Procedure for the continuously monitoring of artificial total gamma activity concentration in seawater

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Authors:
H.-J. Gabriel
I. Goroncy
J. Herrmann
H. Nies
Ch. Wedekind

Federal coordinating office for sea water, suspended particulate matter and sediment
(Leitstelle für Meerwasser, Meerschwebstoff und -sediment)
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1 Scope

The procedure is applied in a measuring network for the continuous monitoring of seawater for its concentrations of artificial gamma emitters. This measuring network forms part of the German nationwide network in the framework of the "Integrated measuring and information system for the monitoring of radioactivity in the environment" (IMIS) and conforms to the requirements of the Precautionary Radiation Protection Act.

Using measurement periods of one hour, the procedure periodically records the total gamma radiation in seawater. The contribution by radiation originating from artificial radioactive emitters is then calculated from the proportional contribution of count rates within predetermined energy ranges of the gamma radiation spectrum. Artificial radionuclides with an activity concentration of as little as 0.5 Bq·l⁻¹ can thus be detected. The procedure furthermore facilitates the measurement and analysis of gamma spectra over extended periods of time. Stationary monitoring units are mounted on oceanographic measuring buoys on the open sea while those on the coast are mounted to permanent structures (e.g., moles, piers), suspended freely into the seawater. Moreover, some vessels of the Bundesamt für Seeschifffahrt und Hydrographie (BSH) serve as mobile measuring stations and are equipped with corresponding measuring equipment that uses a radiation detector mounted in a recess in the bottom of the vessel (trunk).

2 Sampling

No sampling is required for this measuring technique.

3 Analysis

3.1 Principle of the method

The procedure continually meters the total gamma radiation in seawater in a direct manner. Radiochemical processing of samples is not required.

4 Measuring the activity

4.1 Measuring probe

The measuring probe shown as a schematic diagram in Figure 1 was developed by the Bundesamt für Seeschifffahrt und Hydrographie (BSH) specifically to meet the particular requirements of oceanic applications in the framework of IMIS. It is employed at the measuring stations of the national BSH measuring network. At fixed stations, the probes are mounted at a water depth of about 3 m. A probe consists of a waterproof detector with a 3” x 3” NaI(Tl)-detector whose integrated electronic measuring equipment is wired to a control unit above the surface. The electronic measuring equipment is stabilized against temperature and long-term drifts. Coastal stations that are affected by varying water levels use sensors that are ad-
ditionally fitted with a pressure sensor. These record the variable water cover in order to provide data on changes in the shielding from cosmic radiation that will be required for subsequent calculations.

The datasets are usually transmitted at hourly intervals to the central data processing centre of the BSH via telephone lines (coastal stations) or satellite (offshore stations). They are graphically plotted (Figure 2) on the measuring network PC at the BSH once per working day in IMIS normal operations, and every two hours in IMIS intensive operations. After the results have been interactively analysed and checked for plausibility, they are forwarded to IMIS (1, 2).

4.2 Principle of the measuring system

This is an "in situ-measurement" technique that detects the gamma radiation of artificial radioactive substances in the sea. If increased activity concentrations are noted, the simultaneous analysis of gamma radiation spectra enables them to be associated with accident scenarios.

The monitoring of activity concentrations of artificial radioactive substances is generally impeded by the fact that the natural background radiation does not remain constant. In particular, heavy precipitation will often cause high concentrations of natural radionuclides in seawater. These mainly comprise daughter nuclides of Rn-222 from the U-238 decay chain. The artificial emitters differ from natural ones in the ranges of their relevant gamma radiation energies. The gamma radiation spectrum of natural radionuclides extends over a wide energy range, exceeding 2 MeV. In contrast, the major gamma radiation energies of artificial radionuclides are found at levels below 900 keV, as has been demonstrated through the analysis of various accident scenarios (2).

Fig. 1: Gamma detector with above-surface control unit
The monitoring technique exploits this difference by recording the count rates in two channels, one of which will register the gamma radiation with energies $>900$ keV whereas the energies $<900$ keV are registered in the other channel (Fig. 3). If natural radionuclides from the uranium decay chain are present, the count rates in the two channels will increase in a proportion that is characteristic of the spectrum of the Rn-222 decay products. In contrast, the activity of artificial radioactive substances will be registered almost exclusively in the lower energy channel. The activity concentration of artificial radioactive substances can then be calculated from the total count rate and the quotient of contributions by the two channels.

