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Dose Calibrators and Quality Control Tests

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ABSTRACT

Radiopharmaceuticals are used in nuclear medicine diagnosis and treatment protocols. The radiopharmaceutical activity administered to the patient should be determined by a dose calibrator prior to administration. Knowing the activity given to the patient is essential to understand how radiation affects the body. Since radiation cannot be detected by human senses, contact with the substance is required for detection. Sensitive instrumentation must be used to detect and measure radioactive emissions during any procedure involving the administration of a radiopharmaceutical in nuclear medicine. This is especially important for experimental research that contributes to scientific knowledge by relating radiation doses to biological effects, and for ensuring accurate therapeutic levels of radioactivity. Dose calibrators, unlike other ion chamber detectors, are closed and pressurized chambers filled with argon gas. Ionization chamber radionuclide calibrators measure the total ionization produced by the sample to determine the total activity present. Therefore, for both application accuracy and radiation safety, it is crucial that the dose calibrator precisely determines the activity to be delivered to the patient. In this context, the implementation of rigorous and standardized quality control protocols is indispensable not only for ensuring accurate and reproducible dose measurements, but also for minimizing systematic errors, maintaining instrument calibration integrity, and complying with international safety standards such as those set by the IAEA and the FDA. These practices play a vital role in safeguarding patient health, optimizing therapeutic efficacy, and upholding the scientific reliability of nuclear medicine procedures.

Keywords: *Ionisation, ion chamber, dose calibrator, activity*

INTRODUCTION

Although very small doses are administered to the patient in nuclear medicine diagnosis and treatment applications, these doses must be delivered to the patient with complete accuracy. The radiopharmaceutical activity given to the patient must be determined with a dose calibrator before the application. Performing the right tests at the right times to the electronic system used for this purpose is a must for patient health and success in the examination. Photons emitted from radioactive material transfer energy as they pass through the material. This transfer occurs in two ways: ionization and excitation. Both of these processes play an important role in radiation detection; however, ionization is the primary event and therefore the term ionizing radiation is often used when referring to emissions from radioactive material [1]. The dose calibrators used for this detection purpose are defined as well-type ion chambers.

Dose calibrators include an ionization chamber and an electrometer designed to measure ionization current over a wide range. System linearity also depends on the accuracy of the electrometer. The accuracy of the electrometer depends on its type, quality and the accuracy of the standard reference sources used to calibrate the electrometer. Radiation must come into contact with matter in order to be measured. In the interaction of radiation with matter, various phenomena such as chemical, photochemical, ionization excitation occur and the radiation becomes detectable by current. Detectors that measure radiation according to the ionization principle are detectors filled with gas or compressed air. A high-pressure gas is filled between two electrodes with a voltage difference (i.e. electric field) between them. The ion chambers used in the dose calibrator system are filled with high-pressure Argon gas. When the radiopharmaceutical to be administered is in the ion chamber, the radiation emitted interacts with the gas in the ion chamber. As a result of this interaction, ion pairs are formed and with the potential difference between the two electrodes in the ionization chamber, positively charged ions travel towards the cathode and negatively charged ions travel towards the anode, thus creating a measurable signal. These signals are converted into current by devices connected to the ionization chamber (Figure 1) [1]. Under normal conditions, the gas is an insulator and there is no electric current between the electrodes. Radiation passing through the gas causes both direct ionization and secondary ionization. Gas-filled detectors include ionization chambers, proportional counters and Geiger-Müller (GM) counters [2].

