COLLECTION OF FORMULAS
in the course *Nuclide Technique 2p*
Formula, diagrams and data

INTERNAL DOSIMETRY

$1\ \text{eV} = 1.60207 * 10^{-19}\ \text{J}$ (1)

$\text{Dint (Gy)} = 1.6*10^{-13} * n * \bar{E}_\beta / m$ (2)

$dH/dt = 1.6*10^{-13} * W_R * n/h * \bar{E}_\beta / m$ (3)

dH/dt is the dose equivalent rate in Sv/h
W_R the weight factor for radiation quality
n/h is the number of absorbed particles per hour
$\bar{E}_\beta$ is the mean energy in MeV per β particle
m is the mass unit in kg.

Equation (3) is here formulated for β-particles but is of course also true for other charged particles that can be regarded to deposit their energy locally. A more general formulation is: The radioactive decay emits particles of different types i = 1, 2, 3 … The mean energy of particle type i emitted per decay is then

$\Delta_i = k\ n_i\ \bar{E}_i$ (4)

k is a unit dependant constant
n_i is the mean number of particle i per decay
$\bar{E}_i$ is the mean energy of particle i per decay

Δ_i has the dimension energy (J). Usually it is given as (kg * Gy)/(Bq * h). The time-integral of the radioactivity concentration in the organ, $\int A(t)dt$ has the dimension Bq/kg * h. If we multiply the time integral with Δ_i we get absorbed dose as long as the absorption of the emitted particle is 100 % localized in the organ.

Useful relations in the calculations are

$n = A * 1.44 * T½\text{eff}$ (5)

$1/ T½\text{eff} = 1/T½\text{phys} + 1/T½\text{biol}$ (6)

EXTERNAL DOSIMETRY

Beta dose rate on a volume with an even radioactivity concentration.
$dH/dt = 10^{-10} * C * f * E_{max}$ (7)

Beta dose rate from a point source
$dH/dt = 10^{-11} * A * f */ d^2$ (8)

Gamma dose rate from a point source
$dH/dt = \Gamma * A / d^2$ (9)

Sv/h = Dose rate in Sv/h
A = Radioactivity in Bq
C = Radioactivity concentration in Bq/kg
E_{max} = The maximum beta energy in MeV
f = The number emitted beta per decay
d = distance to the source in meter

Table 1 *Physical, biological and effective half-times for some radionuclides*

Nuclide	T½phys	T½biol	T½eff
^{3}H	12 a	10 d	10 d
^{11}C	20 min	10-40 d	20 min
^{14}C	5730 a	10-40 d	10-40 d
^{90}Sr	29 a	5 a	5a
^{125}I	60 d	80 d	35 d
^{131}I	8 d	80 d	7 d
^{137}Cs	30 a	100 d	100 d

Table 2 *Gamma constant,* Γ *for some radioactive nuclides,* $10^{-12}\ Sv*h^{-1}*Bq^{-1}*m^{-2}$

Nuclide	Γ	Nuclide	Γ
^{22}Na	0.32	^{99m}Tc	0.016
^{24}Na	0.47	^{103}Ru	0.090
^{28}Al	0.23	^{110m}Ag	0.38
^{38}Cl	0.19	^{122}Sb	0.064
^{42}K	0.035	^{124}Sb	0.026
^{46}Sc	0.29	^{125}I	0.037
^{51}Cr	0.0043	^{131}I	0.056
^{54}Mn	0.13	^{134}Cs	0.23
^{56}Mn	0.22	^{137}Cs	0.086
^{59}Fe	0.16	^{140}Ba	0.33
^{58}Co	0.14	^{140}La	0.30
^{60}Co	0.34	^{141}Ce	0.013
^{65}Ni	0.083	^{160}Tb	0.14
^{64}Cu	0.032	^{177}Lu	0.0027
^{65}Zn	0.073	^{182}Ta	0.18
$^{69m-69}$Zn	0.064	^{187}W	0.080
^{75}Se	0.051	^{192}Ir	0.12
^{76}As	0.064	^{194}Ir	0.040
^{82}Br	0.039	^{198}Au	0.062
^{86}Rb	0.013	^{201}Tl	0.012
^{95}Zr	0.11	^{203}Hg	0.035
^{99}Mo	0.038	^{226}Ra	0.22

If the nuclide is not in the table this formula can be used to calculate the Γ–constant.

