Procedure for determining the specific activities of radionuclides in marine sediment and suspended particulate matter by gamma spectrometry

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Procedures manual for monitoring of radioactive substances in the environment and of external radiation

(Messanleitungen für die „Überwachung radioaktiver Stoffe in der Umwelt und externer Strahlung“)

Procedure for determining the specific activities of radionuclides in marine sediment and suspended particulate matter by gamma spectrometry

1 Scope

The procedure outlined in the following is suitable for determining the specific activities of fission and activation products as well as naturally occurring radionuclides in marine sediment and suspended particulate matter according to the Radiation Protection Act (Strahlenschutzgesetz, StrlSchG) in the IMIS routine operation mode. In particular, the determination of Cs-137 as a reference nuclide allows recording and evaluating the chronological trend of the long-term contamination.

The procedure is also applicable in the IMIS intensive operation mode after the occurrence of higher activities for both marine sediment and seawater.

2 Sampling

Depending on the type of sediment, samples are taken with the appropriate sampling device:

— the Gemini corer for soft, muddy sediment (see figure 1),
— the large box corer and the small box corer (Reineck corer) for solid sediment, also with high sand content (see figures 2 and 3) and
— the cheeks corer (see figure 4) for sediments from which samples cannot be taken with the above mentioned devices, e.g. gravel and coarse sand.

The Gemini Corer takes two sediment cores directly parallel from the seabed. Relatively undisturbed surfaces can be obtained with this corer.

Sediment cores, usually two parallel cores, are taken from the sediment in the corer boxes aboard using Perspex stabbing tubes. The surfaces of the cores should be kept undisturbed as far as possible, so a few centimetres of seawater must remain above the sample.

The sediment cores are cut horizontally into slices of one to three centimetre thickness (standard is 2 cm) and transferred to PE boxes as mixed samples of the same horizons, so that the vertical profile of the sediment cores can later be determined by gamma spectrometry.

In the case of samples obtained with the cheeks corer without a defined layer structure, it only makes sense to take the top three centimetres.

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Fig. 1: Gemini corer

Fig. 2: Large box corer

Fig. 3: Small box corer

Fig. 4: Cheeks corer

Marine suspended particulate matter is obtained aboard from at least ten cubic metres of seawater using a high-speed tube centrifuge connected to a seawater main. Other filtration methods are too time-consuming to obtain enough sample material because of the low concentration of suspended particulate matter in the seawater.

Both the marine sediment samples taken as well as the marine suspended particulate matter obtained from the tube centrifuge are ideally frozen directly at -5 °C to -20 °C.

3 Analysis

3.1 Principle of the procedure

The samples are measured directly by gamma spectrometry. From the spectra obtained, the specific activities of a variety of natural and artificial gamma-emitting radionuclides can be determined.

3.2 Sample preparation

In order to obtain as homogeneous a sample as possible in a defined geometry, the frozen marine sediment or suspended particulate matter samples are then freeze-dried. Obvious foreign bodies such as shell parts or stones are removed from the sediment samples. The dry samples are then homogenized using a ball mill and weighed into cylindrical plastic measuring containers. The filling level is determined. Experience has shown that the bulk density of the counting sources is about 1 $g \cdot cm^{-3}$. The specific activity is referred to the dry mass.

In the IMIS intensive operation mode, the result must be available quickly. Therefore, the marine sediment or suspended particulate matter samples are not frozen after sampling; drying is not necessary. The samples are then transferred into suitable measuring containers in a wet condition and measured directly.

Seawater samples are also measured directly in suitable measuring containers in the IMIS intensive operation mode.

3.3 Radiochemical separation

A radiochemical separation is not required with this non-destructive measuring method.

4 Measuring the activity

Depending on the expected activity, the counting sources are usually measured in the routine operation mode for 24 to 48 hours.

4.1 General

In the general chapter γ-SPEKT/GRUNDL of these procedures manuals, the fundamentals of gamma spectrometry and technical designs of suitable gamma spectrometry measuring devices are described.

4.2 Calibration

The calibration of the measuring system is carried out with mixed nuclide solutions whose activities are traceable to a national primary standard. For the calibration of the detection efficiency, measurements are carried out in all required geometries and the durations of measurement are selected in such a way that the counting rates of the radionuclides are in the range of one percent of the relative counting uncertainty. For the energy calibration as well as for continuous checking of the detection efficiencies, a europium-152 source is measured weekly. The calculations of the detection efficiencies for the measuring geometries of the respective gamma spectrometry measuring devices as well as their energy calibrations are carried out with a commercial evaluation software for gamma spectrometry.

