Embargo 15 May 2017

APPENDIX to the Examination Coordinating Radiation Protection Expert

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Nuclear Research and Consultancy Group	NRG
Delft University of Technology	TU Delft
Boerhaave CME/LUMC	BN/LUMC
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Eindhoven University of Technology	TU/e

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examination date: 15 May 2017
duration of examination: 13:30 - 16:30

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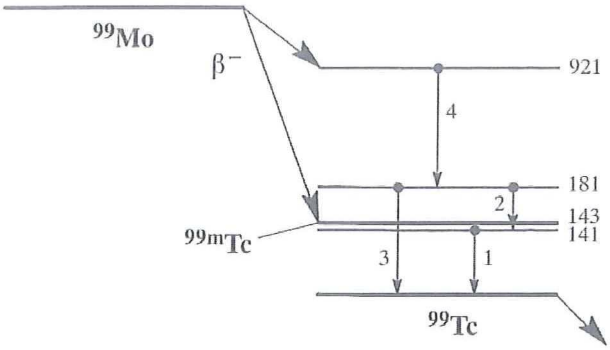
^{99}Mo Z = 42

Half-life and decay constant

$T_{1/2} = 65{,}94$ h = $2{,}37 \times 10^5$ s $\lambda = 2{,}92 \times 10^{-6}$ s^{-1}

Decay scheme (simplified)



Main emitted radiation

Straling	y (Bq·s)$^{-1}$	E (keV)
β^-	0,820	443 | 1214
β^-	0,166	133 | 436
γ_1	0,049	141
γ_2	0,012	41
γ_3	0,061	181
γ_4	0,122	740

Voor straling van dochters ^{99}Tc (y = 0,124) en ^{99m}Tc (y = 0,876): zie aldaar

Source constants

Air kerma rate k = 0,022 μGy/h per MBq/m^2
Ambient dose equivalent rate h = 0,026 μSv/h per MBq/m^2

Miscellaneous

Specific activity A_{sp} = $1{,}77 \times 10^{16}$ Bq/g
Exemption levels C_v = 10^2 Bq/g en $A_v = 10^6$ Bq
Skin contamination H_{huid} = 4×10^{-10} Sv/s per Bq/cm^2
Wound contamination / injection $e(50)$ = $4{,}6 \times 10^{-10}$ Sv/Bq (incl. ^{99m}Tc)
Transport A_1 = 1 TBq
A_2 = 0,6 TBq

^{99}Tc

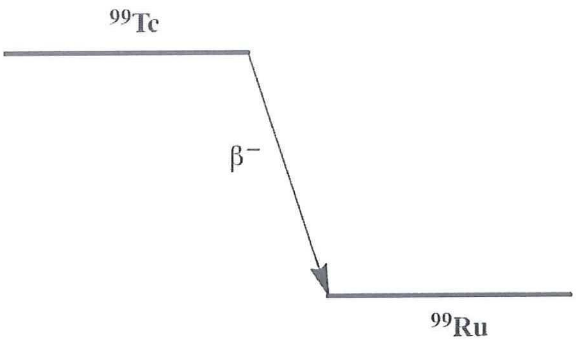
Z = 43

Half-life and decay constant

$T_{1/2} = 2{,}13 \times 10^{5}$ j $= 6{,}72 \times 10^{12}$ s

$\lambda = 1{,}03 \times 10^{-13}$ s^{-1}

Decay scheme (simplified)



Main emitted radiation

Straling	y (Bq·s)$^{-1}$	E (keV)
β^-	1,000	101 | 294

Miscellaneous

Specific activity	A_{sp} = $6{,}27 \times 10^{8}$ Bq/g
Exemption levels	C_v = 10^4 Bq/g en $A_v = 10^7$ Bq
Skin contamination	H_{huid} = 3×10^{-10} Sv/s per Bq/cm^2
Wound contamination / injection	$e(50)$ = $1{,}8 \times 10^{-10}$ Sv/Bq
Transport	A_1 = 40 TBq
	A_2 = 0,9 TBq

Productie en toepassingen

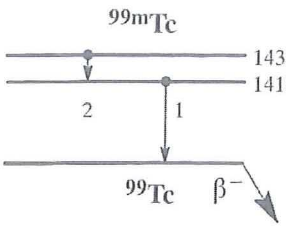
Het radionuclide ^{99}Tc is een splijtingsproduct.

