{234}U	2.5×10^5 yrs	variable, $\leq$ 14 yrs	α, γ, sf	bones, lung, kidney
^{235}U	7×10^8 yrs	variable, $\leq$ 14 yrs	α, γ, sf	bones, lung, kidney
^{238}U	4.5×10^9 yrs	variable, $\leq$ 14 yrs	α, γ, sf	bones, lung, kidney
^{237}Np	2.1×10^6 yrs	variable	α, γ, sf	bones, liver
^{238}Pu	87.7 yrs	46.2 yrs	α, γ, sf	periosteum (bone surface) liver, lung, blood
^{239}Pu	24110 yrs	100 yrs	α, γ, sf	periosteum (bone surface) liver, lung, blood
^{240}Pu	6563 yrs	100 yrs	α, γ, sf	periosteum (bone surface) liver, lung, blood
^{242}Pu	3.8×10^5 yrs	100 yrs	α, γ, sf	periosteum (bone surface) liver, lung, blood
^{241}Am	432 yrs	84 yrs	α, γ, sf	bones
^{242}Cm	163 d	162 d	α, γ, sf	bones, liver, lung
^{243}Cm	29.1 yrs	15 yrs	α, γ, sf	bones, liver, lung
^{244}Cm	18.1 yrs	15 yrs	α, γ, sf	bones, liver, lung
^{249}Bk	320 d	316 d	α, β^-, γ, sf	bones
^{252}Cf	2.6 yrs	2.5 yrs	α, γ, sf	bones
^{253}Es	20.5 d	20.5 d	α, γ, sf	bones

Abbreviations

sf – spontaneous fission
EC – electron capture

References:

B. Lindskoug,
Manual on early medical treatment of possible radiation injury,
Safety series no. 47. Recommendations (IAEA, Vienna, 1978);
Nuclear Instruments and Methods, Vol. 161, issue 1, p. 172 (1979)

Health Physics Society: `www.hps.org/publicinformation/ate/`

Edward Chu, Vincent T. DeVita (eds.)
Physicians' Cancer Chemotherapy Drug Manual
Jones and Bartlett Publishers; Bk and CD-Rom edition 2007

HyperPhysics: `http://hyperphysics.phy-astr.gsu.edu/Hbase/hframe.html`

Radiation Safety Office, G-07 Parran Hall, Pittsburgh, USA
`www.radsafe.pitt.edu/ManualTraining/Appendix%20C.htm`

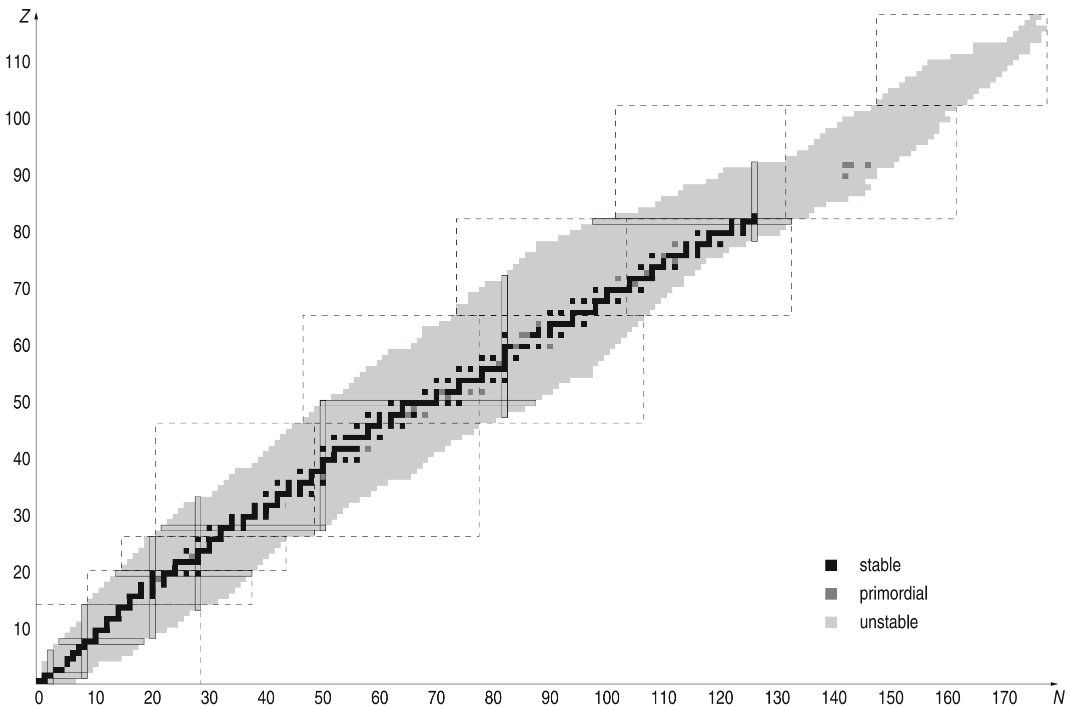
U. Bertsche, Hessisches Ministerium für Umwelt, Wiesbaden,
Radionuklide in der Umweltüberwachung, Medizin und Technik, (2001)

It has to be mentioned that the values for the effective half-life differ in various publications. Also, the effective half-life varies for different organs and tissues. Therefore the quoted figures just give a rough idea for the effective half-life.

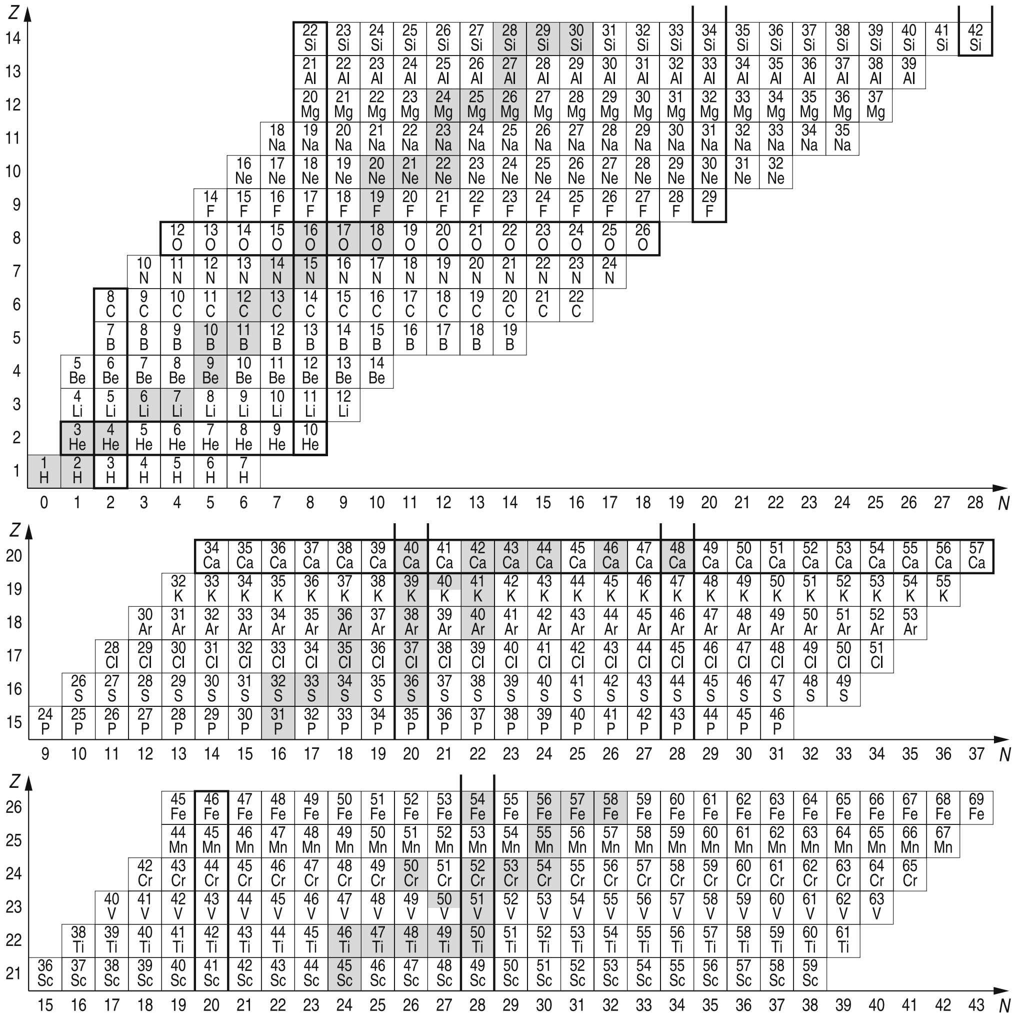
O Simplified Table of Isotopes and Periodic Table of Elements

The isotopes (fixed number of protons Z and variable number of neutrons) of various elements are arranged horizontally. Isotones (fixed number of neutrons N) are put vertically.

In the overview table below, stable, primordial, and unstable nuclides are displayed with different gray scales, and the cut-out tables are marked by dash-dotted frames; the latter are shown in the order from lighter to heavier isotopes, i.e. from the lower left to the upper right. In the cut-out tables the stable nuclides are highlighted by a light gray background and the primordial ones by such a background in the upper half of their small box. Magic numbers are marked by frames of bold solid lines.



An isotope is said to be stable, if its half-life is larger than 10^{10} yrs, which roughly corresponds to the age of the universe. The mass number is conserved in β decays. Such nuclear decays therefore describe transitions in the diagonal (isobars) $A = Z + N =$ const (β^-: one isotope to the upper left; β^+: one isotope to the lower right). α decays change the mass number by 4 units and the nuclear-charge number by 2 units. In the diagram these transitions are obtained by $\Delta N = \Delta Z = -2$. Decays by spontaneous fission only occur for elements with $Z \geq 90$. The decay by spontaneous fission is often in competition to α decay.



Z \ N	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
46																									91 Pd	92 Pd	93 Pd	94 Pd
45																								89 Rh	90 Rh	91 Rh	92 Rh	93 Rh
44																							87 Ru	88 Ru	89 Ru	90 Ru	91 Ru	92 Ru
43																						85 Tc	86 Tc	87 Tc	88 Tc	89 Tc	90 Tc	91 Tc
42																					83 Mo	84 Mo	85 Mo	86 Mo	87 Mo	88 Mo	89 Mo	90 Mo
41																				81 Nb	82 Nb	83 Nb	84 Nb	85 Nb	86 Nb	87 Nb	88 Nb	89 Nb
40																			79 Zr	80 Zr	81 Zr	82 Zr	83 Zr	84 Zr	85 Zr	86 Zr	87 Zr	88 Zr
39																		77 Y	78 Y	79 Y	80 Y	81 Y	82 Y	83 Y	84 Y	85 Y	86 Y	87 Y
38															73 Sr	74 Sr	75 Sr	76 Sr	77 Sr	78 Sr	79 Sr	80 Sr	81 Sr	82 Sr	83 Sr	84 Sr	85 Sr	86 Sr
37														71 Rb	72 Rb	73 Rb	74 Rb	75 Rb	76 Rb	77 Rb	78 Rb	79 Rb	80 Rb	81 Rb	82 Rb	83 Rb	84 Rb	85 Rb
36													69 Kr	70 Kr	71 Kr	72 Kr	73 Kr	74 Kr	75 Kr	76 Kr	77 Kr	78 Kr	79 Kr	80 Kr	81 Kr	82 Kr	83 Kr	84 Kr
35												67 Br	68 Br	69 Br	70 Br	71 Br	72 Br	73 Br	74 Br	75 Br	76 Br	77 Br	78 Br	79 Br	80 Br	81 Br	82 Br	83 Br
34											65 Se	66 Se	67 Se	68 Se	69 Se	70 Se	71 Se	72 Se	73 Se	74 Se	75 Se	76 Se	77 Se	78 Se	79 Se	80 Se	81 Se	82 Se
33								61 As	62 As	63 As	64 As	65 As	66 As	67 As	68 As	69 As	70 As	71 As	72 As	73 As	74 As	75 As	76 As	77 As	78 As	79 As	80 As	81 As
32						58 Ge	59 Ge	60 Ge	61 Ge	62 Ge	63 Ge	64 Ge	65 Ge	66 Ge	67 Ge	68 Ge	69 Ge	70 Ge	71 Ge	72 Ge	73 Ge	74 Ge	75 Ge	76 Ge	77 Ge	78 Ge	79 Ge	80 Ge
31					56 Ga	57 Ga	58 Ga	59 Ga	60 Ga	61 Ga	62 Ga	63 Ga	64 Ga	65 Ga	66 Ga	67 Ga	68 Ga	69 Ga	70 Ga	71 Ga	72 Ga	73 Ga	74 Ga	75 Ga	76 Ga	77 Ga	78 Ga	79 Ga
30				54 Zn	55 Zn	56 Zn	57 Zn	58 Zn	59 Zn	60 Zn	61 Zn	62 Zn	63 Zn	64 Zn	65 Zn	66 Zn	67 Zn	68 Zn	69 Zn	70 Zn	71 Zn	72 Zn	73 Zn	74 Zn	75 Zn	76 Zn	77 Zn	78 Zn
29			52 Cu	53 Cu	54 Cu	55 Cu	56 Cu	57 Cu	58 Cu	59 Cu	60 Cu	61 Cu	62 Cu	63 Cu	64 Cu	65 Cu	66 Cu	67 Cu	68 Cu	69 Cu	70 Cu	71 Cu	72 Cu	73 Cu	74 Cu	75 Cu	76 Cu	77 Cu
28		50 Ni	51 Ni	52 Ni	53 Ni	54 Ni	55 Ni	56 Ni	57 Ni	58 Ni	59 Ni	60 Ni	61 Ni	62 Ni	63 Ni	64 Ni	65 Ni	66 Ni	67 Ni	68 Ni	69 Ni	70 Ni	71 Ni	72 Ni	73 Ni	74 Ni	75 Ni	76 Ni
27	48 Co	49 Co	50 Co	51 Co	52 Co	53 Co	54 Co	55 Co	56 Co	57 Co	58 Co	59 Co	60 Co	61 Co	62 Co	63 Co	64 Co	65 Co	66 Co	67 Co	68 Co	69 Co	70 Co	71 Co	72 Co	73 Co	74 Co	75 Co

