# Minimum activity and maximum impurity rates for SIR samples

by A. Rytz

Bureau International des Poids et Mesures, F-92310 Sèvres

## Abstract

Limiting values of sample activity (for an ionization current of at least 1.8 pA) and impurity content (for a contribution to the overall uncertainty of not more than 0.2 %) are established. A table is presented with data for 49 source nuclides and 83 possible impurity nuclides.

After eight years of experience with the International Reference System for activity measurements of γ-ray emitting nuclides (SIR) - a detailed description of which may be found in [1] -, it is now possible to state useful limits for the activity and impurity of samples suitable for SIR. These limits depend on the sensitivity of the measuring equipment and the precision aimed at. The fact that more than 90 % of all the measurements performed were within these specifications shows that the suggested limits are reasonable.

## 1. Activity limits

The lower limit for the sample activity may be derived from a comparison of chamber response with background current, the latter being 35 nA at most. The chamber response can be expressed by the activity $A_e$ ("equivalent activity") necessary to produce the same ionization current as that obtained with the strongest of the five reference sources taken at a fixed date. Experience has shown that a current less than one half of that produced by the weakest reference source (which is 94 times weaker than the strongest one), or less than 1.8 pA, gives too low a precision to be useful for the SIR. Thus, the sample activity should be not less than $A_e/188$. For radionuclides with a half life shorter than 5 d it is desirable to repeat the measurement several times, with about one half life in between, in order to check the consistency of impurity corrections. Therefore, in these cases the minimum activity is assumed to be eight times higher (see Table 2).

The upper limit for a useful measurement is about 600 times the lower one. However, as this has practically never been exceeded in the past for radionuclides with longer half lives, it seems hardly worth mentioning.

## 2. Impurity level

The statement of a tolerable impurity rate is even more arbitrary than that of a minimum acceptable activity. Impurity rates must be indicated by the participant in percent of the main activity, at the reference date. The shorter the half lives involved, the more important is a correct and unambiguous statement of the reference date. Future misunderstandings will be avoided if the following rule is adopted throughout: the reference date is always the date of the purity analysis (by γ-ray spectroscopy), and the sample activity, measured some time before or after, must be corrected for that time difference. In general, impurity rates are reported with about 20 % relative uncertainty.
A single impurity should not contribute more than, say, 0.2 % to the overall uncertainty of the SIR result which is about the uncertainty obtained with a sample activity at the lower limit defined above, namely

$$A^s_{min} = A^s_e/188 \, , \tag{1}$$

where $A^s_e$ is the equivalent activity for the sample s. Therefore, if $A^i_e$ is the equivalent activity of the impurity nuclide, the ratio

$$p = A^i_e/A^s_e \tag{2}$$

expresses the tolerable percentage impurity rate. Although this assessment is only a crude approximation, it leads to useful values of what can be considered as an acceptable impurity limit.

## 3. List of minimum activities and maximum impurity rates

Table 1 presents limiting values derived along the lines described in the two foregoing sections. The values for $A_e$ are rounded weighted means of the presently available SIR results, calculated according to [1], p. 1053. For each radionuclide, observed or expected [2, 3] impurities are indicated in the order of their mass numbers. Those identified by the SIR participants are underlined. Maximum tolerable impurity rates were calculated according to eq. (2); they are indicated in percent of the main activity at the reference date. Very short-lived impurities have not been considered. $A_e$ values of radionuclides for which no SIR result was available were calculated by means of the formula

$$A_e = 10^6/(60 \sum_{i=1}^{n} E_i \, P_i \, f_i) \, , \tag{3}$$

where
- $E_i$ is the photon energy of the $i^{th}$ γ ray, expressed in MeV,
- $P_i$ is the corresponding emission probability and
- $f_i$ is the ordinate of the (reduced) efficiency curve (see [1], Fig. 10), corresponding to $E_i$ as abscissa.

The decay data were taken from [2, 4, 5].

