APPENDIX to
Coordinated examination: radiation protection
Expertise Level 3

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examination date: 8 December 2014
duration of examination: 13.30 - 16.30

Instructions:

- **If you use data other than that provided in this appendix, please state the source!**
- **This appendix consists of 16 numbered pages. Please check this!**

CONTENTS

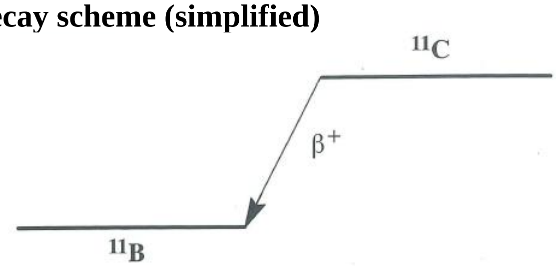
Handboek Radionucliden, A.S. Keverling Buisman (2e druk 2007), blz. 22-23, 11C

^{11}C Z = 6

Half-life and decay constant

$T_{1/2}$ = 20,39 min = 1,22×10³ s $\lambda = 5{,}67\times10^{-4}\ s^{-1}$

Decay scheme (simplified)



Main emitted radiation

Straling	y (Bq·s)$^{-1}$	E (keV)
β^+	1,000	385 | 960
$\gamma^\pm$	2,000	511

Source constants

Kermatempo in lucht	k = 0,135 µGy/h per MBq/m²
Omgevingsdosisequivalenttempo	h = 0,166 µSv/h per MBq/m²

Miscellaneous

Specific activity	A_{sp} = 3,10×10^{19} Bq/g
Exemption levels	C_v = 10 Bq/g
	A_v = 10^9 Bq (CO, CO_2)
	= 10^6 Bq (overige)
Skin contamination	H_{huid} = 5×10^{-10} Sv/s per Bq/cm²
Wound contamination / injection	$e(50)$ = 2,4×10^{-11} Sv/Bq
Transport	A_1 = 1 TBq
	A_2 = 0,6 TBq

Production and applications

The radionuclide ^{11}C is produced using a cyclotron using the $^{11}B(p,n)$ or the $^{14}C(p,\alpha)$ reaction. It is used in positron emission tomography (PET)

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N = 5 ^{11}C

Metabolic model

Voor stralingshygiënische doeleinden wordt aangenomen dat koolstof zich na ingestie en inhalatie momentaan en homogeen over het lichaam verdeelt. Er gelden verschillende biologische halveringstijden zoals aangegeven in onderstaande tabel.

Ingestion and lung clearance classes

		Biologische $T_{1/2}$
Ingestie		
Alle verbindingen	$f_1 = 1$	40 d
Inhalatie		
Organische aerosolen	M	40 d
Organische dampen	SR-2	40 d
CO	SR-1, 40% dep.	200 min
CO_2	SR-2	5 d (18%)
		60 d (81%)
		40 d (1%)

Dose conversion coefficient and radiotoxicity equivalent for both workers and members of the public

	Ingestie	Inhalatie	Inhalatie	Inhalatie	Inhalatie	
	$f_1 = 1$	M	Damp	CO	CO_2	
$e(50)$	$2{,}4\times10^{-11}$	$1{,}8\times10^{-11}$	$3{,}2\times10^{-12}$	$1{,}2\times10^{-12}$	$2{,}2\times10^{-12}$	Sv/Bq
A_{Re}	$4{,}2\times10^{10}$	$5{,}6\times10^{10}$	$3{,}1\times10^{11}$	$8{,}3\times10^{11}$	$4{,}5\times10^{11}$	Bq

