# Ionizing radiation metrology at the service of health: quality control of radiopharmaceutical dose calibrators in nuclear medicine unit -accurarcy,reproducibility and linearity tests-

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***Abstract*—Ensuring the effective use of a dose calibrator used for the practice of nuclear medicine, and the injection of the correct dose to the patient is the subject of a long traceable calibration chain, which serves to establish the relationship between the values of the activity indicated by the dose calibrator and the activity corresponding to ISO 2919 certified sealed sources whose activity is known with an uncertainty of less than 1 %.**

**Our calibration program consists in carrying out various quality control on the CRC 55TR activimeter, namely the daily control which is carried out in the absence of any radioactive source, then the fidelity control carried out by a source of $^{37}$Cs and a source of $^{60}$Co , then the reproducibility check performed with a 137Cs source, and finally the linearity check performed with a $^{99m}$Tc source.**

**In our case the results obtained from the specific tests used to verify the proper functioning of the Capintec CRC 55tR activimeter in a nuclear medicine service in Morocco, shows an agreement with international standards so that the measurement of activities is done with significant results, in addition, to guarantee the metrological quality of the measurements delivered, Our laboratory registers in an accreditation process according to ISO 17025.**

***Keywords—nuclear medicine, quality control, activimeter, ionization, radiation, radiation protection***

## I. INTRODUCTION

Patient safety in nuclear medicine services is the responsibility of all professionals in the domain. Due to the fact that radionuclides used for diagnostic and therapeutic purposes are produced artificially by cyclotrons and nuclear reactors, with short half-lives and are not sealed sources, their handling must be carried out in accordance with national and international radiation protection recommendations [1]. So, it necessary to upgrade a quality control program for measuring the activity of radiopharmaceuticals before being injected in the patient's body as required by the Moroccan LAW N ° 2.79. Indeed, the accurate assay of activity prior to administration is required to assure that patients receive the correct radiopharmaceutical dosage. The appropriate instrument for this task is the activimeter which measures the activity of radionuclides before administration to patients, and which must always be in good operating condition to ensure efficiency, safety and reliability of the results. This work aims to qualify the performance of the Capintec CRC-55tR activimeter which is located in a nuclear medicine service, through preliminary quality control tests which are daily monthly and annual ones, while respecting international standards

## II. LITERATURE REVIEW

The activimeter's components are a cylindrical ionization well-type chamber which maximizes the number of photons crossing the sensitive volume filled with an inert gas (Argon) under a given pressure, an electrometer used to measure the intensity of the ionization current quantifying the activity of the radionuclide, and a high voltage supply between 100 and 400 volts, that it is high enough to collect most ion pairs, and low enough to avoid causing secondary ionization, and associated electronics for calculating and displaying activity.

When the ionizing radiation enters in the chamber, it ionizes the gas creating a pair (electron, ion). The positive ions created migrate towards the cathode because of the electric field and the electrons will migrate towards the anode and there will be a production of an electric current flowing towards the electrometer. The measured current values are converted into activity values using the corresponding calibration factor [2,3].

It is very important to carry out a qualification of the activimeters since the precision of the radiopharmaceutical

dose delivered to a patient depends on the functioning of the activimeter.

Quality control tests are provided by the International Atomic Energy Agency and include accuracy, reproducibility and linearity tests [4]. These tests are designed to ensure the activimeter and the results obtained while respecting the limits of exposure to ionizing radiation provided by the principles of Radiation Protection: the justification of the practice, the limitation of exposures, and the optimization of radiation protection, whether for patients or workers[5].

## III. MATERIEL AND METHODS

In this work, daily control, accuracy, reproducibility, and linearity tests concern a computerized Capintec Ref CRC55TR activimeter of a nuclear medicine service.

Fig. 1. Activimeter model CRC-55tR

In this first part of the quality control of the activimeter, the following sealed and certified sources constancy were used to carry out accuracy, reproducibility, and linearity tests:

TABLE 1. DESCRIPTION OF SOURCES

| Radionuclide | **Energy (keV)** | **Half-life** | **Initial activity** |
|---|---|---|---|
| $^{137}$Cs | 662 | 30 y | 195,3 µCi |
| $^{57}$Co | 122 | 271,77 d | 10.94 mCi |
| $^{99m}$Tc | 141 | 6.0067 d | 34.9 mCi |

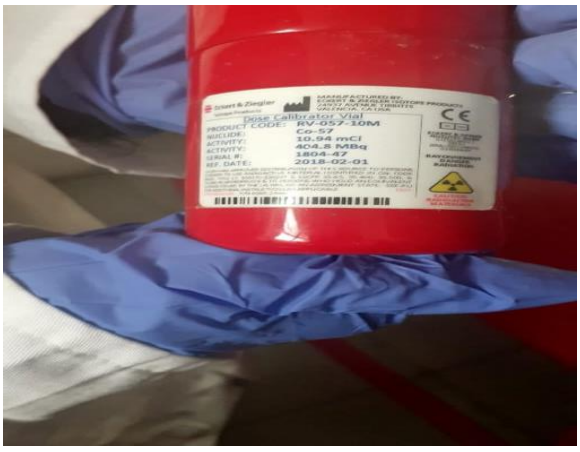

Fig. 2. Source of Co-57 used in this work.