Monitoring data therefore comprise the total count number, $N_g$, measured hourly for one hour each, as well as the quotient $q_g$ that is calculated from the contributions of the two channels A and B and are transmitted at hourly intervals to the BSH for analysis.

Figure 3 illustrates this type of activity measurement schematically. The symbols used therein translate as follows:

$R_A$ continuously measured count rate in channel A in the energy band $<900$ keV;  
$R_B$ continuously measured count rate in channel B in the energy band $>900$ keV;
The count rates of the two channels contain contributions by:

- $R_{A0}$ background count rate in channel A, originating from cosmic and environmental radiation;
- $R_{B0}$ background count rate in channel B, originating from cosmic and environmental radiation;
- $R_{AN}$ count rate in channel A, originating from natural radioactive substances;
- $R_{BN}$ count rate in channel B, originating from natural radioactive substances;
- $R_{AK}$ count rate in channel A, originating from artificial radioactive substances;

The gross count rate, $R_g$, is calculated from the total count number, $N_g$, per measurement period, $t$, according to equation (1):

$$R_g = R_A + R_B = \frac{N_g}{t} \quad (1)$$

In routine measurement operations, $R_g$ will equal the background count rate, $R_0$, in both channels (equation (2)):

$$R_g = R_{A0} + R_{B0} \quad (2)$$

**Fig. 3:** Schematic illustration of count rates in a two-channel measurement

If natural radioactive substances from the uranium decay chain end up in seawater, the count rate $R_g$ will increase by the amounts of $R_{AN}$ and $R_{BN}$. If there are also contributions by artificial radioactive substances, the count rate $R_g$ will be increased further by the amount of $R_{AK}$ (equation (3)):

$$R_g = (R_{A0} + R_{AN} + R_{AK}) + (R_{B0} + R_{BN}) \quad (3)$$
To calculate the activity concentration of artificial radioactive substances, equations (4) through (6) need to be included:

**Ratio \( q_0 \)** for normal background radiation (equation (4)):

\[
q_0 = \frac{R_{A0}}{R_{B0}}
\]  

(4)

**Ratio \( q_g \)** in continuous measurement with possible contributions to the gamma radiation as a result of natural and artificial radioactive substances (equation (5)):

\[
q_g = \frac{R_A}{R_B} = \frac{R_{A0} + R_{AN} + R_{AK}}{R_{B0} + R_{BN}}
\]  

(5)

**Ratio \( q_N \)** the contribution of gamma radiation that is exclusively referable to natural radioactive substances (equation (6)):

\[
q_N = \frac{R_{AN}}{R_{BN}}
\]  

(6)

Using equations (1) through (6), equation (7) can be derived, which specifies the count rate, \( R_{AK} \), originating from artificial radioactivity:

\[
R_{AK} = R_g \cdot \left(1 - \frac{1 + q_n}{1 + q_g}\right) - R_0 \cdot \left(1 - \frac{1 + q_n}{1 + q_0}\right)
\]  

(7)

In addition to measured values of \( N_g \) and \( q_g \), the analysis of the current dataset requires that the parameters \( R_0 \) and \( q_0 \) be known from normal operations. Their values are determined as means from the period of the previous week. The ratio \( q_N \) is determined once with the aid of equation (7) from data taken after a substantial contribution by natural radioactive substances, for example, following rain during a thunderstorm.

Fluctuations in the thickness of the water layer covering the detector will cause fluctuations in the shielding of the detector from above-surface radiation and thus influence the background count rate, \( R_0 \). In order to be able to eliminate such changes in the background effect by mathematical means, the current water level, \( z_w \), is continuously recorded with the aid of a pressure sensor at coastal stations affected thus and compared to the mean water level, \( z_{WN} \). Applying an empirically determined linear attenuation coefficient, \( \mu \), the value of \( R_0 \) is corrected according to equation (8):

\[
R'_0 = R_0 \cdot e^{-\mu(z_{WN}-z_w)}
\]  

(8)

To calculate \( R_{AK} \) under the impact of fluctuating water levels therefore requires equation (9):

\[
R_{AK} = R_g \cdot \left(1 - \frac{1 + q_n}{1 + q_g}\right) - R_0 \cdot e^{-\mu(z_{WN}-z_w)} \cdot \left(1 - \frac{1 + q_n}{1 + q_0}\right)
\]  

(9)

Figure 2 provides an example of a measuring sequence.
4.3 Calibration of the measuring probe

The total gamma measurement will not normally provide information on the type of the radionuclides present and their activity. To identify these would require them to be calibrated for every radionuclide individually (Table 1). If the composition of radionuclides is unknown, no nuclide-specific calibration value can be specified, however (1). In order to obtain such a calibration factor for the total gamma activity concentration in practice, the quantity “artificial total gamma”, in Bq·l⁻¹, was introduced in analogy to the calibration for the total beta measurement. It is an auxiliary quantity that refers to a fictitious radionuclide that emits one gamma quantum per radioactive decay event. The attribute “artificial” is derived from the analytic procedure described in section 4.2.

