ATTACHMENT for Exam
Radiation protection expert on the level of coordinating expert

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Nuclear Research and consultancy Group	NRG
Delft University of Technology	TUD
University of Groningen	RUG
Radboudumc	RUMC

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exam date:

May 9th 2022

exam duration: 13.30 - 16.30 hours

Instructions:

- If you use any data other than the data mentioned in this attachment, state the origin!
- In the original data sheets from the handbook radionuclides commas are used as decimal markers.
- This attachment consists of 15 consecutively numbered pages.
  Check this!

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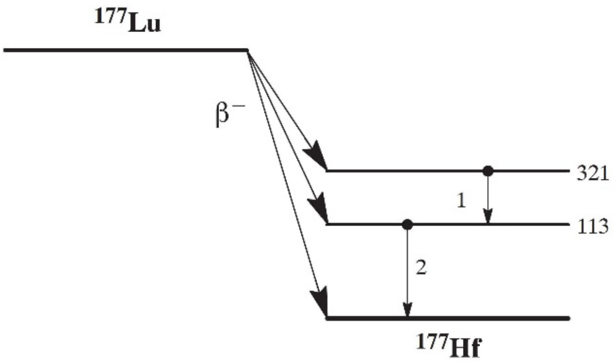
Handboek Radionucliden, A.S. Keverling Buisman (3rd edition 2015), pg. 204-205, ^{177}Lu data

^{177}Lu Z = 71

Half-life and decay constant

$T_{1/2}$ = 6,71 d = 5,80×10^5 s λ = 1,20×10^{-6} s^{-1}

Decay scheme (simplified)



Main emitted radiation

Straling	y (Bq·s)$^{-1}$	E (keV)
β^-	0,122	47 | 176
β^-	0,091	111 | 384
β^-	0,786	149 | 497
γ_1	0,110	208
γ_2	0,064	113
K_α	0,047	55

Source constants

Air kerma rate	k = 0,0043 µGy/h per MBq/m^2
Ambient dose equivalent rate	h = 0,0063 µSv/h per MBq/m^2

Miscellaneous

Specific activity	A_{sp} = 4,07×10^{15} Bq/g
Exemption levels	C_v = 10^3 Bq/g en A_v = 10^7 Bq
Skin contamination	H_{huid} = 4×10^{-10} Sv/s per Bq/cm^2
Wound contamination / injection	$e(50)$ = 5,0×10^{-10} Sv/Bq
Transport	A_1 = 30 TBq
	A_2 = 0,7 TBq

204

N = 106 | ^{177}Lu

Production and applications

The radionuclide ^{177}Lu is an activation product.

Metabolic Model

For radiation protection purposes, it is assumed that lutetium distributes itself from the blood as follows: 60% to the bone, 2% to the liver, 0.5% to the kidneys and the remainder is excreted directly. The biological half-life for all organs and tissues is set at 3500 days, with exception of the kidneys (10 days).

Ingestion and lung clearance classes

Ingestie		
Alle verbindingen	$f_1 = 5\times10^{-4}$	
Inhalatie		
Hydroxide, oxide, fluoride	$f_1 = 5\times10^{-4}$	Klasse S
Overige verbindingen	$f_1 = 5\times10^{-4}$	Klasse M

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

	Ingestie	Inhalatie	Inhalatie	
	$f_1 = 5\times10^{-4}$	M	S	
$e(50)$	$5,3\times10^{-10}$	$1,0\times10^{-9}$	$1,1\times10^{-9}$	Sv/Bq
A_{Re}	$1,9\times10^{9}$	$1,0\times10^{9}$	$9,1\times10^{8}$	Bq

Data for total body count

(after single intake)

Time (d)	Activity in body (Bq per Bq intake)		
0,25	$9,6\times10^{-1}$	$7,2\times10^{-1}$	$7,2\times10^{-1}$
1	$6,5\times10^{-1}$	$4,4\times10^{-1}$	$4,4\times10^{-1}$
2	$2,7\times10^{-1}$	$2,1\times10^{-1}$	$2,0\times10^{-1}$
3	$9,7\times10^{-2}$	$1,1\times10^{-1}$	$9,9\times10^{-2}$
5	$1,1\times10^{-2}$	$4,9\times10^{-2}$	$4,3\times10^{-2}$
7	$1,3\times10^{-3}$	$3,6\times10^{-2}$	$3,0\times10^{-2}$

