APPENDIX
Examination
Radiation Protection Expert on the level of coordinating expert

---

Nuclear Research and Consultancy Group	NRG
Delft University of Technology	TUD
Boerhaave Continuous Medical Education/LUMC	BN/LUMC
University of Groningen	RUG
Radboudumc	RUMC

Date of examination: 10 December 2018
Time of examination: 13.30 - 16.30

Instructions

- When using any data other than those contained in this Appendix, please cite the source!
- This Appendix consists of 14 consecutive numbered pages. Please check that it is complete!

CONTENTS

Appendix

***Handboek Radionucliden*, A. S. Keverling Buisman (third impression, 2007), p 13.**

geen huidbesmetting meer over is. Het zal nooit nodig zijn om een periode langer dan een week in acht te nemen.

Wondbesmetting en injectie

De effectieve volgdosis ten gevolge van een wondbesmetting of injectie is bepaald onder de veronderstelling dat de gehele activiteit in de wond direct en geheel in het bloed wordt opgenomen. De waarden voor de effectieve dosis zijn berekend met behulp van het programma LUDEP (LUD94) of, waar beschikbaar, met het meer recente programma IMBA Professional Plus (HPA04). Het gebruikte metabole model is hetzelfde als aangegeven in de ICRP-publicaties 30, 67, 69 en 71. De lokale dosis, de dosis ter plaatse van de wond, is niet in de beschouwing betrokken.

Transport data

De numerical values for A_1 and A_2, which play an important role in the transport of radioactive substances have been derived from ADR01. These values represent the maximum activity that may be transported in a type-A collo over the road. They have been based on two emergency situations. The first concerns the removal of shielding, without dispersal of activity. This is only possible when nuclides are transported in ‘special form’, that means that the nuclide is embedded in an indestructible matrix. In these emergencies only external (gamma) rays play a role. For this scenario the A_1 value has been introduced. The numerical value for A_1 can be approximated by stating that the external radiation dose may be no larger than 4 mSv per 10 minutes at three meters form the sources.

The limiting value of A_2 is meant to take the inhalation risk into account; inhalation of one millionth of the contents of the contents of the package should not result in a committed effective dose of more than 2mSv.
Both numerical values have a maximum of 40 TBq and always $A_2 \leq A_1$.

The choice for A_1 and A_2 is such that, under every circumstance after an emergency or accident, lifesaving actions may be taken without an irresponsibly big radiation risk.

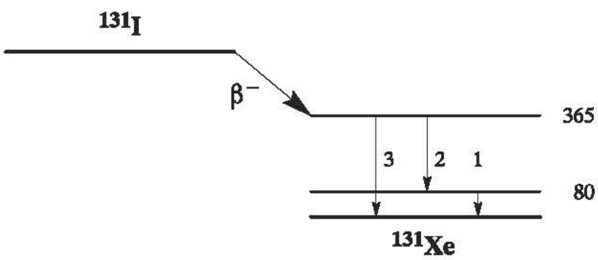
***Handboek Radionucliden*, A. S. Keverling Buisman (third impression, 2007), pp. 164-165, data re. ^{131}I.**

^{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

Source constants (including daughter nuclides)

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 (including daughter nuclides)

Specific activity (only ^{226}Ra)	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

