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Technical Note

Factor of merit and minimum detectable activity for ^{90}Sr determinations by gas-flow proportional counting or Cherenkov counting

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Abstract

The determination of ^{90}Sr in environmental samples can be done by using a gas-flow proportional counter (β-counting) or a liquid-scintillation spectrometer (Cherenkov counting). In this work, we present the factor of merit (FOM) and the minimum detectable activity (MDA) for both the counters. Quantitative relationships are proposed for FOM and MDA determination. © 2001 Elsevier Science Ltd. All rights reserved.

^{90}Sr measurements are performed in our laboratory routinely by means of two methods: first, β-counting using a gas-proportional counter Berthold LB770 (Manjón et al., 1997); second, Cherenkov counting using a liquid scintillation spectrometer Wallac Quantulus 1220 (Vaca et al., 1999).

Ten samples can be simultaneously measured in the Berthold LB770 counter. A 4π passive shield with 20 cm thick lead brick and an active gas-proportional guard counter make sure a low β-background rate, which ranges, in the measurement conditions, from 0.3 to 0.6 cpm, depending on the detector location along the gas-flow pathway.

The preparation of sources for β-counting is described by Manjón et al. (1997). ^{90}Sr is precipitated as $SrCO_3$ and recovered by filtration. The precipitate is dried and transferred into a stainless-steel planchet. Previously, some mg of strontium carrier is added into the sample solution for yield determination. The maximum strontium amount recovered at the end of the separation process must be equal to the amount initially added into the sample, which determines the maximum mass thickness of the final source (18.9 mg cm^{-2} for our routine experiments).

The Quantulus 1220 liquid-scintillation spectrometer has an active liquid-scintillation guard counter and a 4π old lead-passive shielding that protect the spectrometer against the external and cosmic radiation. The type of vial directly influences the Cherenkov background rate. Usually, plastic vials are used in our laboratory in order to minimise the Cherenkov background. ^{90}Y standard sources were made to determine the Cherenkov counting efficiency using a ^{90}Sr–^{90}Y standard solution. Ytrium was isolated by solvent extraction with HDEHP (Vaca et al., 1998). Important quantities needed for an estimate of FOM and MDA are the counting efficiency (ε) and the background count rate (B).

The efficiency of β-counting depends on the mass thickness e (mg cm^{-2}) of the sample. Within the range of the mass thickness studied (5–18 mg cm^{-2}), ε_{Sr} changes noticeably while ε_{Y} decreases only slightly. This is expected due to the difference between the E_{max} of the respective β-spectra. Plots of the efficiencies, ε_{Sr} and ε_{Y}, against $1/e^2$ can be fitted to

$$\varepsilon_{Sr} = a_{Sr} + \frac{b_{Sr}}{e^2} \tag{1}$$

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and

$$\varepsilon_Y = a_Y + \frac{b_Y}{e^2}. \quad (2)$$

If ^{90}Sr and ^{90}Y are in secular equilibrium in the sample, the fitting can be directly applied to the total counting efficiency

$$\varepsilon_{Sr+Y} = a_{Sr+Y} + \frac{b_{Sr+Y}}{e^2}, \quad (3)$$

where

$$\varepsilon_{Sr+Y} = \varepsilon_{Sr} + \varepsilon_Y. \quad (4)$$

The parameters, a_i and b_i, for ^{90}Sr, ^{90}Y and $^{90}Sr + ^{90}Y$, are given in Table 1.

The counting efficiency for the Cherenkov method is a function of the colour quenching in the sample (Vaca et al., 1998). Colour in a sample modifies the efficiency a factor f, the colour factor. Thus,

$$\varepsilon^{Ch} = \varepsilon_0 f. \quad (5)$$

For coloured samples, $f < 1$. It seems also that the background count rate (B) is affected by the colour-quenching effect. Unfortunately, there are large uncertainties. Thus, at the present stage of the work, it is not possible to establish the real functional dependence of B vs. f. Consequently, we assumed that B is independent of f. Table 2 shows the counting and general characteristics of both the methods.

