Annex 3, Appendix 4

Sensitivity of air sampling methods

1 INTRODUCTION

As noted in the introduction of WP4, radiation protection in NORM industries implies the assessment of individual annual effective doses as low as1 mSv/year. In practice, it may be necessary to measure exposures below this level because total exposures often comprise contributions from internal as well as external sources. As well as having the required sensitivity, the assessment should also be sufficiently precise to provide confidence in the interpretation of results, and indeed the selection of protection options.

The assessment of exposures by air sampling is based on the quantitative analysis of the aerosol deposited on the filtrating medium by either radioanalysis (mainly gross alpha and beta counting) or gravimetry[1]. The aim of this Appendix is to show how to derive:

- the minimum detectable annual dose based on one day air sampling: and
- the minimum necessary counting time for gross alpha and beta counting (or the maximum possible specific activity for gravimetric analysis) to assess with a predefined relative uncertainty a given level of annual individual effective dose.

The variables considered are:

- the air sampling duration (sampling time of one week, one day or 1.6 hours);
- the background count rates of the alpha and beta counting equipment (or standard error of the gravimetric analysis); and
- the counting time of the samples (1 hour up to 16 hours)

The results of the calculations presented in this Appendix pertain to individual radionuclides, chain segments, and the whole U-238 and Th-232 decay series in secular equilibrium. They illustrate how the capacity of the various air sampling strategies to assess (with a 10% relative uncertainty) a level of annual effective dose of 1 mSv depends on sampling time and counting time (for gross alpha and beta counting or aerosol specific activity (for gravimetric analysis).
For more details on the calculation methods and results the reader is referred to JP Degrange 04 [1].

2 BASIC RADIOLOGICAL DATA AND CHARACTERISTICS OF AIR SAMPLES ANALYSIS METHODS

2.1 Basic radiological data associated with the ^{238}U and ^{232}Th natural chains

Table 1 and Table 2 show the radionuclide composition of the ^{238}U and ^{232}Th natural chains. For each radionuclide, the equilibrium fraction Eq_{si} (under the secular equilibrium hypothesis) and the ratio R_{si} (respectively R_{si}) between the alpha (respectively beta) and total activity is given. In these tables, pure (or almost pure) alpha emitters are presented in yellow, while pure (or almost pure) beta emitters are presented in blue.

[1] These are the most commonly used analytical techniques, although other techniques (e.g. x-ray fluorescence) are known to have been used.

Table1 : Segment composition, equilibrium fractions and activity ratios (^{238}U chain)

Segment	Nuclide	Equilibrium fraction	Activity ratio	
			Alpha	Beta
		Eq_{si}	$R_{\alpha si}$	$R_{\beta si}$
U238+	**U238**	1	1	
	Th234	1		1
	Pa234m	0.998		1
	Pa234	0.0033		1
U234	**U234**	1	1	
Th230	**Th230**	1	1	
Ra226+	**Ra226**	1	1	
	Rn222	1	1	
	Po-218	1	0.9998	0.0002
	At218	0.9998	1	
	Pb214	0.0002		1
	Bi214	1	0.00021	0.99979
	Po214	0.9998	1	
Pb210+	**Pb210**	1		1
	Bi210	1		1
Po210	**Po210**	1	1	

Table 2 : Segment composition, equilibrium fractions and activity ratios (^{232}Th chain)

Segment	Nuclide	Equilibrium fraction	Activity ratio	
			Alpha	Beta
		Eq_{si}	$R_{\alpha si}$	$R_{\beta si}$
Th232	**Th232**	1	1	
Ra228+	**Ra228**	1		1
	Ac228	1		1
Th228+	**Th228**	1	1	
	Ra224	1	1	
	Rn220	1	1	
	Po216	1	1	
	Pb212	1		1
	Bi212	1	0.359	0.641
	Po212	0.641	1	
	Tl208	0.359		1

Table 3 and Table 4 present the ratio $R_{\ s}$ (respectively $R_{\ s}$) between the alpha (respectively beta) and total activity of each segment. They also give the effective dose by inhalation e_{s1}(AMAD,GSD) of the whole segment per unit activity of the first radionuclide of the segment, for values of AMAD and GSD of 5 µm and 2.5 respectively.

In these tables, segments purely (or almost purely) constituted of alpha emitters are presented in yellow while those constituted of purely (or almost purely) beta emitters are presented in blue.

