A Mobile Bioassay Laboratory for the Assessment of Internal Doses Based on In Vivo and In Vitro Measurements

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Abstract. Accidental internal exposure may occur in practices such as nuclear power reactor operation, production of radioisotopes and use of unsealed radioactive sources in medicine and research. Such practices require an infrastructure for quick response in the case of nuclear and radiological accidents of a wide range of magnitudes. The goal of this work is to design and calibrate a mobile laboratory for the mitigation of accidents involving workers and population exposure as well as for routine monitoring of internal contamination. The detectors available in the mobile laboratory can identify and quantify photon emitters in the energy range of 100-3000 keV in the whole body, organs or tissues and in urine samples. The system was set up in a truck with internal dimensions of 3.30m x 1.60m x 1.70m. A thyroid monitor consisting of a lead-collimated NaI(Tl)3x3 was calibrated with a neck-thyroid phantom developed at the IRD. Whole body measurements are performed with a NaI(Tl)8x4 calibrated with a plastic-bottle phantom containing standard solutions uniformly distributed among its various sections. Urine samples are measured with a second NaI(Tl) 3x3 detector set up in a steel support. Standard radionuclide solutions were prepared and certified by the National Laboratory for Metrology of Ionizing Radiation (LNMRI) located at the IRD. In vitro measurements of urine samples use a calibration curve of efficiency versus energy for standard volumes. In vivo and In vitro detection limits were converted to committed doses for the radionuclides of interest using current biokinetic and dosimetric models to evaluate the applicability and limitations of the system. Dose detection limits obtained for the activation and fission products of high energy show that the system sensitivity is suitable for use in emergency situations as well as in routine monitoring of workers subject to risk of internal exposure by such radionuclides.

KEYWORDS: Bioassay, Internal monitoring, Internal dosimetry

1. Introduction

Internal monitoring requires methodologies to identify and quantify a variety of radionuclides in the human body. Occupationally exposed workers who manipulate unsealed sources should be monitored in a routine basis established by Radiation Safety Officers responsible for the management of the radiation protection programs of Installations where the risk of incorporation is not negligible [1].

This work is aimed to standardize in vivo and in vitro bioassay methodologies to be used in a mobile laboratory, allowing direct and indirect determination of radionuclides incorporated by humans. The system can be used for the monitoring of workers and public in accidents situations where there is a possibility of internal contamination by significant activities of radionuclides emitting high-energy photons.

In such cases, results of in vivo and in vitro measurements are useful for the estimation of committed effective doses related to the activity incorporated by the individual involved in the accident [2, 3, 4].

2. Materials and Methods

The IRD Mobile Bioassay Laboratory was designed to determine high energy photon emitters in the energy range from 100 to 3000 keV in the whole body, thyroid and in urine samples. The detection systems were installed in a truck with loading capacity of 2 tons and internal dimensions of 3.30-m long x 1.60-m width and 1.70-m high (Fig. 1). The truck is equipped with electric connections for using external power supply. The ambient cooling system operates under 220 V and the detection

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systems require a 110 V line. Thus, it is necessary to park the truck close to an electric power line available in the location where the measurements should be performed.

**Figure 1:** The IRD Mobile Bioassay Laboratory

![The IRD Mobile Bioassay Laboratory](image)

The external power supply guarantees autonomy to perform measurements for long periods if needed in case of emergency situations. It also allows good working conditions for the operators and comfort for the subjects.

In vivo measurements are performed in two geometries, i.e., thyroid and whole body, using one NaI(Tl) 3x3 detector and one NaI(Tl) 8x4. Another NaI(Tl) 3x3 detector, mounted in a lead shield, is used for in vitro measurement of urine samples.

Each detector is connected to an independent portable compact electronic module containing the nuclear instruments, including amplifier, ADC and multichannel analyzer. The outputs from the three detectors are transferred to a single Portable PC where the spectra are analyzed with Genie2000 software [5]. Such configuration allows the execution of simultaneous in vivo and in vitro measurements.

The detectors were calibrated for the determination of $^{137}\text{Cs}$ in the whole body and in urine and $^{131}\text{I}$ in thyroid and in urine using standard solutions of $^{137}\text{Cs}$ and $^{133}\text{Ba}$ supplied by the Laboratory for Metrology of Ionizing Radiation located in the IRD.

Physical anthropomorphic phantoms of whole body and thyroid containing standard sources were used to obtain the calibration factors for each geometry. The dimensions of the original whole body phantom developed in the Laboratory of In vivo Measurements of IRD were base in ICRP 23 [6]. The phantom is made of polyethylene bottles of different volumes and cross sections, arranged to approach a human male adult [7]. However, due to restrictions of the chair geometry adopted in the truck, the calibration was performed using solely the sections representing the thorax, gut and head. In order to maximize the contribution of these sections the NaI(Tl) 8x4 detector was positioned close to the thorax (Fig 2 - left).

