Embargo 12 December 2016

APPENDIX for the Examination Co-ordinating Radiation Protection Expert

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

Examination date: 12 December 2016
Duration of examination: 13:30 - 16:30

Instructions:

- **If you use any data other than the data provided in this appendix, please state the source!**
- **This appendix consists of 14 numbered pages. Please check whether it is complete!**

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***Handboek Radionucliden*, [Radionuclides Handbook], A.S. Keverling Buisman (2nd edition 2007), pp. 26-27, ^{18}F data.**

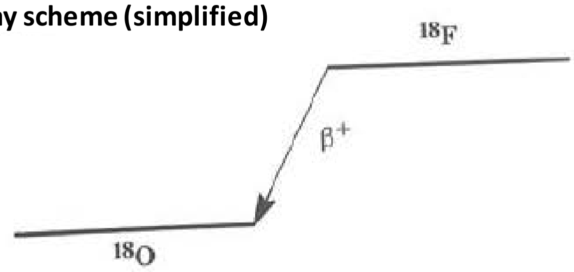
^{18}F Z = 9

Half-life and decay constant

$T_{1/2} = 109{,}70$ min $= 6{,}582\times10^3$ s

$\lambda = 1{,}05\times10^{-4}$ s^{-1}

Decay scheme (simplified)



Main emitted radiation

Straling	y (Bq·s)$^{-1}$	E (keV)
β^+	1,000	250 | 634
$\gamma^\pm$	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} = $3{,}52\times10^{18}$ Bq/g
Exemption levels	C_v = 10^1 Bq/g en $A_v = 10^6$ Bq
Skin contamination	H_{huid} = 5×10^{-10} Sv/s per Bq/cm^2
Wound contamination / injection	$e(50)$ = $1{,}4\times10^{-11}$ Sv/Bq
Transport	A_1 = 1 TBq
	A_2 = 0,6 TBq

Production and applications

Het radionuclide ^{18}F is een cyclotronproduct. Het nuclide wordt toegepast in de nucleaire geneeskunde voor het maken van afbeeldingen met behulp van positronen-emissie-tomografie (PET).

N = 9 ^{18}F

Metabolic model

Voor stralingshygiënische doeleinden wordt aangenomen dat fluor na opname in het bloed volledig in het bot wordt opgenomen.
Gezien de korte fysische halveringstijd van ^{18}F (110 minuten) is de biologische halveringstijd van geen belang.

Ingestion and lung clearance classes

Ingestie		
Alle verbindingen	$f_1 = 1$	
Inhalatie		
Afhankelijk	$f_1 = 1$	Klasse S
van	$f_1 = 1$	Klasse M
bindingskation	$f_1 = 1$	Klasse F

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

	Ingestie $f_1 = 1$	Inhalatie F	Inhalatie M	Inhalatie S	
$e(50)(w)$	$4{,}9\times10^{-11}$	$5{,}4\times10^{-11}$	$8{,}9\times10^{-11}$	$9{,}3\times10^{-11}$	Sv/Bq
$A_{Re}(w)$	$2{,}0\times10^{10}$	$1{,}9\times10^{10}$	$1{,}1\times10^{10}$	$1{,}1\times10^{10}$	Bq
$e(50)(b)$	$4{,}9\times10^{-11}$	$3{,}0\times10^{-11}$	$5{,}7\times10^{-11}$	$6{,}0\times10^{-11}$	Sv/Bq
$A_{Re}(b)$	$2{,}0\times10^{10}$	$3{,}3\times10^{10}$	$1{,}8\times10^{10}$	$1{,}7\times10^{10}$	Bq

Data for total body counting (after single intake)

Time (d) Total body activity (Bq per Bq intake)

Tijd (d)	Lichaamsactiviteit (Bq per Bq inname)			
0,25	$1{,}0\times10^{-1}$	$7{,}7\times10^{-2}$	$7{,}7\times10^{-2}$	$7{,}7\times10^{-2}$
1	$1{,}1\times10^{-4}$	$6{,}8\times10^{-5}$	$6{,}8\times10^{-5}$	$6{,}8\times10^{-5}$