Parameters p, q and r from the Attachment radionuclide laboratory

Value of the dispersion parameter *p* for specific handlings within the laboratory

APPLICATION	*p*
Simple processing steps with gasses Working with powders in 'open' system, e.g. mixing or grinding Liquid with temperature close to boiling point Strongly splashing processing steps	-4
Labeling with a volatile nuclide (e.g. iodine) Cooking of liquids in a 'closed' system Centrifugation and mixing on vortex Simple processing steps of powders in 'closed' system Storage of noble gas in administration system	-3
Labeling with non-volatile nuclide Simple chemical steps with tracers (e.g. RIA)	-2
Simple processing steps in 'closed' systems such as: Elution ^{99m}Tc-generator Pulling back syringes Labeling in closed systems Calibration ^{131}I capsule Measuring substances in hard to disperse form (e.g. in ampule) Storage of radioactive waste in workspace	-1

For *q* the following values can be used:

q = 0 Workspaces outside of laboratory management
q = 1 D-laboratory
q = 2 C-laboratory
q = 3 B-laboratory

The parameter *r* for the local ventilation system is determined as follows:

r = 0 For working outside the fume hood without additional ventilation systems
r = 1 This value may be used in the case of local ventilation or a fume hood which has not been tested according to DIN-12924, but for which has been established that less than 10% of the amount of substance which is released in the fume hood enters the workspace
r = 2 This applies in case of a well-functioning fume hood, with which is meant that from the total amount of substance released in the fume hood less than 1% enters the work space. A fume hood with DIN-12924 qualification in which no setup has been placed that significantly alters the airflow, or a laminar air flow isolator (safety cabinet class II) will in general meet this standard
r = 3 Closed work cabinet. With this a class-III cabinet for biological safety with NEN-EN 12469 qualification of closed laminar air flow isolator which meets these requirements is meant

Density and attenuation coefficients for lead

Density lead = 11.3 g/cm^3

Mass attenuation coefficients for lead

	Energy (MeV)	μ/ρ (cm^2/g)	μ_{en}/ρ (cm^2/g)	μ_{tr}/ρ (cm^2/g)
	1.00000E-02	1.306E+02	1.247E+02	1.247E+02
	1.30352E-02	6.701E+01	6.270E+01	6.251E+01
L3	1.30352E-02	1.621E+02	1.291E+02	1.291E+02
	1.50000E-02	1.116E+02	9.100E+02	9.100E+01
	1.52000E-02	1.078E+02	8.807E+02	8.512E+01
L2	1.52000E-02	1.485E+02	1.131E+02	1.131E+02
	1.55269E-02	1.416E+02	1.083E+02	1.082E+02
	1.58608E-02	1.344E+02	1.032E+02	1.030E+02
L1	1.58608E-02	1.548E+02	1.180E+02	1.180E+02
	2.00000E-02	8.636E+01	6.899E+01	6.879E+01
	3.00000E-02	3.032E+01	2.536E+01	2.536E+01
	4.00000E-02	1.436E+01	1.211E+01	1.206E+01
	5.00000E-02	8.041E+00	6.740E+00	6.709E+00
	6.00000E-02	5.021E+00	4.149E+00	4.119E+00
	8.00000E-02	2.419E+00	1.916E+00	1.900E+00
	8.80045E-02	1.910E+00	1.482E+00	1.469E+00
K	8.80045E-02	7.683E+00	2.160E+00	2.160E+00
	1.00000E-01	5.549E+00	1.976E+00	1.976E+00
	1.50000E-01	2.014E+00	1.056E+00	1.047E+00
	2.00000E-01	9.985E-01	5.870E-01	5.796E-01
	3.00000E-01	4.031E-01	2.455E-01	2.316E-01
	4.00000E-01	2.323E-01	1.370E-01	1.331E-01
	5.00000E-01	1.614E-01	9.128E-01	8.821E-02
	6.00000E-01	1.248E-01	6.819E-01	6.569E-02
	8.00000E-01	8.870E-02	4.644E-02	4.441E-02
	1.00000E+00	7.102E-02	3.654E-02	3.479E-02
	1.25000E+00	5.876E-02	2.988E-02	2.839E-02
	1.50000E+00	5.222E-02	2.640E-02	2.484E-02
	2.00000E+00	4.606E-02	2.360E-02	2.187E-02