Table3 : Activity ratios and effective dose coefficient for each segment (^{238}U chain)

Segment	Activity ratio		Effective dose coefficient by inhalation		
	Alpha	Beta	e_{s1}(AMAD=5µm, GSD=2.5)		
	$R_{\alpha s}$	$R_{\beta s}$	Fast	Moderate	Slow
			$Sv.Bq^{-1}$	$Sv.Bq^{-1}$	$Sv.Bq^{-1}$
U238+	1.00	2.00	5.9E-07	1.7E-06	5.7E-06
U234	1.00		6.5E-07	2.1E-06	6.8E-06
Th230	1.00		1.2E-04	2.8E-05	7.2E-06
Ra226+	4.00	2.00	4.4E-07	2.2E-06	6.9E-06
Pb210+		2.00	1.1E-06	7.4E-07	4.3E-06
Po210	1.00		7.3E-07	2.2E-06	2.7E-06

Table4 : Activity ratios and effective dose coefficient for each segment (^{232}Th chain)

Segment	Activity ratio		Effective dose coefficient by inhalation		
	Alpha	Beta	e_{s1}(AMAD=5µm, GSD=2.5)		
	$R_{\alpha s}$	$R_{\beta s}$	Fast	Moderate	Slow
			$Sv.Bq^{-1}$	$Sv.Bq^{-1}$	$Sv.Bq^{-1}$
Th232	1.00		1.3E-04	2.9E-05	1.2E-05
Ra228+		2.00	1.1E-06	1.7E-06	1.1E-05
Th228+	5.00	2.00	3.4E-05	2.2E-05	2.5E-05

2.2 Characteristics of the methods considered for air samples analysis

Five analysis methods have been considered: gross alpha counting with low and high background levels, and gross beta counting with low and high background levels, as, characterised by their total yield (detection efficiency) Yt and background rate B; and gravimetric analysis (see table 5).

Table5 : Characteristics of the methods considered for air samples analysis

Analysis Method		Detection efficiency	Background rate
		Yt	B
			s^{-1}
Gross α counting	Low background	0.333	0.001
	High background	0.333	0.01
Gross β counting	Low background	0.5	0.01
	High background	0.5	0.1
Gravimetry		1.0	-

2.3 Limits of detection

For information on counting statistics, and the concepts of critical level (Lc), Limit of detection (Ld) and Limit of determination (Lq), the reader is referred to [2] – [5]. How these concepts define the three principal analytical regions is illustrated in figure 1.

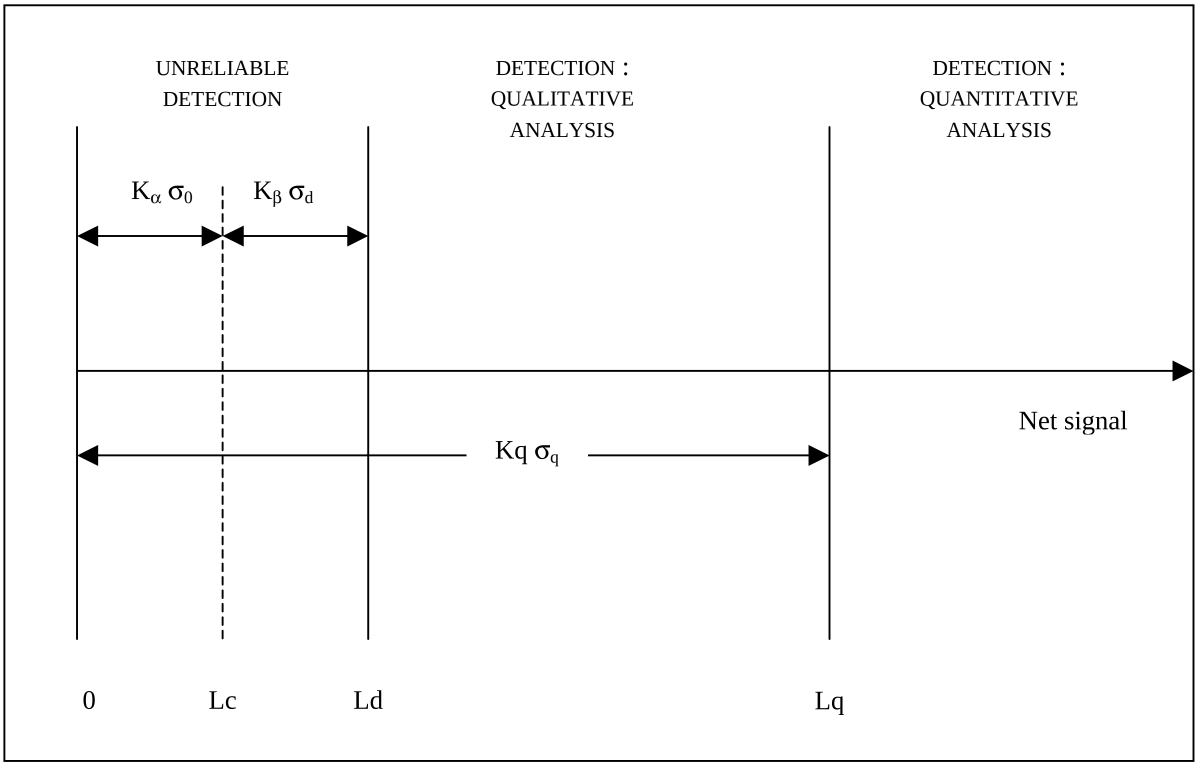

Figure 1: The three principal analytical regions

Figure 2 presents, the variation with counting duration of the limits of detection for the four radiometric analysis methods considered.

