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APPENDIX to
Coordinated examination in radiation protection
Expertise Level 3

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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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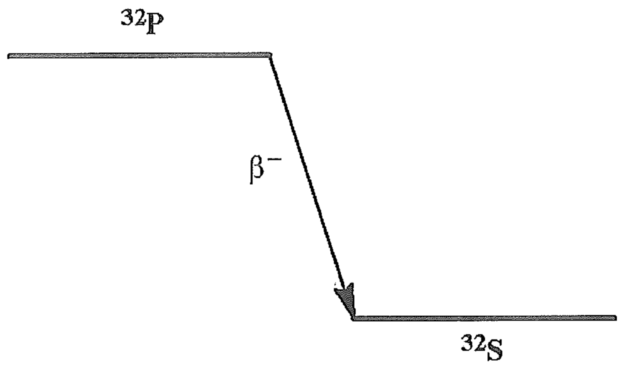
^{32}P Z = 15

Half-life and decay constant

$T_{1/2}$ = 14,29 d = $1{,}23 \times 10^{6}$ s $\lambda = 5{,}61 \times 10^{-7}\ s^{-1}$

Decay scheme



Main emitted radiation

Straling	$y\ (Bq \cdot s)^{-1}$	E (keV)
β^-	1,000	695 | 1710

Miscellaneous

Specific activity	A_{sp} = $1{,}06 \times 10^{16}$ Bq/g
Exemption levels	C_v = 10^3 Bq/g en $A_v = 10^5$ Bq
Skin contamination	H_{huid} = 6×10^{-10} Sv/s per Bq/cm^2
Wound contamination / injection	$e(50)$ = $2{,}2 \times 10^{-9}$ Sv/Bq
Transport	A_1 = 0,5 TBq
	A_2 = 0,5 TBq

Production and applications

Het radionuclide ^{32}P is een activeringsproduct. Het nuclide wordt toegepast bij medisch-biologisch onderzoek als merker.

N = 17 ^{32}P

Metabolic model

For health physics purposes, it is assumed that phosphorus spreads from the blood as follows; 15% direct excretion, 15% to the intracellular fluids, 40% to soft tissue and 30% to the bone. The assumed biological half-lives for the organs are:

Blood	0,5 d
Intracellular	2 d
Soft tissue	19 d
Bone	oneindig

Ingestion and lung clearance classes

Ingestie		
Alle verbindingen	$f_1 = 0{,}8$	
Inhalatie		
Fosfaat van Zn, Sn, Mg, Fe, Bi, lantaniden	$f_1 = 0{,}8$	Klasse M
Overige verbindingen	$f_1 = 0{,}8$	Klasse F

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

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

Data for urine analysis (after single intake)
After single intake:

Time (d)	Urine excretion rate (Bq/d per Bq intake)		
1	$8{,}5\times10^{-2}$	$4{,}9\times10^{-2}$	$3{,}6\times10^{-2}$
2	$5{,}2\times10^{-2}$	$2{,}8\times10^{-2}$	$2{,}3\times10^{-2}$
3	$3{,}1\times10^{-2}$	$1{,}7\times10^{-2}$	$1{,}4\times10^{-2}$
5	$1{,}6\times10^{-2}$	$8{,}9\times10^{-3}$	$7{,}2\times10^{-3}$
7	$1{,}0\times10^{-2}$	$5{,}6\times10^{-3}$	$4{,}5\times10^{-3}$

'Appendix Radionuclide Laboratory' permit appendix, pp. 10, 11 and 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:

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

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:

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

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*.

Table 1: Ambient dose equivalent (µSv) at various distances and positions around the patient for a therapeutic dose of 10 Gy.

The distances are up to the irradiated part of the patient. The angles are relative to the electron beam direction, whereby 0° is the direction through.