Z \ N	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77
46	95 Pd	96 Pd	97 Pd	98 Pd	99 Pd	100 Pd	101 Pd	102 Pd	103 Pd	104 Pd	105 Pd	106 Pd	107 Pd	108 Pd	109 Pd	110 Pd	111 Pd	112 Pd	113 Pd	114 Pd	115 Pd	116 Pd	117 Pd	118 Pd	119 Pd	120 Pd	121 Pd	122 Pd	123 Pd
45	94 Rh	95 Rh	96 Rh	97 Rh	98 Rh	99 Rh	100 Rh	101 Rh	102 Rh	103 Rh	104 Rh	105 Rh	106 Rh	107 Rh	108 Rh	109 Rh	110 Rh	111 Rh	112 Rh	113 Rh	114 Rh	115 Rh	116 Rh	117 Rh	118 Rh	119 Rh	120 Rh	121 Rh	
44	93 Ru	94 Ru	95 Ru	96 Ru	97 Ru	98 Ru	99 Ru	100 Ru	101 Ru	102 Ru	103 Ru	104 Ru	105 Ru	106 Ru	107 Ru	108 Ru	109 Ru	110 Ru	111 Ru	112 Ru	113 Ru	114 Ru	115 Ru	116 Ru	117 Ru	118 Ru			
43	92 Tc	93 Tc	94 Tc	95 Tc	96 Tc	97 Tc	98 Tc	99 Tc	100 Tc	101 Tc	102 Tc	103 Tc	104 Tc	105 Tc	106 Tc	107 Tc	108 Tc	109 Tc	110 Tc	111 Tc	112 Tc	113 Tc	114 Tc	115 Tc					
42	91 Mo	92 Mo	93 Mo	94 Mo	95 Mo	96 Mo	97 Mo	98 Mo	99 Mo	100 Mo	101 Mo	102 Mo	103 Mo	104 Mo	105 Mo	106 Mo	107 Mo	108 Mo	109 Mo	110 Mo	111 Mo	112 Mo	113 Mo						
41	90 Nb	91 Nb	92 Nb	93 Nb	94 Nb	95 Nb	96 Nb	97 Nb	98 Nb	99 Nb	100 Nb	101 Nb	102 Nb	103 Nb	104 Nb	105 Nb	106 Nb	107 Nb	108 Nb	109 Nb	110 Nb								
40	89 Zr	90 Zr	91 Zr	92 Zr	93 Zr	94 Zr	95 Zr	96 Zr	97 Zr	98 Zr	99 Zr	100 Zr	101 Zr	102 Zr	103 Zr	104 Zr	105 Zr	106 Zr	107 Zr	108 Zr									
39	88 Y	89 Y	90 Y	91 Y	92 Y	93 Y	94 Y	95 Y	96 Y	97 Y	98 Y	99 Y	100 Y	101 Y	102 Y	103 Y	104 Y	105 Y	106 Y										
38	87 Sr	88 Sr	89 Sr	90 Sr	91 Sr	92 Sr	93 Sr	94 Sr	95 Sr	96 Sr	97 Sr	98 Sr	99 Sr	100 Sr	101 Sr	102 Sr	103 Sr	104 Sr											
37	86 Rb	87 Rb	88 Rb	89 Rb	90 Rb	91 Rb	92 Rb	93 Rb	94 Rb	95 Rb	96 Rb	97 Rb	98 Rb	99 Rb	100 Rb	101 Rb	102 Rb												
36	85 Kr	86 Kr	87 Kr	88 Kr	89 Kr	90 Kr	91 Kr	92 Kr	93 Kr	94 Kr	95 Kr	96 Kr	97 Kr																
35	84 Br	85 Br	86 Br	87 Br	88 Br	89 Br	90 Br	91 Br	92 Br	93 Br	94 Br																		
34	83 Se	84 Se	85 Se	86 Se	87 Se	88 Se	89 Se	90 Se	91 Se	92 Se																			
33	82 As	83 As	84 As	85 As	86 As	87 As	88 As	89 As																					
32	81 Ge	82 Ge	83 Ge	84 Ge	85 Ge	86 Ge																							
31	80 Ga	81 Ga	82 Ga	83 Ga	84 Ga																								
30	79 Zn	80 Zn	81 Zn	82 Zn																									
29	78 Cu	79 Cu	80 Cu																										
28	77 Ni	78 Ni																											
27																													

Z / N	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
65																											138 Tb	139 Tb	140 Tb	141 Tb
64																									135 Gd	136 Gd	137 Gd	138 Gd	139 Gd	140 Gd
63																						131 Eu	132 Eu	133 Eu	134 Eu	135 Eu	136 Eu	137 Eu	138 Eu	139 Eu
62																						130 Sm	131 Sm	132 Sm	133 Sm	134 Sm	135 Sm	136 Sm	137 Sm	138 Sm
61																					128 Pm	129 Pm	130 Pm	131 Pm	132 Pm	133 Pm	134 Pm	135 Pm	136 Pm	137 Pm
60																				126 Nd	127 Nd	128 Nd	129 Nd	130 Nd	131 Nd	132 Nd	133 Nd	134 Nd	135 Nd	136 Nd
59																121 Pr	122 Pr	123 Pr	124 Pr	125 Pr	126 Pr	127 Pr	128 Pr	129 Pr	130 Pr	131 Pr	132 Pr	133 Pr	134 Pr	135 Pr
58															119 Ce	120 Ce	121 Ce	122 Ce	123 Ce	124 Ce	125 Ce	126 Ce	127 Ce	128 Ce	129 Ce	130 Ce	131 Ce	132 Ce	133 Ce	134 Ce
57														117 La	118 La	119 La	120 La	121 La	122 La	123 La	124 La	125 La	126 La	127 La	128 La	129 La	130 La	131 La	132 La	133 La
56												114 Ba	115 Ba	116 Ba	117 Ba	118 Ba	119 Ba	120 Ba	121 Ba	122 Ba	123 Ba	124 Ba	125 Ba	126 Ba	127 Ba	128 Ba	129 Ba	130 Ba	131 Ba	132 Ba
55											112 Cs	113 Cs	114 Cs	115 Cs	116 Cs	117 Cs	118 Cs	119 Cs	120 Cs	121 Cs	122 Cs	123 Cs	124 Cs	125 Cs	126 Cs	127 Cs	128 Cs	129 Cs	130 Cs	131 Cs
54										110 Xe	111 Xe	112 Xe	113 Xe	114 Xe	115 Xe	116 Xe	117 Xe	118 Xe	119 Xe	120 Xe	121 Xe	122 Xe	123 Xe	124 Xe	125 Xe	126 Xe	127 Xe	128 Xe	129 Xe	130 Xe
53									108 I	109 I	110 I	111 I	112 I	113 I	114 I	115 I	116 I	117 I	118 I	119 I	120 I	121 I	122 I	123 I	124 I	125 I	126 I	127 I	128 I	129 I
52								106 Te	107 Te	108 Te	109 Te	110 Te	111 Te	112 Te	113 Te	114 Te	115 Te	116 Te	117 Te	118 Te	119 Te	120 Te	121 Te	122 Te	123 Te	124 Te	125 Te	126 Te	127 Te	128 Te
51						103 Sb	104 Sb	105 Sb	106 Sb	107 Sb	108 Sb	109 Sb	110 Sb	111 Sb	112 Sb	113 Sb	114 Sb	115 Sb	116 Sb	117 Sb	118 Sb	119 Sb	120 Sb	121 Sb	122 Sb	123 Sb	124 Sb	125 Sb	126 Sb	127 Sb
50				100 Sn	101 Sn	102 Sn	103 Sn	104 Sn	105 Sn	106 Sn	107 Sn	108 Sn	109 Sn	110 Sn	111 Sn	112 Sn	113 Sn	114 Sn	115 Sn	116 Sn	117 Sn	118 Sn	119 Sn	120 Sn	121 Sn	122 Sn	123 Sn	124 Sn	125 Sn	126 Sn
49			98 In	99 In	100 In	101 In	102 In	103 In	104 In	105 In	106 In	107 In	108 In	109 In	110 In	111 In	112 In	113 In	114 In	115 In	116 In	117 In	118 In	119 In	120 In	121 In	122 In	123 In	124 In	125 In
48		96 Cd	97 Cd	98 Cd	99 Cd	100 Cd	101 Cd	102 Cd	103 Cd	104 Cd	105 Cd	106 Cd	107 Cd	108 Cd	109 Cd	110 Cd	111 Cd	112 Cd	113 Cd	114 Cd	115 Cd	116 Cd	117 Cd	118 Cd	119 Cd	120 Cd	121 Cd	122 Cd	123 Cd	124 Cd
47	94 Ag	95 Ag	96 Ag	97 Ag	98 Ag	99 Ag	100 Ag	101 Ag	102 Ag	103 Ag	104 Ag	105 Ag	106 Ag	107 Ag	108 Ag	109 Ag	110 Ag	111 Ag	112 Ag	113 Ag	114 Ag	115 Ag	116 Ag	117 Ag	118 Ag	119 Ag	120 Ag	121 Ag	122 Ag	123 Ag

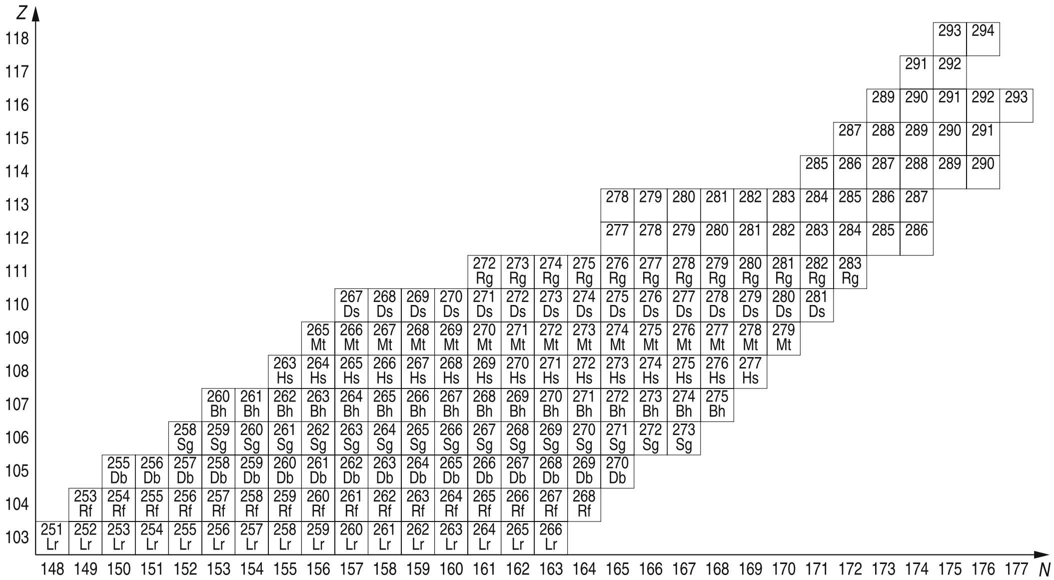
Z / N	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106
65	142 Tb	143 Tb	144 Tb	145 Tb	146 Tb	147 Tb	148 Tb	149 Tb	150 Tb	151 Tb	152 Tb	153 Tb	154 Tb	155 Tb	156 Tb	157 Tb	158 Tb	159 Tb	160 Tb	161 Tb	162 Tb	163 Tb	164 Tb	165 Tb	166 Tb	167 Tb	168 Tb	169 Tb	170 Tb	171 Tb
64	141 Gd	142 Gd	143 Gd	144 Gd	145 Gd	146 Gd	147 Gd	148 Gd	149 Gd	150 Gd	151 Gd	152 Gd	153 Gd	154 Gd	155 Gd	156 Gd	157 Gd	158 Gd	159 Gd	160 Gd	161 Gd	162 Gd	163 Gd	164 Gd	165 Gd	166 Gd	167 Gd	168 Gd	169 Gd	
63	140 Eu	141 Eu	142 Eu	143 Eu	144 Eu	145 Eu	146 Eu	147 Eu	148 Eu	149 Eu	150 Eu	151 Eu	152 Eu	153 Eu	154 Eu	155 Eu	156 Eu	157 Eu	158 Eu	159 Eu	160 Eu	161 Eu	162 Eu	163 Eu	164 Eu	165 Eu	166 Eu	167 Eu		
62	139 Sm	140 Sm	141 Sm	142 Sm	143 Sm	144 Sm	145 Sm	146 Sm	147 Sm	148 Sm	149 Sm	150 Sm	151 Sm	152 Sm	153 Sm	154 Sm	155 Sm	156 Sm	157 Sm	158 Sm	159 Sm	160 Sm	161 Sm	162 Sm	163 Sm	164 Sm	165 Sm			
61	138 Pm	139 Pm	140 Pm	141 Pm	142 Pm	143 Pm	144 Pm	145 Pm	146 Pm	147 Pm	148 Pm	149 Pm	150 Pm	151 Pm	152 Pm	153 Pm	154 Pm	155 Pm	156 Pm	157 Pm	158 Pm	159 Pm	160 Pm	161 Pm	162 Pm	163 Pm				
60	137 Nd	138 Nd	139 Nd	140 Nd	141 Nd	142 Nd	143 Nd	144 Nd	145 Nd	146 Nd	147 Nd	148 Nd	149 Nd	150 Nd	151 Nd	152 Nd	153 Nd	154 Nd	155 Nd	156 Nd	157 Nd	158 Nd	159 Nd	160 Nd	161 Nd					
59	136 Pr	137 Pr	138 Pr	139 Pr	140 Pr	141 Pr	142 Pr	143 Pr	144 Pr	145 Pr	146 Pr	147 Pr	148 Pr	149 Pr	150 Pr	151 Pr	152 Pr	153 Pr	154 Pr	155 Pr	156 Pr	157 Pr	158 Pr	159 Pr						
58	135 Ce	136 Ce	137 Ce	138 Ce	139 Ce	140 Ce	141 Ce	142 Ce	143 Ce	144 Ce	145 Ce	146 Ce	147 Ce	148 Ce	149 Ce	150 Ce	151 Ce	152 Ce	153 Ce	154 Ce	155 Ce	156 Ce	157 Ce							
57	134 La	135 La	136 La	137 La	138 La	139 La	140 La	141 La	142 La	143 La	144 La	145 La	146 La	147 La	148 La	149 La	150 La	151 La	152 La	153 La	154 La	155 La								
56	133 Ba	134 Ba	135 Ba	136 Ba	137 Ba	138 Ba	139 Ba	140 Ba	141 Ba	142 Ba	143 Ba	144 Ba	145 Ba	146 Ba	147 Ba	148 Ba	149 Ba	150 Ba	151 Ba	152 Ba	153 Ba									
55	132 Cs	133 Cs	134 Cs	135 Cs	136 Cs	137 Cs	138 Cs	139 Cs	140 Cs	141 Cs	142 Cs	143 Cs	144 Cs	145 Cs	146 Cs	147 Cs	148 Cs	149 Cs	150 Cs	151 Cs	152 Cs									
54	131 Xe	132 Xe	133 Xe	134 Xe	135 Xe	136 Xe	137 Xe	138 Xe	139 Xe	140 Xe	141 Xe	142 Xe	143 Xe	144 Xe	145 Xe	146 Xe	147 Xe													
53	130 I	131 I	132 I	133 I	134 I	135 I	136 I	137 I	138 I	139 I	140 I	141 I	142 I	143 I	144 I															
52	129 Te	130 Te	131 Te	132 Te	133 Te	134 Te	135 Te	136 Te	137 Te	138 Te	139 Te	140 Te	141 Te	142 Te																
51	128 Sb	129 Sb	130 Sb	131 Sb	132 Sb	133 Sb	134 Sb	135 Sb	136 Sb	137 Sb	138 Sb	139 Sb																		
50	127 Sn	128 Sn	129 Sn	130 Sn	131 Sn	132 Sn	133 Sn	134 Sn	135 Sn	136 Sn	137 Sn																			
49	126 In	127 In	128 In	129 In	130 In	131 In	132 In	133 In	134 In																					
48	125 Cd	126 Cd	127 Cd	128 Cd	129 Cd	130 Cd																								
47	124 Ag	125 Ag	126 Ag	127 Ag																										