Table 6 presents the variation with counting duration of the limits of detection for the four considered methods of radioanalysis of air samples as well as the limit of detection for the analysis by gravimetry (k = 1.645).

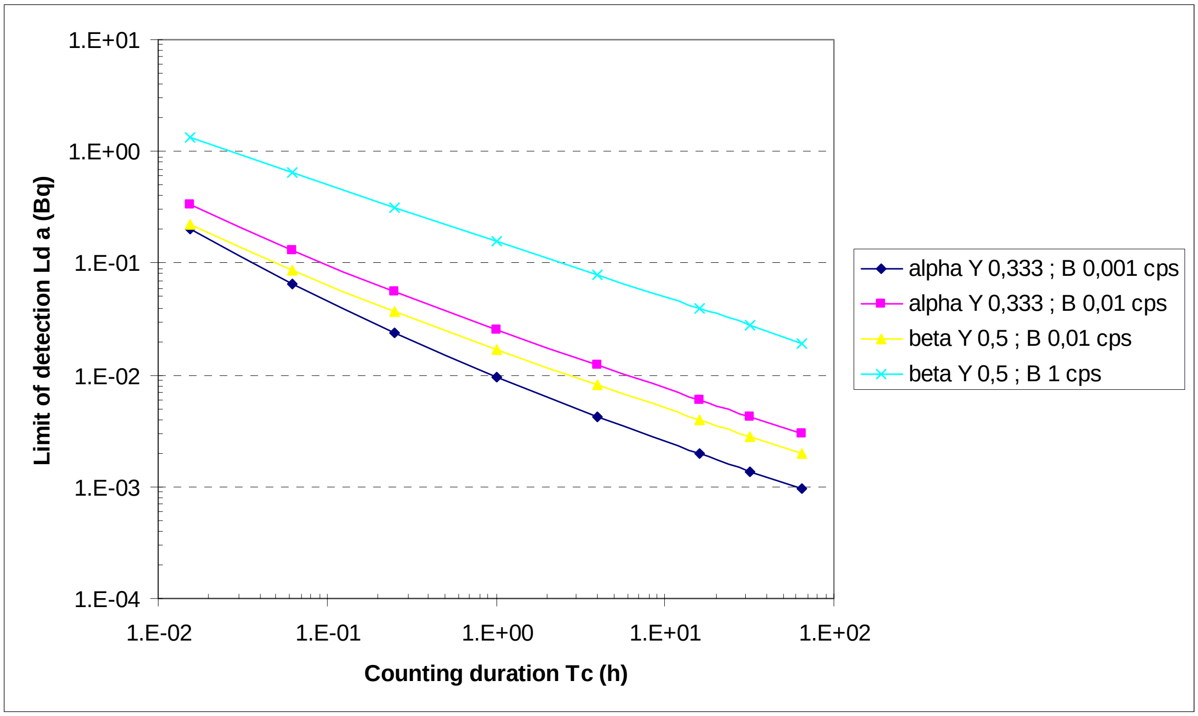

Figure 2: Evolution with counting duration of the limits of detection in activity Ld_a associated with gross alpha and beta radioanalysis (k = 1.645)

Table 6: Limits of detection in activity/mass of the considered analysis methods

Analysis method	**Limit of detection**		**Counting duration T_C (h)**						
			0.06	**0.25**	**1.00**	**4.00**	**16.00**	**32.00**	**64.00**
Gross α counting	**$Ld_{a\,\alpha}$ (Bq)**	**Low background**	6.6E-02	2.4E-02	9.6E-03	4.3E-03	2.0E-03	1.4E-03	9.6E-04
		High background	1.3E-01	5.6E-02	2.6E-02	1.2E-02	6.0E-03	4.2E-03	3.0E-03
Gross β counting	**$Ld_{a\,\beta}$ (Bq)**	**Low background**	8.6E-02	3.7E-02	1.7E-02	8.1E-03	4.0E-03	2.8E-03	2.0E-03
		High background	6.4E-01	3.2E-01	1.6E-01	7.8E-02	3.9E-02	2.8E-02	1.9E-02
Gravi-metry	**Ld_G (g)**		1.00E-04						

In quantitative analysis one is interested in a net value of the signal sufficiently close to the true value, e.g. in a coefficient of variation sufficiently small. The limit of determination Lq is defined as the maximum true value of the net signal above which the standard deviation remains below a predefined value k_q. If the true value of the net signal is above the limit of determination Lq the relative uncertainty will be below $1/k_q$. The limit of determination is given by the following formula:

$$Lq = k_q \sigma_q$$

3 CONVERSION TO EFFECTIVE DOSES

3.1 From airborne activity concentration of the first radionuclide of a segment

The following formula presents the conversion of the airborne activity concentration of the first radionuclide of a segment s of radionuclides C_{s1} into the effective dose by inhalation of the whole segment E_s:

$$E_s = Br \cdot Te \cdot \sum_i e_{si}(AMAD, GSD) \cdot C_{si}$$
$$= Br \cdot Te \cdot e_{s1}(AMAD, GSD) \cdot C_{s1}$$

with

E_s	Effective dose by inhalation of segment s (Sv)
Br	Breathing rate ($m^3 \cdot h^{-1}$)
Te	Exposure duration (h)
e_{si}(AMAD, GSD)	Effective dose coefficient for the ith radionuclide of segment s ($Sv.Bq^{-1}$)
C_{si}	Airborne activity concentration of the ith radionuclide of segment s ($Bq.m^{-3}$)
e_{s1}(AMAD, GSD)	Effective dose coefficient for segment s (effective dose / unit activity of the first radionuclide of segment s) ($Sv.Bq^{-1}$)
C_{s1}	Airborne activity concentration of the first radionuclide of segment s ($Bq.m^{-3}$)
s	Set of radionuclides in a given status of equilibrium

where

$$e_{s1}(AMAD, GSD) = \sum_i Eq_{si} \cdot e_{si}(AMAD, GSD)$$

and

$$Eq_{si} = C_{si} / C_{s1}$$

3.2 From activity or mass of one segment on a filter

3.2.1 Alpha and beta counting

The following formula shows the determination of the airborne activity concentration of the first radionuclide of a segment/chain on the basis of the total alpha (or beta) activity $A_{\alpha\beta s}$ deposited on the filtrating medium:

$$C_{s1} = A_{\alpha\beta s} / (R_{\alpha\beta s} \cdot R_x(AMAD, GSD) \cdot Fr \cdot Ts) \qquad \text{(alpha or beta counting)}$$

with

$A_{\alpha\beta s}$	Total alpha (or beta) activity from segment s deposited on the filter (Bq)
$R_{\alpha\beta s}$	Ratio between the total alpha (or beta) activity of segment s and the activity of the first radionuclide of segment s
R_x(AMAD, GSD)	Ratio between the true airborne activity concentration and

	the sampled activity concentration for a type x sampler
Fr	Sampler flow rate ($m^3 . h^{-1}$)
Ts	Sampling duration (h)
$R_{\alpha\beta si}$	Ratio between the alpha (or beta) activity and total activity of the ith radionuclide of segment s

where

$R_{\alpha\beta s} = \sum_i Eq_{si} . R_{\alpha\beta si}$ (alpha or beta counting)

The effective dose by inhalation E_s of the radionuclides of a given segment s is thus derived from the total alpha (or beta) total activity $A_{\alpha\beta s}$ from segment s deposited on the filtrating medium by the following formula:

$$E_s = A_{\alpha\beta s} . Br . Te . e_{s1}(AMAD, GSD) / (R_{\alpha\beta s} . R_x(AMAD, GSD) . Fr . Ts)$$
for $R_{\alpha\beta s} \neq 0$ (alpha or beta counting)

3.2.2 Gravimetric analysis

The following formula presents the determination of the airborne activity concentration of the first radionuclide of a segment/chain , on the basis of the mass deposited on the filtrating medium as well as the specific activity of the parent radionuclide.

$$C_{s1} = M . S_{s1} / (R_x(AMAD, GSD) . Fr . Ts)$$

with

M	Mass deposited on the filter (kg)
S_{s1}	Specific activity of the first radionuclide of segment s ($Bq.kg^{-1}$)

The effective dose by inhalation of the radionuclides of a given segment is thus derived from the mass deposited on the filtrating medium by the following formula:

$$E_s = Br . Te . e_{s1}(AMAD, GSD) . M . S_{s1} . / (R_x(AMAD, GSD) . Fr . Ts)$$ (gravimetry)

4 DETAILED RESULTS OF AIR SAMPLING SENSITIVITY

The detailed results of the analysis of air sampling methods are presented below. They are based on one hour gross alpha and beta counting with low and high background, on gravimetric analysis and a representative air sampling rate of PAS of 120 l/h.

4.1 Minimum detectable annual doses (one day sampling, 1 hour counting, 1 Bq/g)

The minimum detectable annual doses for the radionuclides, chains and chain segments of the U-238 and Th-232 decay series are shown in Tables 7 and 8. It should also be noted that:

- detectable annual doses for 1 week (5 days) and 1.6 h-long samples may be easily derived by multiplying these results by 0.2 and 5, respectively;
- detectable annual doses for different specific activity may also be easily obtained by multiplying these results by the specific activity value;
- detectable annual doses for different analysis technique detection limits may be easily derived by multiplying these results by the new detection limit divided by the detection limit considered in these calculations; and that
- detectable annual doses for different counting duration may be derived from Figure 3.