Angle(°)	Distance D (m)									
α	1	2	3	4	5	6	7	8	9	10
0	1689.89	422.47	187.77	105.62	67.60	46.94	34.49	26.40	20.86	16.90
15	755.06	188.76	83.90	47.19	30.20	20.97	15.41	11.80	9.32	7.55
30	565.15	141.29	62.79	35.32	22.61	15.70	11.53	8.83	6.98	5.65
45	300.00	75.00	33.33	18.75	12.00	8.33	6.12	4.69	3.70	3.00
60	148.12	37.03	16.46	9.26	5.92	4.11	3.02	2.31	1.83	1.48
90	60.03	15.01	6.67	3.75	2.40	1.67	1.23	0.94	0.74	0.60
120	20.20	5.05	2.24	1.26	0.81	0.56	0.41	0.32	0.25	0.20
150	8.04	2.01	0.89	0.50	0.32	0.22	0.16	0.13	0.10	0.08
180	3.20	0.80	0.36	0.20	0.13	0.09	0.07	0.05	0.04	0.03

Tab. 1: H*(10) values in µSv per 10 Gy to the patient.

Table 2: Measured half-value and tenth-value layers (respectively *HVL* and *TVL*) for broad photon radiation beams for lead, concrete and iron as a function of the applied electron acceleration voltage during IORT.
From: Introduction to Health Physics, Herman Cember, third edition.

	HVL	TVL	HVL	TVL	HVL	TVL
Electron acceleration voltage	Lead	Lead	Concrete	Concrete	Iron	Iron
(MV)	(mm)	(mm)	(cm)	(cm)	(cm)	(cm)
1	7.9	26	4.4	14.7		
2	12.5	42	6.4	21		
3	14.5	48.5	7.4	24.5		
4	16	53	8.8	29.2	2.7	9.1
6	16.9	56	10.4	34.5	3	9.9
8	16.9	56	11.4	37.8	3.1	10.3
10	16.6	55	11.9	39.6	3.2	10.5

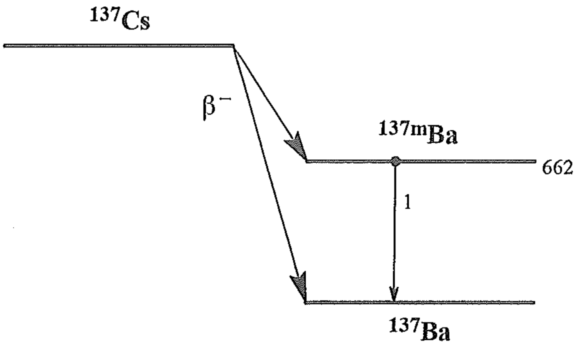
^{137}Cs Z = 55

Half-life and decay

$T_{1/2} = 30{,}25$ j $= 9{,}55\times10^{8}$ s

$\lambda = 7{,}26\times10^{-10}$ s^{-1}

Decay scheme



Main emitted radiation

Van ^{137m}Ba ($T_{1/2}$ = 2,55 m; 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 137mBa in equilibrium with 137Cs

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

Production and applications

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

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N = 82 ^{137}Cs

Metabolic model

For health physics purposes, it is assumed that caesium spreads from the homogenously over all tissues and organs, The biological half-lives for the organs are:

