Appendix to the exam Radiation protection expert on the level of coordinating expert

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Nuclear Research and consultancy Group	NRG
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exam date: May 14th 2018
exam duration: 13.30 - 16.30 hours

Instruction:

- If you use other data than those provided in this appendix, please note the source!
- This appendix contains 10 numbered pages. Check this!

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Decay scheme ^{166}Ho

67-HOLMIUM-166

Halflife = 26.80 Hours Nov-1992

Decay Mode: beta-

Radiations	y(i) $(Bq\text{-}s)^{-1}$	E(i) (MeV)	y(i)×E(i)
beta- 4	9.50×10^{-03}	1.149×10^{-01} *	1.09×10^{-03}
beta- 6	4.87×10^{-01}	6.509×10^{-01} *	3.17×10^{-01}
beta- 7	5.00×10^{-01}	6.936×10^{-01} *	3.47×10^{-01}
gamma 1	6.71×10^{-02}	8.057×10^{-02}	5.41×10^{-03}
ce-K, gamma 1	1.15×10^{-01}	2.309×10^{-02}	2.65×10^{-03}
ce-L, gamma 1	2.65×10^{-01}	7.082×10^{-02} a	1.88×10^{-02}
ce-M, gamma 1	6.44×10^{-02}	7.837×10^{-02} a	5.05×10^{-03}
ce-N+, gamma 1	1.76×10^{-02}	8.012×10^{-02} a	1.41×10^{-03}
gamma 4	1.94×10^{-04}	6.740×10^{-01}	1.31×10^{-04}
gamma 5	1.31×10^{-04}	7.053×10^{-01}	9.24×10^{-05}
gamma 6	1.19×10^{-04}	7.859×10^{-01}	9.35×10^{-05}
gamma 8	9.30×10^{-03}	1.379	1.28×10^{-02}
gamma 12	1.87×10^{-03}	1.582	2.96×10^{-03}
gamma 13	1.20×10^{-03}	1.662	1.99×10^{-03}
gamma 14	2.77×10^{-04}	1.750	4.85×10^{-04}
gamma 15	8.50×10^{-05}	1.830	1.56×10^{-04}
Kalpha1 X-ray	5.48×10^{-02}	4.913×10^{-02}	2.69×10^{-03}
Kalpha2 X-ray	3.09×10^{-02}	4.822×10^{-02}	1.49×10^{-03}
Kbeta X-ray	2.24×10^{-02}	5.570×10^{-02} *	1.25×10^{-03}
L X-ray	7.84×10^{-02}	6.950×10^{-03} *	5.45×10^{-04}
Auger-L	2.83×10^{-01}	5.500×10^{-03} *	1.56×10^{-03}

Listed X, gamma, and gamma$^{\pm}$ Radiations	3.01×10^{-02}
Omitted X, gamma, and gamma$^{\pm}$ Radiations**	4.03×10^{-05}
Listed beta, ce, and Auger Radiations	6.94×10^{-01}
Omitted beta, ce, and Auger Radiations**	4.69×10^{-04}
Listed Radiations	7.24×10^{-01}
Omitted Radiations**	5.10×10^{-04}

* Average Energy (MeV).

[a] Maximum Energy (MeV) for subshell.

** Each omitted transition contributes <0.100% to Sumof y(i)×E(i).

Erbium-166 Daughter is stable.

Mass attenuation and energy absorption cross-sections in lead

(density = 11.34 g/cm^3)

Energie (MeV)	μ/ρ **(cm²/g)**	μ_{en}/ρ **(cm²/g)**
0.005	767	747
0.010	136.6	130.7
0.05	7.71	6.54
0.10	5.78	2.28
0.5	0.1614	0.0951
1.5	0.0518	0.0271
2	0.0455	0.0240

Category classification of transport packaging

Pg 55,56 and 59 of '*Vervoer van radioactieve stoffen over de weg in Nederland en België'*

Category I-WHITE

All packages of which the radiation level complies to the requirement that the dose rate is:
- *no more than 5 µSv per hour at the surface and additional*
- *the transport index is equal to 0, thus the dose rate at 1 meter distance from the surface is not greater than 0,5 µSv per hour*

Category II-YELLOW

All packages of which the radiation level complies to the requirement that the dose rate is:
- *greater than 5 µSv per hour and no more than 500 µSv per hour at the surface and/or*
- *the transport index is greater than 0 and no more than 1, thus the dose rate at 1 meter distance from the surface is greater than 0,5 µSv per hour, and no more than 10 µSv per hour.*

Category III-YELLOW

All packages of which the radiation level complies to the requirement that the dose rate is:
- *greater than 500 µSv per hour and no more than 2 mSv per hour at the surface and/or*
- *the transport index is greater than 1 and no more than 10, thus the dose rate at 1 meter distance from the surface is greater than 10 µSv per hour, and no more than 100 µSv per hour.*

Radiation conditions		
Transport index	**Maximum radiation level at any point on the surface**	**Category**
0	No more than 5 *µSv per hour*	I-WHITE
Greater than 0 but no more than 1	More than 5 *µSv per hour*, but no more than 500 *µSv per hour*	II-YELLOW
Greater than 1 but no more than 10	More than 500 *µSv per hour*, but no more than 2mSv *per hour*	III-YELLOW

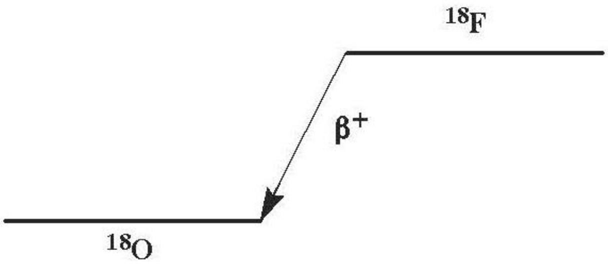
Handboek Radionucliden, A.S. Keverling-Buisman (3rd edition 2015), pg. 26, ^{18}F data