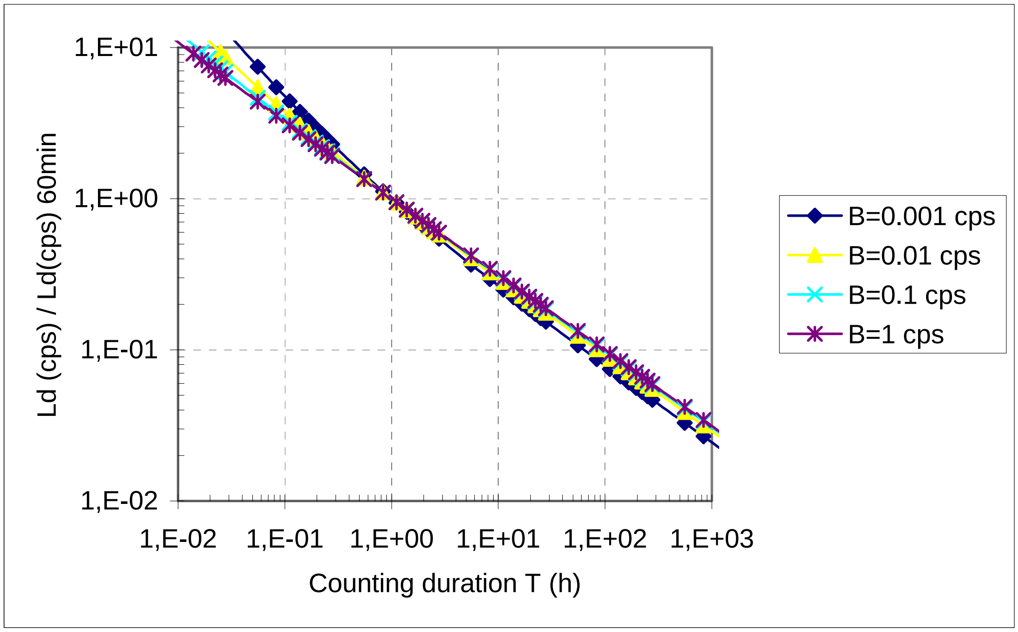

Figure 3: Conversion factor to apply to the detectable doses for a 1 h counting duration to derive the detectable dose for any counting duration.

Table 7. Minimum detectable annual dose, Ld_{ad}, for nuclides and chain segments of the U-238 decay series (120 l/h sampling rate, 1 h counting, 1 day-long samples)

Minimum detectable annual dose (120 l/h sampling rate, 1 h counting, 1 day-long samples)						
Absorp-tion Type	Segment	$Ld_{ad\ \alpha s}$ *		$Ld_{ad\ \beta s}$ *		$Ld_{ad\ Gs}$ **
		Alpha		Beta		Gravimetry
		Low Background	High background	Low background	High background	S_{s1} = 1Bq/g
		mSv/year	mSv/year	mSv/year	mSv/year	mSv/year
Fast	U238++	**2.9E-01**	**7.8E-01**	**6.9E-01**	**6.3E+00**	**2.4E-02**
	U238+	1.1E-02	3.0E-02	1.0E-02	9.2E-02	1.2E-04
	U234	1.3E-02	3.3E-02			1.3E-04
	Th230	2.3E+00	6.0E+00			2.4E-02
	Ra226+	2.1E-03	5.6E-03	7.5E-03	6.9E-02	8.8E-05
	Pb210+			1.9E-02	1.7E-01	2.2E-04
	Po210	1.4E-02	3.7E-02			1.5E-04
Moderate	U238++	**8.8E-02**	**2.3E-01**	**2.1E-01**	**1.9E+00**	**7.3E-03**
	U238+	3.2E-02	8.5E-02	2.8E-02	2.6E-01	3.3E-04
	U234	4.1E-02	1.1E-01			4.2E-04
	Th230	5.3E-01	1.4E+00			5.5E-03
	Ra226+	1.1E-02	2.8E-02	3.7E-02	3.4E-01	4.4E-04
	Pb210+			1.3E-02	1.2E-01	1.5E-04
	Po210	4.2E-02	1.1E-01			4.3E-04
Slow	U238++	**8.1E-02**	**2.2E-01**	**1.9E-01**	**1.8E+00**	**6.7E-03**
	U238+	1.1E-01	2.9E-01	9.7E-02	9.0E-01	1.2E-03
	U234	1.3E-01	3.5E-01			1.4E-03
	Th230	1.4E-01	3.7E-01			1.4E-03
	Ra226+	3.3E-02	8.8E-02	1.2E-01	1.1E+00	1.4E-03
	Pb210+			7.3E-02	6.7E-01	8.5E-04
	Po210	5.2E-02	1.4E-01			5.4E-04

(*) **Tc = 1 h**
(**) **$Ld_{ad\ Gs} = Ld_{ad}'_{Gs}$ for S_{s1} = 1 Bq/g**

Table 8. Minimum detectable annual dose, $Ld_{ad,}$ for nuclides and chain segments of the Th-232 decay series (120 l/h sampling rate, 1 h counting, 1 day-long samples)