$\Gamma=\Sigma\Gamma i = 4.58*10^{-14} * \Sigma Ei * fi* \mu eni$

Ei is the gamma energy in MeV, fi number of gamma emitted of this energy per decay, μeni is the energy absorption coefficient in m^{-1}

SOME IMPORTANT TABLES

Table 3 *Weighting factors for calculation of the effective dose equivalent.*

Organ	Weighting factor, W_T
Gonads	0.25
Breast	0.15
Red marrow	0.12
Lung	0.12
Thyroid	0.03
Bone surface	0.03
Reminder	0.30

Table 4 Density of some common materials

Material	Density (g/cm3)
Air	1.3 * 10-3
Paper	0.6
Wood	0.6
Plastics	1-1.2
Water	1.0
Tissue	1.0
Bone	2.7
Concrete	2.3
Glass	2.5
Rock	2.6
Granite	2.7
Aluminia	2.7
Lead	11.3
Steel	7.8
Brass	8.5
Copper	8.9

Table 5 *W_R-values for some types of radiation*

Type of radiation	Wr
X-ray, gamma	1
electrons, beta	1
protons, slow	10
protons, fast >10 MeV	1-2
neutrons, thermal	2.3
neutrons, fast	10-20
alpha, heavy ions	20

Table 6 *ALI values (Bq) for some common radionuclides. The ALI-values correspond to an effective dose equivalent of 50 mSv.*

Nuclide	ALI	Nuclide	ALI	Nuclide	ALI
^{3}H	$3*10^{9}$	^{65}Zn	$1*10^{7}$	^{129}I	$2*10^{5}$
^{14}C	$9*10^{7}$	^{69m}Zn	$2*10^{8}$	^{130}I	$1*10^{7}$
^{18}F	$2*10^{9}$	^{67}Ga	$3*10^{8}$	^{131}I	$1*10^{6}$
^{22}Na	$2*10^{7}$	^{68}Ga	$6*10^{8}$	^{132}I	$1*10^{8}$
^{24}Na	$1*10^{8}$	^{73}As	$6*10^{7}$	^{129}Cs	$9*10^{6}$
^{32}P	$1*10^{7}$	^{74}As	$3*10^{7}$	^{130}Cs	$2*10^{9}$
^{33}P	$1*10^{8}$	^{75}Se	$2*10^{7}$	^{131}Cs	$8*10^{8}$
^{35}S	$8*10^{7}$	^{76}Br	$1*10^{8}$	^{134}Cs	$3*10^{6}$
^{36}Cl	$9*10^{6}$	^{77}Br	$6*10^{8}$	^{134m}Cs	$4*10^{9}$
^{38}Cl	$6*10^{8}$	^{82}Br	$1*10^{8}$	^{137}Cs	$4*10^{6}$
^{42}K	$2*10^{8}$	^{81m}Rb	$9*10^{9}$	^{131}Ba	$1*10^{8}$
^{43}K	$2*10^{8}$	^{81}Rb	$1*10^{9}$	^{133m}Ba	$9*10^{7}$
^{45}Ca	$3*10^{7}$	^{86}Rb	$2*10^{7}$	^{135m}Ba	$1*10^{8}$
^{47}Ca	$3*10^{7}$	^{88}Rb	$7*10^{8}$	^{140}La	$2*10^{7}$
^{51}Cr	$7*10^{8}$	^{89}Rb	$1*10^{9}$	^{169}Yb	$3*10^{7}$
^{52}Mn	$3*10^{7}$	^{85m}Sr	$8*10^{9}$	^{192}Ir	$8*10^{6}$
^{52m}Mn	$1*10^{9}$	^{85}Sr	$6*10^{7}$	^{198}Au	$4*10^{7}$
^{54}Mn	$3*10^{7}$	^{87m}Sr	$1*10^{9}$	^{197}Hg	$2*10^{8}$
^{56}Mn	$2*10^{8}$	^{89}Sr	$5*10^{6}$	^{203}Hg	$2*10^{7}$
^{52}Fe	$3*10^{7}$	^{90}Sr	$1*10^{5}$	^{201}Tl	$6*10^{8}$
^{55}Fe	$7*10^{7}$	^{90}Y	$2*10^{7}$	^{204}Tl	$6*10^{7}$
^{59}Fe	$1*10^{7}$	^{99}Mo	$4*10^{7}$	^{210}Pb	$9*10^{3}$
^{56}Co	$7*10^{6}$	^{99m}Tc	$3*10^{9}$	^{212}Pb	$1*10^{6}$
^{57}Co	$2*10^{7}$	^{109}Cd	$1*10^{6}$	^{210}Po	$2*10^{4}$
^{58}Co	$3*10^{7}$	^{115}Cd	$3*10^{7}$	^{226}Ra	$2*10^{4}$
^{60}Co	$1*10^{6}$	^{111}In	$2*10^{8}$	^{232}Th	$4*10^{1}$
^{63}Ni	$6*10^{7}$	^{113m}In	$2*10^{9}$	^{238}U	$2*10^{3}$
^{64}Cu	$4*10^{8}$	^{124}Sb	$9*10^{6}$	^{241}Am	$2*10^{2}$
^{67}Cu	$2*10^{8}$	^{123}I	$1*10^{8}$	^{244}Cm	$4*10^{2}$
^{62}Zn	$5*10^{7}$	^{125}I	$1*10^{6}$	^{252}Cf	$1*10^{3}$