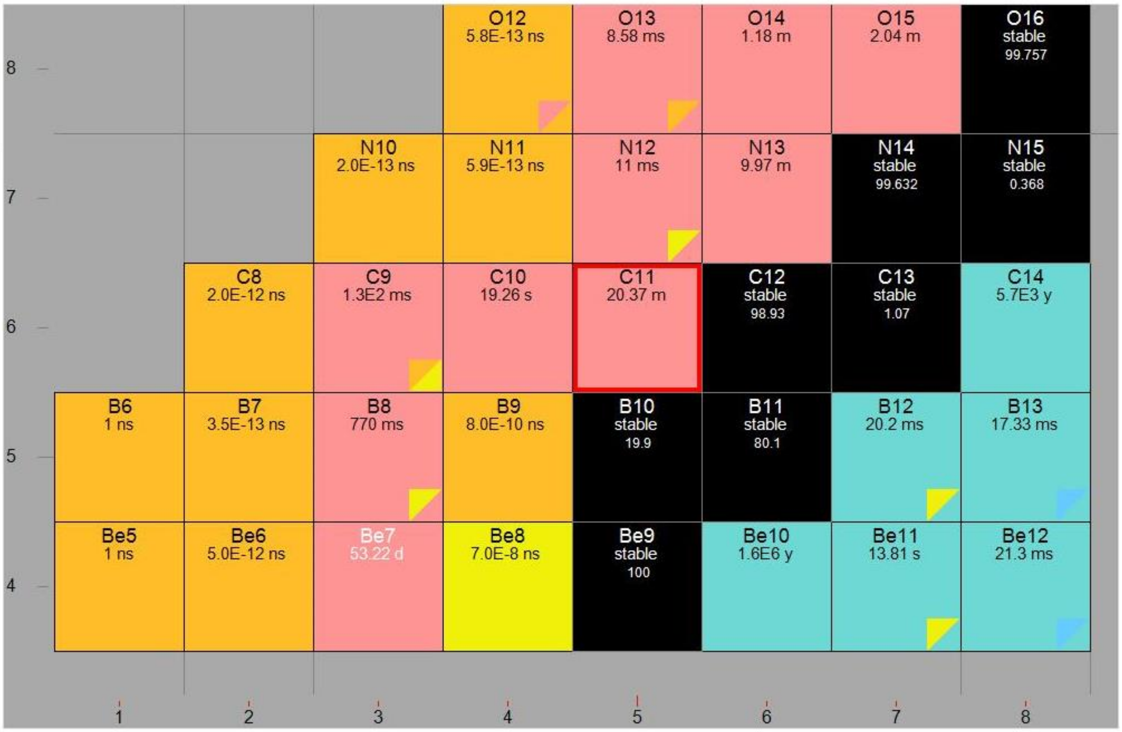
Data for total body counting

After single intake.

Time (d)	Total body activity (Bq per Bq intake)				
0,25	$4{,}9\times10^{-6}$	$3{,}6\times10^{-6}$	$4{,}9\times10^{-6}$	$1{,}1\times10^{-6}$	$4{,}9\times10^{-6}$

Activity in the body at a later time is negligible. ar.

Karlsruher Nuklidkarte, 7. Auflage 2006, detail



Q- and r-factors from the Appendix on Radionuclide Laboratories in the KeW Permit

The amount of radioactivity permissible in a particular workroom is dependent inter alia on the parameter *q*, expressing the protection offered by the room. This takes account of the protection provided by the control measures in place, such as ventilation, underpressure or an airlock. Account is also taken of the expertise of the supervisor, classification as an exposed worker and a stricter permissive regime. The following values for *q* may be adopted:

q = 0 Workrooms outside the management of the laboratory
q = 1 Class D laboratory
q = 2 Class C laboratory
q = 3 Class B laboratory.

Parameter *r* for the provision of local ventilation is determined as follows:

r = 0 For work outside the fume cupboard without supplementary ventilation
r = 1 This value may be used in the case of local extraction or with a fume cupboard not tested to DIN-12924, but where it has been established that less than 10% of the quantity of substances released within the fume cupboard enters the workroom.
r = 2 This applies to a good fume cupboard, which is taken to mean that less than 1% of substances released in the fume cupboard enters the workroom. A fume cupboard complying with DIN-12924 which is not configured in such a way that the air flow is seriously disturbed or with a laminar air flow isolator (a class II safety cabinet) will generally meet this standard.
r = 3 Enclosed work cabinet. This would cover a class III cabinet for biological safety complying with NEN-EN 12469 or an enclosed laminar air flow isolator meeting that standard.

The value to be entered in order to determine the maximal quantity to be used must be seen in relation to the value of *q*. In order to ensure equivalence in the quantities that may be used in the different categories of laboratory, the value for *r* must be limited, depending on the category in question. The value taken for *r* in calculations must never exceed that of *q*. Facilities of a higher standard (that is, with a higher *r*) may of course be used.

