Beta efficiency curve of the SIR ionization chamber

C. Michotte

Introduction

The International Reference System (SIR) is based on the measurement of the ionization current arising from the γ rays emitted by a radioactive solution placed in the SIR ionization chamber (I.C.). Emitted beta particles may also contribute to the ionization current through the production of bremsstrahlung in the chamber walls and electrodes. Moreover, beta particles having an energy above ca 2 MeV are likely to reach the sensitive volume of the chamber and thus contribute directly to the ionization current (Gostely and Laedermann, 1999). However, no correction for the influence of the beta particles is needed when the equivalent activity of an ampoule submitted to the SIR is deduced since any contribution of beta particles to the ionization current will be the same in relative terms for all participants for a given radionuclide.

On the contrary, when evaluating the gamma-ray efficiency curve of the SIR I.C. as a function of the gamma-ray energy, a correction must be made for the contribution from beta particles. In the same way, when using the efficiency curve to calculate the response of the chamber for a given radionuclide, the contribution of beta particles must be taken into account.

Determination of the beta efficiency curve of the SIR I.C.

The equivalent activity A_e of a given radionuclide as defined elsewhere (Rytz, 1983), is related to the gamma and beta efficiencies ε_γ and ε_β by the following equation:

$$\frac{1}{A_\mathrm{e}} = \sum \varepsilon_\gamma \cdot p_\gamma + \sum \varepsilon_\beta \cdot p_\beta \qquad (1),$$

where p_γ and p_β are the emission probabilities.

In a first step, (1) is used to estimate the gamma-ray SIR efficiency curve from experimental A_e values by limiting the calculation to radionuclides for which the influence of beta particles is negligible (see Michotte, 1999a and references therein). Next, the same equation is used for (quasi-)pure beta emitters to deduce the beta efficiency curve of the SIR I.C.. The gamma efficiencies ε_γ are then taken from the gamma-ray SIR efficiency curve determined in the first stage.

The determination of the beta efficiency curve starts with single-beta emitters (like ^{204}Tl) for which the corresponding beta efficiency is directly obtained from (1):

$$\varepsilon_\beta = \left(\frac{1}{A_\mathrm{e}} - \sum \varepsilon_\gamma \cdot p_\gamma \right) / \, p_\beta \quad .$$

For emitters having more than one beta branch, Eq. (1) is rewritten as

$$\varepsilon_{\beta,N} = \left(\frac{1}{A_\mathrm{e}} - \sum \varepsilon_\gamma \cdot p_\gamma - \sum_{i=1}^{N-1} \varepsilon_{\beta,i} \cdot p_{\beta,i} \right) / \, p_{\beta,N}$$

where $\varepsilon_{\beta,i}$ are deduced from the beta efficiency curve already established by the single-beta emitters. The value obtained for $\varepsilon_{\beta,N}$ is then used to derive a better estimate of the beta efficiency curve, allowing a reiteration of the whole process.

The beta efficiency curve obtained is shown in Figure 1 on a log plot and the numerical values are presented in Table 1. The figure shows that the ^{106}Ru-^{106}Rh point is not on the same line as the other points, but much higher. This could be explained by the presence of very high-energy beta particles (end point of the beta spectrum 3.54 MeV) emitted by ^{106}Rh, which, in addition to the production of bremsstrahlung, are likely to reach the sensitive volume of the chamber.

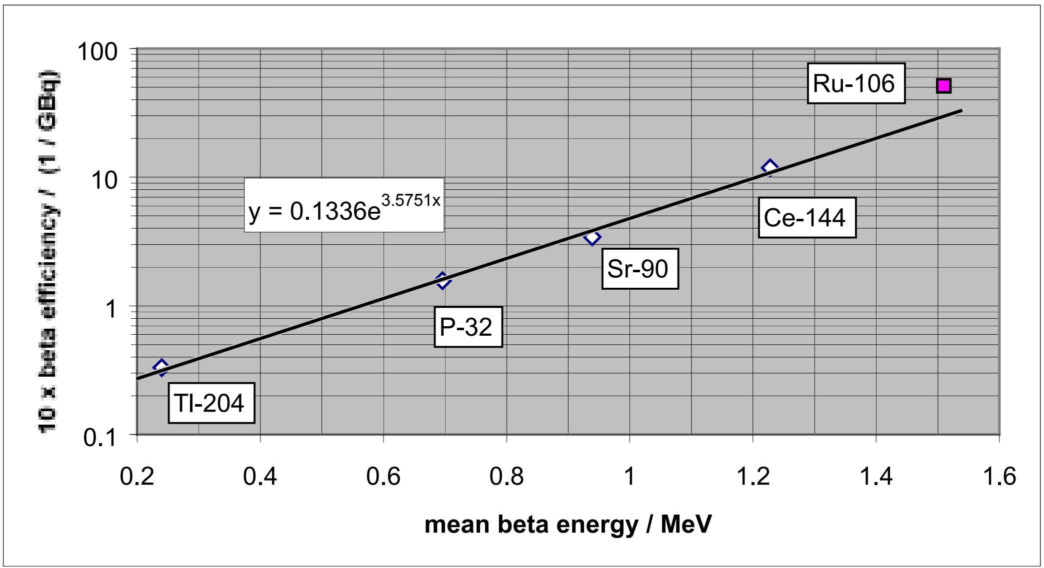

Figure 1: beta efficiency curve of the SIR ionization chamber. The full line is a fit to the white data points.