Z \ N	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
82																									180 Pb	181 Pb	182 Pb	183 Pb	184 Pb	185 Pb
81																							177 Tl	178 Tl	179 Tl	180 Tl	181 Tl	182 Tl	183 Tl	184 Tl
80																					174 Hg	175 Hg	176 Hg	177 Hg	178 Hg	179 Hg	180 Hg	181 Hg	182 Hg	183 Hg
79																			171 Au	172 Au	173 Au	174 Au	175 Au	176 Au	177 Au	178 Au	179 Au	180 Au	181 Au	182 Au
78															166 Pt	167 Pt	168 Pt	169 Pt	170 Pt	171 Pt	172 Pt	173 Pt	174 Pt	175 Pt	176 Pt	177 Pt	178 Pt	179 Pt	180 Pt	181 Pt
77															165 Ir	166 Ir	167 Ir	168 Ir	169 Ir	170 Ir	171 Ir	172 Ir	173 Ir	174 Ir	175 Ir	176 Ir	177 Ir	178 Ir	179 Ir	180 Ir
76													162 Os	163 Os	164 Os	165 Os	166 Os	167 Os	168 Os	169 Os	170 Os	171 Os	172 Os	173 Os	174 Os	175 Os	176 Os	177 Os	178 Os	179 Os
75												160 Re	161 Re	162 Re	163 Re	164 Re	165 Re	166 Re	167 Re	168 Re	169 Re	170 Re	171 Re	172 Re	173 Re	174 Re	175 Re	176 Re	177 Re	178 Re
74											158 W	159 W	160 W	161 W	162 W	163 W	164 W	165 W	166 W	167 W	168 W	169 W	170 W	171 W	172 W	173 W	174 W	175 W	176 W	177 W
73										156 Ta	157 Ta	158 Ta	159 Ta	160 Ta	161 Ta	162 Ta	163 Ta	164 Ta	165 Ta	166 Ta	167 Ta	168 Ta	169 Ta	170 Ta	171 Ta	172 Ta	173 Ta	174 Ta	175 Ta	176 Ta
72									154 Hf	155 Hf	156 Hf	157 Hf	158 Hf	159 Hf	160 Hf	161 Hf	162 Hf	163 Hf	164 Hf	165 Hf	166 Hf	167 Hf	168 Hf	169 Hf	170 Hf	171 Hf	172 Hf	173 Hf	174 Hf	175 Hf
71						150 Lu	151 Lu	152 Lu	153 Lu	154 Lu	155 Lu	156 Lu	157 Lu	158 Lu	159 Lu	160 Lu	161 Lu	162 Lu	163 Lu	164 Lu	165 Lu	166 Lu	167 Lu	168 Lu	169 Lu	170 Lu	171 Lu	172 Lu	173 Lu	174 Lu
70					148 Yb	149 Yb	150 Yb	151 Yb	152 Yb	153 Yb	154 Yb	155 Yb	156 Yb	157 Yb	158 Yb	159 Yb	160 Yb	161 Yb	162 Yb	163 Yb	164 Yb	165 Yb	166 Yb	167 Yb	168 Yb	169 Yb	170 Yb	171 Yb	172 Yb	173 Yb
69			145 Tm	146 Tm	147 Tm	148 Tm	149 Tm	150 Tm	151 Tm	152 Tm	153 Tm	154 Tm	155 Tm	156 Tm	157 Tm	158 Tm	159 Tm	160 Tm	161 Tm	162 Tm	163 Tm	164 Tm	165 Tm	166 Tm	167 Tm	168 Tm	169 Tm	170 Tm	171 Tm	172 Tm
68			144 Er	145 Er	146 Er	147 Er	148 Er	149 Er	150 Er	151 Er	152 Er	153 Er	154 Er	155 Er	156 Er	157 Er	158 Er	159 Er	160 Er	161 Er	162 Er	163 Er	164 Er	165 Er	166 Er	167 Er	168 Er	169 Er	170 Er	171 Er
67	141 Ho	142 Ho	143 Ho	144 Ho	145 Ho	146 Ho	147 Ho	148 Ho	149 Ho	150 Ho	151 Ho	152 Ho	153 Ho	154 Ho	155 Ho	156 Ho	157 Ho	158 Ho	159 Ho	160 Ho	161 Ho	162 Ho	163 Ho	164 Ho	165 Ho	166 Ho	167 Ho	168 Ho	169 Ho	170 Ho
66	140 Dy	141 Dy	142 Dy	143 Dy	144 Dy	145 Dy	146 Dy	147 Dy	148 Dy	149 Dy	150 Dy	151 Dy	152 Dy	153 Dy	154 Dy	155 Dy	156 Dy	157 Dy	158 Dy	159 Dy	160 Dy	161 Dy	162 Dy	163 Dy	164 Dy	165 Dy	166 Dy	167 Dy	168 Dy	169 Dy

Z \ N	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132
82	186 Pb	187 Pb	188 Pb	189 Pb	190 Pb	191 Pb	192 Pb	193 Pb	194 Pb	195 Pb	196 Pb	197 Pb	198 Pb	199 Pb	200 Pb	201 Pb	202 Pb	203 Pb	204 Pb	205 Pb	206 Pb	207 Pb	208 Pb	209 Pb	210 Pb	211 Pb	212 Pb	213 Pb	214 Pb
81	185 Tl	186 Tl	187 Tl	188 Tl	189 Tl	190 Tl	191 Tl	192 Tl	193 Tl	194 Tl	195 Tl	196 Tl	197 Tl	198 Tl	199 Tl	200 Tl	201 Tl	202 Tl	203 Tl	204 Tl	205 Tl	206 Tl	207 Tl	208 Tl	209 Tl	210 Tl	211 Tl	212 Tl	
80	184 Hg	185 Hg	186 Hg	187 Hg	188 Hg	189 Hg	190 Hg	191 Hg	192 Hg	193 Hg	194 Hg	195 Hg	196 Hg	197 Hg	198 Hg	199 Hg	200 Hg	201 Hg	202 Hg	203 Hg	204 Hg	205 Hg	206 Hg	207 Hg	208 Hg	209 Hg	210 Hg		
79	183 Au	184 Au	185 Au	186 Au	187 Au	188 Au	189 Au	190 Au	191 Au	192 Au	193 Au	194 Au	195 Au	196 Au	197 Au	198 Au	199 Au	200 Au	201 Au	202 Au	203 Au	204 Au	205 Au						
78	182 Pt	183 Pt	184 Pt	185 Pt	186 Pt	187 Pt	188 Pt	189 Pt	190 Pt	191 Pt	192 Pt	193 Pt	194 Pt	195 Pt	196 Pt	197 Pt	198 Pt	199 Pt	200 Pt	201 Pt	202 Pt								
77	181 Ir	182 Ir	183 Ir	184 Ir	185 Ir	186 Ir	187 Ir	188 Ir	189 Ir	190 Ir	191 Ir	192 Ir	193 Ir	194 Ir	195 Ir	196 Ir	197 Ir	198 Ir											
76	180 Os	181 Os	182 Os	183 Os	184 Os	185 Os	186 Os	187 Os	188 Os	189 Os	190 Os	191 Os	192 Os	193 Os	194 Os	195 Os	196 Os												
75	179 Re	180 Re	181 Re	182 Re	183 Re	184 Re	185 Re	186 Re	187 Re	188 Re	189 Re	190 Re	191 Re	192 Re															
74	178 W	179 W	180 W	181 W	182 W	183 W	184 W	185 W	186 W	187 W	188 W	189 W	190 W																
73	177 Ta	178 Ta	179 Ta	180 Ta	181 Ta	182 Ta	183 Ta	184 Ta	185 Ta	186 Ta	187 Ta	188 Ta																	
72	176 Hf	177 Hf	178 Hf	179 Hf	180 Hf	181 Hf	182 Hf	183 Hf	184 Hf	185 Hf																			
71	175 Lu	176 Lu	177 Lu	178 Lu	179 Lu	180 Lu	181 Lu	182 Lu	183 Lu	184 Lu																			
70	174 Yb	175 Yb	176 Yb	177 Yb	178 Yb	179 Yb	180 Yb	181 Yb																					
69	173 Tm	174 Tm	175 Tm	176 Tm	177 Tm	178 Tm	179 Tm																						
68	172 Er	173 Er	174 Er	175 Er	176 Er	177 Er																							
67	171 Ho	172 Ho	173 Ho	174 Ho	175 Ho																								
66	170 Dy	171 Dy	172 Dy	173 Dy																									

Z \ N	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131
102																														
101																														
100																														
99																														
98																														
97																														
96																														
95																														
94																														
93																														
92																									218 U	219 U	220 U	221 U	222 U	223 U
91																				212 Pa	213 Pa	214 Pa	215 Pa	216 Pa	217 Pa	218 Pa	219 Pa	220 Pa	221 Pa	222 Pa
90																			210 Th	211 Th	212 Th	213 Th	214 Th	215 Th	216 Th	217 Th	218 Th	219 Th	220 Th	221 Th
89																	207 Ac	208 Ac	209 Ac	210 Ac	211 Ac	212 Ac	213 Ac	214 Ac	215 Ac	216 Ac	217 Ac	218 Ac	219 Ac	220 Ac
88													202 Ra	203 Ra	204 Ra	205 Ra	206 Ra	207 Ra	208 Ra	209 Ra	210 Ra	211 Ra	212 Ra	213 Ra	214 Ra	215 Ra	216 Ra	217 Ra	218 Ra	219 Ra
87												200 Fr	201 Fr	202 Fr	203 Fr	204 Fr	205 Fr	206 Fr	207 Fr	208 Fr	209 Fr	210 Fr	211 Fr	212 Fr	213 Fr	214 Fr	215 Fr	216 Fr	217 Fr	218 Fr
86									196 Rn	197 Rn	198 Rn	199 Rn	200 Rn	201 Rn	202 Rn	203 Rn	204 Rn	205 Rn	206 Rn	207 Rn	208 Rn	209 Rn	210 Rn	211 Rn	212 Rn	213 Rn	214 Rn	215 Rn	216 Rn	217 Rn
85								194 At	195 At	196 At	197 At	198 At	199 At	200 At	201 At	202 At	203 At	204 At	205 At	206 At	207 At	208 At	209 At	210 At	211 At	212 At	213 At	214 At	215 At	216 At
84					190 Po	191 Po	192 Po	193 Po	194 Po	195 Po	196 Po	197 Po	198 Po	199 Po	200 Po	201 Po	202 Po	203 Po	204 Po	205 Po	206 Po	207 Po	208 Po	209 Po	210 Po	211 Po	212 Po	213 Po	214 Po	215 Po
83	185 Bi	186 Bi	187 Bi	188 Bi	189 Bi	190 Bi	191 Bi	192 Bi	193 Bi	194 Bi	195 Bi	196 Bi	197 Bi	198 Bi	199 Bi	200 Bi	201 Bi	202 Bi	203 Bi	204 Bi	205 Bi	206 Bi	207 Bi	208 Bi	209 Bi	210 Bi	211 Bi	212 Bi	213 Bi	214 Bi

