Estimated of the associated uncertainties with the linearity test of activimeters

C H S Sousa¹, G J Teixeira² and J G P Peixoto³
¹Medical Physicist, PhD student at Instituto de Radioproteção e Dosimetria
²Radiology Technologist, PhD student at Instituto de Radioproteção e Dosimetria
³Physicist, PhD at Instituto de Radioproteção e Dosimetria
IRD/CNEN, Salvador Allende av, Recreio dos Bandeirantes, Rio de Janeiro, RJ, Br
E-mail: chenrique@ird.org.br, gt@ird.gov.br, guilherm@ird.gov.br

Abstract. Activimeters determine the activity of radioactive samples and are validated by performance tests. This research determined the expanded uncertainties associated with the linearity test. We used two activimeters and a source of $^{99}$Tc for testing recommended by the IAEA protocol, which consider the decay of radioactive samples. The expanded uncertainties evaluated were not correlated with each other and our analysis considered a rectangular probability distribution. The results are also presented in graphical form by the function of normalized activity measured in terms of conventional true value.

1. Introduction
The knowledge of measurement, either by adjustments, conditionings or indications of instruments, is used for obtaining the value of a phenomenon, body or substance that can be qualitatively distinguished and quantitatively determined called quantity [1]. To determine it, it is necessary to mention the associated uncertainty to the result, which characterizes the dispersion of values around a mean and can be expressed as a standard deviation or half of an interval corresponding to a confidence level stated.

The activimeter is an instrument used in nuclear medicine services for measuring the activity of radioactive materials. It is basically constituted by a well ionization chamber and an associated electronics, which measure and record the ionization current produced by the interactions created from the radiation emitted from samples. They are adjusted at the factory, using a set of standard reference sources, certified and tracked, enabling the determination of the calibration curve of different radionuclides.

The characteristic response of a activimeter depends on the intrinsic nature and pressure of the gas, the material and thickness of the wall chamber [2,3]. The detector consists of two cylindrical coaxial electrodes, contained in a sealed space, filled with a gas under pressure that serves as the ionizing medium. The associated electronics convert the ionization current measured in signal voltage, amplifies it, processes and displays in a digital readout in units of activity. However, the instrument response depends on other factors that may influence the outcome of the measurements, such as different energies and emission rates of photons of various radionuclides to be measured.

According to the technical recommendations [4], all the instrumentation used in diagnostics or therapeutics nuclear medicine services must periodically pass through performance tests, which will
attest the functional conditions of the instruments, focusing on the precision of the measurement and consequent reduction in probabilities of radiobiological interactions.

The linearity test is an acceptance test, which should define the measurement range in which the instrument has a linear response as a function of activity [4], however, their result can not be submitted separately, since it depends directly or indirectly another parameters that can influence the final result of the test. Therefore, the objective of this work was the analysis of the metrological of the linearity test for activimeters focusing on determining uncertainties.

2. Materials and methods

2.1. Materials

As suggested by the literature, radionuclide Technetium-99m (\(^{99}\text{Tc}\text{m}\)) [4], was used because it is an element gamma emitter with a relatively short half-life. The sample was obtained through a single elution of \(^{99}\text{Tc}\text{m}\) generator system, resulting in an initial activity of 66.6 gigabequereis to a declared volume of 6 ml. The material was collected in a vial P6 obtained from the Instituto de Pesquisas Energéticas e Nucleares – IPEN[5].

Two activimeters were selected for these study doses, the first detection system is provided by an ionization chamber [6], of approximately 6.400 cm cubic filled with argon in a pressure of 13 psi and a holder made in polymethylmethacrylate (PMMA). The other one a detector system, equipped with two tubes Geiger Muller [7] in opposed positions to measure the radioactive sources between them. The most relevant features of these instruments are listed in Table 1.

| ACTIVIMETERS | A | B |
|--------------|---|---|
| Range (MBq)  | Min $7,0\times10^{-4}$ | $0,37$ |
|              | Max $7,0\times10^{5}$ | $3,7\times10^{4}$ |
| Resolution (MBq) | $0,001$ | $0,370$ |
| Accuracy (%)   | $\pm 2,0$ | Ni |
| Precision (%)  | $\pm 0,1$ | Ni |
| Linearity (%)  | $\pm 2,0$ | 3,4 |
| Response time (s) | $\approx 10$ | $\approx 50$ |
| Dimension (cm) | 17 X 26 | 2 GM |
| Display        | 4 | 4 |
| Shield         | 3,0 | 6,4 |
| Detector       | IC\(^b\) | GM\(^c\) |

\(^a\)Dosimetric reference  
\(^b\)Ionization chamber  
\(^c\)Geiger-Müller

2.2. Methods

The method defined and applied was the source decay, where measurements of the sample activities were compared to the true conventional values calculated for radionuclide decay. Three measurements series were performed every 3 hours during 105 hours and their standard deviations calculated [8].
Before starting the measurements there was an adjustment to zero for background radiation and input voltage were checked. The background radiation was subtracted from the value measured for evidence net metering. The vial, which containing radioactive sample, was positioned in the holder over the chamfered mark. The time set for each measurement was 15 seconds the same defined for system stabilization between the measurements.