4.3 Background

By a regular, e.g. monthly, recording of background spectra, disturbing contributions from the surroundings or the detector are recorded. Further considerations on the determination of the background can be found in the general chapter γ-SPEKT/NULLEF of these procedures manuals.

4.4 Measurement

For the measurement, the counting sources are placed centrally on the detector, if necessary also by means of centering rings. Depending on the specific activity of the radionuclides to be determined, the duration of measurement is usually between 24 and 48 hours.

5 Calculation of the results

The marine sediment or suspended particulate matter samples are analysed for artificial, cosmogenic and natural radionuclides. This has implications for the calculation of the procedural net count rates and characteristic limits according to DIN ISO 11929. In the case of natural radionuclides, a gamma line may occur at the respective energy even in the background spectrum, which must be taken into account (see the general chapters γ-SPEKT/NATRAD and ERK/NACHWEISGR-ISO-02 of these procedures manuals).

Besides artificial and cosmogenic radionuclides, e.g. Cs-137, Cs-134, Ru-106, Co-60, Sb-125, Am-241 and Be-7, the natural radionuclides Pb-210, Ra-226, Ra-228, Th-228, U-238 as well as the primordial K-40 are also determined.

5.1 Equations

The specific activity a_r of a single nuclide r at the time of sampling is calculated according to equation (1):

$$a_\mathrm{r} = \frac{f_\mathrm{A}}{\varepsilon_\mathrm{r} \cdot p_\gamma \cdot m_\mathrm{TM}} \cdot R_\mathrm{n,r} = \frac{\mathrm{e}^{\lambda_\mathrm{r} \cdot t_\mathrm{A}}}{\varepsilon_\mathrm{r} \cdot p_\gamma \cdot m_\mathrm{TM}} \cdot R_\mathrm{n,r} = \varphi \cdot R_\mathrm{n,r} \quad (1)$$

Herein are:

a_r specific activity of the radionuclide r, in Bq·kg^{-1};

f_A correction factor for the decay;

λ_r decay constant of the radionuclide r, in s^{-1};

t_A time period between sampling and beginning of measurement, in s;

$R_\mathrm{n,r}$ net count rate of the considered gamma line of the radionuclide r, in s^{-1}:
where for artificial radionuclides and Be-7:
$R_\mathrm{n,r} = R_\mathrm{g,r} - R_\mathrm{T,r}$
and for natural radionuclides:
$R_\mathrm{n,r} = (R_\mathrm{g,r} - R_\mathrm{T,r}) - (R_\mathrm{g0,r} - R_\mathrm{T0,r})$
with

- $R_\mathrm{g,r}$ gross count rate of the considered gamma line of the radionuclide r, in s^{-1};
- $R_\mathrm{T,r}$ background count rate of the gamma line of the radionuclide r, e. g. the trapezium background count rate, in s^{-1};
- $R_\mathrm{g0,r}$ gross count rate of the background line of the radionuclide r, in s^{-1};
- $R_\mathrm{T0,r}$ background count rate of the background line of the radionuclide r, e. g. the trapezium background count rate, in s^{-1};

ε_r detection efficiency of the radionuclide r, in Bq^{-1}·s^{-1};

p_γ absolute emission intensity for the gamma emission;

m_TM dry mass of the sample, in kg;

φ procedural calibration factor, in Bq·s·kg^{-1}.

The standard uncertainty $u(a_\mathrm{r})$ of the specific activity for artificial radionuclides and Be-7 is calculated according to equation (2):

$$u(a_\mathrm{r}) = \sqrt{a_\mathrm{r}^2 \cdot u_\mathrm{rel}^2(\varphi) + \varphi^2 \cdot \left[\frac{1}{t_\mathrm{m}} \cdot \left(R_\mathrm{g,r} + R_\mathrm{T,r} \cdot \frac{b_\mathrm{r}}{2 \cdot L_\mathrm{r}}\right)\right]} \quad (2)$$

The standard uncertainty $u(a_\mathrm{r})$ of the specific activity for natural radionuclides is:

$$u(a_\mathrm{r}) = \sqrt{\begin{array}{c} a_\mathrm{r}^2 \cdot u_\mathrm{rel}^2(\varphi) + \varphi^2 \cdot \\ \cdot \left\{\frac{1}{t_\mathrm{m}} \cdot \left[R_\mathrm{n,r} + \left(R_\mathrm{T,r} \cdot \left(1 + \frac{b_\mathrm{r}}{2 \cdot L_\mathrm{r}}\right) + R_\mathrm{n0,r} + \frac{t_\mathrm{m}}{t_0} \cdot \left(R_\mathrm{g0,r} + R_\mathrm{T0,r} \cdot \frac{b_\mathrm{0,r}}{2 \cdot L_\mathrm{0,r}}\right)\right)\right]\right\} \end{array}} \quad (1)$$