Calculation of the Work Load Factor (B_w) from the Appendix on Radionuclide Laboratories in the KeW Permit

2.4.1 The work load factor for the location where activities with radioactive substances take place

In order to determine that the quantity of activity which may be worked with in a laboratory is not exceeded, the Work Load Factor (B_w) for that workroom must be determined. This factor indicates the extent to which the laboratory is loaded, in relation to the situation for which it was designed. The work load factor for the workroom must not exceed 1.

The load factor is determined for the completion of operations with radioactive substances and for their storage outside the storage location. The procedure for the determination of the load factor is described below.

In order to calculate the work load factor it is necessary to estimate the number of hours t_j per week during which each operation *j* occurs. t_j is defined as the number of hours when persons are present in the workroom during the operation *j.* The calculations may be simplified by combining comparable activities with the same radioactive substance. In general the value of t_j will not exceed 40 hours a week. This is particularly important for procedures such as measurements which continue outside working hours. For storage in the workroom and outside the dedicated storage area, 40 hours a week may be assumed, as staff will not work in the laboratory for longer than this. The work load factor for a location can be calculated using the formula:

$$B_w = \sum_{j=1}^{n} \frac{t_j}{40} * \frac{X_j}{X_{\max,j}} \leq 1 \qquad \textbf{(2.6)}$$

where

B_w = work load factor for the working location
n = number of operations *j* which take place in the workroom and which is to be summed over
t_j = number of hours per week when a specified operation *j* is carried out or a situation occurs
X_j = number of radiotoxicity equivalents [Re_{inh}] manipulated during operation *j*
$X_{max,j}$ = maximum number of radiotoxicity equivalents [Re_{inh}] which may be manipulated simultaneously per operation *j*

When B_w is greater than 1, insufficient measures are being taken. This may occur when the different working or storage locations in a room are being used to the maximum in terms of time (t/40) and/or activity (X_j/X_{max}). Supplementary measures must then be taken to compensate for the simultaneous exposure to the different sources of hazard.
The method described above can be used to investigate which control measures are the most effective.

Formula 2.6 expressed in becquerels becomes:

$$B_w = \sum_{j=1}^{n}\sum_{i=1}^{m} \frac{t_j}{40} * \frac{A_{j,i}}{A_{\max,j,i}} \leq 1 \qquad \mathbf{(2.7)}$$

where

B_w = work load factor for the working location
n = number of operations j which take place in the workroom and which is to be summed over
m = number of different radionuclides i which are used simultaneously in an operation j and which is to be summed over
t_j = number of hours per week when a specified operation is carried out or a situation occurs
$A_{j,i}$ = activity [Bq] used in each operation simultaneously with radionuclide *I*
$A_{max,j,I}$ = maximal permissible activity [Bq] for operation j and radionuclide *i.*

Data of the Berthold type LB 122 A
Uit: Comparison Of Scintillation And Gas Filled Detectors For Contamination (Klett e.a.)

Berthold Type	*LB 124 SCINT*	*LB 122 A*
Detector Type	*Scintillation Detector*	*Proportional Counter*
Scintillator/Gas	*ZnS(Ag)*	*Butane*
Sensitive Area	*170 cm^2*	*218 cm^2*
Entrance Window	*Aluminized Plastic*	*Aluminized Plastic*
Thickness	*0.8 mg/cm^2*	*0.4 mg/cm^2*
Detection Mode	*Simultaneous and separate α and β-γ*	*Selectable α or β-γ*
Typical Background Counting Rates	*0.05 cps for α 15 cps for β-γ*	*0.05 cps for α 10 cps for β-γ*
Weight(incl. batteries)	*1300 g*	*2175 g*
Temperature Range	*-20°C to +40°C*	*+5°C to +50°C*
External Dimensions	*240 x 140 x 110 mm^3*	*234 x 140 x 126 mm^3*

Instrument → Radionuclide ↓	LB 122 A 218 cm^2;0.4 mg cm^{-2} Efficiency (%)
^{14}C	11.0
^{18}F	21.0
^{32}P	30.6
^{33}P	18.3
^{36}Cl	27.4
^{51}Cr	30.0
^{57}Co	1.4
^{59}Fe	21.0
^{60}Co	18.8
^{90}Sr/^{90}Y	57.3
^{99m}Tc	3.0
^{125}I	1.7
^{131}I	23.1
^{137}Cs	25.2
^{204}Tl	23.5
^{238}Pu (α–channel)	15.4

The efficiency (cps/Bq in procent) has been determined at 1 cm distance of a homogenously contaminated surface.