Table 7 *Decay scheme for Uranium-238*

Nuclide	Half-time	Dominant γ-energies (MeV)
Uranium-238	4.5 10^9	
Torium-234	24 d	0.09
Protaktinium-234	1.2 min	
Uranium-234	250 000 a	0.05
Thorium-230	80 000 a	
Radium-226	1 600 a	0.19
Radon-222	3.823 d	
Polonium-218	3.1 min	
Lead-214	27 min	0.35, 0.29, 0.24
Bismuth-214	20 min	0.61, 1.12, 1.76
Lead-210	21 a	
Bismuth-210	5 d	
Polonium-210	140 d	
Lead-206	stable	

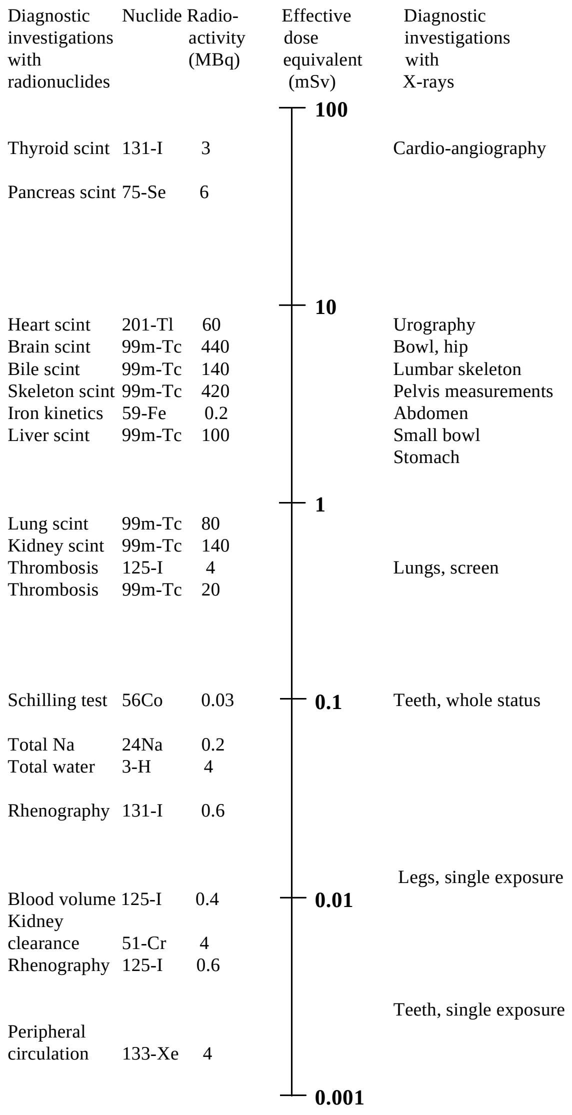
Table 8 *Decay scheme for Thorium-232*

Nuclide	Half-time	Dominant γ-energies (MeV)
Thorium-232	14 10^9	
Radium-228	5.76 a	
Actinium-228	6.13 h	0.91, 0.97, 1.64, 1.59
Thorium-228	1.913 a	
Radium-224	3.66 d	
Radon-220	55 sec	
Polonium-216	0.15 sec	
Lead-212	10.64 h	0.24
Bismuth-212	60.6 sec	
Polonium-208	0.3 10^{-6} sec	
Thallium-208	3.05 min	2.61, 0.58
Lead-208	Stable	