In equations (2) and (3) are:

$u(a_\mathrm{r})$	standard uncertainty of the specific activity of the radionuclide r, in Bq·kg^{-1};
b_r	base width of the gamma line of the radionuclide r of the counting source;
L_r	number of channels to the left and right of the background of the gamma line used for background determination of the radionuclide r of the counting source;
$R_{\mathrm{n0,r}}$	net count rate of the background line of the radionuclide r;
$b_{\mathrm{0,r}}$	base width of the gamma line of the background;
$L_{\mathrm{0,r}}$	number of channels to the left and right of the background of the gamma line used for background determination of the radionuclide r;
t_m	duration of measurement of the counting source, in s;
t_0	duration of measurement of the background, in s;
$u_\mathrm{rel}(\varphi)$	relative standard uncertainty of the procedural calibration factor;
$u_\mathrm{rel}(f_\mathrm{A})$	relative standard uncertainty of the correction factor for the decay;
$u_\mathrm{rel}(m_\mathrm{TM})$	relative standard uncertainty of the dry mass;
$u_\mathrm{rel}(p_\gamma)$	relative standard uncertainty of the absolute emission intensity;
$u_\mathrm{rel}(\varepsilon_\mathrm{r})$	relative standard uncertainty of the detection efficiency of the radionuclide r.

5.2 Worked example

For the worked example, the following numerical values are used. The relative standard uncertainty of the correction factor for the decay $u_\mathrm{rel}(f_\mathrm{A})$ can be neglected.

In the case that no interfering gamma line is present at the energy to be analysed, the base width b is set equal to 1.7 times the full width at half maximum h from calibration measurements. However, L should not be set greater than $b/2$.

5.2.1 Artificial radionuclides

The following input values were determined for the radionuclide Cs-137:

$R_{\mathrm{g,Cs-137}}$	= 0,06 s^{-1};	$b_{\mathrm{Cs-137}}$	= 2,363 keV;
$R_{\mathrm{T,Cs-137}}$	= 0,01 s^{-1};	$L_{\mathrm{Cs-137}}$	= 1,183 keV;
t_A	= 6 months = 1,58·10^{7} s;	t_m	= 86400 s;
φ	= 475,488 Bq·s·kg^{-1};	$\lambda_{\mathrm{Cs-137}}$	= 0,73·10^{-9} s^{-1};
m_TM	= 0,100 kg;	$u_\mathrm{rel}(m_\mathrm{TM})$	= 0,02;
$\varepsilon_{\mathrm{Cs-137}}$	= 0,025 Bq^{-1}·s^{-1};	$u_\mathrm{rel}(\varepsilon_{\mathrm{Cs-137}})$	= 0,05;
p_γ	= 0,851;	$u_\mathrm{rel}(p_\gamma)$	= 0,002.

The specific activity $a_{\mathrm{Cs-137}}$ is calculated according to equation (1):

$$R_{\mathrm{n,Cs-137}} = 0{,}06\ \mathrm{s}^{-1} - 0{,}01\ \mathrm{s}^{-1} = 0{,}05\ \mathrm{s}^{-1}$$

$$a_{\mathrm{Cs-137}} = \frac{\mathrm{e}^{0{,}73\cdot 10^{-9}\ \mathrm{s}^{-1}\cdot 1{,}58\cdot 10^{7}\ \mathrm{s}}}{0{,}025\mathrm{Bq}^{-1}\cdot \mathrm{s}^{-1}\cdot 0{,}851\cdot 0{,}1\ \mathrm{kg}}\cdot 0{,}05\ \mathrm{s}^{-1} = 23{,}77\ \mathrm{Bq}\cdot \mathrm{kg}^{-1}\ (\mathrm{TM})$$

The standard uncertainty of the specific activity $u(a_{\mathrm{Cs-137}})$ is calculated according to equation (2):

$$u(a_{\mathrm{Cs-137}}) = \sqrt{\begin{array}{c}(23{,}77\ \mathrm{Bq}\cdot \mathrm{kg}^{-1})^2\cdot (0{,}02^2 + 0{,}05^2 + 0{,}002^2) + \\ +(475{,}488\ \mathrm{Bq}\cdot \mathrm{s}\cdot \mathrm{kg}^{-1})^2\cdot \left[\frac{1}{86400\ \mathrm{s}}\cdot \left(0{,}06\ \mathrm{s}^{-1} + 0{,}01\ \mathrm{s}^{-1}\frac{2{,}363\ \mathrm{keV}}{2\cdot 1{,}183\ \mathrm{keV}}\right)\right]\end{array}} =$$

$$= 1{,}35\ \mathrm{Bq}\cdot \mathrm{kg}^{-1}\ (\mathrm{TM})$$

The specific activity $a_{\mathrm{Cs-137}}$ for Cs-137 is thus:

$$a_{\mathrm{Cs-137}} = (23{,}8 \pm 1{,}4)\ \mathrm{Bq}\cdot \mathrm{kg}^{-1}\ (\mathrm{TM})$$