To compare the capacity of each method to determine the ^{90}Sr activity concentration, we will use the concepts of factor of merit (FOM) and minimum detectable activity (MDA) concentration.

For low-level activity counting (Oeschger and Wahlen, 1975), FOM is evaluated as follows:

$$FOM = d^2 \frac{\varepsilon^2 A^2}{4B}, \quad (6)$$

d being the relative uncertainty in the determination of the net count rate produced in the counter by the activity A; B is the background count rate and ε the counting efficiency.

To compare both the methods, we assumed that the gas and scintillation detectors count the same activity A, and with the same relative uncertainty d. Thus, FOM can redefined (Schönhofer et al., 1991; Seymour et al., 1992), as

$$FOM = \frac{\varepsilon^2}{B}. \quad (7)$$

In the case of the gas-counting method, the efficiency depends on the sample mass thickness

$$FOM^{GP} = 1.13 + \frac{15.37}{e^2} + \frac{52.4}{e^4} \quad (8)$$

taking into account that $B = 0.363$ cpm (typical value) and the counting efficiency is obtained using Eq. (3), using the parameters listed in Table 1, which give the mass thickness dependence of the counting efficiency in the case of secular equilibrium between ^{90}Sr and ^{90}Y in the final sample.

Table 2 shows that the background Cherenkov, B, is 0.46 cpm and the unquenched Cherenkov counting efficiency, ε_0, is 0.475. Consequently,

$$FOM^{Ch} = 0.49 f^2. \quad (9)$$

The variation of both the FOM values can be seen in Fig. 1. As expected, FOM^{Ch} increases with increase in f, while FOM^{GP} decreases as e increases, if $e < 10$ mg cm^{-2}, and is practically constant, if $10 < e < 18$ mg cm^{-2} since the counting efficiency becomes quasi-constant, but always

$$FOM^{Ch} < FOM^{GP} \quad (10)$$

even in the best of cases, i.e. for $f = 1$ and very large e. For such values $FOM^{Ch} = 0.49$ min^{-1} while $FOM^{GP} = 1.18$ min^{-1}. FOM^{Ch} can reach 1.18 min^{-1} only when $f = 1.8 > 1$, which is not reasonable.

If we now compare the $MDAs$, the results are very similar. According to Currie (1968), we can define an

Table 1
Linear regression of β-counting efficiency vs. $1/e^2$, e being the mass thickness of the sample[a]

Radionuclide	a_i	b_i	C
^{90}Sr	0.23	3.15	0.991
^{90}Y	0.41	1.20	0.969
$^{90}Sr + ^{90}Y$	0.64	4.36	0.992

[a] Eqs. (1–3) from the text. Correlation coefficients (C) are listed in column 4.

Table 2
Background count rate (B), counting efficiency (ε), radiochemical yield (Y), counting time (T) and sample mass used in the evaluation of minimum detectable activity (MDA) for both measurement techniques: Cherenkov counting and gas-proportional counting

Parameter	Cherenkov counting	Gas-proportional counting	
B	0.46	0.363	cpm
ε	47.5[a]	See text[b]	(%)
Y	50	See text[c]	(%)
T	3600	3600	min
M	10	10	g

[a] Cherenkov counting efficiency for an unquenched sample.
[b] The counting efficiency for gas-proportional counting depends on the mass thickness of the sample (see Eq. (3)).
[c] The recovery yield is a function of the mass thickness of the sample (see Eq. (13)).