Production and applications

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

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

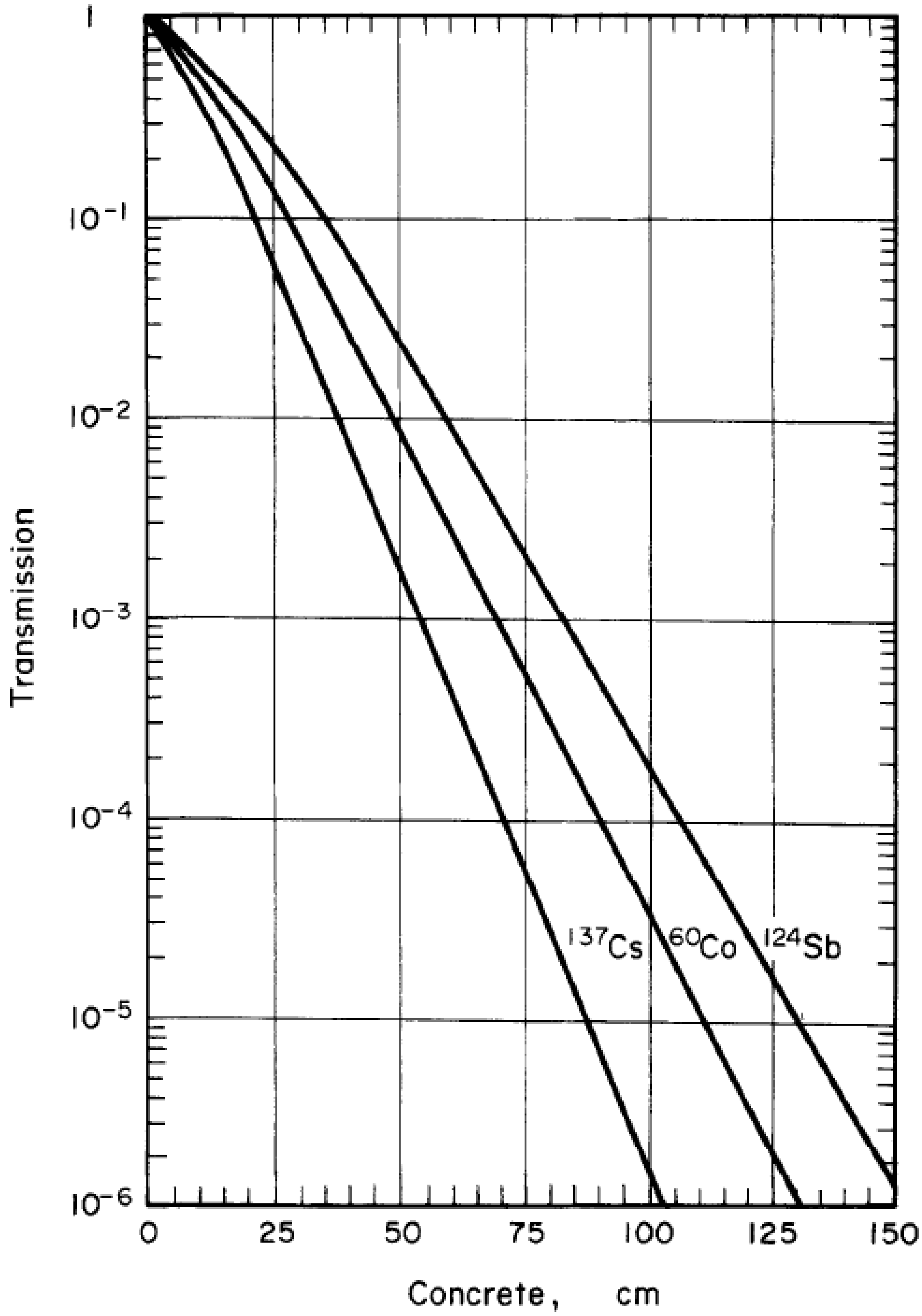


Figure 1. Broad-beam transmission of gamma rays from various radionuclides through concrete, density 2,350 g/cm^3 (ICRP-33).

Opbouwfactor B(μx) voor isotrope puntbron in water

		μx						
E_f (MeV)	μ (m^{-1})	1	2	4	7	10	15	20
0,25	12,8	3,09	7,14	23,0	72,9	166	456	982
0,5	9,7	2,52	5,14	14,3	38,8	77,6	178	334
1,0	7,1	2,13	3,71	7,68	16,2	27,1	50,4	82,2
2,0	4,9	1,83	2,77	4,88	8,46	12,4	19,5	27,7
3,0	4,0	1,69	2,42	3,91	6,23	8,63	12,8	17,0
4,0	3,4	1,58	2,17	3,34	5,13	6,94	9,97	12,9
6,0	2,8	1,46	1,91	2,76	3,99	5,18	7,09	8,85
8,0	2,3	1,38	1,74	2,40	3,34	4,25	5,66	6,95
10,0	2,2	1,33	1,63	2,19	2,97	3,72	4,90	5,98

Table 1. Exposure build-up factor for an isotropic point source in water. (*Inleiding tot de Stralingshygiëne*, Bos et al., second impression, 2007.) Decimal points are represented with comma's.