5.2.2 Natural radionuclides

The specific activity of K-40 $a_{\mathrm{K-40}}$ is calculated using following values:

$R_{\mathrm{T,K-40}}$	= 0,004 s^{-1};	$R_{\mathrm{g,K-40}}$	= 0,096 s^{-1};
$R_{\mathrm{T0,K-40}}$	= 0,0006 s^{-1};	$R_{\mathrm{g0,K-40}}$	= 0,0021 s^{-1};
$b_{\mathrm{K-40}}$	= 14 channels;	$L_{\mathrm{K-40}}$	= 6 channels;
φ	= 7788,162 Bq·s·kg^{-1};	$\lambda_{\mathrm{K-40}}$	= 1,72·10^{-17} s^{-1};
$b_{\mathrm{0,K-40}}$	= 19 channels;	$L_{\mathrm{0,K-40}}$	= 8 channels;
t_{m}	= 260000 s;	t_0	= 260000 s;
t_{A}	= 6 months = 1,58·10^{7} s;		
m_{TM}	= 0,100 kg;	$u_{\mathrm{rel}}(m_{\mathrm{TM}})$	= 0,02;
$\varepsilon_{\mathrm{K-40}}$	= 0,012;	$u_{\mathrm{rel}}(\varepsilon_{\mathrm{K-40}})$	= 0,05;
p_γ	= 0,107;	$u_{\mathrm{rel}}(p_\gamma)$	= 0,002.

The specific activity $a_{\mathrm{K-40}}$ is calculated according to equation (1):

$$R_{\mathrm{n,K-40}} = (0{,}096\ \mathrm{s}^{-1} - 0{,}004\ \mathrm{s}^{-1}) - (0{,}0021\ \mathrm{s}^{-1} - 0{,}0006\ \mathrm{s}^{-1}) = 0{,}0905\ \mathrm{s}^{-1}$$

$$a_{\mathrm{K-40}} = \frac{\mathrm{e}^{1{,}72\cdot 10^{-17}\ \mathrm{s}^{-1}\cdot 1{,}58\cdot 10^{7}\ \mathrm{s}}}{0{,}012\ \mathrm{Bq}^{-1}\cdot \mathrm{s}^{-1}\cdot 0{,}107\cdot 0{,}1\ \mathrm{kg}}\cdot 0{,}0905\ \mathrm{s}^{-1} = 704{,}83\ \mathrm{Bq}\cdot \mathrm{kg}^{-1}\ (\mathrm{TM})$$

The standard uncertainty $u(a_{\mathrm{K-40}})$ of the specific activity is calculated according to equation (3):

$$u(a_{\mathrm{K-40}}) = \sqrt{\begin{array}{l}\left(704{,}83\ \mathrm{Bq}\cdot\mathrm{kg}^{-1}\right)^2\cdot\left(0{,}02^2+0{,}05^2+0{,}002^2\right)+\left(7788{,}162\ \mathrm{Bq}\cdot\mathrm{s}\cdot\mathrm{kg}^{-1}\right)^2\cdot\\ \cdot\left\{\frac{1}{260000\ \mathrm{s}}\cdot\left[0{,}092\ \mathrm{s}^{-1}+\left(\begin{array}{c}0{,}004\cdot\left(1+\frac{14}{2\cdot 6}\right)+0{,}0015+\\+\frac{260000}{260000}\cdot\left(0{,}0021+0{,}0006\cdot\frac{19}{2\cdot 8}\right)\end{array}\right)\mathrm{s}^{-1}\right]\right\}\end{array}} =$$

$$= 38{,}30\ \mathrm{Bq}\cdot\mathrm{kg}^{-1}\ (\mathrm{TM})$$

The specific activity of K-40 $a_{\mathrm{K-40}}$ is thus:

$$a_{\mathrm{K-40}} = (704{,}8\ \pm 38{,}3)\ \mathrm{Bq}\cdot\mathrm{kg}^{-1}\ (\mathrm{TM})$$

5.3 Consideration of uncertainties

The standard uncertainty of the analysis result includes the standard uncertainties of the statistical counting, of the calibration, of the emission intensities and of the mass of the sample. The standard uncertainties of the duration of measurement, of the decay constant, of the position of the peak maximum and of the full width at half maximum h are neglected.

6 Characteristic limits of the procedure

The calculation of the characteristic limits follows the standard ISO 11929.