The quality control consists of a daily, rapid control, covering all the elements of the activimeter and carried out before the preparation of radiopharmaceuticals, a monthly control to check the accuracy of the activimeter for the all the calibration factors and an annual check. Before any measurement, it is imperative to check the absence of radioactive sources near the activimeter and contamination [6].
These tests consist of an Auto Zero operation, a Background adjustment, a Chamber Voltage test, accuracy, reproducibility, and linearity check

### A. *Daily test*

This device allows us an automatically checking and confirmation of the measurement results by using the "DAILY" key, so the program starts the checks, then following the preprogrammed steps.

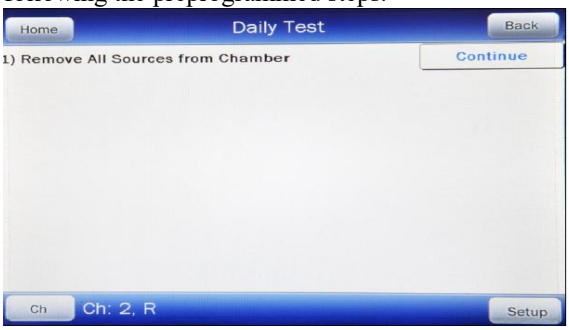


Fig. 3. Activimeter screen in daily test

This test is done in the absence of any radioactive source.

#### 1) *Auto zero*

If the measured value drifted by more than ± 0.30 mV since the last measurement, the message "ZERO DRIFT" is displayed, and if the measured value is out of range (> ± 10 mV), the message "ZERO OUT OF RANGE" is displayed [7].

#### 2) *Background*

Always in the absence of any source, the second part of the daily test is the measurement of the background. The OK button is pressed to accept the result of the auto zero and continue the daily test. A progress of the bar will appear until a measurement is available. When the measurement is available, the result of the background measurement will appear. If the background is high but still acceptable ("R" Chambers: > 16.9µCi [0.625MBq] to < 500µCi [18.5MBq]; "PET" Chambers: 191.4µCi [7.08MBq] to 5.66mCi [209.4MBq]), the message "HIGH" will appear next to the measurement. Although the value is acceptable, the reason for the high value should be investigated. If any sources are found nearby, repeat the measurement. [7]

#### 3) *Chamber voltage*

The measurement of the polarization voltage of the activimeter is compared to the value entered at the factory. If the result is out of range, the message "FAIL" appears on the screen [7]

### B. *Accuracy*

This test consists in choosing two different sources one in the range of medium energies, and the other for the low

energies. In the present work the two sources are $^{137}Cs$ and $^{57}Co$.

The source being placed in the well chamber, and 12 activity measurements were carried out, while calculating the relative difference between the certified activity and the measured one, and the ratio of these two quantities makes it possible to clarify the correction factor:

$$Fc = Certified\ activity / calculated\ activity \quad (1)$$

### C. *Reproducibility*

This test consists of placing the source of $^{137}Cs$ in the well chamber, performing 30 measurements of the activity, during the day, the source is removed and then placed back in the chamber each time, while calculating the relative deviation between the certified activity and the obtained activity.

### D. *Linearity*

This test consists of placing the $^{99m}Tc$ source in the well chamber over a day, and reading the activity value regularly, the Capintec CRC 55tR activimeter does this work automatically, and then calculate the deviation between the measured values and the reference value

## IV. RESULTS AND DISCUSSION

### A. *Daily test*

The auto zero is very close to zero, the background is very small and less than 0.62 MBq, and the chamber voltage

measurement is compared to the value entered at the factory, the message "Passed" appears on the screen the computerized activimeter which proves that the test result is good.