Data of the 1470 Wizard Gamma counter for measurements in a well type crystal.

5 The radionuclides

The radionuclides listed below can be measured with 1470 WIZARD.

ID	Nuclide	Energy (Kev)	Eff. (%) Note 1	Half-life (hours)
1	I-125	29	82	1445
2	Co-57	122	90	6480
3	Cr-51	320	3.7	667
32	Pb-203	279	31	52.1
33	Rb-86	1077	6	448
34	Ru-103	497	15	944
35	Sb-125	428	10	2.37E+4
36	Sc-46	1098	10	2011.2
37	Sc-47	160	80	82.1
38	Se-75	265	31	2880
39	Sm-153	103	86	47
40	Sn-113	392	22	2760
41	Sr-85	514	8	1530
42	Sr-87m	388	12	2.8
43	Tc-99m	140	86	6

Note 1 Eff = CPM/DPM *100 %, typical values, open window.
Efficiency includes transition probability

Handboek Radionucliden, A.S. Keverling Buisman (2e druk 2007), blz. 156-157, 123I

^{123}I

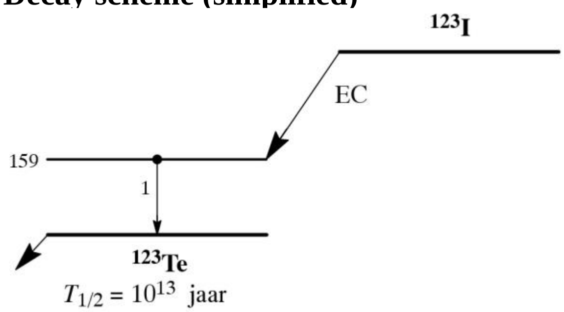
Z = 53

Half-life and decay constant

$T_{1/2}$ = 13,22 h = 4,76×10^4 s

λ = 1,46×10^{-5} s^{-1}

Decay scheme (simplified)



Main emitted radiation

Straling	y (Bq·s)$^{-1}$	E (keV)	Straling	y (Bq·s)$^{-1}$	E (keV)
γ_1	0,828	159	KLL	0,082	23
ce K γ_1	0,135	127	LMM	0,606	3
K_α	0,704	27	LMX	0,311	4
K_β	0,158	31			

Source constants

Air kerma rate	= 0,038 μGy/h per MBq/m^2
Ambient dose equivalent rate	= 0,046 μSv/h per MBq/m^2

Miscellaneous

Specific activity	A_{sp} = 7,13×10^{16} Bq/g
Exemption levels	C_v = 10^2 Bq/g en A_v = 10^7 Bq
Skin contamination	H_{huid} = 1×10^{-10} Sv/s per Bq/cm^2
Wound contamination / injection	$e(50)$ = 2,1×10^{-10} Sv/Bq
Transport	A_1 = 6 TBq
	A_2 = 3 TBq

Production and applications

Het radionuclide ^{123}I is een cyclotronproduct: protonen op xenon. Het wordt toegepast in de nucleaire geneeskunde voor diagnostische doeleinden.

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N = 70 ^{123}I

Metabolic model

Voor stralingshygiënische doeleinden wordt aangenomen dat jodium zich vanuit het bloed als volgt verdeelt: 70% directe uitscheiding en 30% naar de schildklier. Jodium in de schildklier verblijft aldaar met een biologische halveringstijd van 80 dagen, van waaruit het in de vorm van organisch jodium homogeen over het lichaam wordt verdeeld. Het verblijf in andere organen/weefsels dan de schildklier geschiedt met een halveringstijd van 12 dagen. Een tiende van het organisch jodium wordt onmiddellijk uitgescheiden via de faeces, terwijl de rest (90%) terugkeert in het transfercompartiment. Zodoende wordt de biologische halveringstijd in de schildklier effectief gelijk aan 90 dagen.
N.B. Dit model geldt niet voor patiënten, zie pagina 14.