An Excel spreadsheet (see section 7.3.1) as well as a project file for the software UncertRadio (see section 7.3.2) are available on the website of this procedures manual.

Further considerations concerning the characteristic limits are to be found in the general chapters ERK/NACHWEISGR-ISO-01 and ERK/NACHWEISGR-ISO-02 of these procedures manuals.

6.1 Equations

6.1.1 Decision threshold

The decision threshold a_{r}^* for artificial radionuclides and Be-7 is determined according to equation (4), for natural radionuclides according to equation (5):

$$a_{\mathrm{r}}^* = k_{1-\alpha}\cdot\varphi\cdot\sqrt{\frac{R_{\mathrm{T,r}}}{t_{\mathrm{m}}}\cdot\left(1+\frac{b_{\mathrm{r}}}{2\cdot L_{\mathrm{r}}}\right)} \quad (4)$$

$$a_{\mathrm{r}}^{*} = k_{1-\alpha} \cdot \varphi \cdot \sqrt{\frac{1}{t_{\mathrm{m}}} \cdot \left[R_{\mathrm{T,r}} \cdot \left(1 + \frac{b_{\mathrm{r}}}{2 \cdot L_{\mathrm{r}}}\right) + R_{\mathrm{n0,r}} + R_{\mathrm{g0,r}} + R_{\mathrm{T0,r}} \cdot \frac{b_{0,\mathrm{r}}}{2 \cdot L_{0,\mathrm{r}}}\right]} \quad (5)$$

Herein are:

a_{r}^{*} decision threshold of the radionuclide r, in $\mathrm{Bq \cdot kg^{-1}}$;

$k_{1\text{-}\alpha}$ quantile of the normal distribution for $\alpha = 0{,}0014$.

6.1.2 Detection limit

The detection limit $a_{\mathrm{r}}^{\#}$ can be calculated after introducing the auxiliary quantities Ψ and θ according to equation (6):

$$a_{\mathrm{r}}^{\#} = \frac{a_{\mathrm{r}}^{*} \cdot \Psi}{\theta} \cdot \left\{1 + \sqrt{1 - \frac{\theta}{\Psi^2} \cdot \left(1 - \frac{k_{1-\beta}^2}{k_{1-\alpha}^2}\right)}\right\} \quad (6)$$

In equation (6) are:

$a_{\mathrm{r}}^{\#}$ detection limit of the radionuclide r, in $\mathrm{Bq \cdot kg^{-1}}$;

$k_{1\text{-}\beta}$ quantile of the normal distribution for $\beta = 0{,}05$.

with

$$\theta = 1 - k_{1-\beta}^2 \cdot u_{\mathrm{rel}}^2(\varphi)$$

$$\Psi = 1 + \frac{k_{1-\beta}^2}{2 \cdot a_{\mathrm{r}}^{*}} \cdot \varphi \cdot \frac{1}{t_{\mathrm{m}}}$$

6.1.3 Limits of the coverage interval

The calculation of the limits of the coverage interval is not required in this case.

6.2 Worked example

6.2.1 Artificial radionuclides

For the radionuclide Cs-137, the values from section 5.2.1 and the values for

$k_{1-\alpha}$ = 3; $k_{1-\beta}$ = 1,645;

$u_{\mathrm{rel}}^2(\varphi)$ = 0,0029.

the decision threshold $a_{\mathrm{Cs-137}}^{*}$ is calculated according to equation (4)

$$a_{\mathrm{Cs-137}}^{*} = 3 \cdot 475{,}488\ \mathrm{Bq \cdot s \cdot kg^{-1}} \cdot \sqrt{\frac{0{,}01\ \mathrm{s^{-1}}}{86400\ \mathrm{s}} \cdot \left(1 + \frac{2{,}363\ \mathrm{keV}}{2 \cdot 1{,}183\ \mathrm{keV}}\right)} =$$

$$= 0{,}686\ \mathrm{Bq \cdot kg^{-1}}\ \mathrm{(TM)}$$

and the detection limit $a^{\#}_{\mathrm{Cs-137}}$ according to equation (6):

$$a^{\#}_{\mathrm{Cs-137}} = \frac{0{,}686\ \mathrm{Bq \cdot kg^{-1}} \cdot 1{,}011}{0{,}99} \cdot \left\{1 + \sqrt{1 - \frac{0{,}99}{1{,}011^2} \cdot \left(1 - \frac{1{,}645^2}{3^2}\right)}\right\} =$$

$$= 1{,}098\ \mathrm{Bq \cdot kg^{-1}\ (TM)}$$

with:

$$\theta = 1 - 1{,}645^2 \cdot 0{,}0029 = 0{,}99$$

$$\Psi = 1 + \frac{1{,}645^2}{2 \cdot 0{,}686\ \mathrm{Bq \cdot kg^{-1}}} \cdot 475{,}488\ \mathrm{Bq \cdot s \cdot kg^{-1}} \cdot \frac{1}{86400\ \mathrm{s}} = 1{,}011$$