### B. *Accuracy*

TABLE1. MEASUREMENT PERFORMED WITH THE SOURCE OF $^{137}Cs$

| n° measure | A, measured | | | A, theoretical(uCi) | difference |
|---|---|---|---|---|---|
| | A,Min | A, Max | Average | | |
| 1 | 141,2 | 141,6 | 141,4 | 139 | 2,4 |
| 2 | 141,5 | 141,9 | 141,7 | 139 | 2,7 |
| 3 | 140,9 | 141,1 | 141 | 139 | 2 |
| 4 | 140,7 | 141,1 | 140,9 | 139 | 1,9 |
| 5 | 140,2 | 140,7 | 140,45 | 139 | 1,45 |
| 6 | 141 | 141,3 | 141,15 | 139 | 2,15 |
| 7 | 141,5 | 141,6 | 141,55 | 139 | 2,55 |
| 8 | 141 | 141,7 | 141,35 | 139 | 2,35 |
| 9 | 140,9 | 141 | 140,95 | 139 | 1,95 |
| 10 | 140,6 | 140,7 | 140,65 | 139 | 1,65 |
| 11 | 140,3 | 140,6 | 140,45 | 139 | 1,45 |
| 12 | 140 | 140,47 | 140,235 | 139 | 1,235 |
| average | | | 140,982 | | |
| average deviation | | | 1,982 | | |

TABLE 2. RESULT CORRESPONDING TO THE ACCURACY TEST WITH $^{137}Cs$ SOURCE

| medium energy | |
|---|---|
| Source ($^{137}Cs$ ) | |
| Reference activity (µCi) | Average measured activity (µCi) |
| 138,23 | 140,98 |
| Correction factor Fc | |
| 1,02 | |
| Deviation | |
| 1, 9% | |

TABLE3. MEASUREMENT PERFORMED WITH $^{57}Co$ SOURCE

| n° measure | A, measured | | | A, theoretical (uCi) | difference |
|---|---|---|---|---|---|
| | A,Min | A, Max | Average | | |
| 1 | 682 | 683 | 682,5 | 690,9022559 | 8,40225589 |
| 2 | 680 | 684 | 682 | 690,9022559 | 8,90225589 |
| 3 | 694 | 694 | 694 | 690,9022559 | 3,09774411 |
| 4 | 680 | 684 | 682 | 690,9022559 | 8,90225589 |
| 5 | 681 | 684 | 682,5 | 690,9022559 | 8,40225589 |
| 6 | 684 | 687 | 685,5 | 690,9022559 | 5,40225589 |
| 7 | 686 | 686 | 686 | 690,9022559 | 4,90225589 |
| 8 | 691 | 692 | 691,5 | 690,9022559 | 0,59774411 |
| 9 | 691 | 692 | 691,5 | 690,9022559 | 0,59774411 |
| 10 | 683 | 685 | 684 | 690,9022559 | 6,90225589 |
| 11 | 684 | 687 | 685,5 | 690,9022559 | 5,40225589 |
| 12 | 685 | 686 | 685,5 | 690,9022559 | 5,40225589 |
| MOYENNE | | | 686,042 | | |
| ECART MOYEN | | | 4,861 | | |

TABLE 4. RESULT CORRESPONDING TO THE ACCURACY TEST WITH $^{137}Cs$ SOURCE

| low energy | |
|---|---|
| Source ($^{57}Co$ ) | |
| Reference activity (µCi) | Average measured activity (µCi) |
| 690,90 | 686,04 |
| Correction factor Fc | |
| 0.99 | |
| Deviation | |
| 0,71% | |

The deviation results of the 12 measurements found for the two sources of Cs-137 and Co-57 are respectively 1.4% and 0.71%, less than 5%, which is in accordance with the acceptability criteria mentioned in Quality Assurance for Radioactivity Measurement in Nuclear Medicine [AIEA][4].

### *C. Reproducibility*

TABLE5. MEASUREMENT PERFORMED WITH THE SOURCE OF $^{137}$CS

| N°measure | A. measured | | |
|---|---|---|---|
| | A. Min | A.Max | Average |
| 1 | 141,1 | 141.2 | 141,100 |
| 2 | 140,4 | 140,5 | 140,45 |
| 3 | 140,3 | 141 | 140,65 |
| 4 | 141,8 | 142,9 | 142,35 |
| 5 | 142 | 142,1 | 142,05 |
| 6 | 140,9 | 141 | 140,95 |
| 7 | 140,3 | 140,4 | 140,35 |
| 8 | 141,7 | 141,9 | 141,8 |
| 9 | 140,7 | 140,9 | 140,8 |
| 10 | 140,9 | 141 | 140,95 |
| 11 | 141,3 | 141,3 | 141,3 |
| 12 | 141,1 | 141,2 | 141,15 |
| 13 | 140,6 | 140,7 | 140,65 |
| 14 | 141,4 | 141,5 | 141,45 |
| 15 | 141,6 | 141,8 | 141,7 |
| 16 | 141 | 141,2 | 141,1 |
| 17 | 141,4 | 141,5 | 141,45 |
| 18 | 142,1 | 142,4 | 142,25 |
| 19 | 141,6 | 141,7 | 141,65 |
| 20 | 141,2 | 141,3 | 141,25 |
| 21 | 140,5 | 140,6 | 140,55 |
| 22 | 141,6 | 141,7 | 141,65 |
| 23 | 141,2 | 141,3 | 141,25 |
| 24 | 141,3 | 141,5 | 141,4 |
| 25 | 140,7 | 140,8 | 140,75 |
| 26 | 140,9 | 141 | 140,95 |
| 27 | 141,7 | 141,9 | 141,8 |
| 28 | 141,7 | 141,9 | 141,8 |
| 29 | 141,3 | 141,4 | 141,35 |
| 30 | 141,8 | 141,9 | 141,85 |
| **Average** | | 141,292 | |