Table 1 - Minimum activity and maximum-impurity rates for SIR samples

| Radio-nuclide | $A_e$ (kBq) | $A_{min} \approx \frac{A_e}{188}$ (kBq) | Tolerable impurity rate, $p = A_e^i/A_e^s$ (% activity at reference date) | Impurities identified by SIR participants are underlined; an asterisk after the element symbol means "in equilibrium with daughter products". | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{22}$Na | 7 500 | 40 | | | | | | | | | |
| $^{24}$Na | 5 000 | 850 | $^{72}$Ga 1.4 | | | | | | | | |
| $^{46}$Sc | 8 300 | 44 | $^{47}$Sc 20 | $^{48}$Sc 0.6 | | | | | | | |
| $^{47}$Sc | 168 000 | 900 | $^{46}$Sc 0.05 | $^{48}$Sc 0.03 | | | | | | | |
| $^{51}$Cr | 488 000 | 2 600 | $\underline{^{54}\mathrm{Mn}}$ 0.04 | $\underline{^{58}\mathrm{Co}}$ 0.03 | $\underline{^{59}\mathrm{Fe}}$ 0.03 | $\underline{^{60}\mathrm{Co}}$ 0.014 | $\underline{^{65}\mathrm{Zn}}$ 0.06 | $\underline{^{75}\mathrm{Se}}$ 0.09 | $\underline{^{124}\mathrm{Sb}}$ 0.02 | $\underline{^{137}\mathrm{Cs}}$ 0.05 | $\underline{^{192}\mathrm{Ir}}$ 0.04 |
| $^{54}$Mn | 19 200 | 100 | $^{48}$V 0.3 | $\underline{^{51}\mathrm{Cr}}$ 25 | $^{52}$Mn 0.25 | $^{56}$Co 0.25 | $^{58}$Co 0.85 | $^{59}$Fe 0.75 | $\underline{^{60}\mathrm{Co}}$ 0.3 | $\underline{^{65}\mathrm{Zn}}$ 1.5 | |
| $^{56}$Mn | 10 600 | 900 | | | | | | | | | |
| $^{56}$Co | 5 100 | 27 | $\underline{^{57}\mathrm{Co}}$ 32 | $\underline{^{58}\mathrm{Co}}$ 3.2 | $^{60}$Co 1.3 | | | | | | |
| $^{57}$Co | 168 000 | 890 | $\underline{^{56}\mathrm{Co}}$ 0.03 | $\underline{^{58}\mathrm{Co}}$ 0.09 | $\underline{^{60}\mathrm{Co}}$ 0.04 | | | | | | |
| $^{58}$Co | 16 300 | 87 | $^{56}$Co 0.3 | $\underline{^{57}\mathrm{Co}}$ 10 | $\underline{^{60}\mathrm{Co}}$ 0.4 | | | | | | |
| $^{59}$Fe | 14 700 | 78 | $\underline{^{60}\mathrm{Co}}$ 0.4 | | | | | | | | |

Table 1 (cont'd)