^{99m}Tc Z = 43

Half-life and decay constant

$T_{1/2} = 6{,}006$ h = $2{,}17\times10^4$ s $\lambda = 3{,}21\times10^{-5}$ s^{-1}

Decay scheme (simplified)



Main emitted radiation

Straling	y (Bq·s)$^{-1}$	E (keV)
γ_1	0,889	141
ce M γ_2	0,914	2
ce N γ_2	0,076	2
K_α	0,062	18
LMX	0,102	2

Source constants

Air kerma rate k = 0,018 µGy/h per MBq/m^2
Ambient dose equivalent rate h = 0,023 µSv/h per MBq/m^2

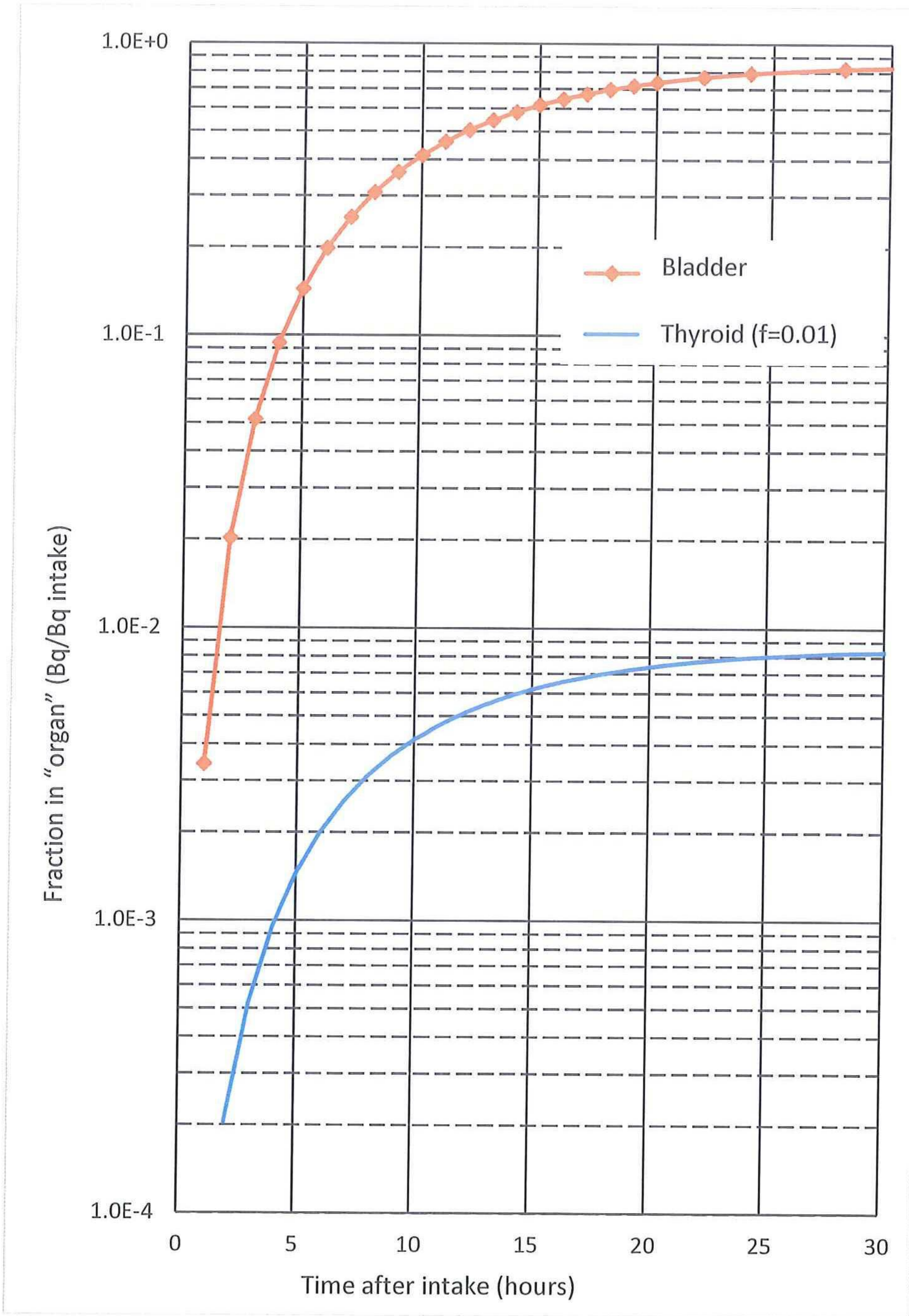
Miscellaneous

Specific activity A_{sp} = $1{,}95\times10^{17}$ Bq/g
Exemption levels C_v = 10^2 Bq/g en $A_v = 10^7$ Bq
Skin contamination H_{huid} = 5×10^{-11} Sv/s per Bq/cm^2
Wound contamination / injection $e(50)$ = $1{,}1\times10^{-11}$ Sv/Bq
Transport A_1 = 10 TBq
A_2 = 4 TBq

Productie en toepassingen

Het radionuclide ^{99m}Tc is de dochter van ^{99}Mo. Het wordt geproduceerd in een Mo/Tc-generator en op zeer grote schaal in de nucleaire geneeskunde gebruikt voor diagnostische doeleinden: voor afbeeldingen en functiestudies.

