Activimeter “in situ” calibration methodology to $^{111}$In and $^{123}$I

Martins$^a$, E. W.; Potiens$^a$, M. P. A.

$^a$ Instituto de Pesquisas Energéticas e Nucleares, Avenida Lineu Prestes, 2242
Cidade Universitária, São Paulo – SP, CEP 05508-000
elainewirney@yahoo.com.br

ABSTRACT

The activimeter calibration has the purpose of ensure greater reliability in measurement results, hence the activimeters used are commonly installed in controlled areas and, in some cases, with difficult access. The activimeter “in situ” calibration methodology presented in this work allows its execution only with the displacement of the radioactive samples and not of the activimeter itself, which simplifies the procedure of nuclear medicine services and at radiopharmaceuticals production centers, without affecting the quality and accuracy of measurements. After the application of the methodology by qualified technicians, the obtained results of the tested activimeters showed its importance since the calibration factors can present correction of up to 5% for $^{111}$In and greater than 5% for $^{123}$I.

Keywords: activimeter, calibration, methodology “in situ”.
1. INTRODUCTION

In a Nuclear Medicine Service (NMS), for therapy or diagnostics, it is necessary to have reliability in the radiopharmaceutical activity value before it is given to the patient. For this purpose, the activitimeter must be appropriately calibrated, otherwise it can raise uncertainty around the measurements, resulting in doubtful diagnostics or improper therapies. Usually, the activimeters are located in controlled areas, hot rooms, of difficult access both for handling and for sending to a Calibration Laboratory. Based on this the Instruments Calibration Laboratory of IPEN has developed a methodology of “in situ” calibration of activimeters where there is not need of equipment transportation, but only the radiopharmaceutical used as reference source [1].

The objective of this study was to implement this methodology exclusively for the control and calibration of the activimeters of the radiopharmaceutical production laboratory of the Radiopharmacy Center of IPEN (CERAF) using the radionuclides $^{111}$In and $^{123}$I.

2. MATERIALS AND METHODS

Since the new methodology development and the execution of the present study, all the steps for the Activimeter calibration had as reference the applied methodology at the National Primary Physical Standardization (NPL), England [2]. The secondary standard activimeter owned by the LCI (Instruments Calibration Laboratory) has traceability to NPL.

2.1. Activimeters Used

Twelve activimeters were used: activimeter reference standard model CRC-25R, series 252669 presented in Figure 1 and tested eleven activimeters belonging to CERAF listed on Table 1.

Figure 1: Reference activimeter - LCI
Table 1: Activimeters used in this study - CERAF

<table>
<thead>
<tr>
<th>Activimeter</th>
<th>Model</th>
<th>Série</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CRC-15 BT</td>
<td>510191</td>
</tr>
<tr>
<td>2</td>
<td>CRC-25 R</td>
<td>252537</td>
</tr>
<tr>
<td>3</td>
<td>CRC-15 R</td>
<td>157874</td>
</tr>
<tr>
<td>4</td>
<td>CRC-15 R</td>
<td>157173</td>
</tr>
<tr>
<td>5</td>
<td>CRC-15 R</td>
<td>157816</td>
</tr>
<tr>
<td>6</td>
<td>CRC-15 R</td>
<td>158945</td>
</tr>
<tr>
<td>7</td>
<td>CRC-15 R</td>
<td>158944</td>
</tr>
<tr>
<td>8</td>
<td>CRC-15 R</td>
<td>154896</td>
</tr>
<tr>
<td>9</td>
<td>CRC-15 R</td>
<td>155183</td>
</tr>
<tr>
<td>10</td>
<td>CRC-35 R</td>
<td>350181</td>
</tr>
<tr>
<td>11</td>
<td>CRC-35 R</td>
<td>350373</td>
</tr>
</tbody>
</table>

2.2. Preparation of the Radioactive Samples

The samples were produced by CERAF, diluted and stored in the IPEN’s vials with volume of 6ml each. The samples handling was done by an authorized CERAF’s technician. The radionuclides produced were $^{111}$In e $^{123}$I, and their characteristics are presented in Table 2 and the characteristics of the two types of vials used, IPEN’s vial and the 10R Schott, are on Table 3.