Z \ N	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161
102																249 No	250 No	251 No	252 No	253 No	254 No	255 No	256 No	257 No	258 No	259 No	260 No	261 No	262 No	263 No
101													245 Md	246 Md	247 Md	248 Md	249 Md	250 Md	251 Md	252 Md	253 Md	254 Md	255 Md	256 Md	257 Md	258 Md	259 Md	260 Md		
100											242 Fm	243 Fm	244 Fm	245 Fm	246 Fm	247 Fm	248 Fm	249 Fm	250 Fm	251 Fm	252 Fm	253 Fm	254 Fm	255 Fm	256 Fm	257 Fm	258 Fm	259 Fm	260 Fm	
99										240 Es	241 Es	242 Es	243 Es	244 Es	245 Es	246 Es	247 Es	248 Es	249 Es	250 Es	251 Es	252 Es	253 Es	254 Es	255 Es	256 Es	257 Es			
98								237 Cf	238 Cf	239 Cf	240 Cf	241 Cf	242 Cf	243 Cf	244 Cf	245 Cf	246 Cf	247 Cf	248 Cf	249 Cf	250 Cf	251 Cf	252 Cf	253 Cf	254 Cf	255 Cf	256 Cf			
97							235 Bk	236 Bk	237 Bk	238 Bk	239 Bk	240 Bk	241 Bk	242 Bk	243 Bk	244 Bk	245 Bk	246 Bk	247 Bk	248 Bk	249 Bk	250 Bk	251 Bk	252 Bk	253 Bk	254 Bk				
96						233 Cm	234 Cm	235 Cm	236 Cm	237 Cm	238 Cm	239 Cm	240 Cm	241 Cm	242 Cm	243 Cm	244 Cm	245 Cm	246 Cm	247 Cm	248 Cm	249 Cm	250 Cm	251 Cm	252 Cm					
95					231 Am	232 Am	233 Am	234 Am	235 Am	236 Am	237 Am	238 Am	239 Am	240 Am	241 Am	242 Am	243 Am	244 Am	245 Am	246 Am	247 Am	248 Am	249 Am							
94			228 Pu	229 Pu	230 Pu	231 Pu	232 Pu	233 Pu	234 Pu	235 Pu	236 Pu	237 Pu	238 Pu	239 Pu	240 Pu	241 Pu	242 Pu	243 Pu	244 Pu	245 Pu	246 Pu	247 Pu								
93	225 Np	226 Np	227 Np	228 Np	229 Np	230 Np	231 Np	232 Np	233 Np	234 Np	235 Np	236 Np	237 Np	238 Np	239 Np	240 Np	241 Np	242 Np	243 Np	244 Np										
92	224 U	225 U	226 U	227 U	228 U	229 U	230 U	231 U	232 U	233 U	234 U	235 U	236 U	237 U	238 U	239 U	240 U	241 U	242 U											
91	223 Pa	224 Pa	225 Pa	226 Pa	227 Pa	228 Pa	229 Pa	230 Pa	231 Pa	232 Pa	233 Pa	234 Pa	235 Pa	236 Pa	237 Pa	238 Pa														
90	222 Th	223 Th	224 Th	225 Th	226 Th	227 Th	228 Th	229 Th	230 Th	231 Th	232 Th	233 Th	234 Th	235 Th	236 Th	237 Th														
89	221 Ac	222 Ac	223 Ac	224 Ac	225 Ac	226 Ac	227 Ac	228 Ac	229 Ac	230 Ac	231 Ac	232 Ac	233 Ac	234 Ac																
88	220 Ra	221 Ra	222 Ra	223 Ra	224 Ra	225 Ra	226 Ra	227 Ra	228 Ra	229 Ra	230 Ra	231 Ra	232 Ra	233 Ra	234 Ra															
87	219 Fr	220 Fr	221 Fr	222 Fr	223 Fr	224 Fr	225 Fr	226 Fr	227 Fr	228 Fr	229 Fr	230 Fr	231 Fr	232 Fr																
86	218 Rn	219 Rn	220 Rn	221 Rn	222 Rn	223 Rn	224 Rn	225 Rn	226 Rn	227 Rn	228 Rn																			
85	217 At	218 At	219 At	220 At	221 At	222 At	223 At																							
84	216 Po	217 Po	218 Po	219 Po	220 Po																									
83	215 Bi	216 Bi	217 Bi	218 Bi																										



A complete overview of known isotopes is given in "Karlsruher Nuklidkarte" from 2006 (G. Pfennig, H. Klewe-Nebenius, W. Seelmann-Eggebert, Forschungszentrum Karlsruhe 2006). Up-to-date information one finds also under e.g. `www.nucleonica.net`.

Periodic Table of Elements

Group																	
Ia	IIa	IIIb	IVb	Vb	VIb	VIIb	VIIIb	VIIIb	VIIIb	Ib	IIb	IIIa	IVa	Va	VIa	VIIa	VIIIa
1 **H** Hydrogen 1.01																	2 **He** Helium 4.00
3 **Li** Lithium 6.94	4 **Be** Beryllium 9.01											5 **B** Boron 10.81	6 **C** Carbon 12.01	7 **N** Nitrogen 14.01	8 **O** Oxygen 16.00	9 **F** Fluorine 19.00	10 **Ne** Neon 20.18
11 **Na** Sodium 22.99	12 **Mg** Magnesium 24.31											13 **Al** Aluminum 26.98	14 **Si** Silicon 28.09	15 **P** Phosphorus 30.97	16 **S** Sulfur 32.07	17 **Cl** Chlorine 35.45	18 **Ar** Argon 39.95
19 **K** Potassium 39.10	20 **Ca** Calcium 40.08	21 **Sc** Scandium 44.96	22 **Ti** Titanium 47.87	23 **V** Vanadium 50.94	24 **Cr** Chromium 52.00	25 **Mn** Manganese 54.94	26 **Fe** Iron 55.85	27 **Co** Cobalt 58.93	28 **Ni** Nickel 58.69	29 **Cu** Copper 63.55	30 **Zn** Zinc 65.39	31 **Ga** Gallium 69.72	32 **Ge** Germanium 72.64	33 **As** Arsenic 74.92	34 **Se** Selenium 78.96	35 **Br** Bromine 79.90	36 **Kr** Krypton 83.80
37 **Rb** Rubidium 85.47	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.91	40 **Zr** Zirconium 91.22	41 **Nb** Niobium 92.91	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium 97.91	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.91	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.87	48 **Cd** Cadmium 112.41	49 **In** Indium 114.82	50 **Sn** Tin 118.71	51 **Sb** Antimony 121.76	52 **Te** Tellurium 127.60	53 **I** Iodine 126.90	54 **Xe** Xenon 131.29
55 **Cs** Cesium 132.91	56 **Ba** Barium 137.33	57-71 Lanthanides	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.95	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.21	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.22	78 **Pt** Platinum 195.08	79 **Au** Gold 196.97	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.38	82 **Pb** Lead 207.20	83 **Bi** Bismuth 208.98	84 **Po** Polonium 208.98	85 **At** Astatine 209.99	86 **Rn** Radon 222.02
87 **Fr** Francium 223.02	88 **Ra** Radium 226.03	89-103 Actinides	104 **Rf** Rutherfordium 261.11	105 **Db** Dubnium 262.11	106 **Sg** Seaborgium 263.12	107 **Bh** Bohrium 262.12	108 **Hs** Hassium 277.15	109 **Mt** Meitnerium 268.14	110 **Ds** Darmstadtium 271.15	111 **Rg** Roentgenium 272.15							

Lanthanide series	57 **La** Lanthanum 138.91	58 **Ce** Cerium 140.12	59 **Pr** Praseodymium 140.91	60 **Nd** Neodymium 144.24	61 **Pm** Promethium 144.91	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.96	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.93	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.93	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.93	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.97
Actinide series	89 **Ac** Actinium 227.03	90 **Th** Thorium 232.04	91 **Pa** Protactinium 231.04	92 **U** Uranium 238.03	93 **Np** Neptunium 237.05	94 **Pu** Plutonium 244.06	95 **Am** Americium 243.06	96 **Cm** Curium 247.07	97 **Bk** Berkelium 247.07	98 **Cf** Californium 251.08	99 **Es** Einsteinium 252.08	100 **Fm** Fermium 257.09	101 **Md** Mendelevium 258.10	102 **No** Nobelium 259.10	103 **Lr** Lawrencium 262.11

For each element the atomic number (top left) and atomic mass (bottom) is given. The atomic mass is weighted by the isotopic abundance in the Earth's crust.

P Decay-Level Schemes

In the following simplified decay-level schemes for some frequently used isotopes in the field of radiation protection are given. For the continuous electron spectra the maximum energies are given. EC stands for electron capture and ‘a’ for annum (year).

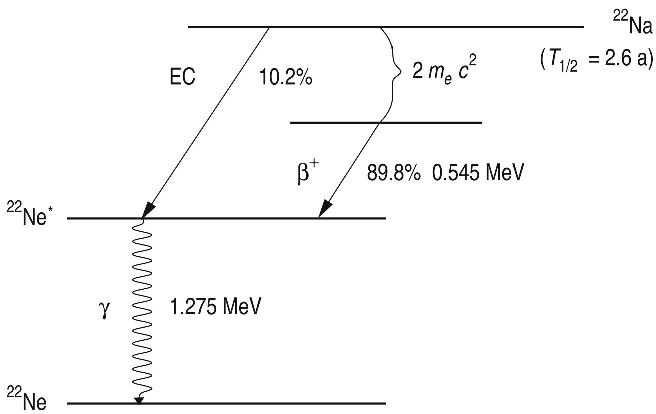
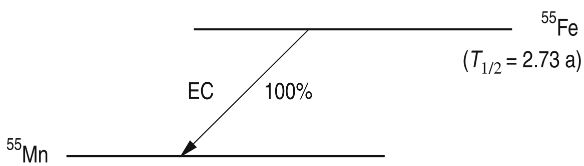


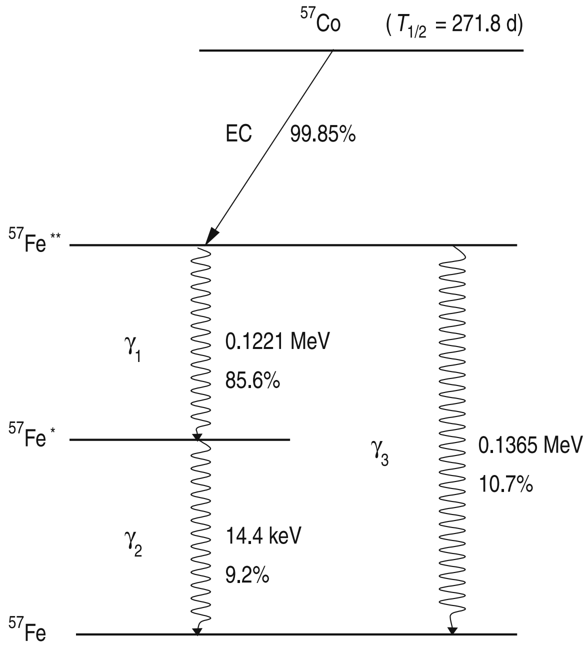
Figure P.1
Decay-level scheme of ^{22}Na



Characteristic X rays of ^{55}Mn:

$K_\alpha = 5.9\,\mathrm{keV}$
$K_\beta = 6.5\,\mathrm{keV}$

Figure P.2
Decay-level scheme of ^{55}Fe



Conversion electrons:

$K(\gamma_1) = 0.115\,\text{MeV}$ $L(\gamma_1) = 0.121\,\text{MeV}$
$K(\gamma_2) = 0.0073\,\text{MeV}$ $L(\gamma_2) = 0.0136\,\text{MeV}$
$K(\gamma_3) = 0.1294\,\text{MeV}$ $L(\gamma_3) = 0.1341\,\text{MeV}$

Figure P.3
Decay-level scheme of ^{57}Co

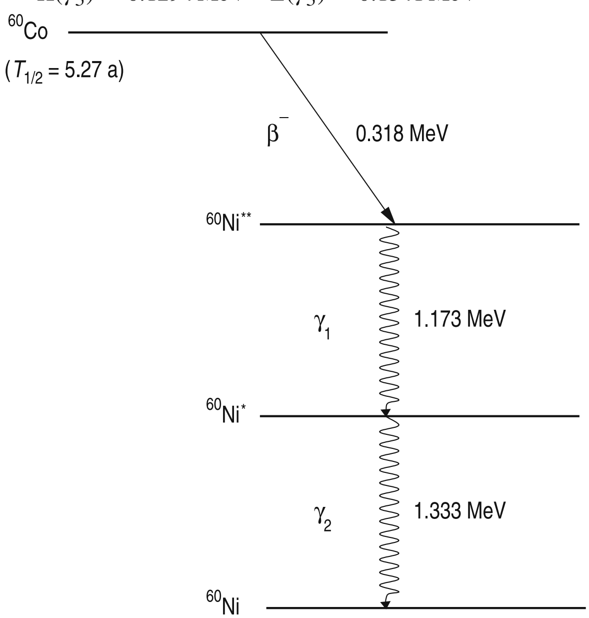


Figure P.4
Decay-level scheme of ^{60}Co

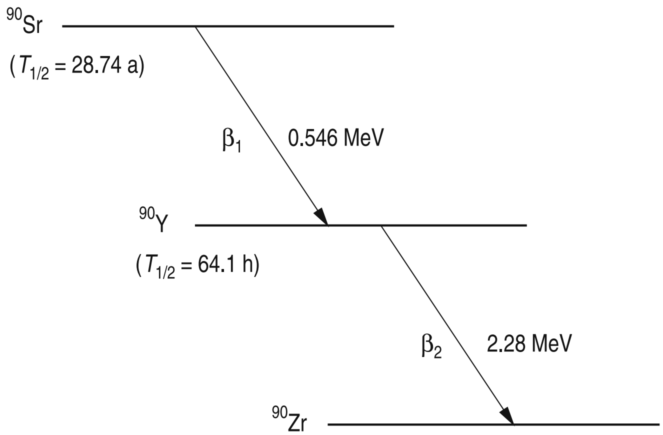


Figure P.5
Decay-level scheme of ^{90}Sr

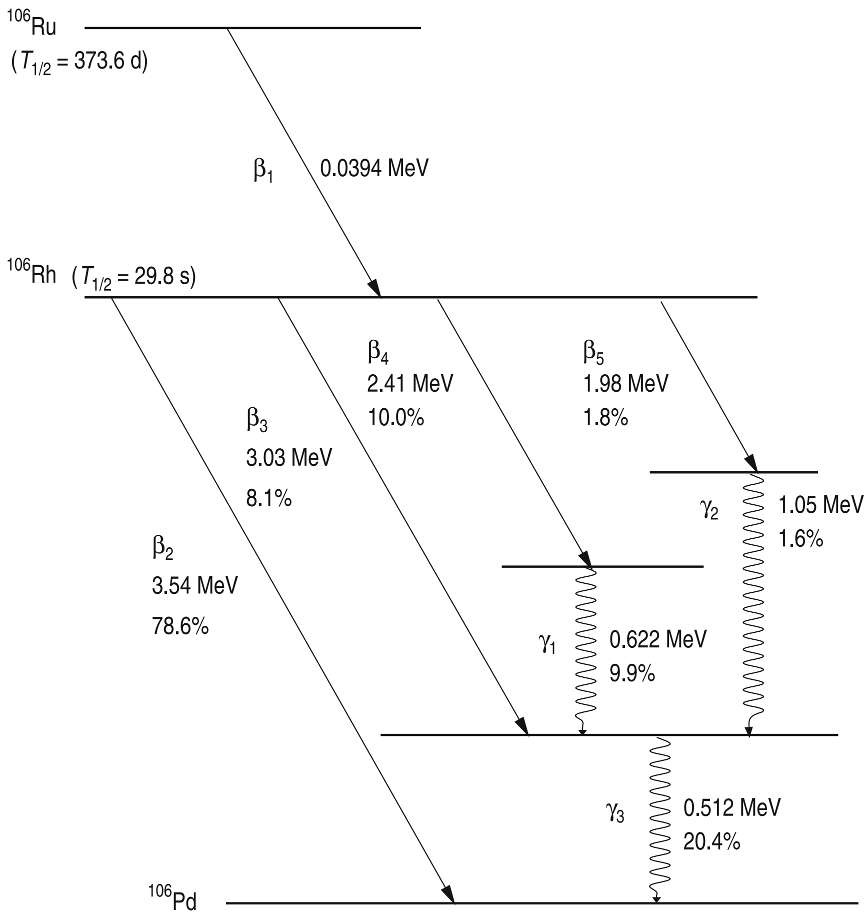
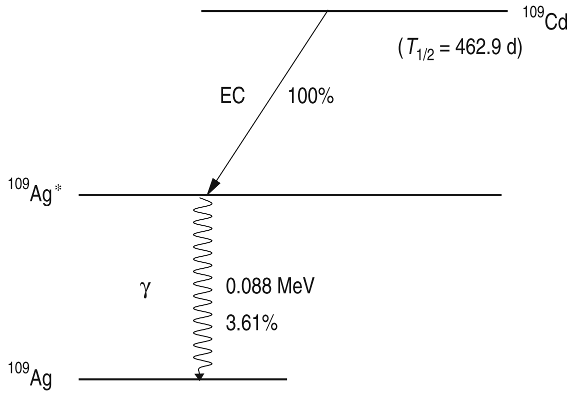