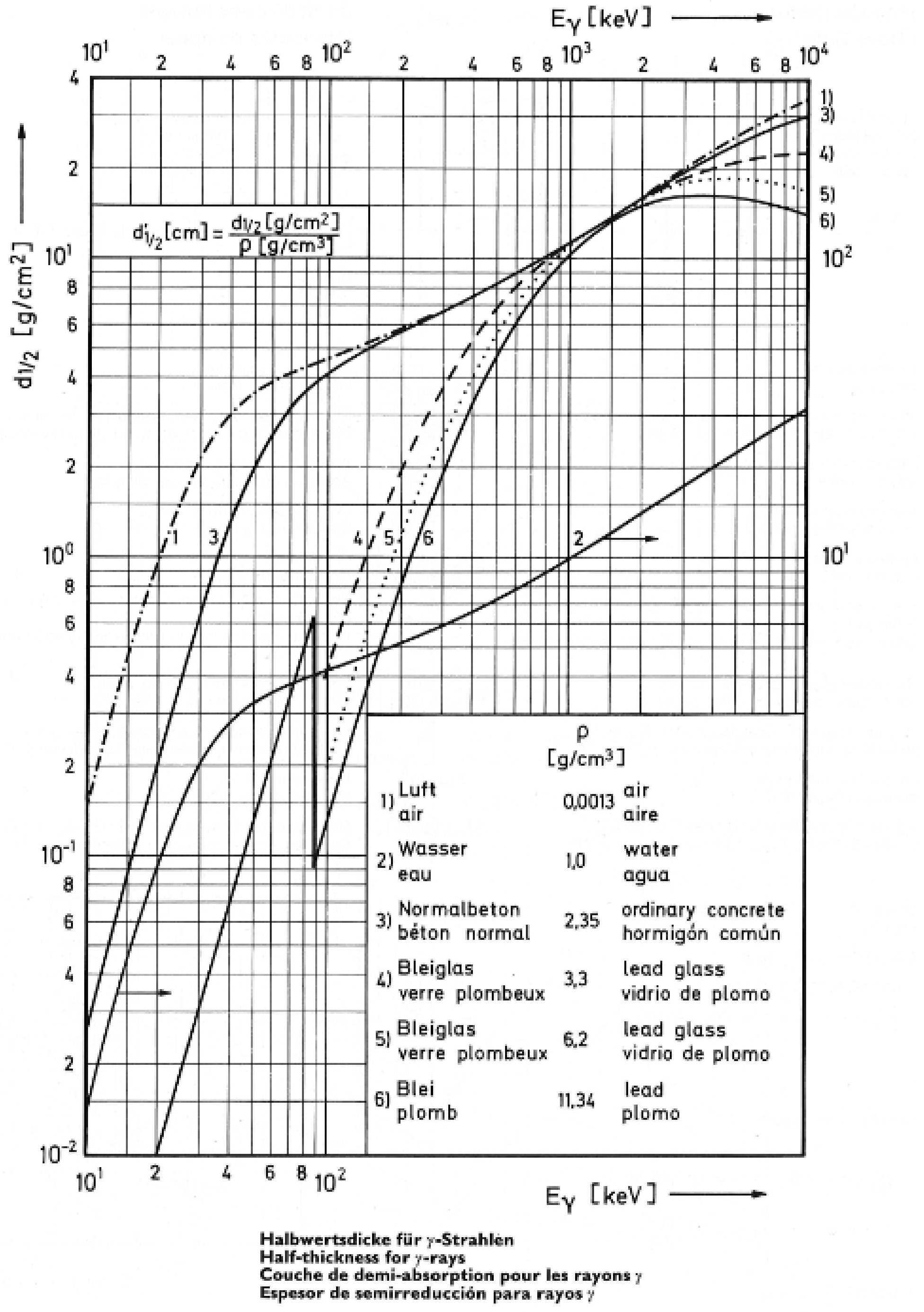


Figure 2. Massic half-value thicknesses of various materials for narrow-beam gamma radiation (in g/cm^2). Please note: for water you need to use the vertical axis on the right hand side. (Č.Dimitrijevic, Praktische Berechnung der Abschirmung vond radioaktiver und Röntgenstrahlung, Verlag Chemie, Weinheim, 1972).