Radionuclide	A_e / kBq	$\left(\sum \varepsilon_\gamma \cdot p_\gamma\right)^{-1}$ / kBq	$\bar{E}_\beta$ / MeV	p_β	ε_β / kBq^{-1}
^{204}Tl	16x10^{6}	33.1x10^{6}	0.24	0.975	0.33x10^{-7}
^{32}P	-	-	0.70	1.	1.57x10^{-7} (a)
^{90}Sr-^{90}Y	2.70x10^{6}	-	0.20 (i=1)	1.	0.27x10^{-7}
			0.94 (N=2)	1.	3.43x10^{-7}
^{144}Ce-^{144}Pr	283 000	421 800	0.27 (i=1)	0.010	0.36x10^{-7}
			0.89 (i=2)	0.011	3.24x10^{-7}
			1.23 (N=3)	0.980	11.8x10^{-7}
^{106}Ru-^{106}Rh	58 300	77 100	0.78 (i=1)	0.017	2.16x10^{-7}
			0.98 (i=2)	0.099	4.41x10^{-7}
			1.26 (i=3)	0.082	12.1x10^{-7}
			1.51 (N=4)	0.789	51.2x10^{-7}

(a) Value taken from (Rytz,1985) as the measured A_e value could not be found in the archives.

Table 1: Relevant data for the determination of the beta efficiency curve of the SIR ionization chamber using equation (1).

The beta efficiency curve shown in Figure 1 may be compared with the curve reported by Rytz (1985) where no data were available for ^{106}Ru-^{106}Rh (Figure 2). If we consider that the experimental values of A_e available in 1985 were slightly different than those listed in Table 1, we can conclude that both curves are essentially identical.

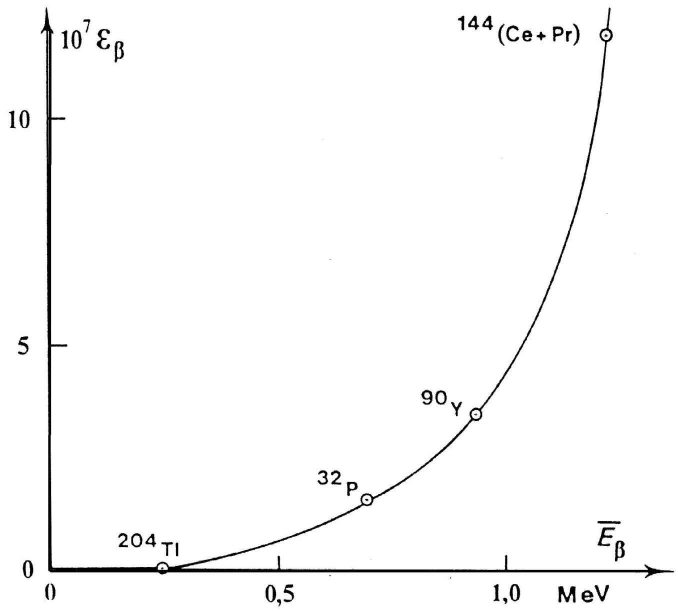

Figure 2: beta efficiency curve from (Rytz, 1985).

From the beta efficiency curve, the term $\sum \varepsilon_\beta \cdot p_\beta$ can be evaluated and compared to $1/A_e$ to estimate the relative effect of the beta particles in SIR measurements. Some values are given in Table 2.

Radionuclide	A_e **/ kBq**	$\left(\sum \varepsilon_\beta \cdot p_\beta\right)^{-1}$ **/ kBq** x 10^{-6}	**Ratio col. 2 / col. 3**
^{24}Na	4 965	10.3	0.000 48
^{47}Sc	164 690	114	0.001 4
^{56}Mn	10 620	1.66	0.006 4
^{99}Mo	64 017	19.0	0.003 4
^{106}Ru-^{106}Rh	58 300	0.24	0.24
^{124}Sb	9 540	10.8	0.000 88
^{131}I	40 340	40.7	0.000 99
^{140}Ba-^{140}La	6 317	8.14	0.000 78
^{144}Ce-^{144}Pr	283 000	0.94	0.30

Table 2: Radionuclides measured in the SIR, for which the relative contribution of beta particles is the greatest. Beta efficiency values are taken from the fit in Figure 1 (except for ^{106}Rh).

Conclusion

The beta efficiency curve of the SIR I.C. has been revised and will be used to update the gamma efficiency curve of the SIR, work on which is in progress (Michotte, 1999a). Both efficiency curves are required to make accurate calculations, using (1), of the equivalent activity of radionuclides not measured yet in the SIR. This is needed to evaluate the correction for a gamma-emitting impurity present in a SIR ampoule when the equivalent activity of this impurity is not known experimentally (see Michotte, 1999b), or to give a comparison point when a radionuclide is measured in the SIR for the first time.

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