Table 2: Characteristics of samples supplied by production sector of CERAF

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Half-Life (hours)</th>
<th>Energy (keV)</th>
<th>Volume (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{111}$In</td>
<td>67.3128 ± 0.010</td>
<td>860</td>
<td>6.0</td>
</tr>
<tr>
<td>$^{123}$I</td>
<td>13.2231 ± 0.002</td>
<td>1228</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Table 3: Main characteristics of the used glass vials

<table>
<thead>
<tr>
<th>Containers</th>
<th>10R Schott</th>
<th>IPEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (mm)</td>
<td>45.0 ± 0.5</td>
<td>57.7 ± 0.02</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>24.0 ± 0.2</td>
<td>26.05 ± 0.02</td>
</tr>
<tr>
<td>Wall Thickness (mm)</td>
<td>1.00 ± 0.04</td>
<td>1.2 ± 0.02</td>
</tr>
<tr>
<td>Maximum Volume (ml)</td>
<td>13.5</td>
<td>22.9 ± 0.02</td>
</tr>
</tbody>
</table>
2.3. Determination of container geometry correction factor

Initially the determining of container geometry correction factor was done for each activimeter tested. The samples were provided on IPEN container and 10R Schott in volume of 6.0 ml each. In order to determine the container geometry correction factor, the steps followed are shown in the diagram below:

**Phase 1:** Determination to vial geometry correction factor

The vial geometry correction factor, $F_{GC}$, is calculated by equation 1 [3].

$$F_{GC} = \frac{\bar{A}_s}{\bar{A}_{fp}}$$  \hspace{1cm} (1)

Where: $\bar{A}_s = $ Average of activities measured in the 10R Schott  
$\bar{A}_{fp} = $ Average of activities measured in the IPEN

2.4. Determination of calibration factor

In order to apply the calibration methodology, the reference container 10R Schott was used. The tests were done respecting identical measurement conditions. In each activimeter were done 10 consecutive measurements, with 30 seconds interval between them. The diagram below shows every step of the methodology applied.
Phase 2: Determination to calibration factor

The measurements were done in all activimeters and calibration factor (CF) was obtained by ration between measurements on the reference activimeter (A_{REF}) and test activimeters (M_{Test}), as shown in the equation 2.

$$ CF = \frac{A_{REF}}{M_{Test}} $$  \hspace{1cm} (2)

2.5. Uncertainty Calculations

The uncertainty calculation was obtained based on the estimates of type A and type B, possibly for a 95% confidence level (k=2). The type A uncertainty were estimated by standard deviation and average deviation standard, type B information were based on a set of variables of each activimeter. The uncertainty of calibration factor was calculated based on variables error propagation correlated on equation 3:

$$ \frac{\sigma_{CF}}{CF} = \sqrt{\left( \frac{\sigma_{A_{REF}}}{A_{REF}} \right)^2 + \left( \frac{\sigma_{M_{Test}}}{M_{Test}} \right)^2 - 2 \frac{\text{cov}(A_{REF}, M_{Test})}{A_{REF} * M_{Test}}} $$  \hspace{1cm} (3)

Were:  \hspace{1cm} \sigma_{CF} = \text{uncertainty of calibration factor}  
\hspace{1cm} CF = \text{calibration factor}
\[ \sigma_{\bar{A}_{REF}} = \sqrt{\frac{A'_{REF} + BG_{sample}}{T_{sample}} + \frac{BG}{T_{BG}}} \]  \hspace{1cm} (4)

\[ \sigma_{\bar{M}_{Test}} = \sqrt{\frac{M'_{Test} + BG}{T_{sample}} + \frac{BG}{T_{BG}}} \]  \hspace{1cm} (5)

\[ \text{cov}(\bar{A}_{REF}, \bar{M}_{Test}) = \sqrt{\frac{BG}{T_{BG}}} \]  \hspace{1cm} (6)

\( \sigma_{\bar{A}_{REF}} \) = propagation of uncertainty of measurement average in the reference activimeter
\( \sigma_{\bar{M}_{Test}} \) = propagation uncertainty of measurement average in the test activimeter
\( A'_{REF} \) = liquid activity (background discounted) reference activimeter
\( M'_{Test} \) = liquid activity (background discounted) test activimeter
\( T_{amostra} \) = time of sample measured
\( T_{BG} \) = time of background measurement
\( n \) = sample size or measurement quantity