6.2.2 Natural radionuclides

For the radionuclide K-40, the values from section 5.2.2 and the values for

$k_{1-\alpha}$ = 3; $k_{1-\beta}$ = 1,645;

$u^2_{\mathrm{rel}}(\varphi)$ = 0,0029.

the decision threshold $a^{*}_{\mathrm{K-40}}$ is calculated according to equation (5)

$$a^{*}_{\mathrm{K-40}} = 3 \cdot 7788{,}162\ \mathrm{Bq \cdot s \cdot kg^{-1}} \cdot$$

$$\cdot \sqrt{\frac{1}{260000\ \mathrm{s}} \cdot \left[0{,}004 \cdot \left(1 + \frac{14}{2 \cdot 6}\right) + 0{,}0015 + 0{,}0021 + 0{,}0006 \cdot \frac{19}{2 \cdot 8}\right] \mathrm{s^{-1}}} =$$

$$= 5{,}220\ \mathrm{Bq \cdot kg^{-1}\ (TM)}$$

and the detection limit $a^{\#}_{\mathrm{K-40}}$ according to equation (6)

$$a^{\#}_{\mathrm{K-40}} = \frac{5{,}220\ \mathrm{Bq \cdot kg^{-1}} \cdot 1{,}001}{0{,}99} \cdot \left\{1 + \sqrt{1 - \frac{0{,}99}{1{,}008^2} \cdot \left(1 - \frac{1{,}645^2}{3^2}\right)}\right\} =$$

$$= 8{,}315\ \mathrm{Bq \cdot kg^{-1}\ (TM)}$$

with

$$\theta = 1 - 1{,}645^2 \cdot 0{,}0029 = 0{,}99$$

$$\Psi = 1 + \frac{1{,}645^2}{2 \cdot 5{,}550\ \mathrm{Bq \cdot kg^{-1}}} \cdot 7788{,}162\ \mathrm{Bq \cdot s \cdot kg^{-1}} \cdot \frac{1}{260000\ \mathrm{s}} = 1{,}008$$

7 Catalogue of chemicals and equipment

7.1 Chemicals

No chemicals are required for this procedure.

7.2 Equipment

— plastic boxes made of polyethylene (PE);
— freezer;
— freeze dryer;
— usual equipment of a radiochemical laboratory;
— ball mill;
— plastic measuring containers with volume graduation made of polypropylene (PP);
— gamma spectrometry measuring device.

7.3 Software supported calculation

7.3.1 Example of an Excel spreadsheet

7.3.1.1 For artificial radionuclides using the example of Cs-137

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SAMPLE IDENTIFICATION: Marine sediment and suspended particulate mattern (artificial radionuclides **and** Be-7)

#Number of parameters p	10
k_alpha	3
k_beta	1,645
gamma	0,05

Create Excel variables!

User-Input:	Input of values
	Definition Excel variables
	Input of Excel formulae
Excel-VBA:	#Keywords
	Values from Vbasic

Data input: variable names: Uncertainty budget:

	#Values of parameters p	Unit	Excel variable	Input values	StdDev	partial derivatives	uncertainty budget:	budget in %
p 1	#Number of gross counts Ng		Ng	5184,00	72,0000	0,00550351	0,39625252	8,605077553
p 2	background count rate radionuclide	1/s	RTr	1,0000E-02	3,4021E-04	-475,50302	0,16176941	1,434179592
p 3	decay constant of the radionuclide	1/s	lam_r	7,3000E-10	0,0000E+00	376688289	0	0
p 4	absolute emission intensity		pgamma	8,5100E-01	1,7020E-03	-27,9378698	0,04755025	0,123912869
p 5	detection efficiency	1/(Bq*s)	etar	2,5000E-02	1,2500E-03	-951,005089	1,18875636	77,44554309
p 6	dry mass of the sample	kg	mTM	1,0000E-01	2,0000E-03	-237,751272	0,47550254	12,39128689
p 7	time period sampl. --> beginn meas.	s	tA	1,5800E+07	0,0000E+00	1,7356E-08	0	0
p 8	duration of measurement	s	tm	8,6400E+04	0,0000E+00	-0,0003302	0	0
p 9	base width gamma line radionuclide		br	2,3630E+00	0,0000E+00	0	0	0
p 10	number of channels radionuclide		Lr	1,1830E+00	0,0000E+00	0	0	0
	(List can be continued here)							