Restricting the energy-dependent calibration of this type of probe to just one run is justified by the major effort required. It has been described by Wedekind (3). The validity of the calibration to the individual probe requires that they are of the same configuration and needs to be verified regularly on the basis of their characteristics.

The calibration of the measurement setup “detector suspended in water” partly requires large sample volumes. Calibration runs (Figures 4 and 6) with Ce-144 (E_\gamma = 0.13 MeV), Ru-106 (E_\gamma = 0.56 MeV) and Mn-54 (E_\gamma = 0.84 MeV) used measuring vessels with a volume of 1 m³. The range of K-40 radiation (E_\gamma = 1.46 MeV) in water necessitates a pool with a volume of approx. 30 m³.

4.3.1 Energy-dependence of the total gamma measurement

The gamma energy-dependent, total gamma detection efficiency, \( \varepsilon_{\gamma}(E_\gamma) \), depends on the procedure used and is defined following equation (10):

\[
\varepsilon_{\gamma}(E_\gamma) = \frac{R_{nt}(E_\gamma)}{c \cdot p_\gamma}
\]  

(10)

It has been derived from the activity concentration, c, of individual radionuclides with only one gamma line each with an associated gamma emission probability, \( p_\gamma \), and applies to the total gamma measurement, that is, the net count rate, \( R_{nt}(E_\gamma) \), integrated over the entire gamma energy range (0.01 MeV to 2 MeV).

Figure 4 illustrates this simple total gamma detection efficiency. The energy range 0.3 MeV to 1.5 MeV hosts a “plateau” of ca. 3 s⁻¹ per Bq·l⁻¹. This means that calibration with K-40 (E_\gamma = 1.46 MeV) is sufficient and adequately representative of the quantity “artificial total gamma Bq·l⁻¹”.

Fig. 4: Total gamma detection efficiency, \( \varepsilon_{\gamma}(E_\gamma) \), according to (3)
The procedure-related total gamma detection efficiency, $\varepsilon_t(E)$, for a specific radionuclide would be of interest in a contamination scenario that mainly is due to this radionuclide. This can be assessed with the aid of the graph in Figure 4 following equation (11). It adds the individual contributions, $\varepsilon_i$, of all gamma lines, $i$, of the radionuclide in question and takes into account the associated emission probabilities, $p_i$, as follows:

$$
\varepsilon_t = \sum_{i=1}^{n} \left( \varepsilon_i \cdot p_i \right)
$$

(11)

Table 1 provides an overview of the procedure-related total gamma detection efficiency, $\varepsilon_{tN}(E)$, for a selection of relevant radionuclides.

**Tab. 1:** Detection efficiencies for selected radionuclides, $\varepsilon_{tN}$ – total gamma measurement, and $\varepsilon_{Sp}$ – gamma spectrometry; Measurement setup: detector freely suspended in water