Ingestion and lung clearance classes

Ingestie		
Alle verbindingen	$f_1 = 1$	
Inhalatie		
Damp (I_2)	$f_1 = 1$	Klasse SR-1
Damp (CH_3I)	$f_1 = 1$	Klasse SR-1 70% depositie
Overige verbindingen	$f_1 = 1$	Klasse F

Dose conversion coefficient and radiotoxicity equivalent for workers (w) and members of the public (b)

	Ingestie $f_1 = 1$	Inhalatie F	Inhalatie I_2	Inhalatie CH_3I	
$e(50)(w)$	$2,1\times10^{-10}$	$1,1\times10^{-10}$	$2,1\times10^{-10}$	$1,5\times10^{-10}$	Sv/Bq
$A_{Re}(w)$	$4,8\times10^{9}$	$9,1\times10^{9}$	$4,8\times10^{9}$	$6,7\times10^{9}$	Bq
$e(50)(b)$	$2,1\times10^{-10}$	$7,6\times10^{-11}$	$2,1\times10^{-10}$	$1,5\times10^{-10}$	Sv/Bq
$A_{Re}(b)$	$4,8\times10^{9}$	$1,3\times10^{10}$	$4,8\times10^{9}$	$6,7\times10^{9}$	Bq

Data for thyroid counting (after a single intake)

Time (d) — Total activity in thyroid (Bq per Bq intake)

Time (d)	$f_1 = 1$	F	I_2	CH_3I
0,25	$4,5\times10^{-2}$	$3,9\times10^{-2}$	$8,3\times10^{-2}$	$7,7\times10^{-2}$
1	$7,4\times10^{-2}$	$3,7\times10^{-2}$	$7,0\times10^{-2}$	$5,6\times10^{-2}$
2	$2,4\times10^{-2}$	$1,2\times10^{-2}$	$2,1\times10^{-2}$	$1,7\times10^{-2}$
3	$6,8\times10^{-3}$	$3,2\times10^{-3}$	$6,1\times10^{-3}$	$4,7\times10^{-3}$
5	$5,4\times10^{-4}$	$2,6\times10^{-4}$	$4,8\times10^{-4}$	$3,7\times10^{-4}$
7	$4,3\times10^{-5}$	$2,1\times10^{-5}$	$3,8\times10^{-5}$	$3,0\times10^{-5}$