Figure P.6
Decay-level scheme of ^{106}Ru

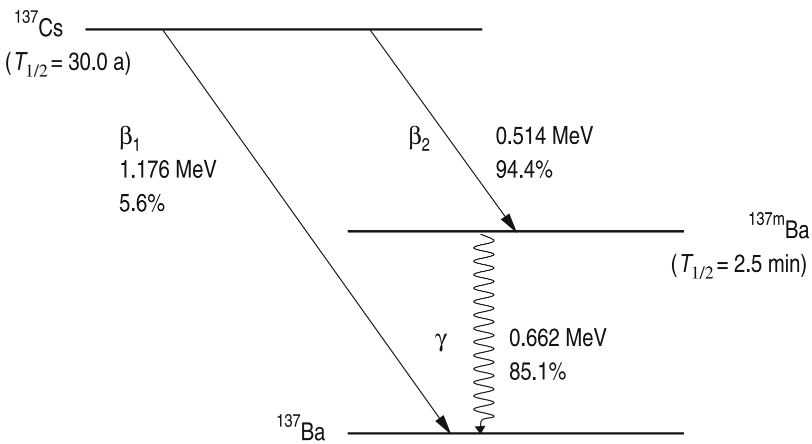


Conversion electrons:

$K(\gamma) = 0.0625\,\text{MeV}$
$L(\gamma) = 0.0842\,\text{MeV}$
$M(\gamma) = 0.0873\,\text{MeV}$

K_α X rays: 0.022 MeV
K_β X rays: 0.025 MeV

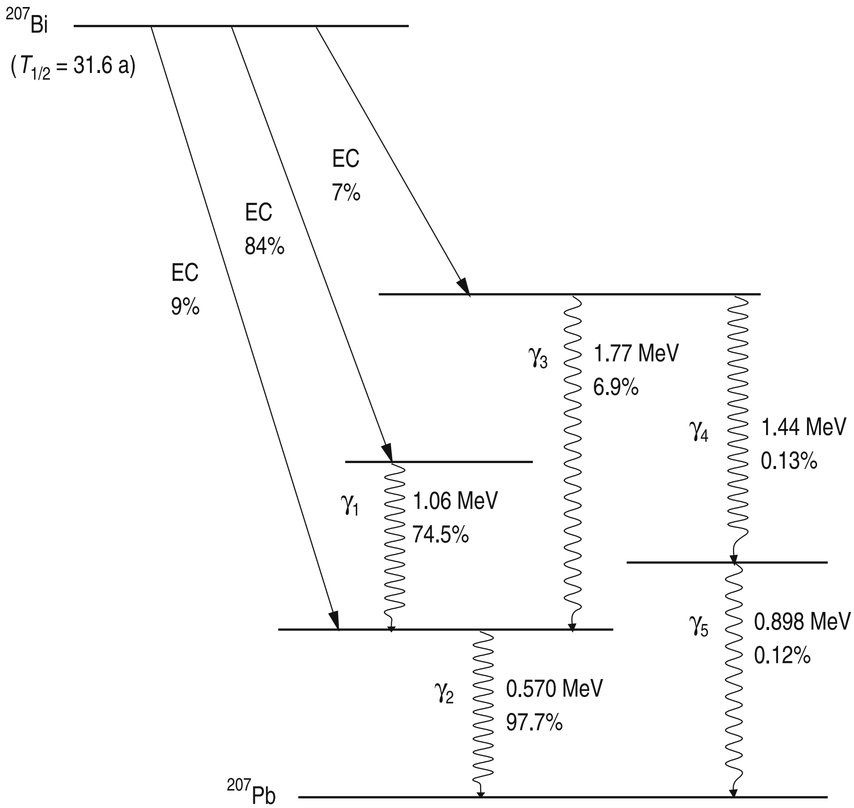
Figure P.7
Decay-level scheme of ^{109}Cd



Conversion electrons:

$K(\gamma) = 0.624\,\text{MeV}$
$L(\gamma) = 0.656\,\text{MeV}$

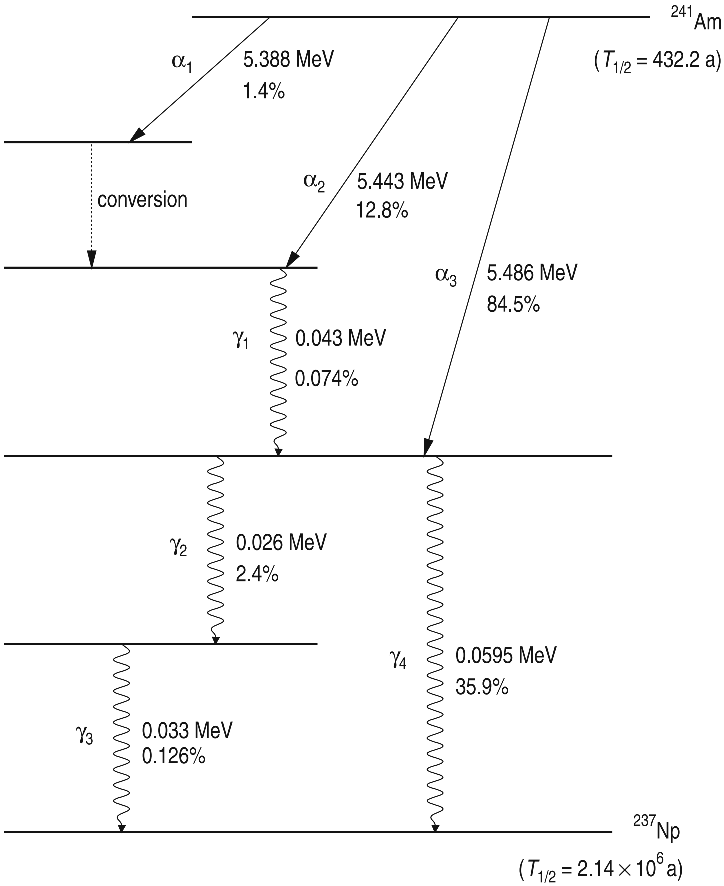
Figure P.8
Decay-level scheme of ^{137}Cs



Conversion electrons:

$\mathrm{K}(\gamma_1) = 0.976\,\mathrm{MeV}$ $\mathrm{L}(\gamma_1) = 1.048\,\mathrm{MeV}$
$\mathrm{K}(\gamma_2) = 0.482\,\mathrm{MeV}$ $\mathrm{L}(\gamma_2) = 0.554\,\mathrm{MeV}$
$\mathrm{K}(\gamma_3) = 1.682\,\mathrm{MeV}$ $\mathrm{L}(\gamma_3) = 1.754\,\mathrm{MeV}$
$\mathrm{K}(\gamma_4) = 1.352\,\mathrm{MeV}$ $\mathrm{L}(\gamma_4) = 1.424\,\mathrm{MeV}$
$\mathrm{K}(\gamma_5) = 0.810\,\mathrm{MeV}$ $\mathrm{L}(\gamma_5) = 0.882\,\mathrm{MeV}$

Figure P.9
Decay-level scheme of ^{207}Bi



Conversion electrons:

K(γ_i) kinematically impossible
$\mathrm{L}(\gamma_1) = 0.0210\,\mathrm{MeV}$
$\mathrm{L}(\gamma_2) = 0.0039\,\mathrm{MeV}$
$\mathrm{L}(\gamma_3) = 0.0108\,\mathrm{MeV}$
$\mathrm{L}(\gamma_4) = 0.0371\,\mathrm{MeV}$

Figure P.10
Decay-level scheme of ^{241}Am

Q Introduction into the Basics of Mathematics

"The physicist in preparing for his work needs three things: mathematics, mathematics, and mathematics."

Wilhelm Conrad Röntgen

Correlations and laws in natural science can most elegantly be represented by diagrams and elementary mathematical functions. The description of physics relations in mere words – like the simple law on the forces between two massive bodies – as it was standard three centuries ago (e.g. in Newton's Philosophiae Naturalis Principia Mathematica, 1687), is hard to understand and lacks the precision of mathematical notation. On the other hand, basic mathematical relations are not easily accessible to everyone, and it requires some experience and basic knowledge of getting used to them.

Nature, however, is governed by some natural laws and functions which cannot easily be described in words. Instead they are best represented by simple mathematical formulae. In the following, therefore, some basic concepts are explained, which are relevant for many aspects associated with radiation protection and radioactivity and which allow a precise representation of correlations and laws for data and facts.

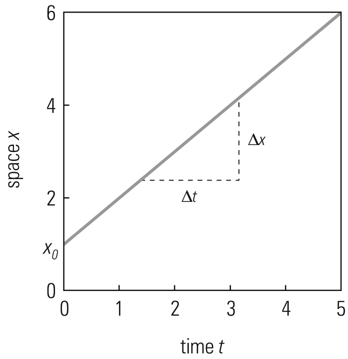
Q.1 Derivatives and Integrals

The temporal and spatial change of a quantity is called its derivative. This feature will be explained for the example of a path–time diagram. Figure Q.1 shows the uniform motion of some object as a function of space x and time t.

The constant slope of this line – expressed by the ratio $\Delta x/\Delta t$ – is the constant velocity v. If the velocity is not constant, the current value of the velocity depends on the size of the finite time and space intervals Δt and Δx. Such a non-linear path–time relation is plotted in Fig. Q.2.

difference quotient

The ratio $\Delta x/\Delta t$ for very small values of intervals leads to the concept of the instantaneous velocity at the time t_1. If the exact value of the velocity at the time t_1 is required, one has to select infinitesimally small space and time intervals. To characterize such infinitesimal intervals Leibniz proposed the notation $\mathrm{d}x/\mathrm{d}t$. The quantity $\mathrm{d}x/\mathrm{d}t$ therefore describes the slope of the path–time relation at the



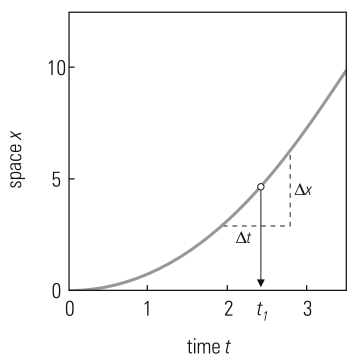


Figure Q.1
Relation between space and time for a uniform motion

Figure Q.2
Example of a non-linear relation between space and time

particular time t_1, which is the instantaneous velocity at the time t_1. Newton, who independently of Leibniz discovered this 'calculus', introduced as notation for the time derivative a dot over the spatial symbol: $\dot{x}$. Therfore we have the equivalence

notation convention

$$\frac{\mathrm{d}x}{\mathrm{d}t} \equiv \dot{x} \ . \tag{Q.1}$$

Leibniz' way to characterize the time derivative by $\mathrm{d}x/\mathrm{d}t$ has advanced the development of calculus (differential and integral calculus) substantially in continental Europe, while Newton's notation using dots on top of quantities – which was kept in England due to Newton's authority – hindered and delayed the advancement of calculus significantly. This was due to the fact that Leibniz' notation could be inverted without problems (see integration below), while this turned out to be difficult with the dot over the symbol.

Presently both notations are used only for time derivatives of physical quantities. Of course, both notations are equivalent. Figure Q.2 clearly shows that for a non-linear path–time relation the velocity $v = \mathrm{d}x/\mathrm{d}t$ changes with time. The object (e.g. a car starting at a traffic light when it turned green) accelerates from $t = 0$, where the acceleration is the change of velocity per time:

time derivative

acceleration

$$\text{acceleration } a = \frac{\mathrm{d}v}{\mathrm{d}t} = \dot{v} \ . \tag{Q.2}$$

Starting from considerations of the difference quotient, one can derive simple rules for the way how to differentiate special functions. For a polynomial

$$x(t) = a + b\,t + c\,t^2 \tag{Q.3}$$

one gets

$$\frac{\mathrm{d}x(t)}{\mathrm{d}t} = b + 2\,c\,t \ , \tag{Q.4}$$

as can be easily seen from Figs. Q.1 and Q.2 (the slope of a constant a is zero, the slope of a linear function $b\,t$ is equal to b, and the slope of a parabola $c\,t^2$ is obtained to be $2\,c\,t$).[1]

In general, a power-law relation is differentiated as

$$\frac{\mathrm{d}}{\mathrm{d}t}\,t^n = n\,t^{n-1} \ . \qquad \text{(Q.5)}$$

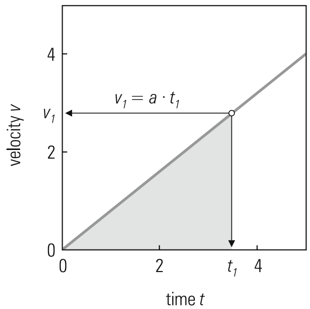


Figure Q.3
Example of a linear velocity–time relation

In this rule t must not necessarily be the time, but it can be any variable.

The inverse of differentiation is the integration. Let us consider the particular velocity–time relation $v(t) = a\,t$, which is the straight line with slope a as shown in Fig. Q.3.

