Characterization of a spectrometric system with NaI(Tl) for ensuring traceability of radiopharmaceuticals

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Abstract. In radiopharmaceutical production centres and nuclear medicine services, short half-life radionuclides are essential. They are used as radiotracers since its uses have increased significantly and they have aroused the interest of national metrology laboratories, which are responsible for providing traceability to radioactive standards. Therefore, knowledge of the activity of administered radiopharmaceuticals must be obtained accurately. However, their short half-lives prevent the provision of traceability. To overcome these obstacles, an itinerant system based on a scintillator detector of the NaI(Tl) type is being developed at the National Laboratory of Metrology of Ionizing Radiations (LNMRI). This work aims to show the schematic arrangement of the system developed and to perform the characterization tests of its parameters in order to ensure traceability of the main radiopharmaceuticals used in nuclear medicine services.

Key-words: radionuclide metrology, activimeters, NaI(Tl) arrangement, characterization

1. Introduction

There is a pressing need to calibrate activimeters used in nuclear medicine practices. This equipment calibration is one of the main regulatory requirements to authorize the operation of radiopharmacies in nuclear medicine production centers and services [1]. Difficulties and limitations appear due to the properties of radiopharmaceuticals, mainly due to their short half-lives that prevent the use of radioactive standards in-situ [2]. To overcome these obstacles, the National Laboratory of Metrology of Ionizing Radiations (LNMRI) is developing an itinerant system to provide traceability of radiopharmaceuticals based on a scintillator detector of the NaI(Tl) type [3].

NaI(Tl) type detection systems that are widely used in the form of radiation monitors in different applications and installations can provide relevant information about the activity of radioactive sources to operators and users, mainly due to their conditions of portability, robustness and accuracy in the data obtained. In this sense, they are widely used as relative calibration systems in metrology laboratories for measuring monoenergetic gamma emitting sources.

Experimental tests and comparisons were made in this study to evaluate the performance of the NaI(Tl) detection system in order to ensure the provision of traceability for different radionuclides that have a simple decay scheme and emit gamma radiation between 100 and 660 keV [4] . This energy

range is predominant in most radiopharmaceuticals supplied by production centers and used in hospitals and clinics for diagnosis or treatment.

Standards of ^{241}Am and ^{137}Cs were tested to verify the main parameters that indicate their performance, such as: environmental conditions, dead time, calibration energy, background radiation, resolution energy, test for sample positioning, detection efficiency and minimum activity detectable (AMD). The characterization results will demonstrate the potential use of the proposed system to provide traceability of the main radiopharmaceuticals used in nuclear medicine services.

2. Materials and methods

Some of the parameters used to characterize scintillator detectors of the NaI(Tl) type will be addressed, with the main focus on their ability to measure with precision and accuracy gamma radiation emitters considering above all the main radiopharmaceuticals used in the country's production centers or clinics and hospitals. which are administered to users.

This characterization shall be performed and documented to demonstrate that the sodium iodide gamma spectrometry system meets specifications and is fit for purpose.

2.1 Calibration system arrangement.

The system arrangement consisted of an inorganic NaI(TI) 2.44 x 4.25 inch OSPREY – DTB (Canberra) portable planar scintillator detector, as shown in figure 1. The Osprey has a multichannel analyzer tube (MCA) that supports scintillation spectrometry. Designed for laboratory and field use, this compact system contains a high voltage power supply (HVPS), preamplifier and a full digital MCA. Spectra are obtained using a Genie 2000 type data acquisition and analysis program, which can be automatically adjusted to a threshold for low energy, defining the start and end of the spectrum, as seen in figure 1a.

The crystal is coupled to a photomultiplier plus associated electronics, the detector being supported by a tripod using an aluminium ring adapted for position adjustment. As shown in figure 1b, the detector is surrounded by a thin layer shielding of lead, tin and copper, necessary to attenuate the radiation of photons of low energies of the spectrum. The adopted arrangement can be controlled by USB or Ethernet, with only one connection cable for the control and data acquisition system [6].