^{131}I uptake, including decay, in two organs after ^{131}I ingestion during the treatment of metastases, calculated using the HARAS model.

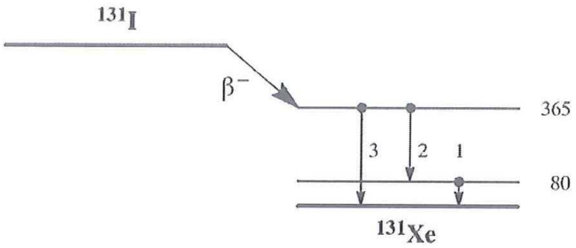


^{131}I Z = 53

Half-life and decay constant

$T_{1/2}$ = 8,021 d = 6,93×10^5 s λ = 1,00×10^{-6} s^{-1}

Decay scheme (simplified)



Main emitted radiation

Straling	y (Bq·s)$^{-1}$	E (keV)
β^-	0,894	192 | 606
γ_1	0,026	80
ce K γ_1	0,036	46
γ_2	0,061	284
γ_3	0,812	365

ISource constants

Air kerma rate	k = 0,052 µGy/h per MBq/m^2
Ambient dose equivalent rate	h = 0,066 µSv/h per MBq/m^2

Miscellaneous

Specific activity	A_{sp} = 4,60×10^{15} Bq/g
Exemption levels	C_v = 10^2 Bq/g en A_v = 10^6 Bq
Skin contamination	H_{huid} = 4×10^{-10} Sv/s per Bq/cm^2
Wound contamination / injection	$e(50)$ = 2,2×10^{-8} Sv/Bq
Transport	A_1 = 3 TBq
	A_2 = 0,7 TBq

Productie en toepassingen

Het radionuclide ^{131}I is een belangrijk splijtingsproduct. Het wordt veelvuldig toegepast in de diagnostische en therapeutische nucleaire geneeskunde.