Figure 2: Half-value layer of different shielding materials for narrow-beam photon radiation

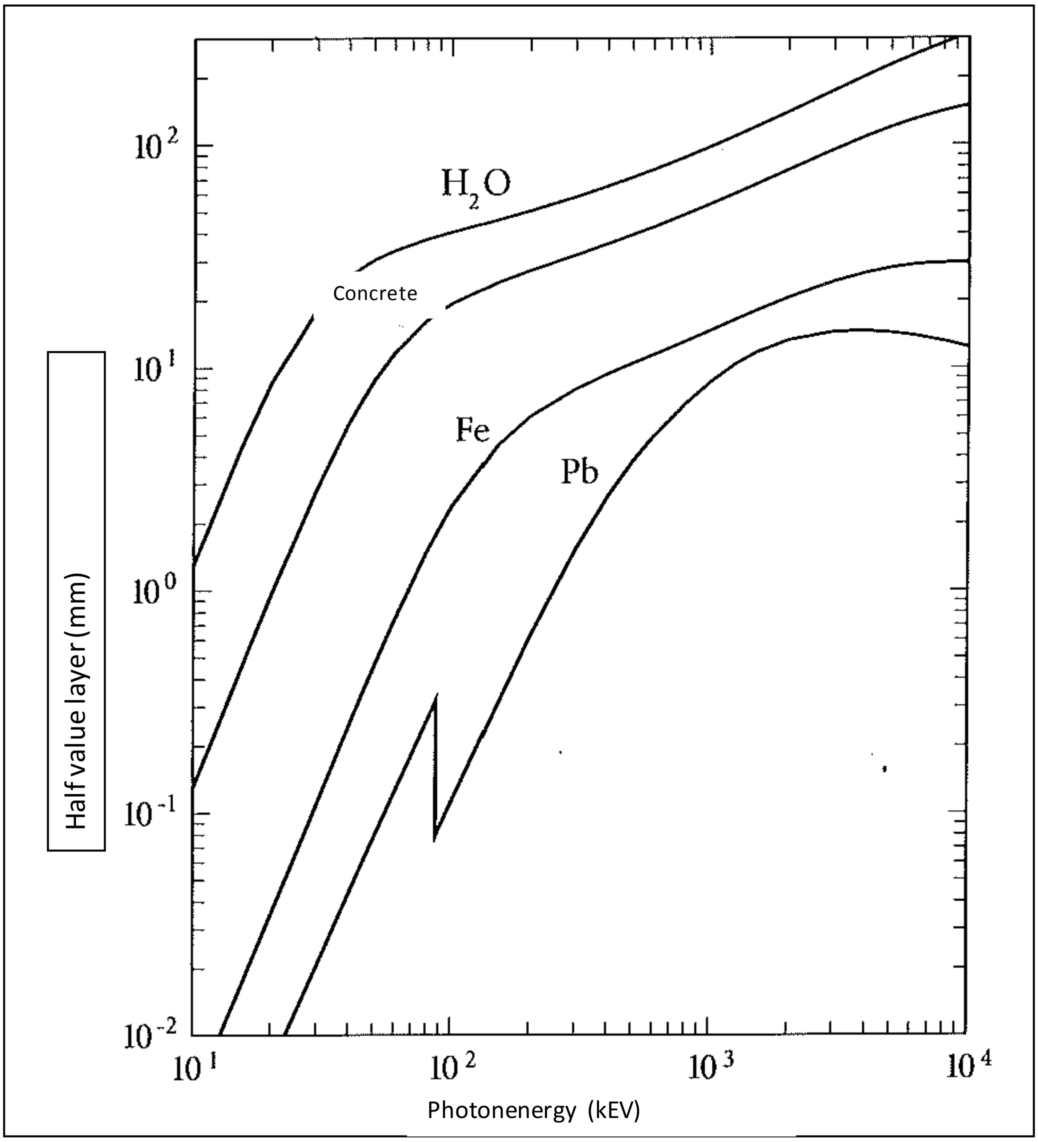


Table 1: Broadbeam transmission factors at 511 keV (AAPM Task Group 108)