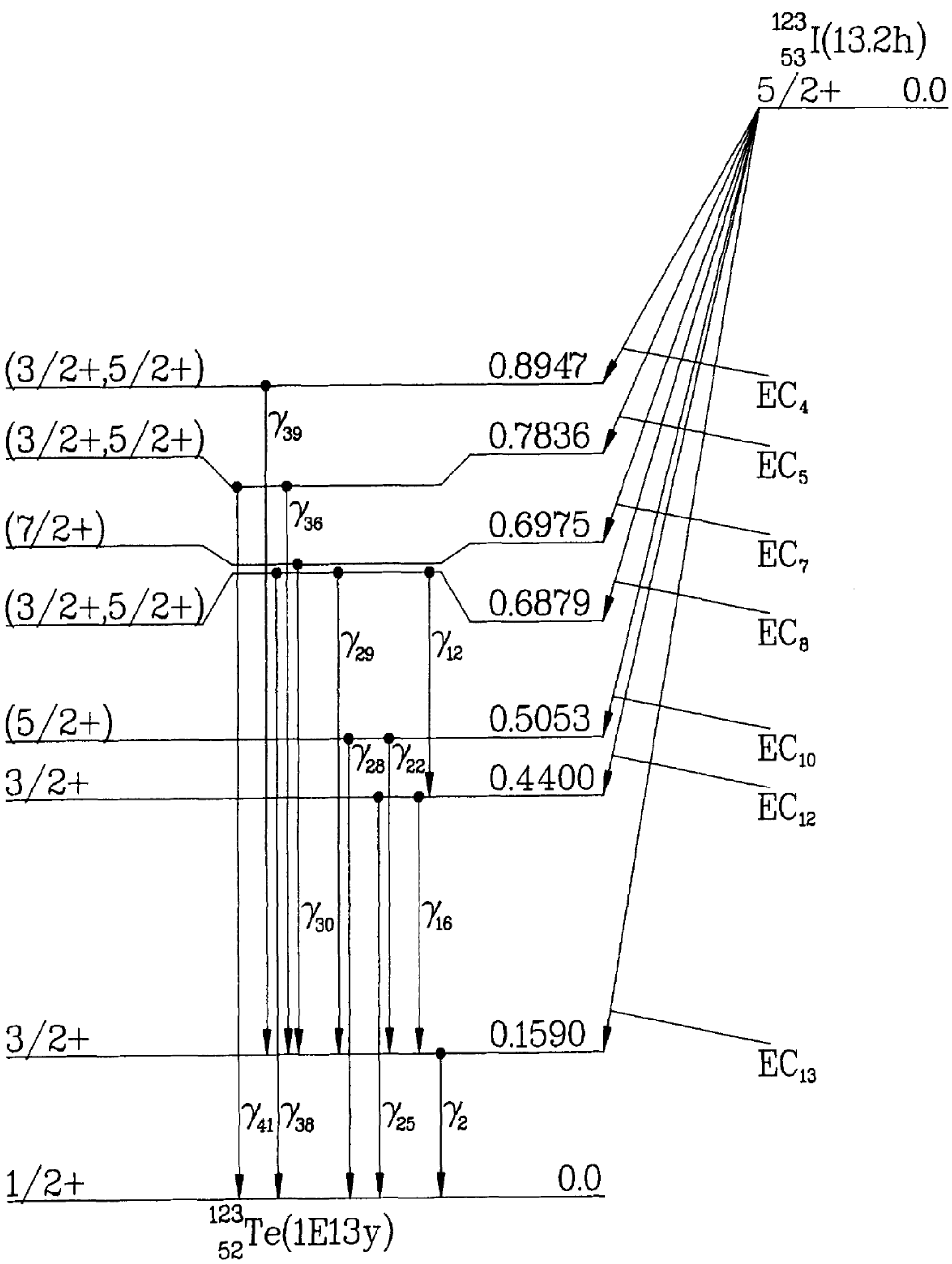
Inleiding tot de Stralingshygiëne, Bos et al (2e druk 2007), blz. 381, Interaction coefficients for photons in tin and in lead (given per photon energy in MeV, NB: 0,004 MeV = 0.004 MeV).

Fotonen-energie (MeV)	Tin $\rho = 7{,}30\ g/cm^3$ μ/ρ (cm^2/g)	μ_{tr}/ρ (cm^2/g)	μ_{en}/ρ (cm^2/g)
0,0010	11130	11110	11110
0,0015	3960	3950	3950
0,0020	1963	1954	1954
0,0030	713	705	705
0,0039288	367	360	360
L_3 edge			
0,0039288	1118	1067	1067
0,0040	1067	1019	1019
0,0041573	973	930	930
L_2 edge			
0,0041573	1244	1187	1187
0,0044648	1016	971	971
L_1 edge			
0,0044648	1264	1207	1207
0,005	919	880	880
0,006	561	540	539
0,008	259	250	249
0,010	141,6	136,5	136,4
0,015	45,8	43,7	43,6
0,020	21,2	19,83	19,81
0,0291947	7,61	6,83	6,82
K edge			
0,0291947	45,4	16,70	16,69
0,030	42,1	16,18	16,17
0,04	18,77	9,97	9,97
0,05	10,20	6,25	6,24
0,06	6,34	4,20	4,19
0,08	3,07	2,19	2,18
0,10	1,720	1,257	1,250
0,15	0,634	0,446	0,442
0,20	0,333	0,211	0,209
0,30	0,1649	0,0853	0,0843

Fotonen-energie (MeV)	Lood $\rho = 11{,}34\ g/cm^3$ μ/ρ (cm^2/g)	μ_{tr}/ρ (cm^2/g)	μ_{en}/ρ (cm^2/g)
M_1 edge	–		
0,003854	1493	1454	1453
0,004	1333	1298	1297
0,005	767	747	747
0,006	493	479	479
0,008	238	230	230
0,010	136,6	131,0	130,7
0,0130406	70,1	66,2	66,0
L_3 edge			
0,0130406	165,7	128,8	128,8
0,015	114,7	91,7	91,7
0,0152053	112,0	86,6	89,6
L_2 edge			
0,0152053	145,4	113,0	113,0
0,015855	129,3	101,7	101,6
L_1 edge			
0,015855	159,2	123,0	123,0
0,02	85,5	69,2	69,1
0,03	29,1	24,6	24,6
0,04	13,80	11,83	11,78
0,05	7,71	6,57	6,54
0,06	4,87	4,11	4,08
0,08	2,37	1,924	1,908
0,088005	1,865	1,494	1,481
K edge			
0,088005	7,30	2,47	2,47
0,10	5,78	2,28	2,28
0,15	2,07	1,164	1,154
0,2	1,014	0,637	0,629
0,3	0,406	0,265	0,259
0,4	0,233	0,1474	0,1432