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N = 78 ^{131}I

Metabolic Model
For radiation protection purposes, it is assumed that iodine distributes itself from the blood as follows: 70% direct excretion and 30% to the thyroid. Iodine in the thyroid remains there with a biological half-life of 80 days and from there it is homogeneously distributed throughout the body in the form of organic iodine. It remains in other organs/tissue with a half-life of 12 days. A tenth of the organic iodine is immediately excreted in faeces, while the rest (90%) is returned to the transfer compartment. In this way, the biological half-life in the thyroid is effectively equal to 90 days.
N.B. This model does not apply to patients; see page 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	
$e(50)(w)$	$2{,}2\times10^{-8}$	$1{,}1\times10^{-8}$	$2{,}0\times10^{-8}$	$1{,}5\times10^{-8}$	Sv/Bq
$A_{Re}(w)$	$4{,}5\times10^{7}$	$9{,}1\times10^{7}$	$5{,}0\times10^{7}$	$6{,}7\times10^{7}$	Bq
$e(50)(b)$	$2{,}2\times10^{-8}$	$7{,}6\times10^{-9}$	$2{,}0\times10^{-8}$	$1{,}5\times10^{-8}$	Sv/Bq
$A_{Re}(b)$	$4{,}5\times10^{7}$	$1{,}3\times10^{8}$	$5{,}0\times10^{7}$	$6{,}7\times10^{7}$	Bq

Data for thyroid count (after single intake)

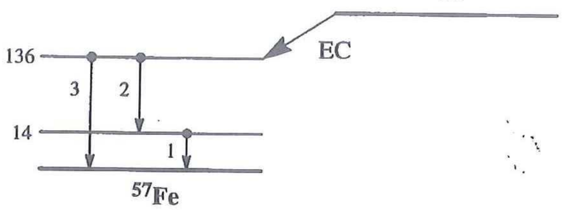
Time (d)	Activity in Thyroid (Bq per Bq intake)			
	$f_1 = 1$	F	I_2	CH_3I
0,25	$6{,}0\times10^{-2}$	$5{,}2\times10^{-2}$	$1{,}1\times10^{-1}$	$1{,}0\times10^{-1}$
1	$2{,}4\times10^{-1}$	$1{,}2\times10^{-1}$	$2{,}3\times10^{-1}$	$1{,}8\times10^{-1}$
2	$2{,}5\times10^{-1}$	$1{,}2\times10^{-1}$	$2{,}2\times10^{-1}$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

^{57}Co   Z = 27

Half-life and decay constant

$T_{1/2}$ = 271,84 d = 2,35×10^{7} s λ = 2,95×10^{-8} s^{-1}

Decay scheme (simplified)



Main emitted radiation

Straling	y (Bq·s)$^{-1}$	E (keV)	Straling	y (Bq·s)$^{-1}$	E (keV)
γ_1	0,092	14	ce K γ_1	0,713	7
γ_2	0,856	122	ce K γ_2	0,018	115
γ_3	0,106	136	ce K γ_3	0,014	129
K_α	0,503	6			

Source constants

Air kerma rate	k = 0,022 μGy·m^2·MBq^{-1}·h^{-1}
Ambient dose equivalent rate	h = 0,023 μSv·m^2·MBq^{-1}·h^{-1}

Miscellaneous

Specific activity	A_{sp} = 3,12×10^{17} Bq·kg^{-1}
Exemption levels	Gemiddeld (3)
Skin contamination	10^2 Bq·g^{-1} en 10^6 Bq
Wound contamination / injection	H_{huid} = 1×10^{-11} Sv·s^{-1}·Bq^{-1}·cm^2
Transport	$e(50)$ = 5,9×10^{-10} Sv·Bq^{-1}
	A_1 = 8 TBq
	A_2 = 8 TBq

Produktie en toepassingen

Het radionuclide ^{57}Co wordt geproduceerd met behulp van een cyclotron: protonen op ijzer. Het wordt toegepast in de geneeskunde (vitamine-B-stofwisseling, testbron voor gamma-camera, botdensitometrie). In de vaste-stoffysica vindt ^{57}Co een speciale toepassing, namelijk als Mössbauer-bron.

N = 30 ^{57}Co

Internal contamination

Metabolic model.

For radiation protection purposes, it is assumed that cobalt distributes itself from the blood as follows: 50% direct excretion, 5% to the liver and 45% to the rest of the body. Biological half-life: 0.5 days.