Thickness [a, b]	Transmission Factors		
	Lead	Concrete [c]	Iron
0	1.0000	1.0000	1.0000
1	0.8912	0.9583	0.7484
2	0.7873	0.9088	0.5325
3	0.6905	0.8519	0.3614
4	0.6021	0.7889	0.2353
5	0.5227	0.7218	0.1479
6	0.4522	0.6528	0.0905
7	0.3903	0.5842	0.0542
8	0.3362	0.5180	0.0319
9	0.2892	0.4558	0.0186
10	0.2485	0.3987	0.0107
12	0.1831	0.3008	0.0035
14	0.1347	0.2243	0.0011
16	0.0990	0.1662	0.0004
18	0.0728	0.1227	0.0001
20	0.0535	0.0904	
25	0.0247	0.0419	
30	0.0114	0.0194	
40	0.0024	0.0042	
50	0.0005	0.0009	

Broadbeam transmission factors at 511 keV in lead, concrete, iron.

[a]Thickness in mm for lead.

[b]Thickness in cm for concrete and iron.

[c]Concrete density $= 2.35\ g / cm^3$.

Table 2: Build-up factors for an isotropic point source

materiaal	Fotonenenergie E (MeV)	μd						
		1	2	4	7	10	15	20
water	0,255	3,09	7,14	23,0	72,9	166	456	982
	0,5	2,52	5,14	14,3	38,8	77,6	178	334
	1,0	2,13	3,71	7,68	16,2	27,1	50,4	82,2
	2,0	1,83	2,77	4,88	8,46	12,4	19,5	27,7
	3,0	1,69	2,42	3,91	6,23	8,63	12,8	17,0
aluminium	0,5	2,37	4,24	9,47	21,5	38,9	80,8	141
	1,0	2,02	3,31	6,57	13,1	21,2	37,9	58,5
	2,0	1,75	2,61	4,62	8,05	11,9	18,7	26,3
	3,0	1,64	2,32	3,78	6,14	8,65	13,0	17,7
ijzer	0,5	1,98	3,09	5,98	11,7	19,2	35,4	55,6
	1,0	1,87	2,89	5,39	10,2	16,2	28,3	42,7
	2,0	1,76	2,43	4,13	7,25	10,9	17,6	25,1
	3,0	1,55	2,15	3,51	5,85	8,51	13,5	19,1
lood	0,5	1,24	1,42	1,69	2,00	2,27	2,65	2,73
	1,0	1,37	1,69	2,26	3,02	3,74	4,81	5,86
	2,0	1,39	1,76	2,51	3,66	4,84	6,87	9,00
	3,0	1,34	1,68	2,43	3,75	5,30	8,44	12,3

Handboek Radionucliden [Radionuclides Handbook], A.S. Keverling Buisman (2nd edition, 2007), pp. 42-43, ^{40}K data

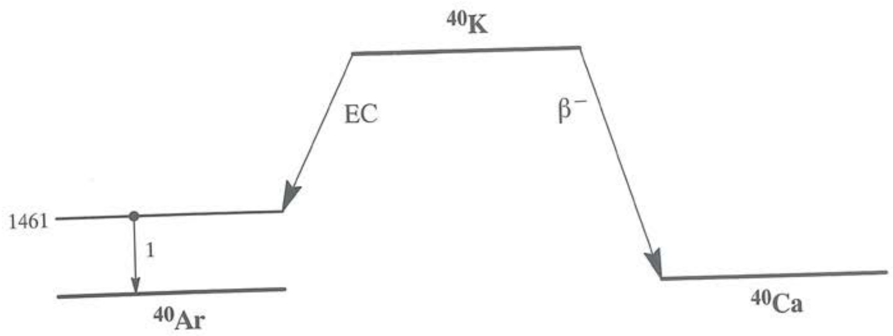
^{40}K Z = 19

Half-life and decay constant

$T_{1/2} = 1{,}277\times10^{9}$ j $= 4{,}03\times10^{16}$ s

$\lambda = 1{,}72\times10^{-17}$ s^{-1}

Decay scheme (simplified)