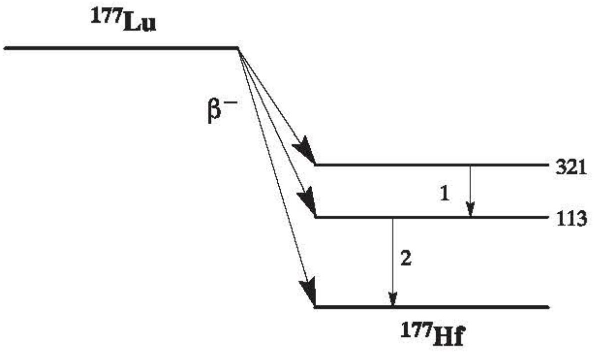
***Handboek Radionucliden*, A. S. Keverling Buisman (third impression, 2007), pp. 204-205, data re. ^{177}Lu.**

^{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 (including daughter nuclides)

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 (including daughter nuclides)

Specific activity (only ^{226}Ra)	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

Het radionuclide ^{177}Lu is een activeringsproduct.

Metabolic model

Voor stralingshygiënische doeleinden wordt aangenomen dat lutetium zich vanuit het bloed als volgt verdeelt: 60% naar bot, 2% naar lever, 0,5% naar nieren en de rest wordt rechtstreeks uitgescheiden.
De biologische halveringstijd voor alle organen/weefsels wordt gesteld op 3500 dagen, met uitzondering van de nieren (10 dagen).

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)	Total body count (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	$1,3\times10^{-3}$	$3,6\times10^{-2}$	$3,0\times10^{-2}$

Appendix to Nuclear Energy Act Licence for Radionuclide Laboratories (*Bijlage radionucliden-laboratoria*), pp. 10, 11, 12

2.2 Criteria with regard to internal contamination

2.2.1 Method of defining individual operations

The risk of internal contamination is important for the classification of operations. When operations are classified, it is assumed that internal contamination in a radiological workplace can be caused by radioactive substances that are spread during operations. As previously stated, the possible radiation dose, which the workers present in the workplace receive by inhaling a radioactive substance, determines the risk. If the main risk is expected to be posed by ingestion, this will have to be proven and a different system will have to be chosen.

The amount that can be inhaled depends on the risk of spread for an operation, on the protection that the laboratory area offers, and on the local ventilation facility. The radiotoxicity of the inhaled substance is important for the radiation dose caused by a particular internal contamination. With the risk of internal contamination in mind, the allowed work amounts for B, C and D workplaces are based on the inhalation dose coefficient, which will hereinafter be indicated by $e(g)_{inh}$ for stochastic effects. This $e(g)_{inh}$ is used for the calculations. The values for this formula are shown in table 5 of Appendix 4 of the Radiation Protection Decree (Bulletin of Acts and Decrees 397. 2001). The actual definition is expressed in radiotoxicity equivalents for inhalation [Re_{inh}].

Using formula (2.1), the value can be determined of the maximum permissible amount of applicable activity expressed in the radiotoxicity equivalent for inhalation [Re_{inh}] under certain circumstances or in the event certain measures are taken. This mainly concerns the risk of spread, the protection of the workplace and the local ventilation. Parameters regarding the above-mentioned aspects have been included in this formula:

$$X_{max,\,j} = 0{,}02 \; * \; 10^{p+q+r} \; [Re_{inh}] \tag{2.1}$$

where:

$X_{max,\,j}$	= maximum number of radiotoxicity equivalents [Re_{inh}] that may be used simultaneously per operation *j* (*X* is independent of the radionuclide)
0,02	= dose limit for exposed workers [*Sv*]
p	= parameter for the risk of spread
q	= protection parameter of the workspace
r	= parameter for the local ventilation facility.

The maximum amount of radioactivity of a radionuclide *i* that may be applied under those circumstances is determined using the following formula:

$$A_{max,\,j,\,i} = \frac{X_{max,\,j}}{e(g)_{inh,j}} \qquad [Bq] \tag{2.2}$$

where:

$A_{max,\,j,\,i}$	= maximum applicable activity [Bq] for operation *j* and radionuclide *i*.
$X_{max,\,j}$	= number of radiotoxicity equivalents [Re_{inh}] that may be used simultaneously per operation *j* (*X* is independent of the radionuclide)
$e(g)_{inh,\,i}$	= inhalation dose coefficient [Sv/ Bq] for stochastic effects of radionuclide *i*.