| Radio- nuclide | $A_e$ (kBq) | $A_{min} \approx \frac{A_e}{188}$ (kBq) | Tolerable impurity rate, $p = A_e^i/A_e^s$ (% activity at reference date) | Impurities identified by SIR participants are underlined; an asterisk after the element symbol means "in equilibrium with daughter products". | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{60}$Co | 7 060 | 37 | | | | | | | | | |
| $^{65}$Zn | 30 000 | 160 | $\underline{^{60}\mathrm{Co}\ 0.23}$ | $^{67}$Cu 5 | $^{69}$Zn$^{m}$* 1.2 | $\underline{^{75}\mathrm{Se}\ 1.4}$ | | | | | |
| $^{67}$Ga | 115 000 | 4 900 | $\underline{^{57}\mathrm{Co}\ 1.4}$ | $\underline{^{60}\mathrm{Co}\ 0.06}$ | $^{66}$Ga 0.06 | | | | | | |
| $^{75}$Se | 43 000 | 230 | $^{60}$Co 0.16 | $^{137}$Cs 0.64 | | | | | | | |
| $^{82}$Sr-$^{82}$Rb | 14 100 | 75 | | | | | | | | | |
| $^{85}$Sr | 30 100 | 160 | $^{59}$Fe 0.5 | $\underline{^{84}\mathrm{Rb}\ 0.6}$ | $\underline{^{86}\mathrm{Rb}\ 6}$ | $\underline{^{89}\mathrm{Sr}\ 2\cdot10^{6}}$ | | | | | |
| $^{88}$Y | 6 900 | 37 | $^{56}$Co 0.75 | $^{57}$Co 24 | | | | | | | |
| $^{95}$Zr-$^{95}$Nb | 7 300 | 39 | $^{60}$Co 1.0 | $^{97}$Zr* 13 | $^{103}$Ru* 4 | | | | | | |
| $^{95}$Nb | 20 600 | 110 | $\underline{^{95}\mathrm{Zr}^*\ 0.35}$ | $^{97}$Zr* 4.5 | $^{123}$Te$^{m}$ 6.5 | $^{125}$Sb 1.7 | $^{125}$Te$^{m}$ 1 700 | $\underline{^{125}\mathrm{I}\ 3\ 100}$ | $^{129}$Te$^{m}$* $5\cdot10^{5}$ | $\underline{^{141}\mathrm{Ce}\ 13}$ | $\underline{^{144}\mathrm{Ce}^*\ 14}$ |
| $^{99}$Mo-$^{99}$Tc$^{m}$ | 64 000 | 2 730 | $^{60}$Co 0.1 | $^{86}$Rb 2.7 | $^{95}$Zr* 0.1 | $^{95}$Nb 0.3 | $^{92}$Nb$^{m}$* 0.25 | $\underline{^{103}\mathrm{Ru}^*\ 0.45}$ | $^{106}$Ru* 1.1 | $^{110}$Ag$^{m}$* 0.09 | $^{124}$Sb 0.14 |
| | | | $\underline{^{127}\mathrm{Sb}^*\ 0.38}$ | $^{131}$I* 0.62 | $\underline{^{132}\mathrm{Te}^*\ 1.2}$ | $^{133}$I* 0.42 | $^{134}$Cs 0.15 | $^{140}$La 0.12 | | | |

Table 1 (cont'd)

| Radio-nuclide | $A_e$ (kBq) | $A_{min} \approx \frac{A_e}{188}$ (kBq) | Tolerable impurity rate, $p = A_e^i/A_e^s$ (% activity at reference date) | | | Impurities identified by SIR participants are underlined; an asterisk after the element symbol means "in equilibrium with daughter products". | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $^{99}Tc^m$ | 153 000 | 6 500 | $^{99}Mo^*$ 0.41 | $^{106}Ru^*$ 1.1 | $^{131}I^*$ 0.25 | $^{132}Te^*$ 0.51 | $^{133}I^*$ 0.17 | | | |
| $^{103}Ru$–$^{103}Rh^m$ | 30 500 | 160 | $^{97}Ru^*$ 2.3 | $^{105}Rh^*$ 6.6 | $^{106}Ru^*$ 2.5 | $^{141}Ce$ 8.7 | | | | |
| $^{106}Ru$–$^{106}Rh$ | 76 500 | 400 | $^{103}Ru^*$ 0.4 | $^{137}Cs$ 0.36 | | | | | | |
| $^{109}Cd$ | $81\cdot10^5$ | 43 000 | $^{57}Co$ 0.02 | $\underline{^{60}Co}$ $\underline{8\cdot10^{-4}}$ | $\underline{^{65}Zn}$ $\underline{0.003}$ | $\underline{^{110}Ag^{m*}}$ $\underline{7\cdot10^{-4}}$ | $\underline{^{115}Cd^{m*}}$ $\underline{0.06}$ | $^{131}I^*$ 0.005 | $\underline{^{134}Cs}$ $\underline{0.001}$ | $\underline{^{152}Eu}$ $\underline{1.8\cdot10^{-3}}$ |
| $^{110}Ag^m$ | 6 000 | 32 | $^{108}Ag^{m*}$ 1.6 | | | | | | | |
| $^{111}In$ | 43 000 | 1 800 | $\underline{^{114}In^{m*}}$ $\underline{5.2}$ | $^{125}Sb$ 0.8 | | | | | | |
| $^{113}Sn$–$^{113}In^m$ | 59 000 | 315 | $\underline{^{114}In^{m*}}$ $\underline{3.7}$ | $^{117}Sn^m$ 2.2 | $^{119}Sn^m$ $1.6\cdot10^3$ | $^{121}Sn^{m*}$ 800 | $^{123}Sn$ 40 | $\underline{^{125}Sb}$ $\underline{0.6}$ | | |
| $^{123}I$ | 120 000 | 20 000 | $\underline{^{125}I}$ $\underline{3.0}$ | | | | | | | |
| $^{125}Sb$ | 37 000 | 200 | $^{113}Sn$ 1.6 | $^{117}Sn^m$ 3.5 | $^{121}Sn^m$ 1 300 | $^{123}Sn$ 67 | $^{125}Sn^*$ 1.5 | | | |
| $^{125}I$ | $6.5\cdot10^7$ | 343 000 | $\underline{^{126}I}$ $\underline{0.000\ 5}$ | $\underline{^{131}I^*}$ $\underline{0.000\ 6}$ | $^{137}Cs$ 0.000 4 | | | | | |