The integral over the velocity–time relation in the limits from $t = 0$ to $t = t_1$ is the area under the curve $v(t) = a\,t$ in these limits, i.e. the shaded area. This can be worked out, in this example, from the area of the rectangular triangle with the base along the time axis t_1 and the height $v_1 = a\,t_1$ divided by 2,

$$\frac{t_1\,a\,t_1}{2} = \frac{1}{2}\,a\,t_1^2 \ . \qquad \text{(Q.6)}$$

integration = determination of an area

For this operation one uses as shorthand the integral over the function $v = a\,t$ in the limits from $t = 0$ to $t = t_1$:[2]

$$\int_0^{t_1} a\,t\,\mathrm{d}t = \frac{1}{2}\,a\,t^2\Big|_0^{t_1} = \frac{1}{2}\,a\,t_1^2 \ . \qquad \text{(Q.7)}$$

power-law integration

The general rule for integrating a polynomial reads:

$$\int_0^{t_1} t^n\,\mathrm{d}t = \frac{t^{n+1}}{n+1}\Big|_0^{t_1} = \frac{t_1^{n+1}}{n+1} \ . \qquad \text{(Q.8)}$$

In case of an integration without giving limits the result of the integral is naturally only determined up to a constant, which can only be fixed by the integration limits (boundary conditions):

$$\int t^n\,\mathrm{d}t = \frac{t^{n+1}}{n+1} + \text{const} \ . \qquad \text{(Q.9)}$$

---

1 $\frac{c\,(t+\frac{\Delta t}{2})^2 - c\,(t-\frac{\Delta t}{2})^2}{\Delta t} = \frac{c\,(t^2 + t\,\Delta t + \frac{\Delta t^2}{4}) - c\,(t^2 - t\,\Delta t + \frac{\Delta t^2}{4})}{\Delta t} = \frac{2\,c\,t\,\Delta t}{\Delta t} = 2\,c\,t$

2 In general, the integral over a linear function between two arbitrary limits t_1 and t_2 is worked out to be:

$$\int_{t_1}^{t_2} a\,t\,\mathrm{d}t = \frac{1}{2}\,a\,t^2\Big|_{t_1}^{t_2} = \frac{1}{2}\,a\,t_2^2 - \frac{1}{2}\,a\,t_1^2 = \frac{1}{2}\,a\,\left(t_2^2 - t_1^2\right) \ .$$

Formally, the consistency of this prescription can be verified by differentiating the result of the integration on the right-hand side. The differentiation of a constant (in this case the integration constant) gives zero (a constant has no slope), and thus the initial function t^n is again retrieved.

Q.2 Exponential Function

radioactive decay

In radioactive decay the number of decayed nuclei ΔN is proportional to the number of existing nuclei N and the observation time Δt. Obviously the number of nuclei decreases by decay. This results in a minus sign as in the following relation:

$$\Delta N \sim -N\,\Delta t \ . \tag{Q.10}$$

Since the decay rate changes in time, a differential notation is appropriate,

$$\mathrm{d}N \sim -N\,\mathrm{d}t \ . \tag{Q.11}$$

The introduction of a constant of proportionality leads to the identity

$$\mathrm{d}N = -\lambda\,N\,\mathrm{d}t \ , \tag{Q.12}$$

where λ is the decay constant. Such a relation – one of the most basic differential equations – is solved by the so-called exponential function[3]

$$N = N_0\,\mathrm{e}^{-\lambda t} \ . \tag{Q.13}$$

The number e, first introduced by Leonhard Euler, has the numerical value of $\mathrm{e} = 2.718\,28\ldots$.

N_0 denotes the number of originally existing nuclei, i.e. at $t = 0$. An example for the exponential function is plotted in Fig. Q.4. The exponential function describes a large number of natural processes, for example, the attenuation of γ rays in matter or the variation of the atmospheric pressure with altitude. For technical reasons the function $\mathrm{e}^{-\lambda t}$ is occasionally also printed as $\exp(-\lambda t)$.

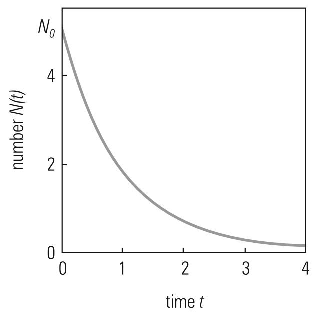


Figure Q.4
Example for the exponential variation of a quantity (e.g. decay rate) with time

properties of the exponential function

The exponential function has a very remarkable property: the slope of the function e^t, i.e. its derivative, is also an exponential, that means, it reproduces exactly itself,

$$\frac{\mathrm{d}}{\mathrm{d}t}\,\mathrm{e}^t = \mathrm{e}^t \ . \tag{Q.14}$$

[3] $\frac{\mathrm{d}N}{N} = -\lambda\,\mathrm{d}t \Rightarrow \int \frac{\mathrm{d}N}{N} = -\int \lambda\,\mathrm{d}t \Rightarrow \ln N = -\lambda t + \text{const}$ (see also Eq. (Q.25)). $\mathrm{e}^{\ln N} = N = \mathrm{e}^{-\lambda t + \text{const}} = \mathrm{e}^{-\lambda t}\mathrm{e}^{\text{const}}$; boundary condition $N(t = 0) = \mathrm{e}^{\text{const}} = N_0 \Rightarrow N = N_0\,\mathrm{e}^{-\lambda t}$.

It is the only function with this astonishing feature. If there is a parameter α as factor in the exponent, one has

$$\frac{\mathrm{d}}{\mathrm{d}t}\,\mathrm{e}^{\alpha t} = \alpha\,\mathrm{e}^{\alpha t} \quad . \tag{Q.15}$$

In the same way the integration of the function e^t retrieves the exponential function,

$$\int \mathrm{e}^t\,\mathrm{d}t = \mathrm{e}^t + \text{const} \ , \tag{Q.16}$$

rules for exponentials

and correspondingly

$$\int \mathrm{e}^{\alpha t}\,\mathrm{d}t = \frac{1}{\alpha}\,\mathrm{e}^{\alpha t} + \text{const} \ . \tag{Q.17}$$

The known rules for powers also apply to exponentials, e.g.

$$\mathrm{e}^{\alpha}\,\mathrm{e}^{\beta} = \mathrm{e}^{\alpha+\beta} \quad . \tag{Q.18}$$

Q.3 Natural Logarithm

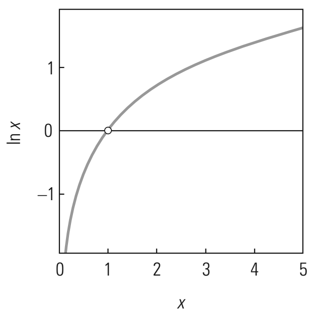


Figure Q.5
Graphical representation of a logarithmic variation of a quantity x

It is desirable that the human senses can perceive a large dynamic range of impressions. Therefore nature, or the evolution of life, has arranged that the sensual perception is proportional to the logarithm of the stimulus (Weber–Fechner law). The logarithm is a weakly rising monotonic function (Fig. Q.5).

The logarithm is the inverse function to the exponential. Equation

$$\mathrm{e}^y = x \tag{Q.19}$$

is exactly fulfilled, if

$$y = \ln x \quad . \tag{Q.20}$$

The logarithm was also the basis for slide rules, which have by now been overcome by pocket calculators. Slide rules were based on the property that the logarithm reduces multiplication to addition and powers to multiplication,[4]

rules for logarithms

[4] If one is willing to memorize a few numbers, one can easily approximate in one's head all logarithms. For the natural logarithm one should memorize $\ln 2 = 0.6931$ and $\ln 10 = 2.30$. Thus, e.g. $\ln 8000 = \ln 8 + \ln 1000 = 3\ln 2 + 3\ln 10 \approx 2.1 + 6.9 = 9.0$. Analogously, one can proceed with the common logarithm (to the base 10), if one is ready to remember just one value, namely $\lg 2 = 0.3010$; see also Footnote 6.

$$\ln(x\ y) = \ln x + \ln y \ , \tag{Q.21}$$

$$\ln \frac{x}{y} = \ln x - \ln y \ , \tag{Q.22}$$

$$\ln x^n = n\ \ln x \ . \tag{Q.23}$$

A plot of the logarithmic function (Fig. Q.5) shows that its slope is large for small x and low for large x. The derivative of the logarithm is obtained to be[5]

integration and differential of the natural logarithm

$$\frac{\mathrm{d}}{\mathrm{d}x} \ln x = \frac{1}{x} \quad \text{(see also } \ln x \text{ from Fig. Q.5).} \tag{Q.24}$$

Since the integration is the inverse operation to differentiation, one has

$$\int \frac{1}{x}\,\mathrm{d}x = \ln x + \text{const} \ . \tag{Q.25}$$

With these rules also the radioactive decay law can now be understood: From

$$N = N_0\, \mathrm{e}^{-\lambda t} \tag{Q.26}$$

one obtains by differentiating

$$\frac{\mathrm{d}N}{\mathrm{d}t} = -\lambda\ N_0\, \mathrm{e}^{-\lambda t} = -\lambda\ N \quad , \tag{Q.27}$$

which can be rewritten as

$$\mathrm{d}N = -\lambda\ N\,\mathrm{d}t \tag{Q.28}$$

(compare (Q.12)).

One can easily recognize that the handling of differentials follows the standard and normal rules of calculation.

So far only the natural logarithm (to the base e) has been introduced. It is, however, possible to define logarithms also for other bases (e.g for the base 10: common, Briggs, or decadic logarithm).[6]

simplifying diagrams by using appropriate scales

The fact that the logarithm linearizes powers can be used to simplify graphical representations. The exponential which characterizes radioactive decay, can be linearized by subdividing the axis that describes the number of nuclei that have not decayed in a logarithmic fashion: Because of

[5] $\mathrm{e}^y = x\,;\ y = \ln x\,;\ \frac{\mathrm{d}\ln x}{\mathrm{d}x} = \frac{\mathrm{d}y}{\mathrm{d}x} = \frac{1}{\frac{\mathrm{d}x}{\mathrm{d}y}} = \frac{1}{\frac{\mathrm{d}\mathrm{e}^y}{\mathrm{d}y}} = \frac{1}{\mathrm{e}^y} = \frac{1}{x}$

[6] The natural (or Napierian) logarithm is usually abbreviated as $\ln x$ ('logarithmus naturalis'); in mathematics it is frequently written as $\log x$, even though this notation is not unique. The common, Briggs, or decadic logarithm to the base 10 is mostly denoted by $\lg x$. Since the natural logarithm has been introduced as the inverse function to the exponential, one has $\ln \mathrm{e} = 1$; analogously $\lg 10 = 1$.

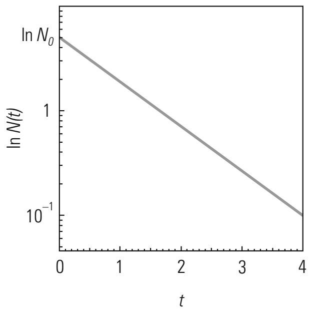


Figure Q.6
Linearization of an exponential in a semilogarithmic plot

$$N = N_0 \, e^{-\lambda t} \tag{Q.29}$$

and

$$\ln N = \ln N_0 - \lambda t \tag{Q.30}$$

one obtains a straight line with a slope of $-\lambda$ and an intersect $\ln N_0$ (Fig. Q.6).

In an analogous way powers – plotted on double logarithmic paper (log–log paper) – result is straight lines. The power law

$$y = x^n \tag{Q.31}$$

leads to

$$\ln y = n \, \ln x \ , \tag{Q.32}$$

which is a straight line with slope n if both axes are subdivided logarithmically, i.e. if $\ln y$ is plotted against $\ln x$.

"Don't worry, it takes an infinite amount of time to sink completely."
© by Claus Grupen

Further Reading

Literature on the History of Radioactivity and on Interactions of Radiation with Matter

W. C. Röntgen **“A New Type of Radiation”; in German: “Eine Neue Art von Strahlen”**, Sitzungsberichte der Würzburger Physik.-medic. Gesellschaft, Würzburg (1895) 1–12

H. A. Becquerel **“Sur les radiations invisibles émises pars les corps phosphorescents”** (**About the invisible radiation emitted from phosphorescent bodies**), Les Comptes Rendus de l’Académie des Sciences de Paris 122, 501–503 (1896)

P. Curie, Mme. M. Curie, and G. Bémont **“Sur une nouvelle substance fortement radio-active, contenue dans la pechblende (On a New, Strongly Radio-active Substance Contained in Pitchblende”)**, Comptes Rendus de l’Académie des Sciences, Paris (1898) (26 December), Vol. 127, pp. 1215–1217.