Table 9 *Natural radiation. Dose contributions in Sweden.*

Source	Effective dose equivalent (mSv/year)
Cosmic radiation	0.25
Ground and buildings	0.5
Body radioactivity	0.2
Radon	3
Medical use	0.7
Nuclear weapon tests	< 0.1
Nuclear power	< 0.1

Table 10 *Common diagnostic investigations. Typical values of radioactivity used and effective dose equivalent given to the patients,*



PHOTON ATTENUATION

$$N = No\ e^{-\mu * x} \qquad (10)$$

No = incoming number of photons
N = outgoing number of photons
m = attenuation coefficient
x = thickness of absorber

HVL(Half Value Layer)=ln(2)/μ = 0.693/μ (11)

DIAGRAMS OF PHOTON ATTENUATION

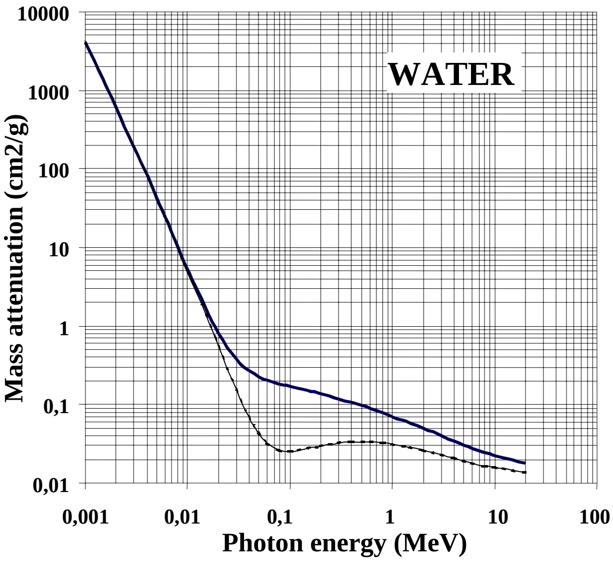


Figure 1 Mass attenuation coefficient for water

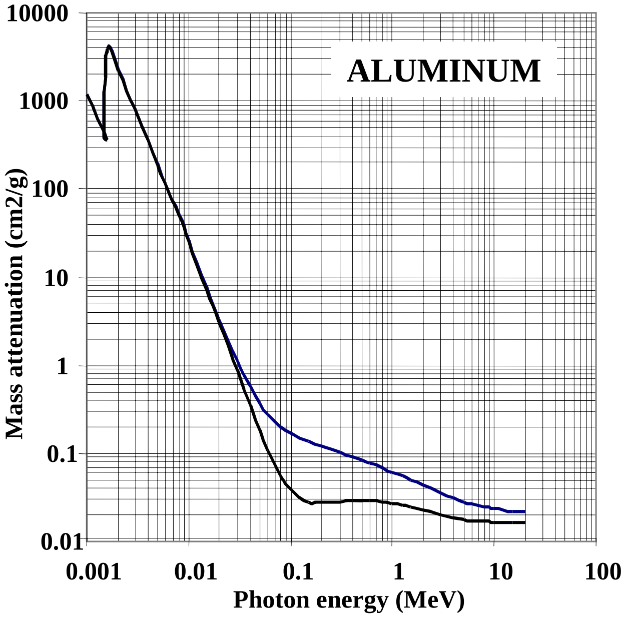


Figure 2 Mass attenuation coefficient for aluminum.