The standard LNMRI radioactive sources used in the tests were point and bulb types for ^{241}Am (59.5 keV) and ^{137}Cs (661.7 keV). The activities were 8 kBq – 45 kBq, point and 9 kBq g^{-1} and 47 kBq g^{-1} for vial geometry, respectively. These sources were positioned directly above the top of the detector using PVC supports specially made for the system, as shown in figure 1c.

To carry out the counts, a measurement time of 2000 s was used for background radiation and 100 s for radioactive sources, time necessary to obtain uncertainties lower than 1%.

Figure 1- Arrangement of the gamma spectrometry system with NaI(TI), assembled for characterization.

2.2 System performance characterization

The main characteristic parameters, performance indicators, that should be tested include:

— Effects of varying environmental conditions on results, such as temperature, humidity and atmospheric pressure, which can be achieved by monitoring the results of quality control checks over an extended period.

— Dead time, related to the accuracy of the correction technique, defined by the difference between real time and live time. According to the ISO 20042 Standard, a dead time of less than 10% is normally sufficient to perform calibrations in energy and less than 5% for other measurements [7].

—Energy calibration, which identifies different radionuclides by their emission energy. Calibration for photopeaks of unknown energies is done via a microcomputer, once the number of each channel is known, where the photopeak appears, according to:

$$E = aX + b$$

where: E is the energy of the gamma radiation (59.5 keV – ^{241}Am; 661.7 keV – ^{137}Cs); and X for the channel number.

— Background radiation, which considers not only the events in the spectrum that form a smooth curve on which the photopeaks are superimposed, but also the contribution of external environmental radiation to the detection system.

The number of counts in the photopeak is calculated by summing the total number of counts in a region of interest around the photopeak and subtracting the counts from the continuous background radiation. The total number of counts is given by:

$$N = \sum_{i=L}^{H} C_i$$

where: N is the total number of counts from the L (lowest) channel to the H (highest) channel in the region of interest; C_i is the number of counts on channel number i.

Assuming that the continuous background radiation to the photopeak is linear, the background radiation in the same region of interest is given by:

$$B = \frac{n(C_L + C_H)}{2}$$

where: B is the number of background radiation counts from the L channel to the H channel; n is the number of channels in the region of interest ($n = H - L + 1$) [7].

— Energy resolution (FWHM), which allows the detector to separate two neighbouring photopeaks. This test must be carried out in the energy range of interest for measurements. The resolution (R_i), indicates the ability of the system to discriminate radiation with similar energies in the spectrum, is given by the expression:

$$R_i = \left(\frac{T_i}{E}\right) 100\%$$

where: T_i is the width at the i-th height, in energy units, of the photopeak of interest; E is the photopeak energy; and i for: 1/2 for width at half height; 1/10 for width at one-tenth of the height and 1/50 for width at one-fifth of the height. According to the equation, we have:

$$R_i = a\,(\frac{C_R - C_L}{E})100\%$$

where: C_R and C_L are the channel numbers on the right and left sides of the peak taken at the i-th part of the maximum count value [7].

—Positioning for the adopted counting geometry, consists of the degree of agreement of the results obtained in different measurement conditions associated with the positioning of the sample. The reproducibility of counts or, where applicable, total energy photopeak efficiencies should be checked periodically using a reference source with a long half-life, emitting gamma rays covering the energy range of interest [7, 8].

—Detection efficiency, which specifies the number of photons detected in the photopeak in relation to the number of emitted photons as a function of emission energy. The experimental efficiency must be calculated as a function of energy, according to the relationship:

$$\varepsilon(E_i) = cps\,\frac{E_i}{A_{(p)}.I(E_i)}$$

where: *cps* (E_i) is the counting rate in each energy; $A_{(p)}$ is the activity of the standard corrected for the reference date, in Bq; and $I(E_i)$ is the gamma emission intensity for each energy of interest [9].

For this characterization, two radioactive standards of the same nature can be used (^{137}Cs in vial geometry in this case), considering one of them as a reference source and the other as a sample, in order to compare and then verify the consistency of the results obtained. in terms of Activity, corrected for the reference date.