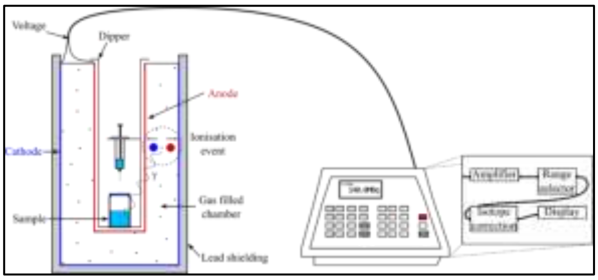

Figure 1: Dose Calibrator [1]

If the current is too low, some ions and electrons will simply recombine without contributing to the electric current (recombination region). When the voltage is high enough to ensure that all the charges generated are completely collected, the saturation region begins. The voltage at which the saturation region begins is called the saturation voltage. Ionisation chambers operate with maximum radiation response at voltages in the saturation region [2]. As ionisation chambers are not suitable for energy discrimination, they cannot be used to detect different gamma ray energies. Ionisation chamber shielding is used to reduce the effect of ambient radiation and to protect the operator from unnecessary radiation exposure. Current production radionuclide calibrators do not have the same behaviour as micro ion chambers against radiation of different types and energies, which allows additional quality control tests to be performed. For this reason, some corrections are made to the voltage that generates the ion current so that different isotopes can be distinguished. For this purpose, standard sources with the same properties as the isotopes used in clinical applications are used during the construction of the device. The radioactive materials used in dose calibrators are in vial form specially designed for use in quality control tests. The International Commission on Radiological Protection (ICRP) defines the acceptance tests that must be performed for the dose calibrator as tests that determine the determination of test parameters that show that it has the characteristics claimed by the manufacturer upon request, accompanied by the user. Achieving the correct result in clinical applications is only possible by ensuring that these devices continuously measure accurately. These measurements also require a number of quality control studies and calibration tests to be performed if necessary as a result of the studies. According to ICRP and NRC (Nuclear Regulatory Commission), some standard tests must be performed within the scope of quality control tests. Some of these tests are performed with long half-life standard sources and some with very short half-life isotopes [3,4]. Among these tests; precision-accuracy tests are performed with specific methods using long half-life standard sources (e.g. Cs137), while linearity tests are performed using short half-life radioisotopes (e.g. Tc99m) [4]. ICRP recommends that tests be performed during installation or after a major service maintenance. In addition to verifying that the radionuclide calibrator meets manufacturer specifications, test or reference data are obtained during acceptance testing and used for comparison with future routine testing [5]. The most comprehensive evaluation of the performance of the dose calibrator occurs during acceptance testing. Routine quality control (QC) testing should be repeated at regular intervals to identify and document changes from the initial performance of the dose calibrator as determined in the acceptance test. The overall objective of QC testing is to ensure the continued accuracy of the radioactive material analysis to be performed. The tests that should be performed by EANM (European Association of Nuclear Medicine) for dose calibrators and their purposes are specified in the table below [4,6,7].

Table 1. Routine quality control tests for dose calibrator. [4].

Test	Objective		Interpretation
Physical Inspection	To check the system, weld holders and other accessories for damage	Daily	The weld holder is broken or Loose accessories that may be inaccessible for physical inspection should be checked.
Voltage Check	for consistency of operating voltage	Daily	Required for accurate activity measurement
Clock Accuracy	Check the accuracy of the dose calibrator's clock	Daily	Required to calibrate radioactivity to a specific time of day; clock time must be the same throughout the clinic
Zero Setting	Zero reading should be taken when there is no activity	Daily	Zero setting should be stored
Background counts	To check the background response of a given radionuclide under appropriate operating conditions; to detect the presence of contamination	Daily	Must be performed with the weld holder in place, which may cause incorrect background reading nearby radioactive sources must be removed.
Repeatability test	Ionization chamber, electrometer and calibrator nuclide settings to check its stability and repeatability	Daily	Measure a long half-life radionuclide, e.g. Cs-137, with its own calibration factor; also obtain relative measurements for each radionuclide setting to be used that day
Precision and accuracy testing	To check counting accuracy and determine reading accuracy	Yearly	Counting accuracy is a measure of the stability of the entire system and measured by repeated measures and the application of the chi-square test.
Linearity test	Ensure that the calibration setting of a particular radionuclide is done to verify that it shows the correct activity.	6 monthly/annual	When the measurement range is changed, the change in response should be minimal;