TABLE 6. RESULT CORRESPONDING TO THE REPRODUCIBILITY TEST WITH THE SOURCE OF 137CS

| Source ($^{137}$Cs) | |
|---|---|
| Reference activity (µCi) | Average measured activity (µCi) |
| 138,23 | 141,292 |
| Standard deviation of measurements | |
| 0,529 | |
| Relative standard déviation | |
| 0,37% | |

The relative standard deviation of the 30 measurements gives a value of 0.4% and which is less than 1%, so in accordance with the criteria of acceptability cited in Quality Assurance for Radioactivity Measurement in Nuclear Medicine [IAEA][4].

### *B. Linearity*

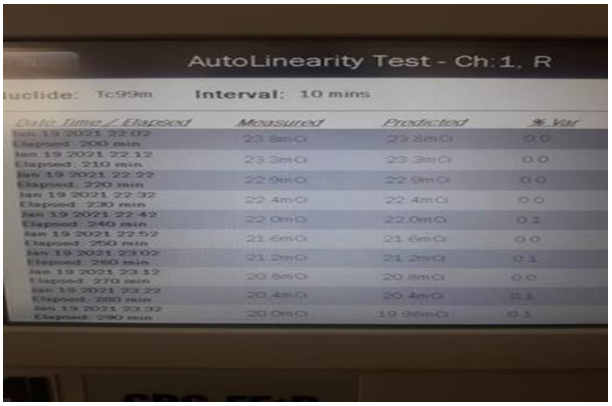


Fig. 4. Screen result of linearity test

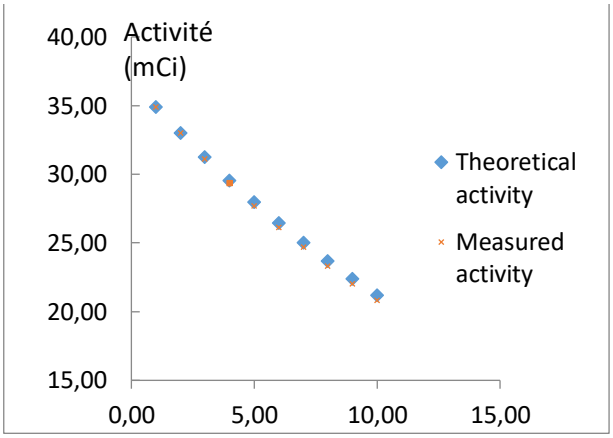


Fig. 5. graph representing the reference activity and measured activity estimated from the linearity test

In the linearity test, the results show that the dose calibrator response is linear since the ratio of measured activity to expect activity remained is almost constant.

System linearity reflects both the linearity of the ionization chamber (saturation characteristics) and the linearity of the electrometer[8].

## V. CONCLUSION

The results obtained show that the activimeter performs well, therefore it is compliant as it has shown excellent results with all 3 reference sources, which reflects the high-quality metrology of this system, as all results tests are within the acceptability limits given by International Atomic Energy Agency (IAEA).

In order to maintain the good competence and reputation of a nuclear medicine service, the instruments used must be calibrated and compliant during its operation to ensure its reliable results, and to obtain good quality examination images to allow an accurate diagnosis. The quality control tests of these instruments are required by the LAW N° 2.79 RELATING TO MEASUREMENT UNITS PROMULGATED BY THE DAHIR N° 1-56-193 OF 28 REBIA II 1407 (31 DECEMBER 1986), and which are

extremely important and indispensable to verify the conformity of the activimeter, in order to preserve the safety of the patients and respect the principles of radiation protection which ensures the protection of man and the environment against the harmful effects of ionizing radiation.

The radioactive sources used in this work are shielded sealed sources and are safe for patients, workers and the environment.

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