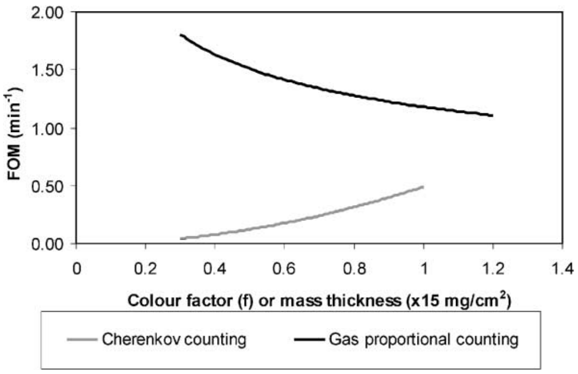

Fig. 1. Factor of merit (*FOM*) vs. colour factor in samples measured by Cherenkov counting and by β-counting.

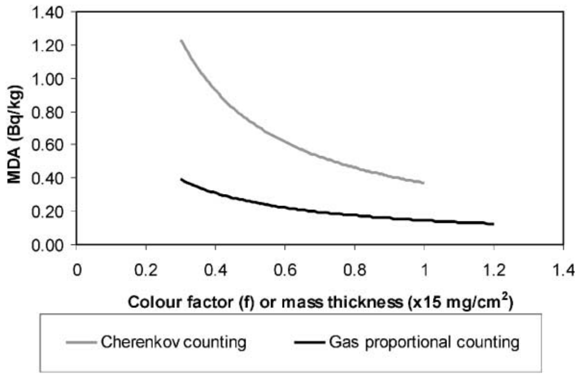

Fig. 2. Minimum detectable activity (*MDA*) vs. colour factor in samples measured by Cherenkov counting and *MDA* vs. mass thickness in samples measured by β-counting. Data corresponding to soil samples and fitting curve (see Eqs. (12) and (14) of text) are shown.

MDA as

$$MDA = \frac{2.71 + 4.65\sqrt{BT}}{\varepsilon YTM60}, \tag{11}$$

T being the counting time, Y the chemical recovery yield, M the analysed mass and the factor 60 serves us to give MDA in Bq kg^{-1}, provided T is given in min, M in kg and B in cpm.

As Cherenkov-counting efficiency varies with colour factor according to Eq. (9), using the data in Table 2, we can find that

$$MDA^{\rm Ch} = \frac{0.37}{f}(\text{Bq kg}^{-1}). \tag{12}$$

On the other hand, the radiochemical yield, Y, and mass thickness, e, are not independent on the gas-flow proportional counting. Indeed, the radiochemical yield is proportional to the precipitate mass on the planchet, but a higher precipitate amount also means a higher mass thickness of the source. Thus, radiochemical yield, Y, and the mass thickness of the sample, e, are related:

$$Y = \frac{e}{18.197}. \tag{13}$$

According to this last expression, the mass thickness of a source, obtained with a 100% radiochemical yield, would be 18.197 mg cm^{-2}. Using a counting time of 3600 min, $M = 0.01$ kg, $B = 0.363$ cpm (typical value) and the counting efficiency as a mass thickness function, the MDA (see Eq. (11)) corresponding to a β-counting would be

$$MDA^{\rm GP} = \frac{1.43}{0.64e + 4.36/e}(\text{Bq kg}^{-1}). \tag{14}$$

In both the cases, MDA is in Bq kg^{-1} (dry weight).

The variation of the MDAs are plotted in Fig. 2. $MDA^{\rm Ch}$ decreases as f approaches 1. At the same way, $MDA^{\rm GP}$ decreases as e increases, since Y becomes higher. However

$$MDA^{\rm Ch} \underset{f\to 1}{\to} 0.37 \ \text{Bq kg}^{-1}$$

and

$$MDA^{\rm GP} \underset{e\to 18.197}{\to} 0.13 \ \text{Bq kg}^{-1}.$$

In other words, the best $MDA^{\rm Ch}$ is higher than the best $MDA^{\rm GP}$. Moreover, it can be calculated that the counting time needed to obtain a $MDA^{\rm Ch}$ equal to the $MDA^{\rm GP}$ is $\approx 10^4$ min, which is one order of magnitude higher than the current time used for the measurements.

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