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Characterization protocol for a surface barrier-type alpha and beta detector

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Abstract: The purpose of this work is to present a protocol for characterization of an alpha (α), beta (β) (and also α+β) radiation detector of the surface-barrier type, currently in operation at the Institute of Chemical, Biological and Nuclear Defense of the Brazilian Technology Center (CTEx), located in Rio de Janeiro, Brazil. The detector has been efficiently used to measure the amount of contamination in samples collected from sites where accidental or deliberate releases of radioactive have occurred. Standard ²⁴¹Am and ⁹⁰Sr sources have been used for calibration and have consistently yielded the following values of efficiency for alpha and beta counting: 38% and 29%, respectively. Self absorption effects have also been investigated, providing data that were compared to those reported by a reference laboratory (LAPOC) in Poços de Caldas, Minas Gerais, Brazil.

1. INTRODUCTION
Providing scientific advisory on issues related to radiological events is one of the primary roles assigned to the Nuclear and Radiological Department of the Institute of Chemical, Biological and Nuclear Defense of the Brazilian Technology Center (CTEx). In order to be prepared for events when contamination by alpha and beta emitters occur, IDQBRN needs to be capable of performing accurate measurements with equipment already available in its laboratories, with includes a semiconductor type, surface barrier detector (iMatic).

These were the first systematic tests performed with the equipment intended to define procedures that will be routinely used for alpha and beta counting in the laboratory. The work is also part of a Master’s thesis focused at providing guidelines for the future use of the equipment by other professionals.

Detector efficiencies and self-absorption curves for alpha and beta primary standard sources have been determined and used to analyze contaminated samples.

The purpose of this work is to present a characterization protocol for the use of an alpha (α), beta (β) (and also α+β) iMatic radiation detector of the surface-barrier type so that it can be routinely used to determine the amount of contamination of samples with alpha and beta emitters.

2. MATERIALS AND METHODS
The alpha, beta surface barrier (iMatic) detector used in this work had a depletion layer of 300µm, an useful area of 2,000mm²; energy response range from 125 keV to 2.2 MeV for beta and 3.0 to 9.6 MeV for alpha; minimum detectable alpha count of 0.05cpm and 0.60 cpm for beta; estimated alpha efficiency for americium-241 sources of 39% and beta efficiency for strontium-90 sources of 30%.

The methodology proposed by the manufacturers was applied [1] in order to determine the
experimental efficiencies. The measurements were carried out with calibration sources provided by Canberra: $^{241}\text{Am}$ (658 Bq) and $^{90}\text{Sr}$ (558 Bq), the figures in parentheses are activities corrected for the time of the experiments.

Alpha, beta and a mixed alpha and beta self-absorption curves were first determined. Primary standard samples were prepared. They consisted of 5 grams of alumina (for each sample) in grams of agate; added to the alumina was a $^{241}\text{Am}$ volumetric pipet of 3.8011 Bq to obtain the standard for the alpha self-absorption curve, likewise a $^{90}\text{Sr}$ standard amount of 307.259 Bq was added in order to obtain the sample for determining the beta self-absorption curve and one mixture of $^{241}\text{Am}$ and $^{90}\text{Sr}$ standards, 38.019 Bq and 6.828 Bq, respectively were added to produce the mixed radioactive standard. The standard samples were then dried in an oven for 2 hours at 60 °C and, after cooling, the samples were homogenized and packed in appropriate recipients.

The preparation of the standard samples used for determination of the self-absorption curves was carried out according to the following steps: 21 stainless steel platelets (7 for each standard sample) were decontaminated; the platelet count was obtained using an analytical balance; 30 mg, 50 mg, 80 mg, 100 mg, 150 mg, 200 mg and 300 mg were weighed from the primary to obtain platelet standards. A small amount of PA Ethyl Alcohol was added with graduated pipette to the platelet mass; the dough was homogenized using a teflon stick in order to prevent it from flowing to the edges of the plate and it was then dried in an oven for 1 hour at 60 °C. After cooling, the platelets were again weighed in an analytical balance and the standard samples were counted for 1 hour using the equipment.

The Zero Efficiency parameter was obtained using a $^{241}\text{Am}$ point source for alpha, $^{90}\text{Sr}$ for beta and a mixture of $^{241}\text{Am}$ and $^{90}\text{Sr}$ for the mixed sample, according to the formula below [2].

$$\text{Zero efficiency} = \frac{\text{pattern count} - \text{BG}}{\text{activity} \times \text{count time}}$$

$$\text{determined efficiency} = \frac{\text{pattern count} - \text{BG}}{\text{platelet activity} \times \text{count time}}$$

where,

- Bq / g = Activity added / Total alumina mass (5g)
- Plate area = Area to be used in the plate in cm$^2$ (area of a circle)
- Mg / cm$^2$ = mass (mg) / platelet area (cm$^2$)

By using the zero efficiency and the determined efficiency, the coefficient of self absorption (Nabs) was calculated, according to the following formula:

$$Nabs = \frac{\text{determined efficiency}}{\text{Zero efficiency}}$$

3. RESULTS AND DISCUSSIONS

The counting efficiencies determined for the iMatic equipment were 38% for alpha and 29% for beta particles, while the percent deviations from the predicted values [3] were 1.9% for beta and 2% for alpha. The uncertainty associated to the measured count rate: 1.4% for LAPOC equipment and 8.4% for iMatic (upper calculated limit).