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>$t_r$ in a</th>
<th>$E_\gamma$ in MeV</th>
<th>$p_\gamma$</th>
<th>$\varepsilon_{tN}$ in l·Bq$^{-1}$·s$^{-1}$</th>
<th>$\varepsilon_{Sp}$ in l·Bq$^{-1}$·s$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-40</td>
<td>1,28·10$^9$</td>
<td>1,46</td>
<td>0,11</td>
<td>0,33</td>
<td>0,011</td>
</tr>
<tr>
<td>Mn-54</td>
<td>0,855</td>
<td>0,84</td>
<td>1,0</td>
<td>3,3</td>
<td>0,13</td>
</tr>
<tr>
<td>Co-60</td>
<td>5,27</td>
<td>1,33</td>
<td>1,0</td>
<td>6,3</td>
<td>0,10</td>
</tr>
<tr>
<td>Zn-65</td>
<td>0,669</td>
<td>1,11</td>
<td>0,5</td>
<td>1,5</td>
<td>0,055</td>
</tr>
<tr>
<td>Ru-106</td>
<td>1,02</td>
<td>0,51</td>
<td>0,21</td>
<td>1,5</td>
<td>0,038</td>
</tr>
<tr>
<td>I-131</td>
<td>0,022</td>
<td>0,36</td>
<td>0,82</td>
<td>2,8</td>
<td>0,19</td>
</tr>
<tr>
<td>Cs-134</td>
<td>2,07</td>
<td>0,60</td>
<td>0,98</td>
<td>7,1</td>
<td>0,16</td>
</tr>
<tr>
<td>Cs-137</td>
<td>30,2</td>
<td>0,66</td>
<td>0,85</td>
<td>2,7</td>
<td>0,13</td>
</tr>
<tr>
<td>Ce-144</td>
<td>0,780</td>
<td>0,13</td>
<td>0,11</td>
<td>0,2</td>
<td>0,033</td>
</tr>
</tbody>
</table>

4.3.2 Calibration procedure for measuring “artificial total gamma”

4.3.2.1 Measurement setup: Detector freely suspended in water

The calibration of this setup is based upon the following parameters:

- Monitoring is effected in seawater using a 3” x 3” NaI(Tl)-detector incorporated into a network measurement probe of the type described in section 4.1.
- Calibration is based upon the quantity “artificial total gamma, Bq·l$^{-1}$” as defined by IMIS.
- The calibration for measuring the total gamma activity concentration employs K-40 as a reference nuclide ($E_\gamma = 1,461$ MeV, $p_\gamma = 0,11$).
- The pool used for the calibration measures 3 m x 3 m x 2,7 m (studies on the range of K-40 gamma radiation in water have demonstrated that the probe needs to be positioned at least 1 m from the walls of the chamber).
- The detector is positioned in the centre of the pool.

Natural K-40 is present in potassium chloride salt with a specific activity of 16 207 Bq·kg$^{-1}$ (cf. chapter IV.6.4 of this procedures manual). For the purpose of
calibration, a solution is produced from 7.0 g·l⁻¹ of potassium chloride that possesses an activity concentration, \( c_{K-40} \), of 113.4 Bq·l⁻¹.

Using the background count rate, \( R_0 \), of 25 s⁻¹, the gross count rate of the calibration solution, \( R_b \), of 59 s⁻¹, and the emission probability, \( p_\gamma \), of 11 %, the simple total gamma detection efficiency, \( \varepsilon_t \), for a 3” x 3” NaI(Tl)-detector for the measurand “artificial total gamma, Bq·l⁻¹” is calculated according to equation (10) as follows:

\[
\varepsilon_t = \frac{59 - 25}{113.4 \cdot 0.11} \text{ l·Bq}^{-1} \cdot \text{s}^{-1} = 2.73 \text{ l·Bq}^{-1} \cdot \text{s}^{-1}
\]

The total gamma detection efficiency, \( \varepsilon_{\text{TN}} \), for the radionuclide K-40 is then given by equation (11):

\[
\varepsilon_{\text{TN}} = 2.73 \cdot 0.1 \text{ l·Bq}^{-1} \cdot \text{s}^{-1} = 0.30 \text{ l·Bq}^{-1} \cdot \text{s}^{-1}
\]

### 4.3.2.2 Measurement setup: Probe mounted in bottom of vessel

A trunk of 400 mm in diameter and 120 mm deep is built into the bottom of a vessel. It is open to the seawater, and the 3” x 3” NaI(Tl)-detector extends into it, protected by a titanium cap. Considering the impossibility to duplicate this setup in a laboratory, the calibration was performed with a probe installed on the research vessel “FS Gauss” at sea and by comparing results at various degrees of salinity of the water.

The activity concentration in the sea is determined by the potassium content of seawater (4). The potassium content in seawater in the open North Sea corresponds to an activity concentration, \( c_{K-40} \), of 12 Bq·l⁻¹. For the background effect in the River Elbe, the potassium content in its freshwater is negligible.

- The count rate, \( R_y \), measured in the North Sea at a salinity of 35 PSU (0.74 g·l⁻¹) amounted to 10 s⁻¹.
- The background effect count rate, \( R_0 \), measured in the freshwater of the River Elbe was 8.5 s⁻¹.