Table 1 (cont'd)

| Radio-nuclide | $A_e$ (kBq) | $A_{min} \approx \frac{A_e}{188}$ (kBq) | Tolerable impurity rate, $p = A_e^i/A_e^s$ (% activity at reference date) | Impurities identified by SIR participants are underlined; an asterisk after the element symbol means "in equilibrium with daughter products". | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $^{131}$I | 40 400 | 215 | $^{75}$Se 1.0 | $^{125}$I 1 600 | $^{126}$I 0.8 | | | | |
| $^{133}$Ba | 44 000 | 235 | $^{60}$Co 0.16 | $^{65}$Zn 0.6 | $^{131}$Ba 0.8 | $^{132}$Cs 32 | $^{134}$Cs 0.2 | $^{135}$Ba$^{m}$ 8 | $^{140}$La 2 |
| $^{134}$Cs | 10 100 | 54 | $^{22}$Na 0.7 | $^{84}$Rb 1.7 | $^{86}$Rb 17 | | | | |
| $^{137}$Cs | 27 600 | 150 | $^{60}$Co 0.25 | $^{134}$Cs 0.3 | | | | | |
| $^{139}$Ce | 134 000 | 700 | $^{141}$Ce 2 | | | | | | |
| $^{141}$Ce | 266 000 | 1 400 | $^{51}$Cr 1.8 | $^{113}$Sn* 0.2 | $^{137}$Ce$^{m}$* 1.7 | $^{137}$Ce 4 | $^{139}$Ce 0.5 | $^{143}$Ce* 0.2 | $^{144}$Ce* 1.1 |
| $^{144}$Ce-$^{144}$Pr | 282 000 | 1 500 | $^{137}$Cs 0.09 | $^{139}$Ce 0.4 | $^{141}$Ce 0.9 | $^{154}$Eu 0.04 | $^{192}$Ir 0.06 | | |
| $^{152}$Eu | 14 700 | 78 | $^{154}$Eu 0.9 | $^{155}$Eu 32 | | | | | |
| $^{154}$Eu | 13 800 | 73 | $^{155}$Eu 35 | | | | | | |
| $^{169}$Yb | 78 000 | 410 | $^{175}$Yb 5 | | | | | | |