### 3. RESULTS AND DISCUSSIONS

Table 4 and 5 show the results found to the radionuclides \(^{111}\)In and \(^{123}\)I using the methodology proposed. The calibration factors were obtained using the equation 2 and are reported on Table 6 and 7.
Table 4: Tests accomplished with radionuclide $^{111}$In to vial geometry correction factor

<table>
<thead>
<tr>
<th>Activimeter</th>
<th>IPEN vial, A1 Initial Activity (GBq)</th>
<th>10R Schott vial, A2 (GBq)</th>
<th>$F_{GC}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.200 ± 0.039</td>
<td>0.191 ± 0.032</td>
<td>0.955 ± 0.9 %</td>
</tr>
<tr>
<td>2</td>
<td>0.200 ± 0.037</td>
<td>0.192 ± 0.048</td>
<td>0.955 ± 1.4 %</td>
</tr>
<tr>
<td>3</td>
<td>0.193 ± 0.050</td>
<td>0.185 ± 0.033</td>
<td>0.959 ± 0.7 %</td>
</tr>
<tr>
<td>4</td>
<td>0.202 ± 0.072</td>
<td>0.194 ± 0.032</td>
<td>0.960 ± 0.5 %</td>
</tr>
<tr>
<td>5</td>
<td>0.208 ± 0.038</td>
<td>0.197 ± 0.050</td>
<td>0.947 ± 1.4 %</td>
</tr>
<tr>
<td>6</td>
<td>0.196 ± 0.049</td>
<td>0.188 ± 0.049</td>
<td>1.000 ± 1.0 %</td>
</tr>
<tr>
<td>7</td>
<td>0.198 ± 0.031</td>
<td>0.188 ± 0.032</td>
<td>0.949 ± 1.1 %</td>
</tr>
<tr>
<td>8</td>
<td>0.202 ± 0.040</td>
<td>0.193 ± 0.067</td>
<td>0.955 ± 1.8 %</td>
</tr>
<tr>
<td>9</td>
<td>0.195 ± 0.049</td>
<td>0.188 ± 0.046</td>
<td>0.964 ± 1.0 %</td>
</tr>
<tr>
<td>10</td>
<td>0.192 ± 0.048</td>
<td>0.185 ± 0.031</td>
<td>0.964 ± 0.7 %</td>
</tr>
<tr>
<td>11</td>
<td>0.198 ± 0.052</td>
<td>0.191 ± 0.026</td>
<td>1.037 ± 0.5 %</td>
</tr>
</tbody>
</table>

Table 5: Tests accomplished with radionuclide $^{123}$I to vial geometry correction factor

<table>
<thead>
<tr>
<th>Activimeter</th>
<th>IPEN vial, A1 Initial Activity (GBq)</th>
<th>10R Schott vial, A2 (GBq)</th>
<th>$F_{GC}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.740 ± 0.008</td>
<td>0.737 ± 0.001</td>
<td>0.996 ± 1.5 %</td>
</tr>
<tr>
<td>2</td>
<td>0.737 ± 0.049</td>
<td>0.731 ± 0.007</td>
<td>0.992 ± 0.1 %</td>
</tr>
<tr>
<td>3</td>
<td>0.687 ± 0.005</td>
<td>0.724 ± 0.005</td>
<td>1.054 ± 0.2 %</td>
</tr>
<tr>
<td>4</td>
<td>0.784 ± 0.006</td>
<td>0.718 ± 0.001</td>
<td>0.916 ± 0.2 %</td>
</tr>
<tr>
<td>5</td>
<td>0.747 ± 0.021</td>
<td>0.712 ± 0.018</td>
<td>0.953 ± 0.8 %</td>
</tr>
<tr>
<td>6</td>
<td>0.679 ± 0.012</td>
<td>0.705 ± 0.019</td>
<td>1.038 ± 1.5 %</td>
</tr>
<tr>
<td>7</td>
<td>0.729 ± 0.008</td>
<td>0.699 ± 0.008</td>
<td>0.959 ± 1.0 %</td>
</tr>
<tr>
<td>8</td>
<td>0.755 ± 0.008</td>
<td>0.693 ± 0.011</td>
<td>0.918 ± 1.5 %</td>
</tr>
<tr>
<td>9</td>
<td>0.803 ± 0.011</td>
<td>0.687 ± 0.010</td>
<td>0.856 ± 1.1 %</td>
</tr>
<tr>
<td>10</td>
<td>0.705 ± 0.012</td>
<td>0.681 ± 0.012</td>
<td>0.966 ± 0.6 %</td>
</tr>
<tr>
<td>11</td>
<td>0.874 ± 0.015</td>
<td>0.675 ± 0.007</td>
<td>0.772 ± 0.6 %</td>
</tr>
</tbody>
</table>
Table 6: Calibration factors obtained with radionuclide $^{111}$In for the activimeters under test. Activity on the reference: 0.195 ± 0.029 GBq