The total gamma detection efficiency, \( \varepsilon_{\text{TK}} \), for a trunk-housed 3” x 3” NaI(Tl)-detector and the measurand “artificial total gamma, Bq·l⁻¹” is calculated using equation (10):

\[
\varepsilon_{\text{TK}} = \frac{10 - 8.5}{11 \cdot 0.12} \text{ l·Bq}^{-1} \cdot \text{s}^{-1} = 1.14 \text{ l·Bq}^{-1} \cdot \text{s}^{-1}
\]

### 4.3.3 Calibration procedure for a gamma spectrometric measurement

#### Measurement setup: Probe suspended in water

Aside from measuring the artificial total gamma activity concentration, the monitoring network probes also record gamma radiation spectra. Even though the low energy resolution capabilities of NaI(Tl)-detectors limit the nuclide-specific analyses, radionuclide compositions that are characteristic of accidents can well be recognized and distinguished from natural radioactive substances (2).

For example, Figure 5 shows not only the gamma radiation spectra of natural radionuclides of the U-238 decay chain and the contribution of K-40 contained in the water of the Baltic Sea, but also the 662 keV-line of Cs-137 that originates from Chernobyl fallout.
Fig. 5: Weekly spectrum of week 41 of 1997 metered at Station “Kühlungsborn”

In order to derive nuclide-specific information from clearly identifiable gamma lines like that, the gamma spectrometric detection efficiencies of the probe deserves some attention.

The detection efficiency, $\varepsilon_{Sp}(E_\gamma)$, for a specific radionuclide with an activity concentration, $c$, with the pulse count, $N_{Sp}$, in its line during a measurement period, $t$, is calculated following equation (12) as follows:

$$
\varepsilon_{Sp}(E_\gamma) = \frac{N_{Sp}}{c \cdot p_i \cdot t}
$$

Figure 6 illustrates the energy-dependent detection efficiency, $\varepsilon_{Sp}(E_\gamma)$, for gamma spectrometry. It has been determined on the basis of the setup described in section 4.3 and on the radionuclides mentioned there, taking into account the associated gamma emission probability, $p_i$.

Table 1 summarizes the spectrometric detection efficiency, $\varepsilon_{Sp}$, of a selection of relevant radionuclides.

Fig. 6: Energy-dependent detection efficiency, $\varepsilon_{Sp}(E_\gamma)$, for gamma spectrometry according to (3).
5 Calculation of the results

The artificial total gamma activity concentration in seawater, \( c_{AK} \), is calculated from the count rate of the contribution by artificial radiation, \( R_{AK} \), given in equations (7) and (9) in section 4.2, by rearranging equation (10) to equation (13):

\[
c_{AK} = \frac{R_{AK}}{\varepsilon_t}
\]  

(13)

The radioactive decay does not need to be taken into account in this procedure.

If in a specific case only one radionuclide is to be monitored, the activity concentration, \( c_N \), of this nuclide may be determined by equation (13) but by replacing \( \varepsilon_t \) with the associated procedure-related summated total gamma detection efficiency \( \varepsilon_{tn} \) (Table 1).

The standard deviation, \( s_{AK} \), of the artificial count rate contribution, \( R_{AK} \), is derived from the approach by equation (7) and can be computed by equation (14):

\[
s(R_{AK}) = t_m^{-1} \sqrt{N_g \cdot \left( 1 + \frac{(1 + q_n)^2}{1 + q_g} \right)}
\]  

(14)

In accordance with equation (13), the uncertainty, \( s(c_{AK}) \), of the artificial activity concentration, \( c_{AK} \), is obtained from equation (15):

\[
s(c_{AK}) = \frac{s(R_{AK})}{\varepsilon_t}
\]  

(15)

Chapter IV.1 of this procedures manual is referred to in conjunction with the analysis of recorded gamma radiation spectra. The activity concentrations of individual radionuclides from the pulse counts, \( N_{Sp} \), in the line within the spectrum are computed according to equations (12) and (13) in analogy to the computation of the total gamma activity concentration.

5.1 Worked example

The calibration of the measurement setup and the measurement itself have produced the following values:

\( \varepsilon_t = 2.73 \text{ l·Bq}^{-1} \cdot \text{s}^{-1} \);

\( t_m = 3600 \text{ s} \);

\( N_g = 60338 \);

\( R_0 = 8.89 \text{ s}^{-1} \);

\( q_g = 6.55 \);

\( q_0 = 3.39 \);

\( q_n = 14 \).