A correction was made during calibration with the standard sources in order to account for the 25/42 ratio between the sensitive areas of the detectors, the one at LAPOC being 42mm, much larger than the iMatic which is 25mm. The coefficients of self-absorption (Nabs) for alpha, beta and for mixtures of alpha and beta emitters were calculated. The results obtained from iMatic and LAPOC under the same conditions are shown in Tables 1 and 2.
Table 1. IMatic self-absorption coefficient

|                | Nabs α | Nabs β | Nabs α in the mixture | Nabs β in the mixture |
|----------------|--------|--------|-----------------------|-----------------------|
| Platelet 30mg  | 0.512  | 0.956  | 0.635                 | 0.469                 |
| Platelet 50mg  | 0.466  | 1.142  | 0.578                 | 0.738                 |
| Platelet 80mg  | 0.333  | 1.112  | 0.432                 | 0.821                 |
| Platelet 100mg | 0.331  | 1.034  | 0.304                 | 0.849                 |
| Platelet 150mg | 0.235  | 1.029  | 0.265                 | 0.818                 |
| Platelet 200 mg| 0.188  | 1.021  | 0.169                 | 0.821                 |
| Platelet 300 mg| 0.137  | 1.004  | 0.117                 | 0.782                 |

Table 2. Coefficient of self absorption of LAPOC

|                | Nabs α | Nabs β | Nabs α in the mixture | Nabs β in the mixture |
|----------------|--------|--------|-----------------------|-----------------------|
| Platelet 30mg  | 0.335  | 0.837  | 0.555                 | 0.855                 |
| Platelet 50mg  | 0.340  | 0.943  | 0.513                 | 0.698                 |
| Platelet 80mg  | 0.255  | 0.905  | 0.400                 | 0.710                 |
| Platelet 100mg | 0.224  | 0.897  | 0.339                 | 0.696                 |
| Platelet 150mg | 0.190  | 0.845  | 0.258                 | 0.768                 |
| Platelet 200 mg| 0.153  | 0.817  | 0.201                 | 0.702                 |
| Platelet 300 mg| 0.118  | 0.797  | 0.132                 | 0.662                 |

Based on the calculated figure for Nabs, the self-absorption curves were plotted, mg / cm² x self-absorption factor, and compared with the self-absorption curves provided by the reference laboratory. The results are presented in Figure 1 (alpha self-absorption curve), Figure 2 (beta self-absorption curve), Figure 3 (alpha self-absorption curve in the mixture) and Figure 4 (beta self-absorption curve in the mixture).

In Figure 1, both curves are seen to display significant decreasing exponential trends, the one from IMatic being consistently above the curve from LAPOC, as expected, due to the fact that the efficiency of IMatic is higher than the alpha efficiency of LAPOC, 38% and 32%, respectively.

![Self-absorption curves for alpha radiation](image)

Figure 1: Comparative graph of self-absorption curves for alpha radiation

In Figure 2, it can be observed that the curves exhibit a non-accentuated decreasing exponential trend, which shows that there is no need to submit to the beta counts an auto-absorption curve. It is
also worth noticing is that the curve referring to iMatic is above the one from LAPOC because the threshold of the equipment for the former is lower than the one used by the Reference Laboratory.

![Graph](image_url)

**Figure 2:** Comparative graph of self-absorption curves for beta radiation

In Figure 3, data from both sources exhibit similar decreasing exponential trends, as expected. In contrast, in figure 4 the curves depart significantly due to the fact that the detection threshold for alpha and beta radiations are different and such difference is not properly accounted for by the iMatic system as mixed (alpha and beta) samples are used.

![Graph](image_url)

**Figure 3:** Comparative graph of self-absorption curves for mixed alpha radiation

![Graph](image_url)

**Figure 4:** Comparative graph of self-absorption curves for mixed beta radiation

### 4. CONCLUSIONS
Inspection of the plots leads to the conclusion that the measurements performed with iMatic closely resemble the reference data provided by LAPOC not only in terms of trends but also in magnitude. Thus, it can be concluded that the absolute self-absorption data measured with the iMatic detection system is in good agreement with the standard data provided by LAPOC. The findings also allow us to conclude that the iMatic alpha, beta counting system provides accurate results independently of the width of the samples, so that it can be efficiently used in the analyses of contaminations performed at the IDQBRN. Further analyses must be performed in order to reduce the current uncertainty of the iMatic measurements.

### 5. REFERENCES
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