Main emitted radiation

Straling	y (Bq·s)$^{-1}$	E (keV)
β^-	0,893	585 | 1312
γ_1	0,107	1461
KLL	0,065	3

Source constants

Air kerma rate	k = 0,018 µGy/h per MBq/m^2
Ambient dose equivalent rate	h = 0,021 µSv/h per MBq/m^2

Miscellaneous

Specific activity	A_{sp} = 2,59×10^5 Bq/g
Exemption levels	C_v = 10^2 Bq/g en A_v = 10^6 Bq
Skin contamination	H_{huid} = 5×10^{-10} Sv/s per Bq/cm^2
Wound contamination / injection	$e(50)$ = 5,1×10^{-9} Sv/Bq
Transport	A_1 = 0,9 TBq
	A_2 = 0,9 TBq

Production and applications

Kalium-40 is een primordiaal radionuclide, dat wil zeggen het is sinds de nucleogenese (het moment van ontstaan van de zwaardere nucliden) nog niet vervallen. Het komt voor

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N = 21 ^{40}K

in het menselijk lichaam, via ingestie. De ^{40}K-activiteit in de referentiemens bedraagt 4000 Bq. Natuurlijk kalium heeft een ^{40}K-gehalte van 0,0118% (at), hetgeen leidt tot een specifieke activiteit van kalium van 30 Bq/g. Het nuclide wordt veel gebruikt als ijkbron, aangezien de activiteit door weging kan worden gevonden.

Metabolic model

Voor stralingshygiënische doeleinden wordt aangenomen dat kalium zich vanuit het bloed homogeen over alle organen/weefsels verdeelt.
De biologische halveringstijd voor deze organen/weefsels wordt gesteld op 30 dagen.

Ingestion and lung clearance classes

Ingestie		
Alle verbindingen	$f_1 = 1$	
Inhalatie		
Alle verbindingen	$f_1 = 1$	Klasse F

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

	Ingestie	Inhalatie	
	$f_1 = 1$	F	
$e(50)$(w)	$6{,}2\times10^{-9}$	$3{,}0\times10^{-9}$	Sv/Bq
A_{Re}(w)	$1{,}6\times10^{8}$	$3{,}3\times10^{8}$	Bq
$e(50)$(b)	$6{,}2\times10^{-9}$	$2{,}1\times10^{-9}$	Sv/Bq
A_{Re}(b)	$1{,}6\times10^{8}$	$4{,}8\times10^{8}$	Bq

Data for total body counting (after single intake)

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

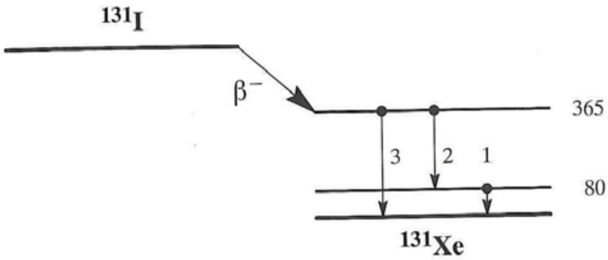
Handboek Radionucliden **[Radionuclides Handbook], A.S. Keverling Buisman (2nd edition, 2007), pp. 164-165, ^{131}I data**

^{131}I Z = 53

Halveringstijd en vervalconstante

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

Vervalschema (vereenvoudigd)



Belangrijkste uitgezonden straling

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

Bronconstanten

Kermatempo in lucht	k = 0,052 µGy/h per MBq/m^2
Omgevingsdosisequivalenttempo	h = 0,066 µSv/h per MBq/m^2

Diversen

Specifieke activiteit	$A_{sp} = 4{,}60 \times 10^{15}$ Bq/g
Vrijstellingsgrenzen	$C_v = 10^2$ Bq/g en $A_v = 10^6$ Bq
Huidbesmetting	$H_{huid} = 4 \times 10^{-10}$ Sv/s per Bq/cm^2
Wondbesmetting; Injectie	$e(50) = 2{,}2 \times 10^{-8}$ Sv/Bq
Vervoer	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.