Source: https://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z82.html

Build-up-factors for lead

Table 3 Exposure absorption build up factors for lead.
R(mfp) = µd

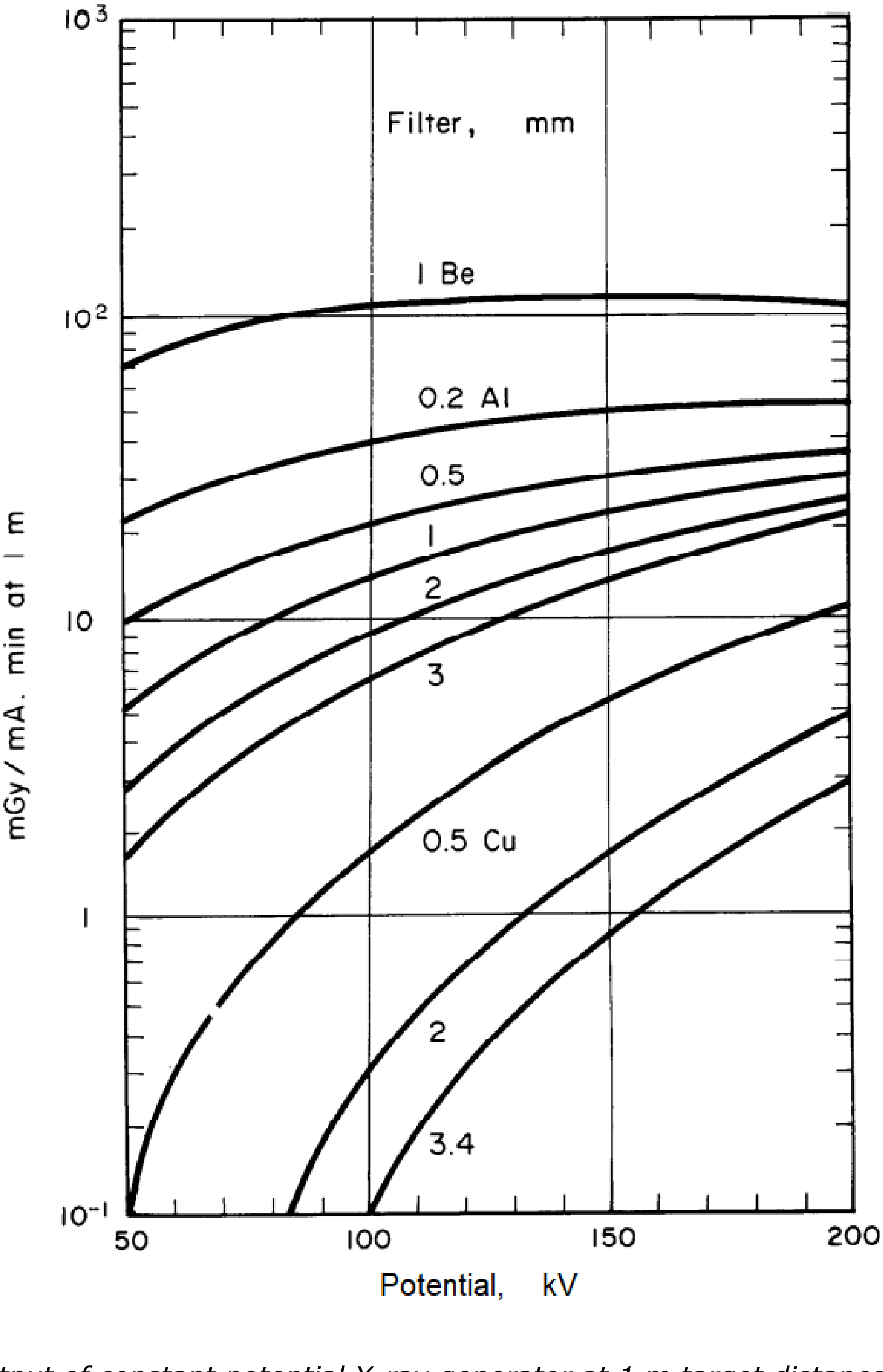
	Energy (Mev)							
R(mfp)	0.3	0.2	0.15	0.1	0.08	0.06	0.05	0.04
0.5	1.08	1.14	1.25	1.52	1.02	1.01	1.01	1.01
1.0	1.12	1.19	1.41	2.05	1.03	1.02	1.01	1.01
2.0	1.19	1.23	1.60	3.44	1.05	1.03	1.02	1.01
3.0	1.24	1.25	1.72	5.72	1.06	1.03	1.02	1.01
4.0	1.28	1.26	1.82	9.90	1.08	1.04	1.02	1.01
5.0	1.31	1.28	1.90	1.77E1	1.09	1.04	1.03	1.02
6.0	1.34	1.29	1.96	3.22E1	1.09	1.05	1.03	1.02
7.0	1.37	1.31	2.03	5.83E1	1.10	1.05	1.03	1.02
8.0	1.39	1.31	2.11	1.02E2	1.11	1.06	1.04	1.02
10.0	1.43	1.34	2.27	3.20E2	1.12	1.06	1.04	1.02
15.0	1.51	1.37	2.77	6.55E3	1.15	1.08	1.05	1.03
20.0	1.57	1.40	3.36	1.55E5	1.17	1.09	1.06	1.03
25.0	1.62	1.42	4.26	4.01E6	1.18	1.10	1.07	1.04
30.0	1.65	1.44	5.71	1.09E8	1.20	1.10	1.08	1.04