Minimum detectable annual dose (120 l/h sampling rate, 1 h counting, 1 day-long samples)							
Absorp-tion Type	Segment	$Ld_{ad\ \alpha s}$ *		$Ld_{ad\ \beta s}$ *		$Ld_{ad\ Gs}$ **
		Alpha		Beta		Gravimetry
		Low background	High background	Low background	High background	S_{s1} = 1Bq/g
		mSv/year	mSv/year	mSv/year	mSv/year	mSv/year
Fast	Th232++	**5.2E-01**	**1.4E+00**	**1.4E+00**	**1.3E+01**	**3.3E-02**
	Th232	2.5E+00	6.5E+00			2.6E-02
	Ra228+			1.9E-02	1.7E-01	2.2E-04
	Th228+	1.3E-01	3.5E-01	5.8E-01	5.4E+00	6.8E-03
Moderate	Th232++	**1.7E-01**	**4.5E-01**	**4.5E-01**	**4.2E+00**	**1.1E-02**
	Th232	5.6E-01	1.5E+00			5.8E-03
	Ra228+			2.9E-02	2.7E-01	3.4E-04
	Th228+	8.5E-02	2.3E-01	3.8E-01	3.5E+00	4.4E-03
Slow	Th232++	**1.6E-01**	**4.1E-01**	**4.1E-01**	**3.8E+00**	**9.7E-03**
	Th232	2.3E-01	6.1E-01			2.4E-03
	Ra228+			1.9E-01	1.8E+00	2.3E-03
	Th228+	9.7E-02	2.6E-01	4.3E-01	4.0E+00	5.0E-03

(*) Tc = 1 h
(**) $Ld_{ad\ Gs} = Ld_{ad}'_{Gs}$ for S_{s1} = 1 Bq/g

4.2 Minimum counting time and maximum specific activity for determining 1 mSv/a with 10% coefficient of variation

Minimum counting times and maximum specific activities required for determining exposures of 1 mSv/a with 10% coefficient of variation are provided in Tables 9 and 10 for the U-238 and the Th-232 decay series, respectively. They are based on a sampling time of 1 day (one shift). Note that for 5 day sampling times the minimum counting times and maximum specific activities should be divided by a factor of 5 and for 1.6 hour sampling times multiplied by factor of 5.

4.3 Minimum sampling duration to dertermine 1 mSv/a with a 10% coefficient of variation

Tables 11 and 12 show the minimum sampling times at 120 l/h required to determine an exposure of 1 mSv/a with 10% coefficient of variation. The results are based on an assumed counting time of up to 16 hours.

4.4 Summary of capacities of analytical methods to determine 1 mSv/a with 10% coefficient of variation

The capacities of the analytical methods to determine 1 mSv/a with a 10% coefficient of variation have been summarised in Table 13 and 14 for the U-238 and Th-232 chains respectively. The assumed maximum counting time is 16 hours and the maximum specific activity is < 10 Bq/g.

Table 9: Minimum counting duration / Maximum specific activity to determine 1 mSv/year with a 10% coefficient of variation (120 l/h sampling rate, 1 day-long samples) for radionuclides and chain segments of the U-238 decay chain

Minimum counting duration / Maximum specific activity to determine 1 mSv/year with a 10% coefficient of variation (120 l/h sampling rate, 1 day-long samples)						
Absorption Type	Segment	Tc min				S_{s1} max
		Alpha		Beta		Gravimetry
		Low background	High background	Low background	High background	
		H	h	h	h	Bq/g
Fast	U238++	**3.0E+00**	**7.16E+00**	**5.9E+00**	**3.7E+02**	**1.4E+01**
	U238+	9.9E-02	1.1E-01	3.3E-02	1.1E-01	2.8E+03
	U234	1.1E-01	1.2E-01			2.5E+03
	Th230	4.8E+01	3.0E+02			1.4E+01
	Ra226+	1.8E-02	1.9E-02	2.5E-02	6.8E-02	3.7E+03
	Pb210+			6.4E-02	3.4E-01	1.5E+03
	Po210	1.2E-01	1.3E-01			2.3E+03
Moderate	U238++	**8.0E-01**	**1.2E+00**	**1.0E+00**	**347E+01**	**4.5E+01**
	U238+	2.8E-01	3.3E-01	9.8E-02	7.0E-01	9.9E+02
	U234	3.6E-01	4.4E-01			7.8E+02
	Th230	6.2E+00	2.0E+01			5.9E+01
	Ra226+	9.2E-02	9.7E-02	1.3E-01	1.2E+00	7.5E+02
	Pb210+			4.3E-02	1.6E-01	2.2E+03
	Po210	3.7E-01	4.5E-01			7.6E+02
Slow	U238++	**7.4E-01**	**1.1E+00**	**9.0E-01**	**2.9E+01**	**4.9E+01**
	U238+	1.0E+00	1.6E+00	3.9E-01	7.6E+00	2.9E+02
	U234	1.2E+00	2.1E+00			2.4E+02
	Th230	1.3E+00	2.2E+00			2.3E+02
	Ra226+	2.9E-01	3.5E-01	4.9E-01	1.1E+01	2.4E+02
	Pb210+			2.8E-01	4.3E+00	3.9E+02
	Po210	4.6E-01	5.9E-01			6.1E+02