The $e(g)_{inh,\,i}$ and the *p*, *q* and *r* parameters will be explained below.

The different parameters from the formula will first be described. Then the calculation of the maximum amounts for use will be discussed.

2.2.2 Inhalation dose coefficient $e(g)_{inh}$

The value of the factor 10^{p+q+r} is the factor that must be taken into account when the maximum amount of radioactivity allowed for work is determined. This factor is a measure of the amount of radioactivity that may cause a radiation dose as a result of contamination.

In order to determine the maximum amount of radioactivity allowed for work, the factor 10^{p+q+r} must be divided by the inhalation dose coefficient $e(g)_{inh}$ and multiplied by the dose limit for exposed workers for stochastic effects (0.02 Sv).
The inhalation dose coefficient $e(g)_{inh}$ is taken from table 5 of Appendix 4 of the Radiation Protection Decree.

2.2.3 Spread parameter *p*

The parameter *p* was introduced to allow the risk of spread of radioactive substances to be determined. The risk of spread not only depends on the form of the substance, but also on the nature of the operations. The parameter *p* is determined here by the risk of spread of radioactive substances during certain operations. This list is shown in table 2.

Table 2: Value of the spread parameter *p* for certain operations within the laboratory

APPLICATION	*p*
Simple operation with gases Using powders in an 'open' system, e.g. mixing or grinding Liquid with temperature approaching the boiling point Operations involving considerable splashing	- 4
Labelling with volatile nuclide (e.g. iodine) Boiling with liquids in a 'closed' system Spinning and mixing on a vortex Simple processing of powders in a ‘closed’ system Storage of noble gas in an administration system	- 3
Labelling with non-volatile nuclide Simple chemical determination with tracers (e.g. RIA)	- 2
Simple operations in ‘closed’ systems, such as: Elution Tc generator Syringe filling Labelling in closed systems Calibration I-131 capsule Measurements of substances in poorly dispersible form (e.g. in ampoules) Storage of radioactive waste in workspaces	- 1

The elution of a Mo/TC generator is a special application. The operations can be regarded as operations with Tc-99m. For storage, Mo-99 should naturally be assumed.

In practice, operations that are not listed will have to be given a *p* value that has been assigned to operations with a similar risk of spread.

2.2.4 Protection parameter *q*

The amount of radioactivity that may be used in a given workspace partly depends on the parameter *q* for the protection that the space offers. This accounts for the effect of the protection provided by the existing facilities, such as ventilation, vacuum and sluice. The expertise of the supervisor, the classification of the exposed worker and a stricter admission regime are also taken into account. The following values may be used for *q*:

q = 0 Workspaces outside the laboratory control
q = 1 D Laboratory
q = 2 C Laboratory
q = 3 B Laboratory.

2.2.5 Ventilation parameter *r*

The parameter *r* for the local ventilation facility is assigned as follows:

r = 0 For working outside the fume hood without supplementary ventilation facilities
r = 1 This value may be used in the case of local exhaust ventilation or a fume hood that has not been tested according to DIN-12924, but for which it has been established that less than 10% of the amount of substance that is released in the fume hood will enter the workspace.
r = 2 This applies in the case of a good fume hood, understood as one in which less than 1% of the substance released in the fume hood enters the workspace. Fume hoods that have been qualified according to DIN-12924 and contain no setup that seriously disrupts the airflow, or laminar air flow insulators (Class II safety cabinets), will generally comply with this standard.
r = 3 Closed work cabinet. This refers to a Class III cabinet for biological safety with a qualification according to NEN-EN 12469, or a closed laminar air flow insulator that meets these requirements.

The value that may be used to determine the maximum applicable amount must be seen in connection with the value of *q*. In order to ensure that the amounts that may be applied in the different laboratory categories are balanced, the value of *r* must be limited in accordance with that category. In calculations, the value of *r* may therefore never be greater than *q*. Obviously, superior facilities (i.e. with a higher *r*) may be used.