The values were recorded and entered into a spreadsheet to make a log-linear graph, which already contained the conventional true values (CTV) of the activity corrected for source decay. The analysis also considered the measurement value standardization, which was defined as the ratio (R) result of the measured activity (Aa) by source reference activity corrected by the time of measurement (Ca), (equation 1). The average was applied to the end of the test to obtain the percentage deviation.

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R = \frac{Aa}{Ca}
\]  

This study did not consider the environmental conditions of the laboratory, because sealed ionization chambers were used, and factors such as temperature, relative humidity and atmospheric pressure are not significant [9].

Type A uncertainties were defined as the percentage standard deviation of the measurement of linearity tests (\(\sigma_L\)) and background radiation (\(\sigma_b\)) because their repeatability. The probability distribution of these tests was described as rectangular due to marking ± 10% as determined by the technical document.

All the other parameters and contributions such as accuracy (\(\sigma_a\)), precision (\(\sigma_p\)), reproducibility (\(\sigma_r\)), the resolution (\(\sigma_{res}\)), radionuclides impurities (\(\sigma_i\)) and volume (\(\sigma_v\)), had their standard deviations and percentages recorded considered as type B uncertainties, emphasizing that testing accuracy, precision and reproducibility have been previously applied to the linearity test.

3. Results and discussions
The results of the performance tests of the instruments analyzed were described as percentages for a posterior determination of the value uncertainties uncorrelated to the tests. The amplitude of the measures of the reproducibility test performed with the standard reference source 137Cs was 1.8% for the calibrator A and 6.8% for the calibrator B, but these value are not so certain as the uncertainties associated with testing.

The calculation of the average measurements and standard deviations for the linearity test found that both instruments have a linear response within the acceptance limits recommended. After the application of Equation 1, the results were easier to be viewed graphically (figure 1).

Performance tests on both instruments showed concordant results with the limits of acceptability and are presented in Table 2. The combined standard uncertainty for the calibrator, equipped with IC was estimated at 3.802% with an expanded uncertainty (U) of 8.802% to a degree of freedom (k) equal to 2.32 (Table 2). The instrument B, with 2 GM tubes, presented a combined standard uncertainty of 9.02% with an expanded uncertainty (U) of 19.69% for a degree of freedom (k) was 2.18 (Table 2).

4. Conclusions
After analyzing the results, we conclude that volume and radionuclide impurities were considered important in estimating of associated uncertainties of the linearity test. The activimeter A, showed an uncorrelated expanded uncertainty lower than 4.0% and the activimeter B an uncorrelated expanded uncertainty below 10.0%. The possibility of correlation between the quantities can influence the final results. The results obtained in this study refer exclusively related to this research instruments and under the same conditions, it is not our goal, set or recommend the use of any type of instrument.
Figure 1: Graph linearity tests and standard deviations of activimeters A and B, showing percentage results in the dotted area representing the lower and upper bounds for this parameter.

Table 2: Results of the percentual standard deviation from performance tests, types of probability distributions adopted for each test and the results of the estimation of uncertainties.

| Quantity      | Distribution | N   | ACTIVIMETER A Type A | ACTIVIMETER A Type B | ACTIVIMETER B Type A | ACTIVIMETER B Type B |
|---------------|--------------|-----|----------------------|----------------------|----------------------|----------------------|
| Background    | normal       | 10  | 0,052                | 3,82                 |                      |                      |
| Accuracy      | normal       |     | 0,097                | 0,46                 |                      |                      |
| Precision     | normal       |     | 0,020                | 0,48                 |                      |                      |
| Reproducibility | normal     |     | 0,046                | 1,21                 |                      |                      |
| Volume        | normal       |     | 0,043                | 0,04                 |                      |                      |
| Impurities    | normal       |     | 0,003                | 0,01                 |                      |                      |
| Resolution    | normal       |     | 0,004                | 1,62                 |                      |                      |
| Linearity     | rectangular  | 10  | 3,8                  | 7,9                  |                      |                      |
|               | combined standard uncertainty | 3,802 | 9,02               |                      |                      |
|               | expanded uncertainty   | $U = 8.820$ | 19,69            |                      |                      |
|               | $k = 2.32$               | 2,18                       |                      |                      |

results in percentage

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