Tc min < 1 h	1 h < Tc min < 16 h	Tc min> 16 h
S_{s1} max < 10	10 < S_{s1} max < 100	S_{s1} max > 100

Table 10: Minimum counting duration / Maximum specific activity to determine 1 mSv/year with a 10% coefficient of variation (120 l/h sampling rate, 1 day-long samples) for radionuclides and chain segments of the Th-232 decay chain

Minimum counting duration / Maximum specific activity to determine 1 mSv/year with a 10% coefficient of variation (120 l/h sampling rate, 1 day-long samples)						
Absorption Type	**Segment**	**Tc min**				**S_{s1} max**
		Alpha		**Beta**		**Gravimetry**
		Low background	**High background**	**Low background**	**High background**	
		H	**h**	**h**	**h**	**Bq/g**
Fast	**Th232++**	**6.0E+00**	**1.9E+01**	**1.9E+01**	**1.5E+03**	**1.0E+01**
	Th232	5.4E+01	3.5E+02			1.3E+01
	Ra228+			6.4E-02	3.3E-01	1.5E+03
	Th228+	1.2E+00	2.1E+00	4.50E+00	2.6E+02	4.8E+01
Moderate	**Th232++**	**1.6E+00**	**3.0E+00**	**3.0E+00**	**1.6E+02**	**3.1E+01**
	Th232	6.6E+00	2.2E+01			5.6E+01
	Ra228+			1.0E-01	7.3E-01	9.7E+02
	Th228+	7.8E-01	1.1E+00	2.3E+00	1.1E+02	7.4E+01
Slow	**Th232++**	**1.5E+00**	**2.7E+00**	**2.7E+00**	**1.3E+02**	**3.4E+01**
	Th232	2.3E+00	4.9E+00			1.4E+02
	Ra228+			9.2E-01	3.E+01	1.4E+02
	Th228+	8.9E-01	1.4E+00	2.8E+00	1.4E+02	6.5E+01

Tc min < 1 h	1 h < Tc min < 16 h	Tc min> 16 h
S_{s1} max < 10	10 < S_{s1} max < 100	S_{s1} max > 100

Table 11: Minimum sampling duration to determine 1 mSv/year with a 10% coefficient of variation (120 l/h) for radionuclides and chain segments of the U-238 decay chain

Minimum sampling duration * to determine 1 mSv/year with a 10% coefficient of variation (120 l/h)						
Absorption Type	**Segment**	**Tc min < 16 h**				**S_{s1} max > 10 Bq/g**
		Alpha		**Beta**		**Gravimetry**
		Low background	**High background**	**Low background**	**High background**	
		D	**D**	**D**	**W**	**D**
	U238+	H	H	H	H	H
	U234	H	H			H
	Th230	W	W			D
	Ra226+	H	H	H	H	H
	Pb210+			H	H	H
	Po210	H	H			H
Moderate	U238++	**H**	**H**	**H**	**W**	**D**
	U238+	H	H	H	H	H
	U234	H	H			H
	Th230	D	W			H
	Ra226+	H	H	H	D	H
	Pb210+			H	H	H
	Po210	H	H			H
Slow	U238++	**H**	**H**	**H**	**W**	***H***
	U238+	H	D	H	D	H
	U234	H	D			H
	Th230	H	D			H
	Ra226+	H	H	H	D	H
	Pb210+			H	D	H
	Po210	H	H			H

Hourly	Daily	Weekly	< Weekly

(*) H: 1.5 h sampling (1000 samples/year), D: Daily sampling (200 samples/year), W: Weekly sampling (40 samples/year)

Bh: Gross beta counting, high background (Min. counting duration < 16h)

G: Gravimetry (Max. specific activity > 10Bq/g)

Table 12: Minimum sampling duration to determine 1 mSv/year with a 10% coefficient of variation (120 l/h) for radionuclides and chain segments of the Th-232 decay chain

Minimum sampling duration * to detect 1 mSv/year with a 10% coefficient of variation (120 l/h)						
Absorption Type	**Segment**	**Tc min < 16 h**				**S_{s1} max > 10 Bq/g**
		Alpha		**Beta**		**Gravimetry**
		Low background	**High background**	**Low background**	**High background**	
Fast	**Th232++**	**D**	**W**	**W**		**D**
	Th232	W	*W*			D
	Ra228+			H	H	H
	Th228+	H	D	D	W	D
Moderate	**Th232++**	**H**	**D**	**D**	**W**	**D**
	Th232	D	W			H
	Ra228+			H	*H*	H
	Th228+	H	H	D	W	H
Slow	**Th232++**	**H**	**D**	**D**	**W**	**D**
	Th232	D	D			H
	Ra228+			H	W	H
	Th228+	H	D	D	W	H