In our country, the "Regulation on Quality Compliance and Quality Control Tests of Diagnostic Radiology, Nuclear Medicine and Radiotherapy Group Devices" was issued by the Ministry of Health of the Republic of Turkey TİTCK (Medical Drug Medical Device Institution) and the guideline for the implementation of the provisions of the regulation was published with the latest revision on 26.12.2023[8]. In this guideline, the tests to be performed for dose calibrators, the source and measurement methods to be used, and the interpretation criteria are clearly defined, and the tests have been made mandatory as of the relevant date and the execution process has been given the responsibility of the nuclear medicine medical physicist [8].

The quality control tests listed in the table above can be summarised as follows:

1. Repeatability Test: This is a daily test and is performed using a long half-life caesium-137 (137Cs)

radioisotope source. Before starting the test, the presence of radioactive material in the environment and in the instrument is checked and a background measurement is made. The 137Cs source is placed in the dose calibrator. The dose scale is set to Technetium-99m (99mTc), which is the most commonly used dose scale in routine practice. For background Bg correction, the Bg activity is subtracted from the measured activity values. It is checked that the maximum error is within ±5% of the initial activity measurement value of the radioactive source.[4,9].

2. Precision and Accuracy test:

The precision and accuracy test is performed using the same measurements and is interpreted using different formulae in the evaluation phase. 57Co and 137Cs radioisotopes, which are long-lived standard sources, are used in these tests.

For accuracy test; 10 measurements are taken with 57Co and 137Cs radioisotope sources on their own scales. After the sources are removed from the dose calibrator, a background measurement of the environment is made. The background activity is subtracted from the measured activity value to obtain the net activity. The result of the certainty test is calculated using the formula given below.

% Accuracy= (Ai-Amean)/Amean x 100

Here; Amean: Average of 10 measured activities

Ai: i. It is the amount of activity measured.

The results of the precision test should be within ±5% error limit [3]. The test should be performed at least once a year [4,9,10]

For the accuracy test; 10 measurements are taken with 57Co and 137Cs radioisotope sources on their own scales. After the sources are removed from the dose calibrator, the background measurement of the environment is made. The background activity values are subtracted from the measured activity values to obtain the net values. The accuracy test result is calculated using the formula given below:

% Accuracy= [(Amean-ACertificate)/ACertificate] x 100 ;

Amean: Average of 10 measured activities

A Certificate: Amount of activity in the calibration certificate of the source

Accuracy test results should be within ±10% error limit [10]. The test should be performed at least once a year

3. Linearity Test :

This is a test to check that the Dose Calibrator can accurately measure different activity values. One of the methods used is the dose decay method. This method tests the linearity of the source during radioactive decay. 99mTc, a radioactive substance with a short half-life and easy to supply, is preferred for this test. The radioactive source used is measured during the day at hours according to its half-life value on its own scale and its activities are recorded. The background activity is subtracted from the measured value to give the net activity. In addition, the theoretical time-dependent decay activities are calculated taking into account the decay law of the radioactive source used. A comparison between the experimental value and the theoretically calculated values is made by plotting a graph. The experimentally measured time-dependent activity decrease of the source should be equal to the theoretically calculated activity values within the maximum error limits of ±5%. [4,10]. After the tests specified in the table have been carried out, the completion and filing of the TİTCK forms shall be in accordance with the TİTCK regulations.[8].

CONCLUSION

The dose calibrator is a very important detection system in nuclear medicine applications. It is very important that the dose calibrator operates under proper conditions and makes accurate measurements, both in terms of the necessity and accuracy of the treatment and in terms of the radiation safety of the patient. This article describes the quality control tests that must be performed to ensure accurate and error-free measurements from the dose calibrator.

Conflict of Interest

There are no conflicts of interest and no acknowledgements.

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