ICRP 38, (1983), blz 442-443, decay scheme ^{123}I

RADIONUCLIDE TRANSFORMATIONS



ICRP 38, (1983), blz 442-443, decay scheme ^{123}I

IODINE

53-IODINE-123

HALFLIFE = 13.2 HOURS 24-FEB-77
DECAY MODE(S): EC

RADIATION	y(i) $(Bq-s)^{-1}$	E(i) (MeV)	y(i)×E(i)
γ 2	8.28E-01	1.590E-01	1.32E-01
ce-K, γ 2	1.35E-01	1.272E-01	1.72E-02
ce-L_1, γ 2	1.60E-02	1.540E-01	2.47E-03
ce-L_2, γ 2	1.09E-03	1.544E-01	1.69E-04
ce-L_3, γ 2	3.46E-04	1.546E-01	5.35E-05
ce-M, γ 2	3.46E-03	1.582E-01*	5.48E-04
ce-N^+, γ 2	8.27E-04	1.590E-01*	1.32E-04
γ 12	7.07E-04	2.480E-01	1.75E-04
γ 16	7.86E-04	2.810E-01	2.21E-04
γ 22	1.25E-03	3.463E-01	4.33E-04
γ 25	4.25E-03	4.400E-01	1.87E-03
γ 28	3.14E-03	5.053E-01	1.59E-03
γ 29	1.38E-02	5.290E-01	7.31E-03
ce-K, γ 29	9.90E-05	4.971E-01	4.92E-05
γ 30	3.79E-03	5.385E-01	2.04E-03
γ 36	8.28E-04	6.246E-01	5.17E-04
γ 38	2.66E-04	6.879E-01	1.83E-04
γ 39	6.12E-04	7.358E-01	4.50E-04
γ 41	5.90E-04	7.836E-01	4.62E-04
$K\alpha_1$ X-ray	4.58E-01	2.747E-02	1.26E-02
$K\alpha_2$ X-ray	2.46E-01	2.720E-02	6.70E-03
$K\beta_1$ X-ray	8.66E-02	3.100E-02	2.69E-03
$K\beta_2$ X-ray	2.66E-02	3.171E-02	8.43E-04
$K\beta_3$ X-ray	4.46E-02	3.094E-02	1.38E-03
Auger-KLL	8.15E-02	2.254E-02*	1.84E-03
Auger-KLX	3.69E-02	2.635E-02*	9.73E-04
Auger-KXY	4.92E-03	3.013E-02*	1.48E-04
Auger-LMM	6.06E-01	3.080E-03*	1.87E-03
Auger-LMX	3.11E-01	3.849E-03*	1.20E-03
Auger-LXY	4.40E-02	4.380E-03*	1.93E-04
Auger-MXY	1.80E 00	6.991E-04*	1.26E-03

LISTED X, γ AND $\gamma\pm$ RADIATIONS	1.71E-01
OMITTED X, γ AND $\gamma\pm$ RADIATIONS**	6.76E-04
LISTED β, ce AND Auger RADIATIONS	2.80E-02
OMITTED β, ce AND Auger RADIATIONS**	1.21E-04
LISTED RADIATIONS	1.99E-01
OMITTED RADIATIONS**	7.97E-04

* AVERAGE ENERGY (MeV)
** EACH OMITTED TRANSITION CONTRIBUTES <0.100% TO $\Sigma y(i)\times E(i)$ IN ITS CATEGORY.
TELLURIUM-123M DAUGHTER, YIELD 5.00E-05, IS RADIOACTIVE.
TELLURIUM-123 DAUGHTER, YIELD 9.999E-01, IS RADIOACTIVE.

SBD-TU/e, graph of transmission (transmissie) of photons from ^{123}I through lead (thickness (=looddikte) indicated in cm).