The neck-thyroid phantom used for the calibration of the NaI(Tl) 3x3 detector for the measurement of $^{131}\text{I}$ in the thyroid was developed at the IRD In Vivo Monitoring Laboratory. The neck phantom is made of polyurethane-base tissue equivalent material. A filter paper simulating a human thyroid is contaminated with a known amount of $^{133}\text{Ba}$ liquid source. After being sealed with a plastic film, the filter paper is contained in an acrylic part and inserted in the neck phantom. (Fig 2 - right) [8]. The neck-thyroid phantom is positioned on the monitoring chair of the truck using a Lawrence Livermore thorax phantom as a base.

The detection system used for thyroid monitoring is installed in a lead shield in order to minimize possible cross-contributions from other organs. Taking into account the stress under emergency
conditions the in vivo measurement protocol must consider a balance between count time, sensitivity and comfort for the subject being monitored. For that reason, a 10-minutes count time was established with the detector positioned at 26 cm distance.

The calibration of the NaI(Tl) 3x3 detector for the measurement of urine samples was performed using polyethylene bottles of 1 and 2 liters containing standard liquid sources of $^{131}$I and $^{137}$Cs. The volumes were completed with 1M nitric acid. The calibration factors were obtained by positioning the bottles directly on the face of the detector.

**Figure 2:** (Left) calibration of the NaI(Tl) 8x4 for the measurement of $^{137}$Cs in the whole body. (Right) Thyroid phantom developed in the IRD

3. Results

Tables 1 and 2 present the calibration factors of the detection systems installed in the IRD Mobile Bioassay laboratory for in vivo and in vitro measurement of $^{131}$I and $^{137}$Cs.

The minimum detection activities for each radionuclide of interest in thyroid and in the whole body were calculated based on the corresponding calibration factors and in a series of in vivo measurements of thyroid and whole body carried out in a group of non-exposed subjects. The MDA values for the measurement of $^{131}$I in the thyroid and $^{137}$Cs in the whole body were estimated as 351 and 449 Bq for a 10 minutes counting. In the case of urine analysis the MDAs for a 60 minutes counting were estimated as 12 Bq for $^{131}$I and 10 Bq for $^{137}$Cs.

**Table 1:** Calibration factors for the measurement of $^{137}$Cs in the whole body and $^{133}$Ba in thyroid

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Detector</th>
<th>Geometry</th>
<th>CF (Bq/cpm)</th>
<th>Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{137}$Cs</td>
<td>NaI(Tl) 8”x4”</td>
<td>Whole body</td>
<td>3.62</td>
<td>1.7</td>
</tr>
<tr>
<td>$^{133}$Ba</td>
<td>NaI(Tl) 3”x3”</td>
<td>Thyroid</td>
<td>7.95</td>
<td>1.9</td>
</tr>
</tbody>
</table>

**Table 2:** Calibration factors for the measurement of $^{137}$Cs and $^{133}$Ba in urine using NaI (Tl)3”x3”

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Geometry</th>
<th>CF (Bq/cpm)</th>
<th>Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{137}$Cs</td>
<td>1L</td>
<td>2.76</td>
<td>1.9</td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>2L</td>
<td>4.02</td>
<td>2.1</td>
</tr>
<tr>
<td>$^{133}$Ba</td>
<td>1L</td>
<td>3.33</td>
<td>1.6</td>
</tr>
<tr>
<td>$^{133}$Ba</td>
<td>2L</td>
<td>3.63</td>
<td>1.7</td>
</tr>
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4. Conclusions

As shown in Table 3, the values of Minimum Detectable Effective Dose (MDED) for in vivo and in vitro measurements using the detection systems available in the Mobile Bioassay Laboratory are far below 1 mSv for both incorporations by inhalation or ingestion. The dose calculations were performed using the software AIDE [9] assuming that the measurements should be carried out 1 day after the incorporation.

Table 3: Sensitivity of the detection systems installed in the IRD Mobile Bioassay Laboratory

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Measurement condition</th>
<th>MDA (Bq)</th>
<th>MDED&lt;sup&gt;a&lt;/sup&gt; (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Inhalation</td>
</tr>
<tr>
<td>I&lt;sup&gt;131&lt;/sup&gt;</td>
<td>Thyroid -10 minutes</td>
<td>351</td>
<td>3.06 x 10&lt;sup&gt;-2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cs&lt;sup&gt;137&lt;/sup&gt;</td>
<td>Whole body - 10 minutes</td>
<td>449</td>
<td>5.04 x 10&lt;sup&gt;-3&lt;/sup&gt;</td>
</tr>
<tr>
<td>I&lt;sup&gt;131&lt;/sup&gt;</td>
<td>1-Liter Urine -60 minutes</td>
<td>12</td>
<td>4.54 x 10&lt;sup&gt;-4&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cs&lt;sup&gt;137&lt;/sup&gt;</td>
<td>1-Liter Urine -60 minutes</td>
<td>10</td>
<td>8.44 x 10&lt;sup&gt;-3&lt;/sup&gt;</td>
</tr>
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</table>

<sup>a</sup>Minimum Detectable Effective Dose

Based on the sensitivity expressed in terms of minimum detectable committed effective dose equivalent for each measurement condition, it can be concluded that the Mobile Bioassay Laboratory is suitable for the monitoring of occupationally exposed workers and for public screening in accident situations involving the release of I<sup>131</sup> and Cs<sup>137</sup> to the environment.

REFERENCES