The biological half-lives for the organs are:

Fraction	$T_{1/2}$
0,6	6 d
0,2	60 d
0,2	800 d

Ingestion and lung clearance classes

Ingestie

Oxide, hydroxide en anorganisch	f_1 = 0,05	
Overige verbindingen	f_1 = 0,1	

Inhalatie

Oxide, hydroxide, halogenide, nitraat	f_1 = 0,05	Klasse S
Overige	f_1 = 0,1	Klasse M

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

	Ingestie	Ingestie	Inhalatie	Inhalatie
	f_1 = 0,1	f_1 = 0,05	M	S
e(50) (Sv/Bq)	$2{,}1\times10^{-10}$	$1{,}9\times10^{-10}$	$3{,}9\times10^{-10}$	$6{,}0\times10^{-10}$
RE (Bq)	5×10^{9}			2×10^{9}

Data for total body counting

Single intake

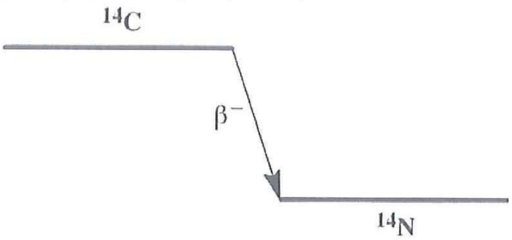
Time (d)	Total body activity (Bq per Bq intake)			
0,25	$9{,}7\times10^{-1}$	$9{,}8\times10^{-1}$	$7{,}4\times10^{-1}$	$7{,}4\times10^{-1}$
1	$6{,}8\times10^{-1}$	$7{,}1\times10^{-1}$	$4{,}8\times10^{-1}$	$4{,}9\times10^{-1}$
2	$3{,}7\times10^{-1}$	$3{,}3\times10^{-1}$	$2{,}5\times10^{-1}$	$2{,}5\times10^{-1}$
3	$2{,}2\times10^{-1}$	$1{,}5\times10^{-1}$	$1{,}4\times10^{-1}$	$1{,}4\times10^{-1}$
5	$1{,}3\times10^{-1}$	$3{,}7\times10^{-2}$	$8{,}2\times10^{-2}$	$7{,}8\times10^{-2}$
7	$1{,}0\times10^{-1}$	$1{,}9\times10^{-1}$	$7{,}0\times10^{-2}$	$6{,}6\times10^{-2}$
Continuous intake				
Bq/ (Bq·d^{-1})	3,5	13	8,4	13
Sv·j^{-1}·Bq^{-1}	$8{,}7\times10^{-9}$	$1{,}9\times10^{-8}$	$1{,}7\times10^{-8}$	$1{,}8\times10^{-8}$

^{14}C $Z = 6$

Half-life and decay constant

$T_{1/2}$ = 5730 j = $1{,}81\times10^{11}$ s $\qquad$ $\lambda = 3{,}83\times10^{-12}$ s^{-1}

Decay scheme (simplified)



Main emitted radiation

Straling	y (Bq·s)$^{-1}$	E (keV)
β⁻	1,000	49 | 156

Miscellaneous

Specific activity	A_{sp}	=	$1{,}65\times10^{11}$ Bq/g
Exemption levels	C_v	=	10^8 Bq/g (CO)
		=	10^7 Bq/g (CO_2)
		=	10^4 Bq/g (overige)
	A_v	=	10^{11} Bq (CO, CO_2)
		=	10^7 Bq (overige)
Skin contamination	H_{huid}	=	5×10^{-11} Sv/s per Bq/cm^2
Wound contamination / injection	$e(50)$	=	$5{,}8\times10^{-10}$ Sv/Bq
Transport	A_1	=	40 TBq
	A_2	=	3 TBq