	Model section		**c = phix * Rn**			
	Auxiliary equations h			(Formulae)		
h 1	#Gross count rate Rg	1/s	Rg	0,06		
h 2	decay correction factor measurement		_f3	9,9997E-01		
h 3	decay correction factor sampling		_f4	1,0116E+00		
	(List can be continued here)					
	#Net count rate Rn	1/s	Rn	5,0000E-02		
	#Calibration factor, proc.dep.	Bq*s/kg	phix	4,7550E+02		
	#Value output quantity	Bq/kg	Result	2,3775E+01	1,09544293	<-- output value modifiable by VBA
	#Combined standard uncertainty	Bq/kg	uResult	1,3508E+00		
	#Decision threshold	Bq/kg		0,686329492		
	#Detection limit	Bq/kg		1,09544282		

Calculate!

further derived values			
Auxiliary quantity Omega		Omega	1
Best estimate	Bq/kg	BestEst	2,3775E+01
Uncertainty best estimate	Bq/kg		1,3508E+00
Lower confidence limit	Bq/kg		2,1128E+01
Upper confidence limit	Bq/kg		2,6423E+01

The corresponding Excel spreadsheet is available on the website of this procedures manual.

7.3.1.2 For natural radionuclides using the example of K-40

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SAMPLE IDENTIFICATION: Marine sediment and suspended particulate mattern (natural radionuclides)

#Number of parameters p	15
k_alpha	3
k_beta	1,645
gamma	0,05

Create Excel variables!

User-Input:	Input of values
	Definition Excel variables
	Input of Excel formulae
Excel-VBA:	#Keywords
	Values from Vbasic

Data input: variable names: Uncertainty budget:

	#Values of parameters p	Unit	Excel variable	Input values	StdDev	partial derivatives	uncertainty budget:	budget in %
p 1	#Number of gross counts Ng		Ng	2,4960E+04	1,5799E+02	0,02995461	4,73244987	1,527044435
p 2	background count rate radionuclide	1/s	RTr	4,0000E-03	1,2403E-04	-7788,1997	0,96600728	0,063626851
p 3	decay constant of the radionuclide	1/s	lam_r	1,7200E-17	0	4,0979E+19	0	0
p 4	absolute emission intensity		pgamma	0,1070	2,1400E-04	-6587,20906	1,40966274	0,135490882
p 5	detection efficiency	1/(Bq*s)	etar	0,0120	6,0000E-04	-58735,9474	35,2415685	84,68180147
p 6	dry mass of the sample	kg	mTM	0,10	2,0000E-03	-7048,31369	14,0966274	13,54908824
p 7	time period sampl. --> start measurem	s	tA	1,5800E+07	0	1,4391E-14	0	0
p 8	duration of measurement	s	tm	2,6000E+05	0	-0,00016475	0	0
p 9	base width gamma line radionuclide		br	14	0	0	0	0
p 10	number of channels radionuclide		Lr	6	0	0	0	0
p 11	duration background measurement	s	t0	2,6000E+05	0	0	0	0
p 12	gross count rate background line	1/s	Rg0r	2,1000E-03	8,9872E-05	-7788,1997	0,69993877	0,033404097
p 13	background count rate background line	1/s	RT0r	6,0000E-04	4,8038E-05	7788,19981	0,37413302	0,009544028
p 14	base width gamma line background		b0r	19	0	0	0	0
p 15	number of channels background gamma line		L0r	8	0	0	0	0

(List can be continued here)

	Model section		**c = phix * Rn**	
	Auxiliary equations h			(Formulae)
h 1	#Gross count rate Rg	1/s	Rg	0,096
h 2	decay correction factor measurement		_f3	9,99995E-01
h 3	decay correction factor sampling		_f4	1,0000

(List can be continued here)

Calculate!

#Net count rate Rn	1/s	Rn	0,0905	
#Calibration factor, proc.dep.	Bq*s/kg	phix	7,7882E+03	
#Value output quantity	Bq/kg	Result	7,0483E+02	8,03794338 <-- output value modifiable by VBA
#Combined standard uncertainty	Bq/kg	uResult	3,8297E+01	