Table 1 (cont'd)

| Radio-nuclide | $A_e$ (kBq) | $A_{min} \approx \frac{A_e}{188}$ (kBq) | Tolerable impurity rate, $p = A_e^i/A_e^s$ (% activity at reference date) | Impurities identified by SIR participants are underlined; an asterisk after the element symbol means "in equilibrium with daughter products". | | | |
|---|---|---|---|---|---|---|---|
| $^{182}$Ta | 13 800 | 70 | | | | | |
| $^{192}$Ir | 19 000 | 100 | $^{193}$Ir$^m$ 4·10$^5$ | $^{194}$Ir 11 | | | |
| $^{195}$Au | 325 000 | 1 727 | $^{196}$Au 0.11 | | | | |
| $^{201}$Tl | 309 000 | 13 000 | $^{200}$Tl 0.04 | $^{202}$Tl 0.11 | $^{203}$Pb 0.18 | | |
| $^{203}$Hg | 67 400 | 360 | $^{54}$Mn 0.28 | $^{58}$Co 0.24 | $^{60}$Co 0.10 | $^{197}$Hg 7.0 | $^{197}$Hg$^m$* 3.6 |
| $^{203}$Pb | 56 700 | 300 | $^{200}$Tl 0.23 | $^{201}$Tl 5.4 | $^{201}$Pb* 0.39 | | |
| $^{207}$Bi | 10 900 | 60 | | | | | |
| $^{241}$Am | 2.05·10$^6$ | 11 000 | $^{239}$Pu 250 | $^{242}$Cm 27 | $^{243}$Am 0.28 | | |

Table 2 - SIR samples having an activity below the "acceptable" lower limit, $A_{min}$

| Radionuclide | Supplier | Year | Activity (kBq) | $A_{min}$* | $r_3$ (%) | $S(A_e)$ (%) |
|---|---|---|---|---|---|---|
| $^{57}Co$ | NPL | 1976 | 430 | 891 | 0.2 | 2.02 |
| $^{67}Ga$ | LMRI | 1981 | 2 290 | 4 900 (613) | 0.18 | 0.23 |
| $^{109}Cd$ | UVVVR | 1978 | 3 802 | 43 000 | 0.23 | 1.38 |
| | NPL | 1980 | 39 300 | | 0.16 | 1.65 |
| | AECL | 1981 | 17 741 | | 0.28 | 1.41 |
| $^{123}I$ | LMRI | 1981 | 4 118 | 5 100 (637) | 0.17 | 0.33 |
| | BCMN | 1983 | 1 860 | | 0.27 | 0.61 |
| | LMRI | 1983 | 1 795 | | 0.27 | 0.54 |
| $^{125}I$ | NBS | 1977 | 273 500 | 343 000 | 0.20 | 1.49 |
| | ASMW | 1977 | 36 280 | | 1.19 | 1.22 |
| | LMRI | 1980 | 22 500 | | 4.55 | 4.56 |
| $^{201}Tl$ | LMRI | 1983 | 3 480 | 13 100 (1 642) | 0.62 | 2.5 |
| $^{241}Am$ | OMH | 1977 | 8 113 | 11 000 | 0.17 | 0.37 |
| | AAEC | 1977 | 4 362 | | 0.19 | 0.37 |
| | UVVVR | 1978 | 3 475 | | 0.19 | 0.39 |
| | " | 1979 | 5 476 | | 0.17 | 0.38 |

* For $^{67}Ga$, $^{123}I$ and $^{201}Tl$ the values have been multiplied by 8 because of the short half lives. The net values are indicated in parentheses.

## 4. SIR measurements of samples with $A < A_{min}$

Table 2 summarizes fifteen SIR measurements on samples with activities below the "acceptable" limit, $A_{min}$.

It can be seen that $r_3$, the uncertainty of the ionization-chamber measurement alone, was mostly of the order of 0.2 %, except where impurities were significant. The overall uncertainty, $S(A_e)$, is the sum in quadrature of $r_3$ and the components $r_1$ and $r_2$ of the activity measurement, as indicated in the corresponding SIR registration tables. In all these examples $S(A_e)$ is larger than 0.2 %, which is in most cases due to an activity lower than $A_{min}$.

## References

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