Source: New gamma-ray buildup factor data for point kernel calculations: ans-6.4.3 standard reference data, page 40.
https://technicalreports.ornl.gov/1988/3445605718328.pdf

Labeling class 7

class	sticker	max. dose rate at surface	maximum transport index
I-white		5 µSv/h	
II-yellow		0.5 mSv/h	1.0 (10 µSv/h)
III-yellow		2 mSv/h	10 (100 µSv/h)

Output air kerma rate of X-ray systems with varying filters and tube currents



Output of constant potential X-ray generator at 1 m target distance for various beam filtrations and a tungsten reflector target. The 1 mm beryllium is the tube window. [ICRP 33, figure 2]

Texts from the license of the vet

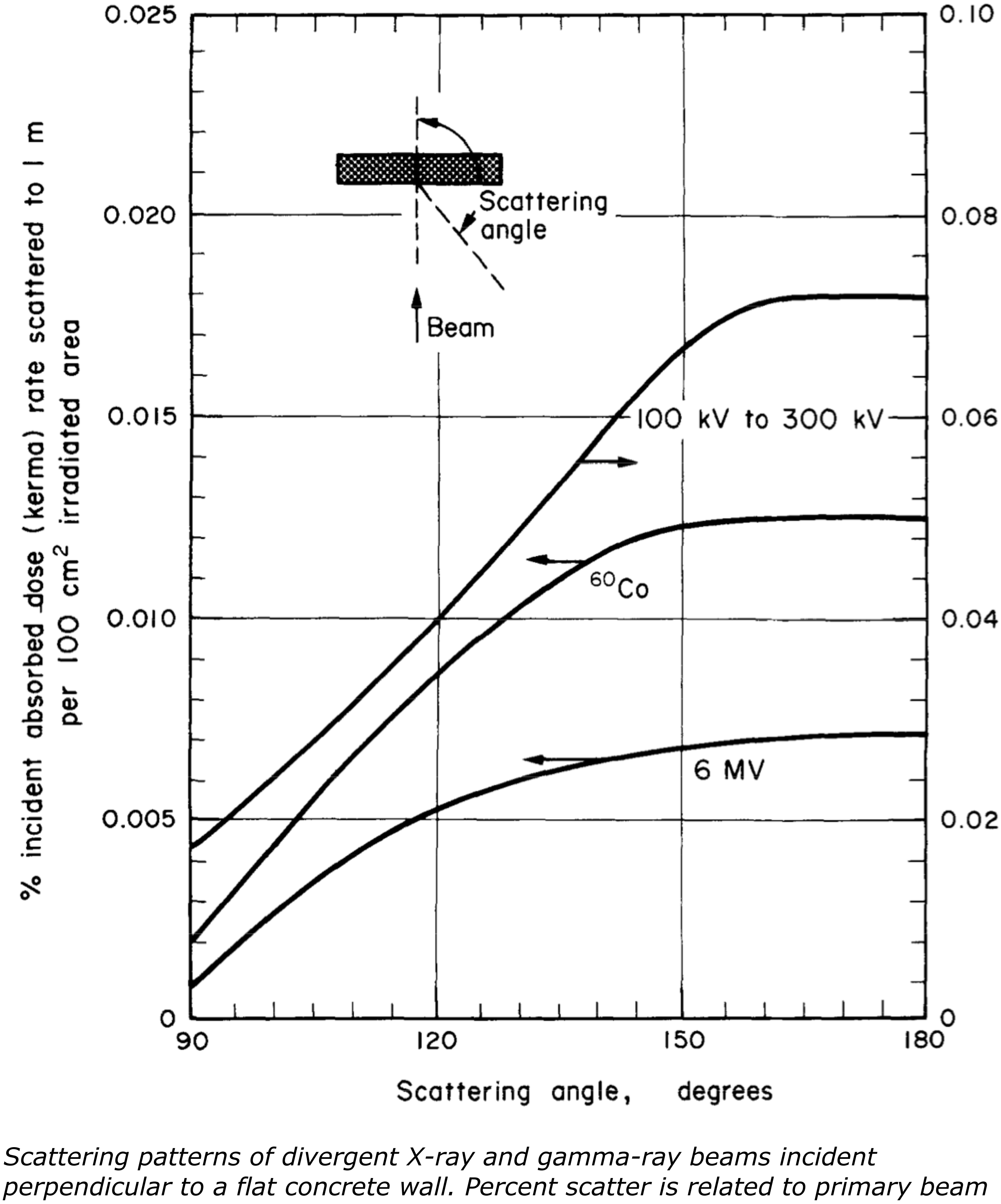
Environmental impact varying locations

Outside each location other than the fixed location, the contribution to the effective dose for persons caused by the licensed actions as a result from actions at varying locations in the Netherlands is as low as reasonably achievable (the ALARA principle). Under no circumstances does the MID exceed the value of 10 microsieverts per year per work location.

Considerations

In these considerations it has been taken into account that the MID in no way exceeds the value of 10 μSv per year at third party location(s), as evidenced from the added terrain boundary calculations, where the regulations from the work instructions are strictly followed. This means that x-rays at third party location(s) will only be made if there is sufficient shielding available in the form of a wall of steel, stone, concrete or lead. This is for the consideration and assessment of the radiation protection officer.
Section 1.2 under II.1 describes that direct supervision by a radiation protection officer (TMS) is required for the relevant application. Direct supervision means that a designated TMS monitors the performed actions at that location. Direct supervision is required, because irradiation takes place in the open field with the risk of exposing members of the population when measures are not (correctly) implemented.

Scattering angle and dose(kerma)rate of divergent beams of X-ray and gamma radiation incident perpendicular to a flat concrete wall.



Scattering patterns of divergent X-ray and gamma-ray beams incident perpendicular to a flat concrete wall. Percent scatter is related to primary beam measurements in free air at the point of incidence. [ICRP 33, figure 22]

Efficiency MiniTRACE, type CSDF

The efficiency of the MiniTRACE, type CSDF, is given below for a few radionuclides. The values have been determined by keeping a point source at the position of the cover, in the center above the detector. This in fact results in a 2π-geometry.

Radionuclide	Closed cover (cps/Bq)	Open cover (cps/Bq)
C-14	0	0.071
Cl-36	0	0.18
Co-60	0.0088	0.15
Sr-90	0.077	0.60
Cs-137	0.006	0.23
U-238	0.013	0.47
Am-241	0.00015	0.13

Based on: Manual MiniTRACE, type CSDF (Saphymo, 2012), pg. 33.