Dependant upon the information you want different attenuation coefficient can be used. In the gamma attenuation diagrams shown here the upper curve is the total mass attenuation coefficient while the lower curve is the mass energy absorption coefficient. Linear and mass attenuation coefficients are related by the material density, ρ

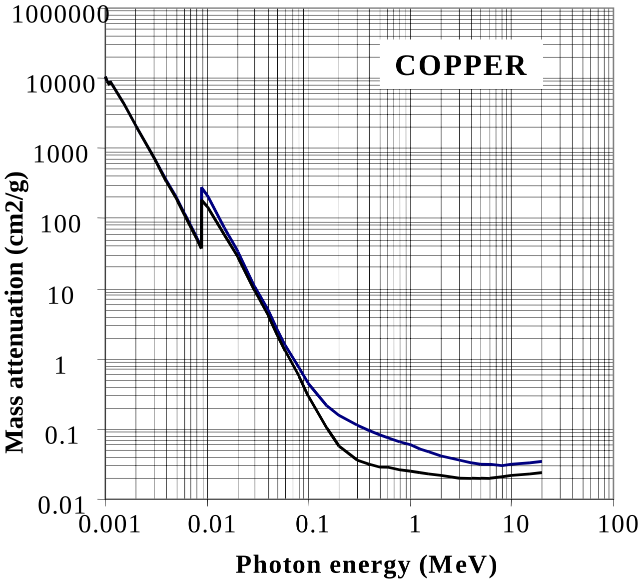


Figure 3 Mass attenuation coefficient for copper

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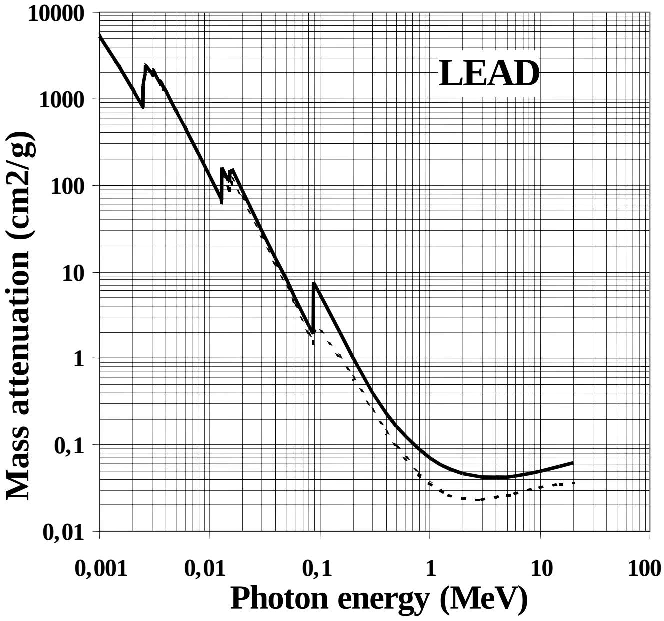

Figure 4 Mass attenuation coefficient for lead.