The count rate, \( R_{AK} \), due to artificial radioactive substances is quantified following equation (7):

\[
R_{AK} = \frac{60338}{3600} \cdot \left( 1 - \frac{1 + 14}{1 + 6.55} \right) \text{s}^{-1} - 8.89 \cdot \left( 1 - \frac{1 + 14}{1 + 3.39} \right) \text{s}^{-1} = 4.95 \text{ s}^{-1}
\]
Using this result, equation (13) will determine the artificial total gamma activity concentration, $c_{AK}$, in seawater:

$$c_{AK} = \frac{4.95}{2.73} \text{Bq} \cdot \text{l}^{-1} = 1.81 \text{Bq} \cdot \text{l}^{-1}$$

while the uncertainty, $s(c_{AK})$, of the artificial total gamma activity concentration, $c_{AK}$, is computed according to equations (14) and (15):

$$s(c_{AK}) = \frac{1}{2.73 \cdot 3600} \cdot \sqrt{60338 \cdot \left(1 + \frac{(1+14)^2}{1+6.55}\right)} \text{Bq} \cdot \text{l}^{-1} = 0.139 \text{Bq} \cdot \text{l}^{-1}$$

The artificial total gamma activity concentration, $c_{AK}$, in seawater therefore amounts to:

$$c_{AK} = (1.81 \pm 0.14) \text{Bq} \cdot \text{l}^{-1}$$

### 5.2 Consideration of uncertainties

The evaluation of the standard deviation, $s(c_{AK})$, needs to take into account the errors associated with the parameters $q_g$, $q_N$ and $q_0$ used in equation (14). This can be illustrated on the basis of the calculation example.

The value of $q_g = 6.55$ in the worked example was derived from the quotient between the two channel contributions $A = 52349$ to $B = 7987$ ($A + B = N_g = 60338$ pulses). The approach of equation (14) does not contain a difference for $q_g$ which is why the relative standard deviation of $q_g$ of 1.56% derived from the channel contributions $A$ and $B$ hardly contributes to the standard deviation $s(c_{AK})$.

The quotient $q_0$ originates from the average of 24 measurement periods of one hour each during the seven 24-hour periods metered during the course of one week, i.e., from 168 individual measurements. The contribution by $q_0$ to the overall uncertainty is therefore significantly smaller than that by $q_g$. For its part, the quotient $q_N$ is based on a singular measurement with a high count rate contribution by natural radioactivity that has caused the measured gross pulse count, $N_g$, to take on a very high value. Compared to the contribution by the error in $q_g$, the respective contribution by $q_N$ is therefore also rather insignificant. Both $q_0$ and $q_N$ are considered as constants in the calculation and do therefore not contribute to the total uncertainty.

### 6 Characteristic limits of the procedure

The detection limit, $g_{AK}$, for the activity concentration in a single one-hour measurement is derived from equation 14 and calculated according to equation 16 (see chapter IV.5 of this procedures manual):

$$g_{AK} = \frac{k_{1-\alpha} + k_{1-\beta}}{\varepsilon_t} \cdot \sqrt{\frac{R_0}{t_m} \left(1 + \frac{(1+q_0)^2}{1+q_n}\right)}$$

Using the worked example in section 5.1 as well as the quantiles $k_{1-\alpha} = 3$ and $k_{1-\beta} = 1.645$, equation (16) will yield a detection limit of the procedure for the activity concentration of:
This detection limit for activity concentrations only applies if the background count rate, \( R_0 \), remains sufficiently constant. As equation (7) indicates, fluctuations in the count rates of \( R_0 \) will have a direct impact on \( R_{AK} \). As has emerged from day-to-day practice, \( R_0 \) must be expected to fluctuate. Analogous to equation (13), a detection efficiency of \( \varepsilon = 2,73 \text{ l}\cdot\text{Bq}^{-1}\cdot\text{s}^{-1} \) results in a realistic detection limit of \( g_{AK} = 0,74 \text{ Bq}\cdot\text{l}^{-1} \) in practical measuring network operations.

7 Catalogue of chemicals and equipment

7.1 Chemicals

— Standard solutions (activity standards) from the Physikalisch-Technische Bundesanstalt, Brunswick;
— Potassium chloride, technical quality.

7.2 Equipment

Described here is an underwater probe manufactured by the BSH for practical network measurements that employs a 3” x 3” NaI(Tl)-scintillation counter and a micro-computer control unit (1). For laboratory purposes, the procedure can be duplicated with commercially available electronic measuring equipment.

References