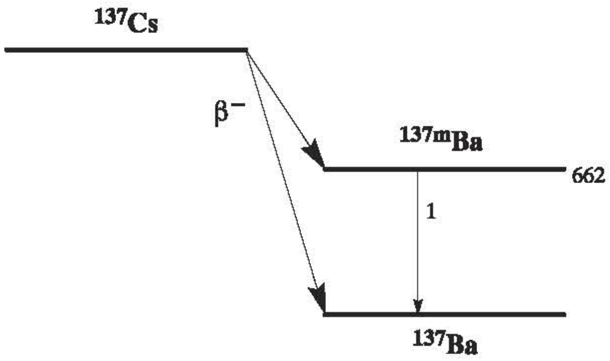
Handboek Radionucliden, A.S. Keverling Buisman (3rd edition 2015), pg. 172, ^{137}Cs data

^{137}Cs Z = 55

Half-life and decay constant

$T_{1/2}$ = 30,25 j = 9,55×10^{8} s λ = 7,26×10^{-10} s^{-1}

Decay scheme (simplified)



Main emitted radiation of ^{137m}Ba ($T_{1/2}$ = 2.55 min; y =0.946)

Straling	y (Bq·s)$^{-1}$	E (keV)	Straling	y (Bq·s)$^{-1}$	E (keV)
β^-	0,946	173 | 512	γ_1	0,898	662
β^-	0,054	425 | 1173	ce K γ_1	0,083	624

Source constants (of daughter ^{137m}Ba in equilibrium with ^{137}Cs)

Air kerma rate	k = 0,077 µGy/h per MBq/m^2
Ambient dose equivalent rate	h = 0,093 µSv/h per MBq/m^2

Miscellaneous

Specific activity	A_{sp} = 3,19×10^{12} Bq/g
Exemption levels	C_v = 10^1 Bq/g en A_v = 10^4 Bq
Skin contamination	H_{huid} = 5×10^{-10} Sv/s per Bq/cm^2 (incl. ^{137m}Ba)
Wound contamination / injection	$e(50)$ = 1,4×10^{-8} Sv/Bq (incl. ^{137m}Ba)
Transport	A_1 = 2 TBq
	A_2 = 0,6 TBq

Productie en toepassingen

Het radionuclide ^{137}Cs is een belangrijk splijtingsproduct. Het wordt onder meer gebruikt als gamma-referentiebron en als bron bij brachytherapie.

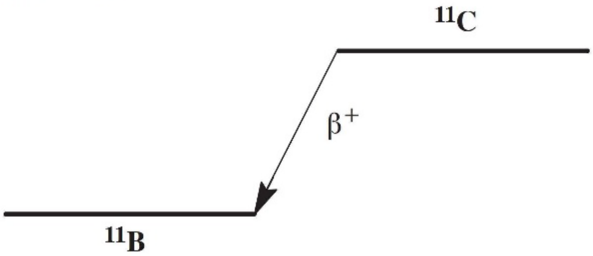
Handboek Radionucliden, A.S. Keverling Buisman (3rd edition 2015), pg. 22-23, ^{11}C data

^{11}C Z = 6

Half-life and decay constant

$T_{1/2}$ = 20,39 min = $1{,}22\times10^3$ 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

Air kerma rate	k = 0,135 µGy/h per MBq/m^2
Ambient dose equivalent rate	h = 0,166 µSv/h per MBq/m^2

Miscellaneous

Specific activity	A_{sp} = $3{,}10\times10^{19}$ 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/cm^2
Wound contamination / injection	$e(50)$ = $2{,}4\times10^{-11}$ Sv/Bq
Transport	A_1 = 1 TBq
	A_2 = 0,6 TBq

Productie en toepassingen

Het radionuclide ^{11}C wordt geproduceerd met een cyclotron via de ^{11}B(p,n)- of de ^{14}C(p,α)-reactie. Het wordt toegepast voor positron-emissie-tomografie (PET).

N = 5 ^{11}C

Metabolic Model
For radiation protection purposes, it is assumed that carbon distributes itself instantaneous over the whole body after ingestion and inhalation.
Different biological half-lives apply as indicated in the table underneath.

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 workers (w) and members of the public (b)

	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 count (after single intake)

Time (d)	Activity in Body (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 body at later time intervals is negligible.