—Characteristic thresholds, such as minimal detectable activity (AMD), for low activity measurements, indicates limitations of the measurement. They are used to decide whether or not activity is present in the sample and to estimate the sensitivity of the measurement. Therefore, they depend on the measurement system, the background radiation and the detection efficiency for a given energy. In measurements with environmental samples or from places with natural radioactivity, it is common to know the minimum detectable activity, which corresponds to the lowest activity concentration value that the sample must contain for the detection of a given radionuclide to be possible, depending on the characteristics of the measurement system and the analytical methods adopted [10]. According to the specialized literature, this AMD for a given radionuclide can be expressed by:

$$AMD = \left[4{,}66.\frac{\sqrt{B_k}}{\varepsilon.I.m.\Delta t} \right]$$

where: *AMD* is the minimum detectable activity concentration for the radionuclide, given in Bq.kg^{-1}; B_k is the area of counts corresponding to background radiation in the region of interest of k-gamma energy; ε is the detection efficiency interpolated into the curve for the considered gamma energy; I is the probability of emission of the gamma photon by disintegration (intensity), obtained from an updated nuclear data table; m is the mass of the sample, in kg; and Δt is the measurement time interval (live time), in seconds [11].

It is important to emphasize that a quality control and maintenance program must be defined, together with the operating procedure. However, other tests can be performed as recommended by the manufacturer, such as peak-Compton ratio.

In order to analyse the performance of these parameters, appropriate statistical tests (such as control charts, ANOVA, Chauvenet data rejection test) were used to demonstrate compliance with the expected specifications for the spectrometry system [12, 13 and 14].

3. Results

The analysis of the results describes by statistical methods the behavior and performance of the proposed calibration system for each selected parameter.

3.1- Effects of variation in environmental conditions temperature, humidity and atmospheric pressure

These parameters were monitored for a certain interval of time and, according to the technical specifications contained in the equipment's operating manual, they remained strictly within the respective ranges specified by the manufacturer, demonstrating the robustness of this measurement system in the face of parameter variations. environmental.

3.2 Dead time

The dead time for all the measurements carried out in this system did not exceed the value of 3.9%, indicating that, according to Standard 20042, in energy calibration this must be less than 10% and that for the other measurements this dead time must be less than 5%. So that for all the experimental measurements carried out here, the dead time remained adequate sufficiently.

3.3 Energy calibration

The energy calibration was carried out with the energies of 59.5 and 661.6 keV, making it possible to identify the radionuclides ^{241}Am,^{137}Cs by their emission energies according to the number of each channel where the photopic appears. This energy range was chosen since it covers the region where the emission of the main radiopharmaceuticals predominates.

3.4 Background radiation

For the background radiation figure 2 shows the results of the control chart of individual values and moving amplitude. The data obtained for background radiation show that the points remained between the upper and lower control limits.

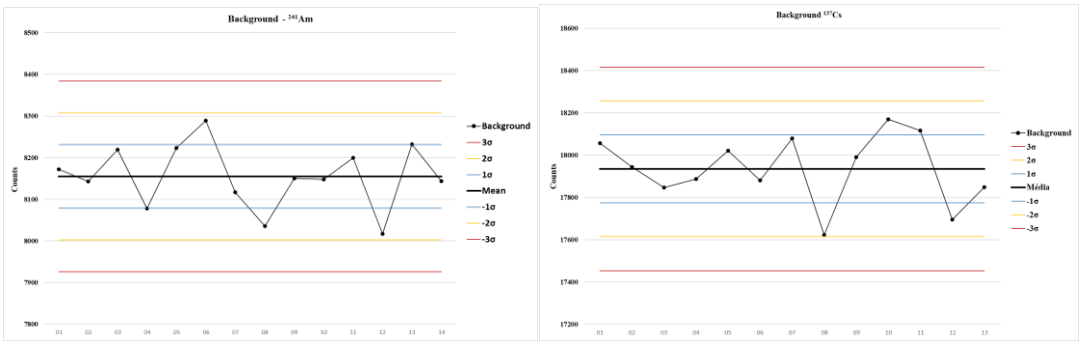

Figure 2 - Background behaviour for ^{241}Am and ^{137}Cs sources using a control chart.