^{18}F $Z = 9$

Half-life and decay constant

$T_{1/2} = 109{,}70$ min $= 6{,}582 \times 10^3$ s $\lambda = 1{,}05 \times 10^{-4}\ s^{-1}$

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	$A_{sp} = 3{,}52 \times 10^{18}$ Bq/g
Exemption levels	$C_v = 10^1$ Bq/g en $A_v = 10^6$ Bq
Skin contamination	$H_{huid} = 5 \times 10^{-10}$ Sv/s per Bq/cm^2
Wound contamination / injection	$e(50) = 1{,}4 \times 10^{-11}$ Sv/Bq
Transport	$A_1 = 1$ TBq
	$A_2 = 0{,}6$ TBq

Productie en toepassingen

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).

Broad beam transmission factors at 511 keV in lead, concrete, iron, Madsen et al.: AAPM Task Group 108: PET and PET/CT Shielding

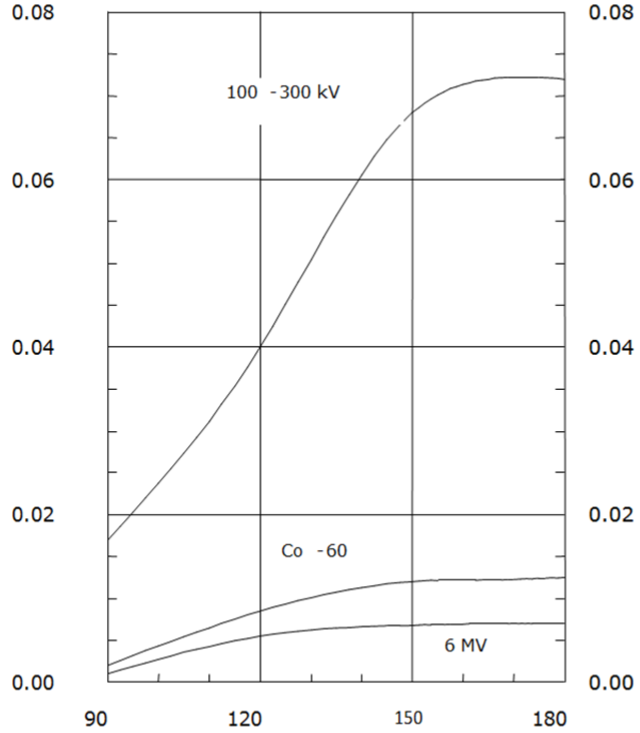
TABLE IV. Broadbeam transmission factors at 511 keV in lead, concrete, iron.

	Transmission Factors		
Thickness[a],[b]	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	

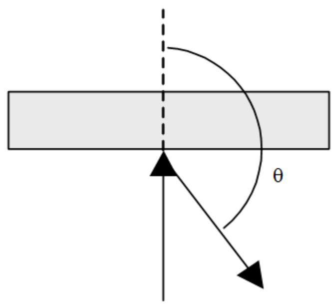
[a]Thickness in mm for lead.
[b]Thickness in cm for concrete and iron.
[c]Concrete density $=2.35\ g/cm^3$.
The Monte Carlo transmission data have been fitted to the model proposed by Archer *et al.* (Ref. 10): $\mathbf{B}=\{(1+(\beta/\alpha))e^{\alpha\gamma x}-(\beta/\alpha)\}^{(1/\gamma)}$. This can be inverted to obtain x (material thickness) as a function of transmission (B): $x=(1/\alpha\gamma)\ln\{[B^{-\gamma}+(\beta/\alpha)]/[1+(\beta/\alpha)]\}$.

Scattering fraction of kerma

At 1 meter distance from irradiated concrete surface in percent per 100 cm² irradiated concrete surface



Scattering angle θ degrees



Scattering angle θ degrees

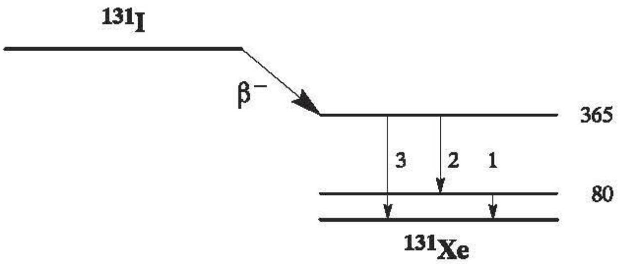
Handboek Radionucliden, A.S. Keverling Buisman (3rd edition 2015), pg. 164-165, data ^{131}I

^{131}I Z = 53

Half-life and decay constant

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

Decay scheme (simplified)



Main emitted radiation

Straling	$y\ (Bq \cdot s)^{-1}$	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

Source constants

Air kerma rate	k = 0,052 µGy/h per MBq/m²
Ambient dose equivalent rate	h = 0,066 µSv/h per MBq/m²

Miscellaneous

Specific activity	$A_{sp} = 4{,}60 \times 10^{15}$ Bq/g
Exemption levels	$C_v = 10^2$ Bq/g en $A_v = 10^6$ Bq
Skin contamination	$H_{huid} = 4 \times 10^{-10}$ Sv/s per Bq/cm²
Wound contamination / injection	$e(50) = 2{,}2 \times 10^{-8}$ 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.

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	Inhalatie	Inhalatie	Inhalatie	
	$f_1 = 1$	F	I_2	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	$1{,}6\times10^{-1}$	$7{,}5\times10^{-2}$	$1{,}4\times10^{-1}$	$1{,}1\times10^{-1}$