N = 78 ^{131}I

Metabolic model

Iodine in the blood: 70% direct excretion , 30% to the thyroid. Thyroidal iodine has a half-life of 80 days from the thyroid it spreads to other organs. Half-life in the other organs is 12 days. 1/10 of the organic iodine is excreted immediately with the faeces, the other 90% returns to the transfer compartment. So eventually the biological half-life in the thyroid is 90 days.

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

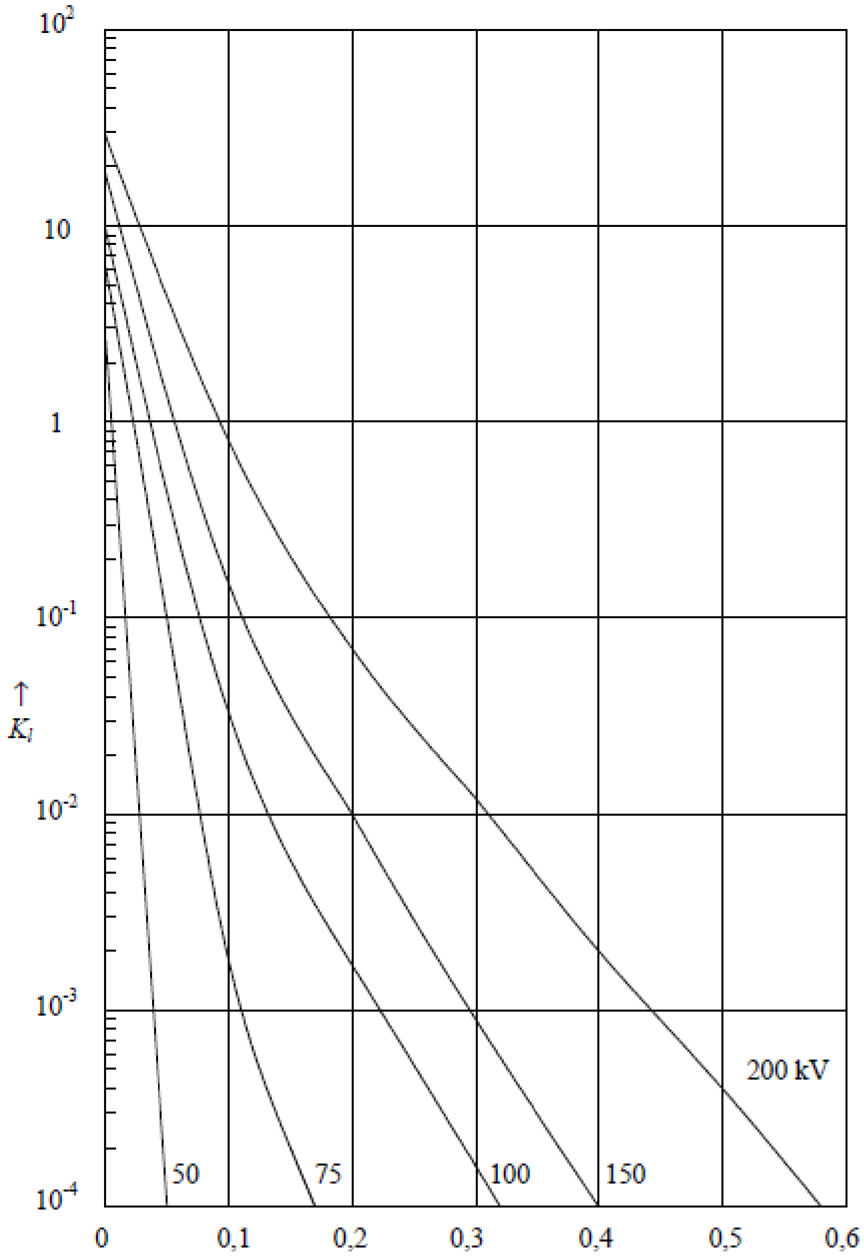
Data for thyroid count (after single intake)