H. A. Becquerel **“On Radioactivity, a New Property of Matter”**, Nobel-Lectures in Physics (1901–1921), Elsevier Publishing Company, Amsterdam (1967)

P. Curie **“Radioactive Substances, Especially Radium”**, Nobel-Lectures in Physics (1901–1921), Elsevier Publishing Company, Amsterdam (1967)

Mme P. Curie Marie Sklodowska **“Traité de Radioactivité”** (**Treatise on Radioactivity**), Gauthier-Villars, Paris (1910)

M. Curie **“Radioactivity”; in German: “Die Radioaktivität”**, Akad. Verlagsgesellschaft, Leipzig (1912)

M. Curie **“Radium and the New Concepts in Chemistry”**, Nobel-Lectures in Chemistry (1901–1921), Elsevier Publishing Company, Amsterdam (1967)

E. Rutherford **“Radioactive Substances and their Radiations”; in German: “Radioaktive Substanzen und ihre Strahlungen”**, in E. Marx “Handbuch der Radiologie”, Akad. Verlagsgesellschaft, Leipzig (1913)

F. Soddy **“Chemistry of Radioelements”; in German: “Chemie der Radioelemente”**, Verlag. J. A. Barth, Leipzig (1914)

K. W. Kohlrausch, eds. W. Wien, F. Harms **“Radioactivity”, in German: “Radioaktivität”**, Akad. Verlagsgesellschaft, Leipzig (1928)

R. D. Evans **"The Atomic Nucleus"**, McGraw-Hill Book Co., New York (1955)

K. Siegbahn **"Alpha-, Beta- and Gamma-Ray Spectroscopy"**, Vol. 1/2, North-Holland, Amsterdam (1968)

H. F. Henry **"Fundamentals of Radiation Protection"**, John Wiley & Sons, New York (1969)

P. Marmier, E. Sheldon **"Physics of Nuclei and Particles"**, Academic Press, New York (1969)

A. Martin, S. A. Harbison **"An Introduction to Radiation Protection"**, J. W. Arrowsmith Ltd., Bristol (1986)

W. S. C. Williams **"Nuclear and Particle Physics"**, Clarendon Press, Oxford (1991)

J. E. Martin **"Physics for Radiation Protection"**, John Wiley & Sons, New York (2000)

G. I. Brown **"Invisible Rays: A History of Radioactivity"**, Sutton Publishing, Phoenix Mill, England (2002)

B. R. Martin **"Nuclear and Particle Physics"**, John Wiley & Sons, The Atrium, Chichester, England (2005)

J. Magill, J. Galy **"Radioactivity – Radionuclides – Radiation. Featuring the Universal Nuclide Chart: With the Fold-out Karlsruhe Chart of the Nuclides"**, Springer, Berlin, Heidelberg (2005)

Particle Data Group **"Review of Particle Properties"**, Eur. Phys. J. C15 (2000), K. Hagiwara et al., Phys. Rev. D66 (2002) 010001; `http://pdg.web.cern.ch/pdg/`; W.-M. Yao et al., J. Phys. G: Nucl. Part. Phys. **33** (2006) 1–1232; `http://pdg.lbl.gov`

"Radiation Protection", `http://web.wn.net/~usr/ricter/web/radpro.html`

M. F. L'Annunziata **"Radioactivity: Introduction and Early History"**, Elsevier Science, Amsterdam (2007)

Literature on Radiation Detectors and Radiation Protection

C. B. Braestrup, H. O. Wyckoff **"Radiation Protection"**, Charles Thomas, Springfield (1958)

W. J. Price **"Nuclear Radiation Detectors"**, McGraw-Hill Book Co., New York (1964)

W. H. Tait **"Radiation Detection"**, Butterworths, London (1980)

D. C. Stewart **"Handling Radioactivity"**, John Wiley & Sons, New York (1981)

J. R. Greening **"Fundamentals of Radiation Dosimetry"**, Taylor and Francis, London (1985)

R. L. Kathren **"Radiation Protection"**, Taylor and Francis, London (1985)

J. E. Turner **"Atoms, Radiation, and Radiation Protection"**, Pergamon Press, New York (1986); **"Atoms, Radiation, and Radiation Protection"**, Wiley-VCH, Weinheim (1995 and 2007)

S. E. Hunt **"Nuclear Physics for Engineers and Scientists"**, John Wiley & Sons, New York (1987)

K. R. Kase et al. **"The Dosimetry of Ionizing Radiation"**, Academic Press, San Diego (1990)

M. Oberhofer **"Advances in Radiation Protection"** Kluwer Academic Publishers Group, Dordrecht (1991)

C. F. G. Delaney, E. C. Finch **"Radiation Detectors"**, Oxford Science Publ., Clarendon Press, Oxford (1992)

W. R. Leo **"Techniques for Nuclear and Particle Physics Experiments"**, Springer, Berlin (1994)

W. H. Hallenbeck **"Radiation Protection"**, Taylor and Francis, London (1994)

G. Gilmore, J. Hemingway **"Practical Gamma-Ray Spectrometry"**, John Wiley & Sons, New York (1995)

C. Grupen **"Particle Detectors"**, Cambridge University Press, Cambridge (1996)

M. C. O'Riordan (ed.) **"Radiation Protection Dosimetry. Becquerel's Legacy: A Century of Radioactivity"**, Nuclear Technology Publishing, London (1996)

J. Sabol, P. S. Weng **"Introduction to Radiation Protection Dosimetry"**, World Scientific, Singapore (1996)

G. F. Knoll **"Radiation Detection and Measurement"**, John Wiley & Sons, New York (1999); Wiley Interscience, New York (2000)

R. K. Bock, A. Vasilescu **"The Particle Detector BriefBook"**, Springer, Berlin, Heidelberg (1999, 2007); On-line version: `http://rkb.home.cern.ch/rkb/titleD.html`

D. Green **"The Physics of Particle Detectors"**, Cambridge University Press, Cambridge (2000)

F. A. Smith **"A Primer in Applied Radiation Physics"**, World Scientific, Singapore (2000)

J. E. Martin **"Physics for Radiation Protection: A Handbook"**, Wiley-VCH, Weinheim (2006)

A. Martin, S. A. Harbison **"An Introduction to Radiation Protection"**, Oxford University Press, A Hodder Arnold Publication, New York City (2006)

K. Kleinknecht **"Detectors for Particle Radiation"**, Cambridge University Press, Cambridge (2007)

Syed Naeem Ahmed, **"Physics & Engineering of Radiation Detection"**, Elsevier, Amsterdam (2007)

M. W. Charles, J. R. Greening **"Fundamentals of Radiation Dosimetry, Third Edition"**, Taylor and Francis, London (2008)

C. Grupen, B. Shwartz **"Particle Detectors"**, 2nd edition, Cambridge University Press, Cambridge (2008)

International Commission on Radiation Units and Measurements (ICRU) `www.icru.org/ic_basic.htm`

Literature on Technical Aspects of Radiation Protection and Radiation-Protection Regulations

See also references in Chap. 6 on 'International Safety Standards for Radiation Protection'.

K. L. Miller and W. A. Weidner **"CRC Handbook of Management of Radiation Protection Programs"** 3. edition, CRC Press, Boca Raton, Florida (1986) and later editions

"Council Directive 96/29/EURATOM (1996) laying down basic safety standards for the protection of health of workers and the general public against the dangers arising from ionizing radiation", The Council of the European Union, `http://eur-lex.europa.eu/LexUriServ/site/en/consleg/1996/L/01996L0029-20000513-en.pdf` (1996)

"Council Directive 97/43/EURATOM (1997) on health protection of individuals against the dangers of ionizing radiation in relation to medical exposures" `http://ec.europa.eu/energy/nuclear/radioprotection/doc/legislation/9743_en.pdf`

J. S. Walker **"Permissible Dose"** Univ. California Press, Berkeley (2000)

Health and Safety Executive **"Work with Ionising Radiation; Ionising Radiations Regulations 1999: Approved Code of Practice"** HSE Books, Norwich, England (2000)

E. Seeram **"Rad Tech's Guide to Radiation Protection (Rad Tech Series)"** Wiley-Blackwell, Malden, Massachusetts, 1. edition (2001)

J. Shapiro, **"Radiation Protection: A Guide for Scientists, Regulators and Physicians"** 4. edition, Harvard University Press, Cambridge, Massachusetts (2002)

Organization for Economic Co-Operation and Development, **"Nuclear legislation. Analytical study. Regulations governing nuclear installations and radiation protection"**, OECD Nuclear Energy Agency, Paris (2003)

"Handbook for Implementation of EU Environmental Legislation – Nuclear safety and radiation protection", `http://ec.europa.eu/environment/enlarg/handbook/nuclear.pdf` (last update 2006)

US Environmental Protection Agency **"Radiation Protection"** `www.epa.gov/radiation/` (last update 2007)

L. A. Burchfield, **"Radiation Safety, Protection and Management: For Homeland Security and Emergency Response"**, Wiley-Interscience, New York (2008)

The International Commission on Radiological Protection, ICRP; `www.icrp.org/` (2008)

Literature on Environmental Radioactivity

A. W. Wolfendale **"Cosmic rays"**, George Newnes Ltd., London (1963)

J. R. Cooper, K. Randle, R. S. Sokhi **"Radioactive Releases in the Environment: Impact and Assessment"**, John Wiley & Sons Inc., New York (1969)

O. C. Allkofer **"Introduction to Cosmic Radiation"**, Thiemig, München (1975)

L. M. Libby **"The Uranium People"**, Crane Russak, New York (1979)

A. W. Klement (ed.) **"CRC Handbook on Environmental Radiation"**, CRC Press, Boca Raton (1982)

M. Eisenbud **"Environmental Radioactivity"**, Academic Press, Orlando (1986)

R. L. Kathren **"Radioactivity in the Environment"**, Harwood Acad. Publ., New York (1986)

C. R. Cothern et al. **"Environmental Radon"**, Plenum Press, New York (1987)

M. Eisenbud **"Environmental Radioactivity from Natural, Industrial and Military Sources"**, Academic Press, New York (1987)

R. F. Mould **"Chernobyl. The Real Story"**, Pergamon Press, Oxford (1988)

V. M. Chernousenko **"Chernobyl"**, Springer, Berlin (1991)

R. Bertell **"No Immediate Danger – Prognosis for a Radioactive Earth"**, The Book Publ. Comp., Summertown, Tn. (1995)

R. Tykva & J. Sabol **"Low-Level Environmental Radioactivity: Sources and Evaluation"**, Technomic Publishing, Basel (1995)

M. Eisenbud & Th. F. Gesell **"Environmental Radioactivity"**, Academic Press, San Diego (1997)

L. I. Dorman **"Cosmic Rays in the Earth's Atmosphere and Underground"**, Kluwer Academic Publishers, Dordrecht (2004)

Literature on Biological Effects and Applications of Radiation

W. D. Claus (ed.) **"Radiation Biology and Medicine"**, Addison-Wesley, Reading (1958)

W. V. Mayneord **"Radiation and Health"**, The Nuffield Provincial Hospital Trust (1964)

G. Z. Morgan, J. E. Turner **"Principles of Radiation Protection, A Textbook of Health Physics"**, John Wiley & Sons, New York (1967)

T. D. Luckey **"Hormesis with Ionizing Radiation"**, CRC Press, Boca Raton, Florida (1980)

N. A. Dyson **"Nuclear Physics with Applications in Medicine and Biology"**, John Wiley & Sons, New York (1981)

United Nations **"Ionizing Radiation: Sources and Biological Effects"**, United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General Assembly, New York (1982)

J. E. Coggle **"Biological Effects of Radiation"**, Taylor & Francis, London (1983)

J. D. Boice Jr., J. F. Fraumeni Jr. **"Radiation Carcinogenesis. Epidemiology and Biological Significance"**, Progress in Cancer Research and Therapy, Vol. 26, Raven Press, New York (1984)

W. R. Hendee **"Health Effects of Low Level Radiation"**, Appleton-Century-Crofts, Norwalk, Conn. (1984)

F. Sauli **"Applications of Gaseous Detectors in Astrophysics, Medicine and Biology"**, Nucl. Instr. Meth. A323 (1992) 1

N. A. Dyson **"Radiation Physics with Applications in Medicine and Biology"**, Ellis Horwood, New York (1993)

R. Wootton (ed.) **"Radiation Protection of Patients"**, Cambridge University Press, Cambridge (1993)

M. E. Noz, G. Q. Maguire Jr. **"Radiation Protection in Health Science"**, World Scientific, Singapore (1995)

P. F. Sharp, H. G. Gemmell, F. W. Smith **"Practical Nuclear Medicine"**, Oxford University Press, Oxford (1998)

W. R. Hendee (ed.) **"Biomedical Uses of Radiation"**, Wiley-VCH, Weinheim (1999)

N. Birsen and K. K. Kadyrzhanov (eds.) **"Environmental Protection Against Radioactive Pollution"** Kluwer Academic Publishers, Dordrecht (2002)

C. J. Martin, D. G. Sutton **"Practical Radiation Protection in Healthcare"**, Oxford University Press, Oxford (2002)

S. Forshier **"Essentials of Radiation Biology and Protection"**, Delmar Thomson Learning, Florence, USA (2002)

S. R. Cherry, J. Sorenson, M. Phelps **"Physics in Nuclear Medicine"**, Saunders/Elsevier Science, Philadelphia, Pa. (2003)

F. M. Khan **"The Physics of Radiation Therapy"**, Lippincott Williams & Wilkins, Philadelphia, Pa. (2003)

C. J. Martin **"Medical Imaging and Radiation Protection"**, John Wiley & Sons, New York (2003)

M. H. Lombardi **"Radiation Safety in Nuclear Medicine"**, Taylor & Francis Ltd, London (2006)

P. J. Hoskin **"Radiotherapy in Practice: Radioisotope Therapy"**, Oxford University Press, Oxford (2007)

M. G. Stabin **"Radiation Protection and Dosimetry: An Introduction to Health Physics"**, Springer, Heidelberg (2007)

J. V. Trapp, T. Kron **"An Introduction to Radiation Protection in Medicine"**, Institute of Physics Publishing, Bristol (2008); Taylor and Francis, London (2007)

M. E. Noz, G. Q. Maguire **"Radiation Protection in the Health Sciences"**, World Scientific, Singapore (2007)

S. Forshier **"Essentials of Radiation Biology and Protection"**, 2. edition, Cengage Learning Services, Delmar (2008)

"Radiation and Health Physics", `www.umich.edu/~radinfo/`

"Health Physics/Radiation Protection", `www.umr.edu/~ehs/radiological.htm`

International Commission on Radiological Protection (ICRP), `www.icrp.org/`

Literature on Nuclear Power Plants

S. Glasstone **"Principles of Nuclear Reactor Engineering"**, D. van Nostrand Comp., Princeton (1955)

S. Villani (ed.) **"Uranium Enrichment"**, Springer, Heidelberg (1979)

W. Marshall **"Nuclear Power Technology"**, Vol. 1: Reactor Technology, Vol. 2: Fuel Cycle, Vol. 3: Nuclear Radiation, Clarendon Press, Oxford (1983)

E. Pochin **"Nuclear Radiation: Risks and Benefits"**, Clarendon Press, Oxford (1983)

B. Ma **"Nuclear Reactor Materials and Applications"**, Van Nostrand Reinhold Comp., New York (1983)

J. G. Collier, G. F. Hewitt **"Introduction to Nuclear Power"**, Taylor and Francis, Abingdon, UK (1987)

R. L. Murray **"Nuclear Energy"**, Pergamon Press, New York (1988)

Uranium Institute **"The Safety of Nuclear Power Plants"** Uranium Institute, London (1988)

C. Salvetti, R. A. Ricci, E. Sindoni (eds.) **"Status and Perspectives of Nuclear Energy: Fission and Fusion"**, North-Holland, Amsterdam (1992)

R. Murray **"Nuclear Energy"**, Pergamon Press, Oxford (1993)

D. Bodansky **"Nuclear Energy, Principles, Practices, and Prospects"**, American Institute of Physics, Woodbury, New York (1996)

R. Murray **"Nuclear Energy: An Introduction to the Concepts, Systems, and Applications of Nuclear Processes"**, Butterworth-Heinemann (Reed Elsevier Group), Woburn, USA (2001)