Hourly	Daily	Weekly	< Weekly

(*) H: 1.5 h sampling (1000 samples/year), D: Daily sampling (200 samples/year), W: Weekly sampling (40 samples/year)
Bh: Gross beta counting, high background (Min. counting duration < 16h)
G: Gravimetry (Max. specific activity > 10Bq/g)

Table 13 : Capacity of the analysis methods to determine 1 mSv/year with a 10% coefficient of variation (120 l/h sampling rate, hour/day/week-long samples), U-238 chain

Capacity of the analysis methods * to determine 1 mSv/year with a 10% coefficient of variation (120 l/h))										
Absorption Type	**Segment**	**1.6 h - long samples**			**1 day - long samples**			**1 week - long samples**		
Fast	**U238++**				**Ah**	**Bl**		**Ah**	**Bh**	**G**
	U238+	**Ah**	**Bh**	**G**	**Ah**	**Bh**	**G**	**Ah**	**Bh**	**G**
	U234	**Ah**		**G**	**Ah**		**G**	**Ah**		**G**
	Th230						**G**	**Ah**		**G**
	Ra226+	**Ah**	**Bh**	**G**	**Ah**	**Bh**	**G**	**Ah**	**Bh**	**G**
	Pb210+		**Bh**	**G**		**Bh**	**G**		**Bh**	**G**
	Po210	**Ah**		**G**	**Ah**		**G**	**Ah**		**G**
Moderate	**U238++**	**Ah**	**Bl**		**Ah**	**Bl**	**G**	**Ah**	**Bh**	**G**
	U238+	**Ah**	**Bh**	**G**	**Ah**	**Bh**	**G**	**Ah**	**Bh**	**G**
	U234	**Ah**		**G**	**Ah**		**G**	**Ah**		**G**
	Th230			**G**	**Al**		**G**	**Ah**		**G**
	Ra226+	**Ah**	**Bl**	**G**	**Ah**	**Bh**	**G**	**Ah**	**Bh**	**G**
	Pb210+		**Bh**	**G**		**Bh**	**G**		**Bh**	**G**
	Po210	**Ah**		**G**	**Ah**		**G**	**Ah**		**G**
Slow	**U238++**	**Ah**	**Bl**	***G***	**Ah**	**Bl**	**G**	**Ah**	**Bh**	**G**
	U238+	**Al**	**Bl**	**G**	**Ah**	**Bh**	**G**	**Ah**	**Bh**	**G**
	U234	**Al**		**G**	**Ah**		**G**	**Ah**		**G**
	Th230	**Al**		**G**	**Ah**		**G**	**Ah**		**G**
	Ra226+	**Ah**	**Bl**	**G**	**Ah**	**Bh**	**G**	**Ah**	**Bh**	**G**
	Pb210+		**Bl**	**G**		**Bh**	**G**		**Bh**	**G**
	Po210		**Bh**	**G**		**Bh**	**G**		**Bh**	**G**

Al: Gross alpha counting, low background (Min. counting duration < 16h)
Ah: Gross alpha counting, high background (Min. counting duration < 16h)
Bl: Gross beta counting, low background (Min. counting duration < 16h)
G: Gravimetry (Max. specific act. > 10Bq/g)

Table 14 : Capacity of the analysis methods to determine 1 mSv/year with a 10% coefficient of variation (120 l/h sampling rate, hour/day/week-long samples), Th-232 chain

Capacity of the analysis methods to determine 1 mSv/year with a 10% coefficient of variation (120 l/h)										
Absorp-tion Type	**Segment**	**1.6 h - long samples**			**1 day - long samples**			**1 week - long samples**		
Fast	**Th232++**				**Al**		**G**	**Ah**	**Bl**	**G**
	Th232						**G**	**Ah**		**G**
	Ra228+		**B h**	**G**		**Bh**	**G**		**Bh**	**G**
	Th228+	**Al**			**Ah**	**Bl**	**G**	**Ah**	**Bh**	**G**
Moderate	**Th232++**	**Al**			**Ah**	**Bl**	**G**	**Ah**	**Bh**	**G**
	Th232			**G**	**Al**		**G**	**Ah**		**G**
	Ra228+		**Bl**	**G**		**Bh**	**G**		**Bh**	**G**
	Th228+	**Ah**		**G**	**Ah**	**Bl**	**G**	**Ah**	**Bh**	**G**
Slow	**Th232++**	**Al**			**Ah**	**Bl**	**G**	**Ah**	**Bh**	**G**
	Th232			**G**	**Ah**		**G**	**Ah**		**G**
	Ra228+		**Bl**	**G**		**Bl**	**G**		**Bh**	**G**
	Th228+	**Al**		**G**	**Ah**	**Bl**	**G**	**Ah**	**Bh**	**G**

Al: Gross alpha counting, low background (Min. counting duration < 16h)
Ah: Gross alpha counting, high background (Min. counting duration < 16h)
Bl: Gross beta counting, low background (Min. counting duration < 16h)
G: Gravimetry (Max. specific act. > 10Bq/g)

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