<table>
<thead>
<tr>
<th>Activimeter</th>
<th>Measured activity in activimeter under test $M_{\text{Test}}$ (GBq)</th>
<th>Calibration Factor $A_{\text{REF}}/M_{\text{Test}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.191 ± 0.032</td>
<td>1.019 ± 0.038</td>
</tr>
<tr>
<td>2</td>
<td>0.192 ± 0.152</td>
<td>1.013 ± 0.013</td>
</tr>
<tr>
<td>3</td>
<td>0.185 ± 0.033</td>
<td>1.052 ± 0.069</td>
</tr>
<tr>
<td>4</td>
<td>0.194 ± 0.032</td>
<td>1.002 ± 0.047</td>
</tr>
<tr>
<td>5</td>
<td>0.197 ± 0.050</td>
<td>0.990 ± 0.013</td>
</tr>
<tr>
<td>6</td>
<td>0.188 ± 0.049</td>
<td>1.036 ± 0.037</td>
</tr>
<tr>
<td>7</td>
<td>0.188 ± 0.032</td>
<td>1.035 ± 0.071</td>
</tr>
<tr>
<td>8</td>
<td>0.193 ± 0.067</td>
<td>1.007 ± 0.069</td>
</tr>
<tr>
<td>9</td>
<td>0.188 ± 0.046</td>
<td>1.036 ± 0.097</td>
</tr>
<tr>
<td>10</td>
<td>0.185 ± 0.031</td>
<td>1.054 ± 0.068</td>
</tr>
<tr>
<td>11</td>
<td>0.191 ± 0.026</td>
<td>1.020 ± 0.049</td>
</tr>
</tbody>
</table>

Table 7: Calibration factors obtained with radionuclide $^{123}$I for the activimeters under test. Activity on the reference: 0.669 ± 0.013 (GBq)

<table>
<thead>
<tr>
<th>Activimeter</th>
<th>Measured activity in activimeter under test $M_{\text{Test}}$ (GBq)</th>
<th>Calibration Factor $A_{\text{REF}}/M_{\text{Test}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.737 ± 0.001</td>
<td>0.908 ± 0.143</td>
</tr>
<tr>
<td>2</td>
<td>0.731 ± 0.007</td>
<td>0.916 ± 0.137</td>
</tr>
<tr>
<td>3</td>
<td>0.724 ± 0.005</td>
<td>0.924 ± 0.241</td>
</tr>
<tr>
<td>4</td>
<td>0.718 ± 0.001</td>
<td>0.932 ± 0.162</td>
</tr>
<tr>
<td>5</td>
<td>0.712 ± 0.018</td>
<td>0.941 ± 0.841</td>
</tr>
<tr>
<td>6</td>
<td>0.705 ± 0.019</td>
<td>0.949 ± 1.570</td>
</tr>
<tr>
<td>7</td>
<td>0.699 ± 0.008</td>
<td>0.957 ± 1.000</td>
</tr>
<tr>
<td>8</td>
<td>0.693 ± 0.011</td>
<td>0.966 ± 1.387</td>
</tr>
<tr>
<td>9</td>
<td>0.687 ± 0.010</td>
<td>0.974 ± 0.925</td>
</tr>
<tr>
<td>10</td>
<td>0.681 ± 0.012</td>
<td>0.983 ± 0.587</td>
</tr>
<tr>
<td>11</td>
<td>0.675 ± 0.007</td>
<td>0.991 ± 0.483</td>
</tr>
</tbody>
</table>
4. CONCLUSIONS

The results show that the calibration methodology applied in the radiopharmaceutical center production, although presenting difficulties in its execution, shows its importance considering that the calibration factors may present correction until 5% for $^{111}$In and greater than 5% for $^{123}$I.

ACKNOWLEDGMENT

The authors acknowledge the partial financial support of the CAPES, FAPESP, CNPq, CNEN and PCI (Institutional Training Program).

REFERÊNCIAS