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	$1{,}6\times10^{-1}$	$7{,}5\times10^{-2}$	$1{,}4\times10^{-1}$	$1{,}1\times10^{-1}$

Table 3: Tissue weighting factors (derived from ICRP-60)

Tissue or Organ	Tissue weighting factor (W_T)
Gonads	0.20
Red bone marrow	0.12
Large intestine	0.12
Lungs	0.12
Stomach	0.12
Breast tissue	0.05
Bladder	0.05
Liver	0.05
Oesophagus	0.05
Thyroid gland	0.05
Skin	0.01
Bone surface	0.01
Other organs	0.05

Figure 3: Kerma rate free in air of X-radiation through lead

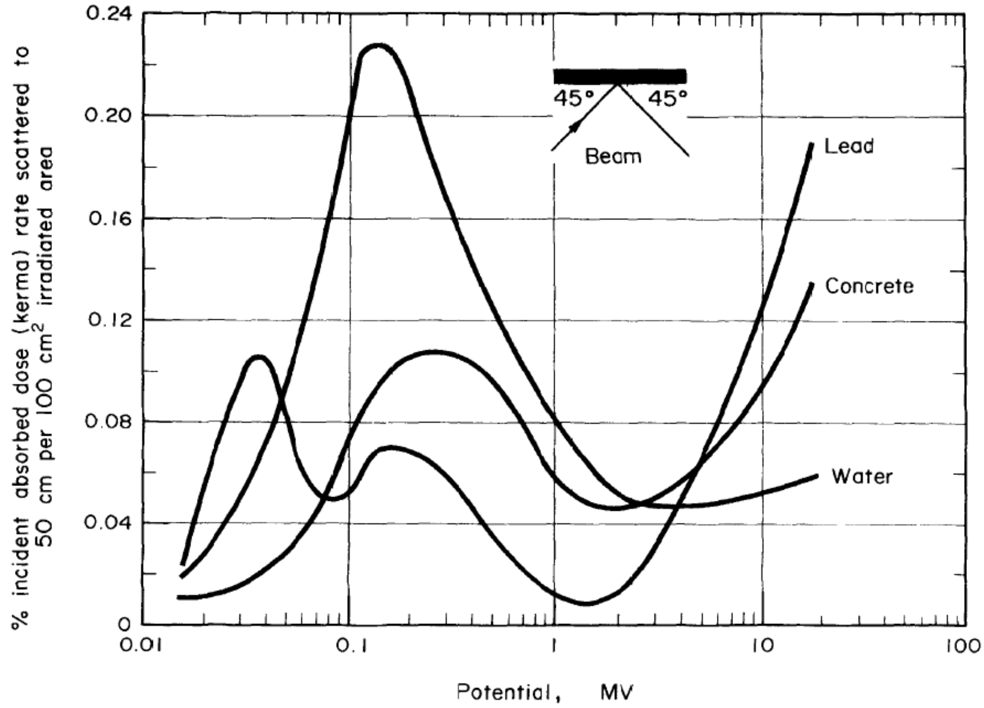


lead thickness (cm) →

Yield of a broad beam of X-rays through lead, expressed in kerma K_1 free in air:
in mGy·m^2·mA^{-1}·min^{-1} as a function of high voltage in kV.
Constant high voltage; tungsten target; 2 mm A1 pre-filtering
Intersection with the Y axis, so kerma without shielding (mGy·m^2·mA^{-1}·min^{-1}):

50 kV 2.6	75 kV 6.1	100 kV 9.6	150 kV 18.3	200 kV 28.7

Figure 4: Scattering fraction of kerma in air



Variation with potential of the absorbed dose (kerma)rate measured in air due to X-rays scattered at 90° from various materials (ICRP 33, Figure 21)