#Decision threshold	Bq/kg	5,061177581
#Detection limit	Bq/kg	8,037929976

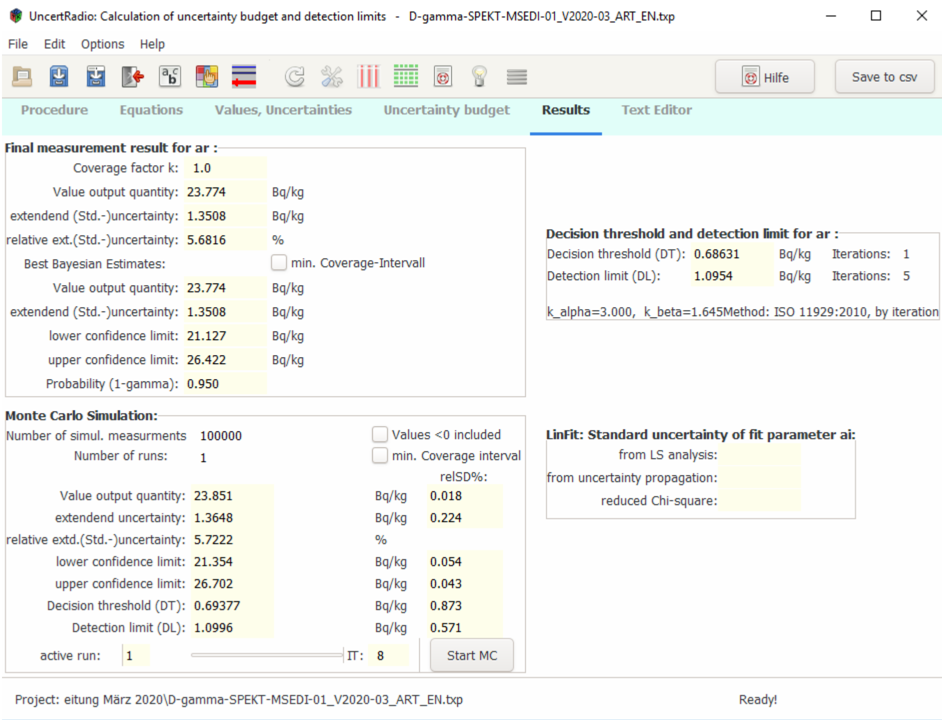
further derived values

Auxiliary quantity Omega		Omega	1
Best estimate	Bq/kg	BestEst	7,048321E+02
Uncertainty best estimate	Bq/kg		3,829660E+01
Lower confidence limit	Bq/kg		6,297721E+02
Upper confidence limit	Bq/kg		7,798920E+02

The corresponding Excel spreadsheet is available on the website of this procedures manual.

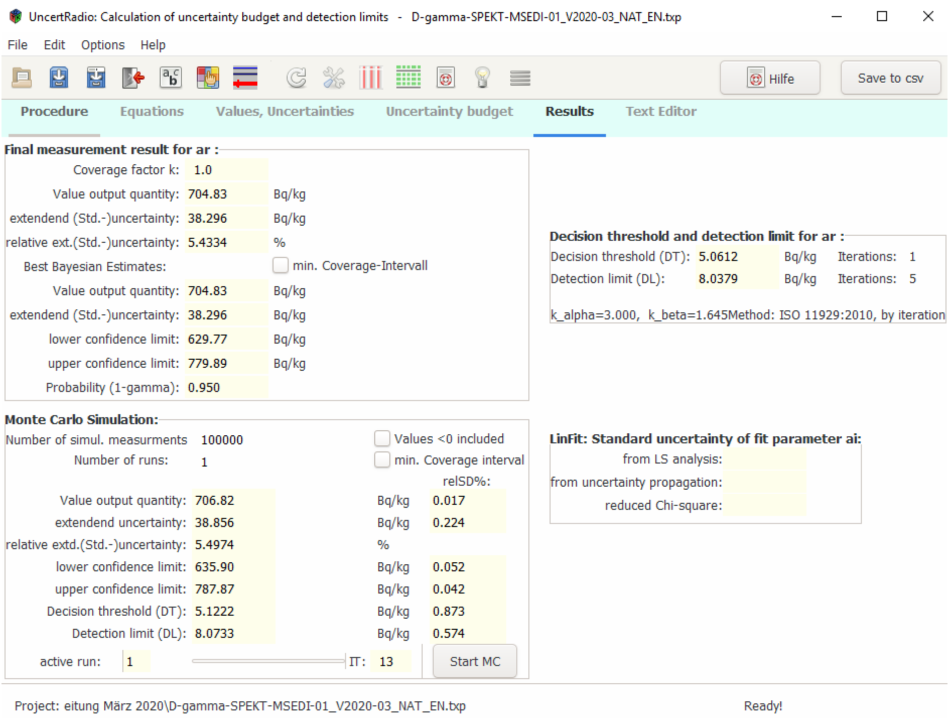
7.3.2 Example of an UncertRadio project

7.3.2.1 For artificial radionuclides using the example of Cs-137



The corresponding UncertRadio project file is available on the website of this procedures manual.

7.3.2.2 For natural radionuclides using the example of K-40



The corresponding UncertRadio project file is available on the website of this procedures manual.