Therefore, there was no significant contribution from external environmental radiation to the detection system, showing that the background radiation is under control and must be considered in the corrections of the measurements to be carried out.

3.5 Energy resolution

Measurements were performed for the energies of 59.5 and 661.7 keV for the resolution control (FWHM) of the proposed system. Figure 3 presents the Control Chart, which shows the good capacity of the measurement system to discriminate the energies in the spectra obtained within the considered interval. The range considered is within the expected specifications for NaI(TI).

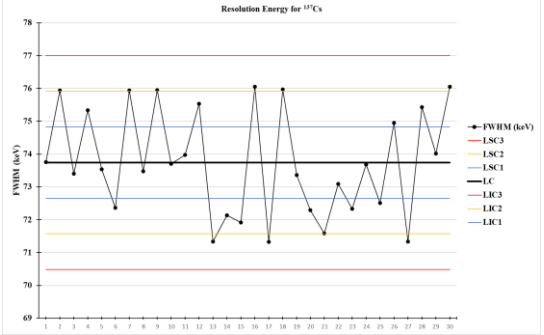

Figure 3- FWHM behaviour for a ^{137}Cs source

3.6 Sample placement test

Four different positions were taken for the set of vials and sources supports with half-life radionuclide in vial geometry. In each position, 10 measurements were performed. The applied statistical test (ANOVA, F test) verified that the averages obtained in each position are considered significantly equal, according to tables 1 and 2. Therefore, there is no variation in the positioning of the samples for the liquid standard of ^{137}Cs adopted, indicating a degree of agreement of the results obtained under different measurement conditions.

Table 1- Measurements obtained for the study of the positioning of the ^{137}Cs source.

Group	*Measurements*	*Counting*	*Mean*	*Variance*
Position 1	10	2322597	232259.7	1251298.90
Position 2	10	2318030	231803.0	550089.78
Position 3	10	2321625	232162.5	1130854.28
Position 4	10	2319312	231931.2	1424076.62

Table 2 – F-statistical test, analysis of variance indicating that the means obtained in table 1 are significantly equal.

Variation	*SQ*	*gl*	*MQ*	*F*	*value-P*	*F critic*
Between groups	1312775	3	437591.80	**0.402**	**0.753**	**2.866**
Within of groups	39206876	36	1089079.89			
Total	40519652	39				

According to the F Test (ANOVA) used for a ^{137}Cs reference source, in which the F value is much lower than the critical F value. Then, the means are significantly equal for the 4 variations taken, with regard to the positioning test.

3.7 Detection efficiency

For this characterization test, two-point radioactive standard sources of ^{137}Cs and ^{241}Am certified by LNMRI were used. One as a sample and the other as a reference. The answer to these results can be seen in Table 3, where the adequacy of the Activity values was observed, indicating consistency for efficiencies as a function of energy. Total uncertainties are in percentage and Δ indicates the percentage deviation from the certified value.

Table 3 - Values of Activities in relation to a radioactive standard

Radionuclide	Measurement value (kBq g^{-1})	Certified value (kBq g^{-1})	Δ (%)
^{241}Am	7.79 ± 1.1	7.73 ± 0.32	-0.7
^{137}Cs	24.26 ± 1.0	24.53 ± 0.49	1.1

3.8 Characteristic limits, AMD

Here AMD for ampoule geometry was determined for ^{241}Am and ^{137}Cs, whose values obtained were respectively 4 and 9 Bq at the reference date. These values demonstrate the minimum capacity of this system to detect and determine the activity of radiopharmaceuticals. Evidently, the maximum detection capacity is limited by the dead time of less than 5%.

4. Conclusion

The control parameters adopted here proved to be adequate to evaluate the performance regarding the characterization of the proposed detection system. According to the monitoring carried out for the performance parameters, via statistical tests, Control Charts, comparison between detection efficiencies and monitoring of environmental conditions, these proved to be compatible, not only in relation to portability conditions, but also robustness and precision in the data obtained for the presented system.

In short, this phase of characterizing the spectrometric array demonstrated the potential and ability of the proposed system to provide in the future radiopharmaceuticals calibration *in-situ* which will be applied in the activimeter standardization used in nuclear medicine services.

5. References

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