Productie en toepassingen

Het radionuclide ^{14}C wordt gevormd in de buitenste lagen van de atmosfeer, voornamelijk door de (exotherme) reactie $^{14}N(n,p)^{14}C$. De concentratie van $^{14}CO_2$ in de biosfeer is hierdoor ongeveer 220 Bq/kg C. De stofwisseling van planten (CO_2 in en O_2 uit) maakt dat plantaardige stoffen dezelfde ^{14}C-concentratie bevatten als in de atmosfeer. Na de dood van de plant neemt de ^{14}C-concentratie af met de halveringstijd van 5730 jaar. Door meting van deze concentratie kan dus de ouderdom van plantaardige stoffen worden bepaald: de koolstofdateringsmethode. Door het verbranden van (zeer oude) fossiele brandstoffen neemt de ^{14}C-concentratie de laatste jaren geleidelijk af.
De mens bevat enig ^{14}C: de referentiemens is opgebouwd uit 16 kg koolstof en bevat

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zodoende 3500 Bq ^{14}C. Door bovengrondse kernproeven is sinds 1945 ongeveer 0,2 EBq in de atmosfeer terechtgekomen. Het radionuclide wordt verder gebruikt als merker van biologische verbindingen en als zeer stabiele lichtbron.

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

	Ingestie	Inhalatie	Inhalatie	Inhalatie	Inhalatie	
	$f_1 = 1$	M	Damp	CO	CO_2	
$e(50)$	$5{,}8\times10^{-10}$	$2{,}0\times10^{-9}$	$5{,}8\times10^{-10}$	$8{,}0\times10^{-13}$	$6{,}2\times10^{-12}$	Sv/Bq
A_{Re}	$1{,}7\times10^{9}$	$5{,}0\times10^{8}$	$1{,}7\times10^{9}$	$1{,}3\times10^{12}$	$1{,}6\times10^{11}$	Bq

Data for urine analysis

After single intake

Time (d) Urine excretion rate (Bq/d per Bq intake) with F_u=0.017

Time (d)					
1	$1{,}2\times10^{-4}$	$9{,}3\times10^{-6}$	$1{,}2\times10^{-4}$	$1{,}6\times10^{-2}$	$3{,}7\times10^{-4}$
2	$2{,}7\times10^{-4}$	$1{,}8\times10^{-5}$	$2{,}7\times10^{-4}$	$1{,}1\times10^{-4}$	$3{,}2\times10^{-4}$
3	$2{,}8\times10^{-4}$	$1{,}9\times10^{-5}$	$2{,}8\times10^{-4}$	$3{,}5\times10^{-7}$	$2{,}9\times10^{-4}$
5	$2{,}7\times10^{-4}$	$1{,}9\times10^{-5}$	$2{,}7\times10^{-4}$	–	$2{,}0\times10^{-4}$
7	$2{,}6\times10^{-4}$	$1{,}8\times10^{-5}$	$2{,}6\times10^{-4}$	–	$1{,}5\times10^{-4}$

Interaction coefficients for photons in iron
Inleiding tot de Stralingshygiëne [Introduction to Radiation Protection], (Bos et al., 2nd edition, 2007), page 384.

Photon energy (MeV)	μ/ρ ($cm^2\ g^{-1}$)	μ_{en}/ρ ($cm^2\ g^{-1}$)
0.02	25.7	22.1
0.03	8.18	7.2
0.04	3.63	3.18
0.05	1.96	1.63
0.06	1.20	0.944
0.08	0.595	0.411
0.10	0.372	0.219
0.15	0.196	0.080

Dose conversion coefficients for external exposure to photons
Inleiding tot de Stralingshygiëne [Introduction to Radiation Protection] (Bos et al., 2nd edition, 2007), p. 386

Photon energy (MeV)	K_a/Φ ($pGy\ cm^2$)	$H^*(10)/\Phi$ ($pSv\ cm^2$)
0.02	1.73	1.05
0.03	0.739	0.81
0.04	0.438	0.64
0.05	0.328	0.55
0.06	0.292	0.51
0.08	0.308	0.53
0.10	0.372	0.61
0.15	0.600	0.89