W. M. Stacey **"Nuclear Reactor Physics"**, Wiley, New York (2001)

R. E. H. Clark, D. H. Reiter (eds.) **"Nuclear Fusion Research"**, Springer Series in Chemical Physics, Vol. 78, New York (2005)

K. Miyamoto **"Plasma Physics and Controlled Nuclear Fusion"**, Springer Series on Atomic, Optical, and Plasma Physics, Vol. 38, New York (2005)

L. C. Woods **"Theory of Tokamak Transport: New Aspects for Nuclear Fusion Reactor Design"**, Wiley, New York (2005)

I. Hore-Lacy **"Nuclear Energy in the 21st Century: World Nuclear University Press"**, Academic Press, New York (2006)

A. M. Herbst and G. W. Hopley **"Nuclear Energy Now: Why the Time Has Come for the World's Most Misunderstood Energy Source"**, Wiley, New York (2007)

Watt Committee Energy **"Nuclear Energy: A Professional Assessment"**, Taylor and Francis, Abingdon, UK (2007)

D. Bodansky **"Nuclear Energy: Principles, Practices, and Prospects"**, 2. edition, Springer, New York (2008)

Literature on Radiation Sources

M. Oberhofer **"Safe Handling of Radiation Sources"**, Verlag K. Thiemig, München (1982)

United Nations Publication **"Ionizing Radiation Sources and Biological Effects"**, Renouf Publ. Co. Ltd., United Nations Publications, Geneva (1982)

F. D. Sowby **"Protection Against Ionizing Radiation from External Sources Used in Medicine"** Elsevier Science and Technology, Amsterdam (1982)

W. Scharf **"Particle Accelerators"**, Applications in Technology and Research, John Wiley & Sons Inc., New York (1989)

H. Bergmann, H. Sinzinger (eds.) **"Radioactive Isotopes in Clinical Medicine and Research"**, Birkhäuser, Basel (1995)

National Research Council, Committee On Biomedical Institute Of Medicine, F. J. Manning (eds.) **"Isotopes for Medicine and the Life Sciences"**, National Academy Press, Washington (1995)

F. Hinterberger **"Physics of Particle Accelerators", in German: "Physik der Teilchenbeschleuniger"**, Springer, Heidelberg (1997)

R. B. Firestone, **"Table of Isotopes, 2 Volume Set"**, John Wiley & Sons, New York (1998)

E. J. Morton **"Radiation Sources and Radiation Interactions"** SPIE Press, Colorado (1999)

K. Wille **"The Physics of Particle Accelerators"**, Oxford University Press, Oxford (2000)

United Nations Scientific Committee on the Effects of Atomic Radiation **"Sources and Effects of Ionizing Radiation: Sources"**, Stationery Office Books, Norwich, UK (2001)

V. Vylet, G. Stevenson **"Accelerator Radiation Protection"**, Ramtrans Publishing, Ashford, England (2001)

G. Faure, T. M. Mensing **"Isotopes: Principles and Applications"**, John Wiley & Sons, New York (2004)

B. Fry **"Stable Isotope Ecology"**, Springer, Heidelberg (2006)

H. Wiedemann (ed.) **"Advanced Radiation Sources and Applications"**, Proceedings of the NATO Advanced Research Workshop, held in Nor-Hamberd, Yerevan, Armenia (2004), Nato Science Series, Springer, Dordrecht (2006)

H. Wiedemann **"Particle Accelerator Physics"**, Springer, Berlin (2007)

Literature on Non-Ionizing Radiation

J. Law and J. W. Haggith **"Practical Aspects of Non-ionizing Radiation Protection"**, Hilger in collaboration with the Hospital Physicists' Association, Bristol (1982)

R. Doll **"Electromagnetic Fields and the Risk of Cancer: Report of an Advisory Group on Non-ionising Radiation"**, National Radiological Protection Board (NRPB), London (1992)

D. Hughes **"Management of Protection Against Ionising and Non-ionising Radiations"**, Hyperion Books, New York (1995)

European Communities **"Non-ionizing Radiation"**, European Communities, Luxembourg (1997)

R. Matthes, J. H. Bernhardt & A. F. McKinlay (eds.) **"Guidelines on Limiting Exposure to Non-Ionizing Radiation: A Reference Book"**, International Commission on Non-Ionizing Radiation Protection, Oberschleissheim (2000)

IARC (International Agency for Research on Cancer) and WHO **"Non-Ionizing Radiation, Part 1: Static and Extremely Low-Frequency (ELF) Electric and Magnetic Fields"**, (IARC Monographs) World Health Organisation (2002)

A. W. Wood & C. Roy **"Non-Ionizing Radiation Protection"**, Wiley-Interscience, New York (2005, 2008)

Tables of Isotopes and Nuclear Data Sheets

C. M. Lederer, V. S. Shirley **"Table of Isotopes"**, John Wiley & Sons, New York (1979)

R. C. Weast, M. J. Astle (eds.) **"Handbook of Chemistry and Physics"**, CRC Press, Boca Raton (1986) and following editions, 87th edition (2007)

E. Browne, R. B. Firestone, V. S. Shirley **"Table of Radioactive Isotopes"**, John Wiley & Sons, New York (1986)

G. Pfennig, H. Klewe-Nebenius, W. Seelmann-Eggebert **"Karlsruher Nuklidkarte"**, Forschungszentrum Karlsruhe 1995, New edition at Marktdienste Haberbeck, Lage, Germany (2006)

Particle Data Group **"Review of Particle Properties"**, Eur. Phys. J. **C15** (2000); K. Hagiwara et al., Phys. Rev. **D66** (2002) 010001; `http://pdg.web.cern.ch/pdg/`; W.-M. Yao et al. J. Phys. G: Nucl. Part. Phys. **33** (2006) 1–1232; `http://pdg.lbl.gov`

"Applied Nuclear Physics Data", `http://atom.kaeri.re.kr/`, `http://isotopes.lbl.gov/education`

Photo Credit for Commercial Products and other Copyrighted Material

We would like to thank the following companies and institutions for providing photographic material, images, and diagrams:

AEA Technology QSA GmbH
see QSA Global GmbH

AREVA
Saint-Quentin-Yvelines, Cedex, France
1, rue des Hérons
78182 Saint-Quentin-Yvelines Cedex
France
`www.sogefibre.com`

Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439
USA
`www.anl.gov/`
see also
`www.chemcases.com/nuclear/nc-05.htm`

automess Automation und Meßtechnik GmbH
Daimlerstrasse 27
68526 Ladenburg
Germany
`www.automess.de/`

BAM
Federal Institute for Materials Research and Testing
Unter den Eichen 44–46
D-12203 Berlin
Germany
`www.tes.bam.de/e_ram/pdf/BAM-PM_16-78.pdf`
`www.tes.bam.de/ram/bauart/bauart-2.htm`

BERTHOLD TECHNOLOGIES GmbH & Co. KG
Calmbacher Strasse 22
75323 Bad Wildbad
Germany

Berthold Technologies U.S.A. LLC
99 Midway Lane, Oak Ridge, TN 37830
USA

Representatives in 8 countries
www.berthold.com

BICRON RADIATION MEASUREMENT PRODUCTS
6801 Cochran Road
Solon, Ohio 44139, USA

Budker Institute Novosibirsk
Dr. Boris Shwartz
Novosibirsk, Russia
www.ipp.ac.cn/qy/WS97/node252.html

Canadian Centre for Occupational Health and Safety
135 Hunter Street East
Hamilton ON
Canada L8N 1M5
www.ccohs.ca/
see also
www.ccohs.ca/oshanswers/phys_agents/ultravioletradiation.html

Canberra Eurisys GmbH
Walter-Flex-Strasse 66
65428 Rüsselsheim
Germany

Canberra Industries, Inc.
800 Research Parkway
Meriden, Connecticut 06450
USA
www.canberra.com

Many international representatives (75) to be found under:
www.canberra.com/about/default.asp

CERN European Centre for Particle Physics
CH-1211 Geneva 23
Switzerland
www.cern.ch

Cole-Parmer Instrument Company
625 East Bunker Court
Vernon Hills
Illinois 60061
USA
www.coleparmer.com/
Representatives in Canada, China, United Kingdom, and India to be found under:
www.coleparmer.com/catalog/login.asp

Culham Science Centre
Abingdon, Oxon
OX14 3DB
England
www.nda.gov.uk/sites/culhamjet/

Ecole Polytechnique Federale de Lausanne
CH-1015 Lausanne
Switzerland
www.epfl.ch/index.en.html

EG&G Berthold GmbH & Co. KG
Calmbacher Strasse 22
75312 Bad Wildbad
Germany
American Laboratory Trading LLC
70 Bridge Street
Groton, CT 06340
USA
www.americanlaboratorytrading.com/product-details-EGG-Berthold-140095-1157-4965.html

ESM Eberline Instruments GmbH,
Thermo Fisher Scientific Inc.
81 Wyman Street
Waltham, MA 02454
USA
www.thermo-esm.com

Freiwillige Feuerwehr Eßfeld e.V.
D-97232 Eßfeld
Germany
www.ffwessfeld.de/

GRAETZ Strahlungsmesstechnik GmbH
Westiger Strasse 172
58762 Altena
Germany
www.graetz.com/

GSF – Forschungszentrum für Umwelt und Gesundheit GmbH
GSF National Research Center for Environment and Health in the Helmholtz Association
Ingolstädter Landstrasse 1
85764 Neuherberg
Germany
www.gsf.de/

Harshaw TLD
see Thermo Scientific
www.thermo.com/com/

ICx Radiation GmbH (former: target systemelectronic GmbH)
Kölner Strasse 99
42651 Solingen
Germany
100 Midland Road
Oak Ridge, Tennessee 37830
USA
www.icx-radiation.de/
Headquarters ICx Technologies
2100 Crystal Drive
Arlington, VA 22202, USA

JL Goslar, Kerntechnik und Strahlenschutz
Im Schleeke 108
D-38640 Goslar
Germany
www.jlgoslar.de

Lawrence Livermore National Laboratory
7000 East Avenue
Livermore, CA 94551
USA
www.llnl.gov/

L. Meitner and K. Freitag
Zeitschrift für Physik, Vol. 37, page 481 (1926)
also in K.W.F. Kohlrausch 'Radioaktivität', page 478;
Akademische Verlagsgesellschaft, Leipzig 1928
www.aka-verlag.com/

mab Strahlenmesstechnik
Neuer Höltigbaum 30
D-22143 Hamburg
Germany
www.pmabode.de

Materialprüfungsamt Nordrhein-Westfalen
Marsbruchstrasse 186
D-44287 Dortmund
Germany
www.mpanrw.de/start.html

Mini Instruments
Perspective Instruments Ltd
Pinewood
61 Folly Lane, Shaw
Wiltshire SN12 8HB
England
www.perspectiveinstruments.co.uk/

Oxford Technologies Ltd
7 Nuffield Way
Abingdon
Oxon, UK
OX14 1RJ
www.oxfordtechnologies.co.uk

PTW–Freiburg
Physikalisch–Technische Werkstätten Dr. Pychlau GmbH
Lörracher Strasse 7
79115 Freiburg
Germany
www.ptw.de

QSA Global GmbH
Gieselweg 1
38110 Braunschweig
Germnay

QSA Global Inc.
40 North Avenue
Burlington, MA 01803
USA
Sales offices also in France and Honk Kong
www.qsa-global.de
www.isotrak.de

RadiologyInfo™
www.radiologyinfo.org
nmap@acr.org
mamm-accred@acr.org

Radon Lab
Forskningsveien 3 B
0373 Oslo
Norway
www.radonlab.net/tracketch.htm

RADOS Technology GmbH
Ruhrstrasse 49
D-22761 Hamburg
Germany
World Headquarters
Bishop Ranch 8
3000 Executive Parkway Suite 220
San Ramon, CA 94583
USA
www.rados.com www.mirion.com/index.php?p=dosimetry_division
Many international representatives (21) to be found under:
www.mirion.com/index.php?p=locations#noram

S.E.A. GmbH
(Strahlenschutz- Entwicklungs- und Ausrüstungs-Gesellschaft)
Ortsdamm 139
48249 Dülmen
Germany
www.sea-duelmen.de

Siemens Healthcare
Wittelsbacherplatz 2
80333 München
Germany
Representatives in 35 countries
www.medical.siemens.com/

Strahlenzentrum of the Justus-Liebig University Giessen
Leihgesterner Weg 217
35392 Giessen
Germany
`www.strz.uni-giessen.de/`

Synchrotron Radiation Angiography (St. Fiedler)
Canadian Light Source Inc.
University of Saskatchewan
101 Perimeter Road
Saskatoon, SK.
Canada, S7N 0X4
`www.lightsource.ca/`
`www.lightsource.ca/bioimaging/Saskatoon_2004_sf.pdf`

Terra Universal, Inc.
800 S. Raymond Avenue,
Fullerton, CA 92831
USA
`www.terrauniversal.com`
Many international representatives (21) to be found under:
`www.terrauniversal.com/international/localreps.shtml`

Thermo Eberline ESM
Frauenauracher Strasse 96
91056 Erlangen
Germany
`www.esm-online.de/`

Thermo Fisher Scientific Inc.
81 Wyman Street
Waltham, MA 02454
USA
`www.thermo.com/`
Many international representatives (209) to be found under:
`www.thermo.com/com/cda/article/general/1,,882,00.html`

US Department of Energy
Office of Civilian Radioactive Waste Management
Yucca Mountain Project
1551 Hillshire Drive
Las Vegas, NV 89134
USA
`www.ocrwm.doe.gov/contact/index.shtml`
`www.ocrwm.doe.gov/factsheets/doeymp0010.shtml`

VacuTec Meßtechnik GmbH
Dornblüthstrasse 14
D-01277 Dresden
Germany
www.e-meditec.de/firm05/vacutec_messtechnik_4508.htm

Wikipedia
http://en.wikipedia.org/wiki/Radioisotope_thermoelectric_generator
http://commons.wikimedia.org/wiki/Image:Coolidge_xray_tube.jpg
http://en.wikipedia.org/wiki/Radium_Girls

This list has been checked early in 2009. Many companies occasionally change their name and can no longer be found easily. The 'Supplier Name Change' list helps to locate the companies with their new names. This list can be found under
www.purchasing.upenn.edu/buyinfo/suppliers/name_changes.php.

Index*

* Pages in italics refer to the glossary.