Fractie	$T_{1/2}$
0,1	2 d
0,9	110 d

Ingestion and lung clearance

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

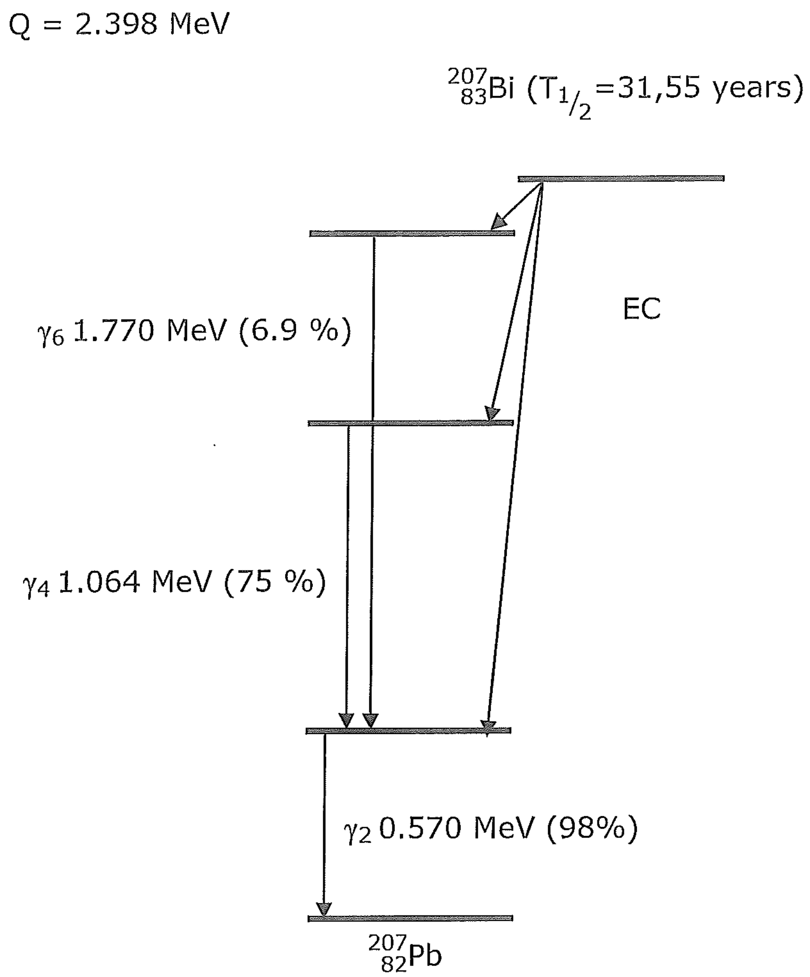
Dose conversion coefficient and radiotoxicity equivalent for workers (w) and members of the public (b)

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

Data for total body counting (after single intake)

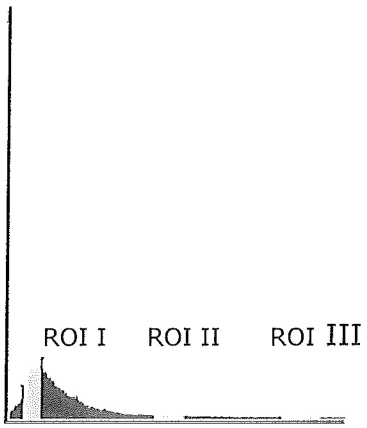
Time (d)	Total body activity (Bq per Bq intake)	
0,25	$1,0\times10^{0}$	$7,4\times10^{-1}$
1	$9,9\times10^{-1}$	$6,0\times10^{-1}$
2	$9,6\times10^{-1}$	$5,1\times10^{-1}$
3	$9,4\times10^{-1}$	$4,7\times10^{-1}$
5	$9,0\times10^{-1}$	$4,4\times10^{-1}$
7	$8,8\times10^{-1}$	$4,2\times10^{-1}$

Simplified decay scheme of ^{207}Bi

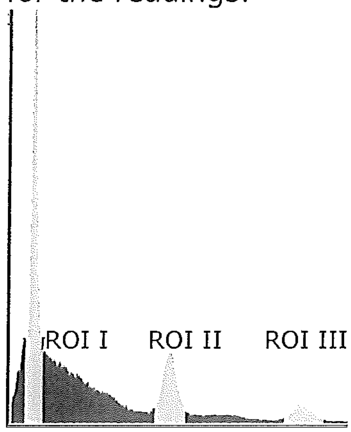


Photon spectra measured at the ^{207}Bi source

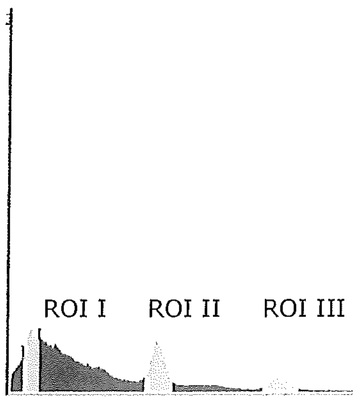
The count time for all spectra was 10 minutes. When the source was measured, the distance from the source to the top of the detector was 10 cm each time.
The peaks fall in the marked regions – the ROIs. The limit values for the ROIs are:
ROI I from 54 – 113 keV; II from 517 – 626 keV; III from 994 – 1141 keV.
See the table on the next page (Appendix 4) for the readings.