2.2.6 Maximum amount of radioactivity permissible for certain operations

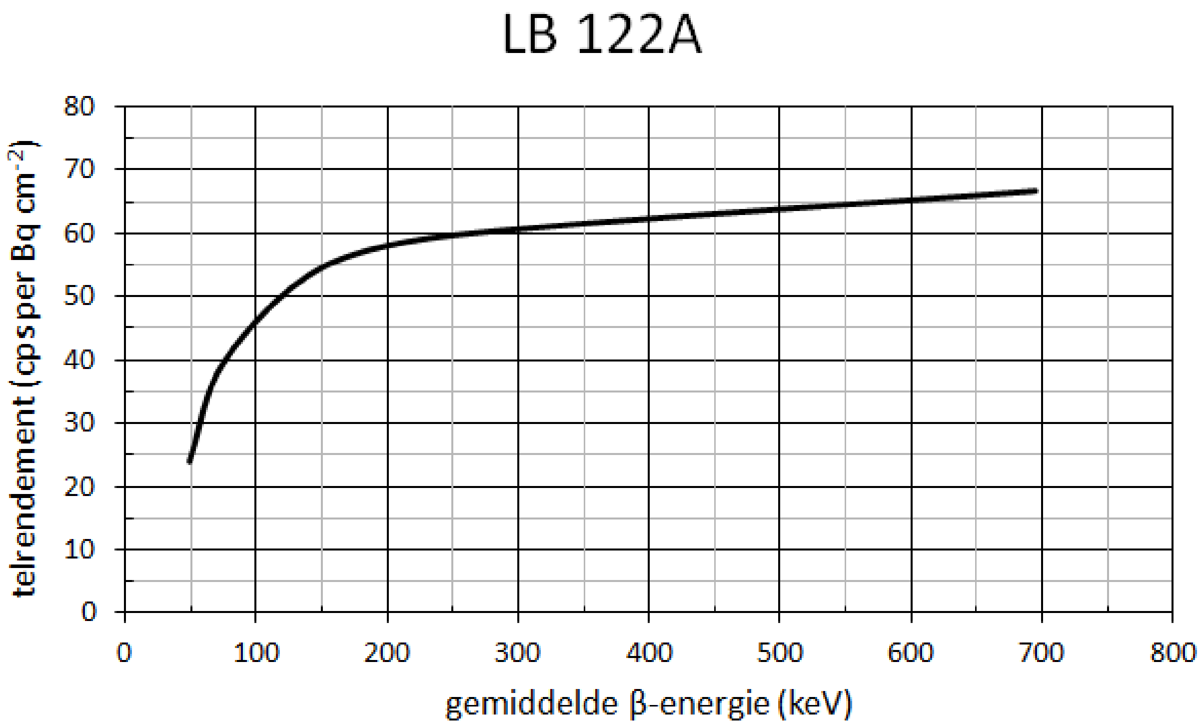
The number of radiotoxicity equivalents $X_{j,i}$, corresponding to an amount of activity $A_{j,i}$ of radionuclide *i* to be applied during an operation *j*, is equal to:

$$X_{j,i} = A_{j,i} * e(g)_{inh,i} \qquad (2.3)$$

where:

$X_{j,i}$ = the number of radiotoxicity equivalents [Re_{inh}] used during operation *j* with radionuclide *i*
$A_{j,i}$ = activity [Bq] that must be applied simultaneously for each operation *j* with radionuclide *i*
$E(g)_{inh,i}$ = inhalation dose coefficient [Sv/ Bq] for stochastic effects of radionuclide *i*.

Figure 1. Counting efficiency (in cps per Bq cm^{-2}) of the contamination monitor (Berthold LB 122A) as a function of the average β energy (in keV), assuming a yield of 1.



***Inleiding tot de stralingshygiëne*, A. J. J. Bos et al., Table 9-6**

Deposition fractions (in %) of the inhaled activity for two AMAD values.

Region	AMAD: 1 µm	AMAD: 5 µm
ET1	16.5	33.9
ET2	21.1	29.9
BB	1.2	1.8
bb	1.7	1.1
AI	10.7	5.3
total	51.2	82.0