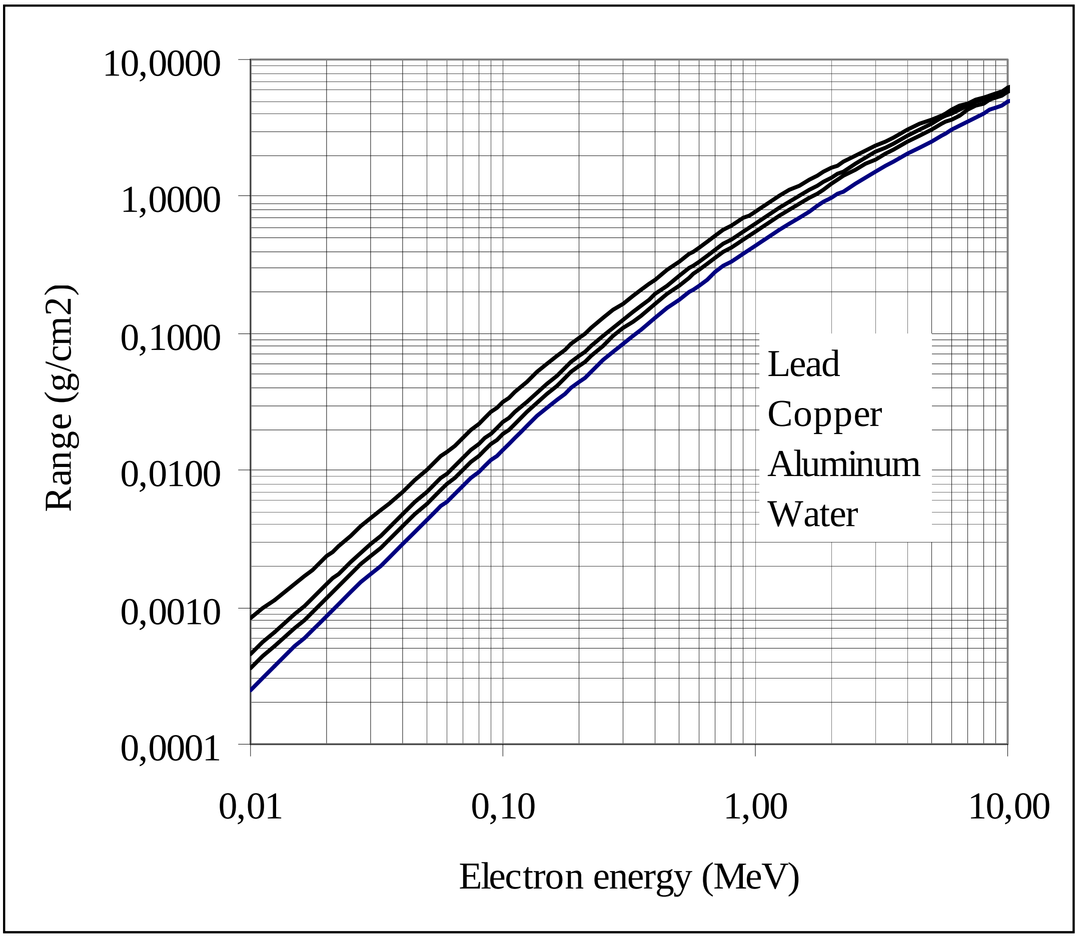

Figure 5 *Electron range in four materials. The curves are placed in the following order. Water: Bottom curve; Aluminum: Next; Copper: Next; Lead: Next, which also is the upper curve.*

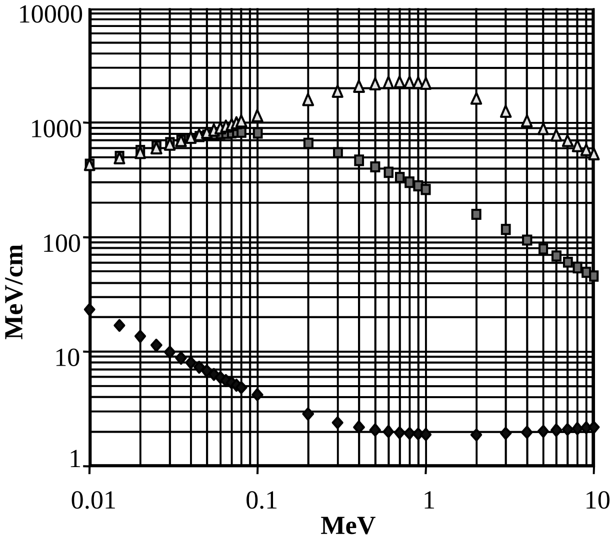

Figure 6 *Stopping power in water for electrons (lower curve), protons (middle curve and alpha (upper curve),*

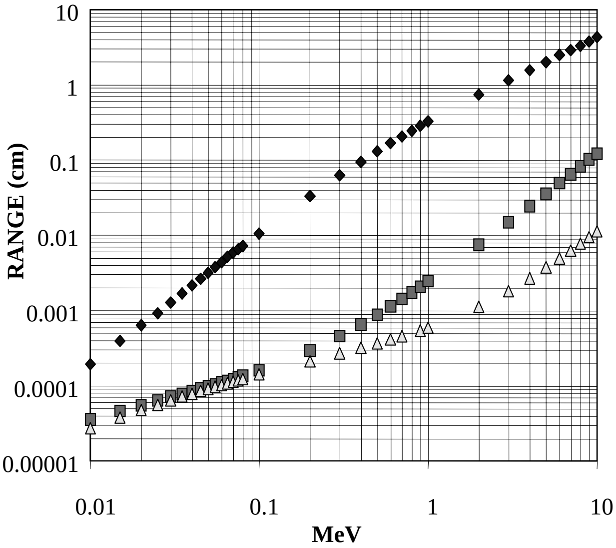

Figure 7 Range in water for electrons (upper curve), protons (middle curve) and alpha (lower curve)