Background spectrum



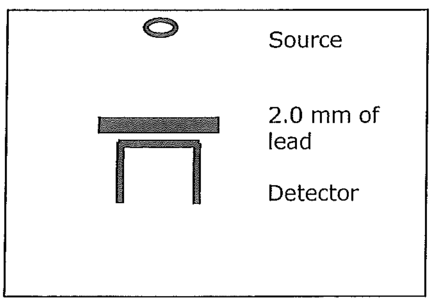
Spectrum 1
^{207}Bi unshielded source

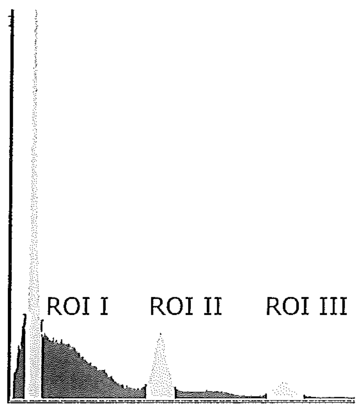


Spectrum 2A
^{207}Bi shielded source,
2.0 mm thick lead plate between source and detector

↕

Situation 2A side view:





Spectrum 2B
^{207}Bi unshielded source,
2.0 mm thick lead plate on top of the source

↕

Situation 2B side view:

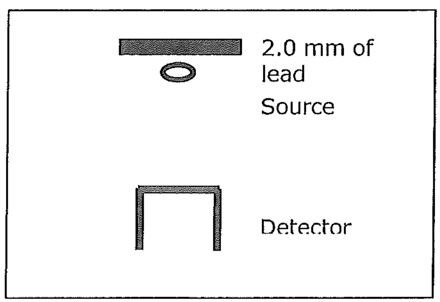


Table with quantitative data for the photon spectra

The table shows the total number of net counts, already adjusted for the background, in 10 minutes in the measurement region in question. The dead time correction has also been incorporated.

	ROI I 54 – 113 keV	**ROI II** 517 – 626 keV	**ROI III** 994 – 1141 keV	**Full width** 6 – 1147 keV
	net counts	net counts	net counts	net counts
Spectrum 1	104,695	40,849	13,295	259,534
Spectrum 2A	8,569	31,630	11,635	120,979
Spectrum 2B	112,012	40,938	13,451	275,510

Radiation emitted by 83-Bismuth-207

Radiation	γ (i) $(Bq \cdot s)^{-1}$	E (i) (keV)
β^+	$1.20 \cdot 10^{-4}$	383
$\gamma^\pm$	$2.40 \cdot 10^{-4}$	511
gamma 1	**$6.70 \cdot 10^{-6}$**	**328**
ce-K, gamma 1	$1.91 \cdot 10^{-6}$	240
ce-L, gamma 1	$3.26 \cdot 10^{-7}$	312
ce-M, gamma 1	$7.63 \cdot 10^{-8}$	324
ce-N+, gamma 1	$2.47 \cdot 10^{-8}$	327
gamma 2	**0.977**	**570**
ce-K, gamma 2	0.016	482
ce-L, gamma 2	0.004	554
gamma 3	**0.001**	**898**
ce-K, gamma 3	$2.43 \cdot 10^{-5}$	810
ce-L, gamma 3	$4.04 \cdot 10^{-6}$	882
gamma 4	**0.745**	**1,064**
ce-K, gamma 4	0.072	976
ce-L, gamma 4	0.018	1,048
ce-M+, gamma 4	0.006	1,061
gamma 5	**0.001**	**1,442**
ce-K, gamma 5	$3.55 \cdot 10^{-6}$	1,354
ce-L, gamma 5	$6.11 \cdot 10^{-7}$	1,426
gamma 6	**0.069**	**1,770**
Kalpha1 X-ray	0.366	75.0
Kalpha2 X-ray	0.218	72.8
Kbeta X-ray	0.163	84.9
L X-ray	0.332	10.6
Auger-K	0.028	56.7
Auger-L	0.544	7.97

Table copied from http://www.orau.org library nuclide data