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Calibration and Effective Use of a Dose Calibrator

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ABSTRACT

Maximum count rate, accuracy, precision, constancy and linearity measurement have been undertaken on two dose calibrators at the Nuclear medicine department, Korle-Bu Teaching Hospital as part of quality control test. Both calibrators show some dependence on measurement geometry which deminishes with increasing depth in the well. It was observed that the measured activities for Co-57, Cs-137 and Tc-99m, obtained from the VDR-15R were larger than those from the reference dose calibrator, Capintec CRC-25R. It was found that, the maximum depth of sensitivity in the Capintec was 6.8 cm and 5.6 cm for Co-57 and Cs-137.VDR showed a maximum sensitivity depth of 5.2 cm for both Co-57 and Cs-137. For accuracy and precision, it was observed that, the percentage differences for the reference dose calibrator, Capintec CRC-25R was a little different from that of the VDR-15 but both calibrators were in the range of ±5% of the mean measured activity. The main difference was their maximum height of sensitivities with values of 6.8 cm and 5.2 cm for Co-57 and 5.6 cm and 5.2 cm for Cs-137 for Capintec and VDR-15R respectively. From the linearity test, there were systematic departures of the data points from the fitted straight line in the upper part and lower part and such discrepancies indicated non-linearity. These discrepancies in the upper and lower part were due to impurities (Mo-99 contaminants and Tc-99 contaminants respectively) in the Tc-99m used in the test which revealed itself in apparent levelling out of the activity in the final part and beginning part of the graph. Since most of the points fitted in the straight line, it showed that, almost all the individual activities measured in the test were within the range of ±10% of the values corresponding to the straight line fitted in the data points. It was observed that, the measured activities difference for both calibrators were very small which was as a result of the differences in depth of their wells. The dose calibrators can be used for dose measurements.

Keywords: *Maximum count rate, accuracy, precision, constancy, linearity measurement, dose calibrator*

1. INTRODUCTION

Nuclear Medicine is a specialty of medicine which utilises radiopharmaceuticals in unsealed form either for therapy or to study a particular physiological function. It is also used to carry out morphological examination *in vitro* or *in vivo* for diagnosis making use of the pharmacokinetic properties or selective localisation of a radiopharmaceutical in a particular organ or tissue and performing measurements of radioactivity either on a biological specimen or on the patient. Nuclear medicine is primarily diagnostic [1]. Its reputation is mainly because of its all – pervasive and non – invasive nature of its investigation.

Nuclear medicine tests (also known as scans, examinations, or procedures) are safe and painless. In a nuclear medicine test, small amounts of pharmaceuticals that have been labelled with radionuclides (radiopharmaceuticals) are introduced into the body by injection, swallowing, or inhalation, and the radiation emitted is detected [4].

Radiopharmaceuticals are substances that are attracted to specific organs, bones, or tissues. The amount of radiopharmaceutical used is carefully selected to provide the least amount of radiation exposure to the patient but ensure an accurate test [5].

In therapy, radionuclides are administered to treat disease or provide palliative pain relief. For example, administration of Iodine-131 is often used for the treatment of thyrotoxicosis and thyroid cancer. Those treatments rely on the killing of cells by high radiation exposure, as compared to diagnostics in which the exposure is kept as low as reasonably achievable (ALARA policy) so as to reduce the chance of creating a cancer [2].

Nuclear medicine differs from an x-ray, ultrasound or other diagnostic test because it determines the presence of disease based on biological changes rather than changes in anatomy and also in that the tests primarily show the physiological function of the system being investigated as opposed to traditional anatomical imaging such as CT or MRI [3].

Diagnostic tests in nuclear medicine exploit the way that the body handles substances differently when there is disease or pathology present.

Activity to be administered to a patient is measured with an equipment called the Dose Calibrator. They are well-type ionization chambers, extremely useful in the assay of generator eluents', ^{99}Mo breakthrough measurements, preparation of radiopharmaceuticals, and dispensing dosages of radiopharmaceuticals for patients. Some dose calibrators are

specially designed for beta emitters, and some for Positron Emission Tomography radiopharmaceuticals [3].

To ensure accuracy in administered activity, the dose calibrator must undergo a series of routine test and evaluation

2. METHODOLOGY

2.1 Precision and Accuracy Method Materials

They include source holder, standard vial-type (gamma-radiation source) and remote handling device (forceps)

Procedure

The operational conditions appropriate to the radionuclide concerned were selected. The background reading was recorded and subtracted from subsequently measured activities. The radionuclide was picked with the forceps, placed in the source holder and inserted into the dose calibrator. Sufficient time was given to allow the reading to stabilize. The activity was read, recorded and subtract the background reading. The procedure was repeated five times at different heights. The source holder was removed from the dose calibrator and the source was extracted from it by means of the forceps [6].

2.2 Decaying Source Method (Linearity Test of Activity Response)

Materials

They include sample vial, remote handling device for sample vial, source holder and remote pipetting device.

Procedure

A solution of the radionuclide was formed and transferred to the sample vial by means of the remote pipetting device. The vial was firmly capped and the operational conditions appropriate to the concerned radionuclide were selected. Solution in sample vial was grouped into three: X, X/2, and X/3 with volume 4ml, 3ml and 2ml respectively. Background reading was subtracted from subsequently measured activities. The sample vial was inserted into the source holder by means of remote handling device and introduced into the dose calibrator. Sufficient time was allowed for the reading to stabilize and the activities of the radionuclides, was measured subtracting background reading. The exact time of day corresponding to the measurement was recorded. The source holder was removed from the instrument and the sample vial extracted by means of the remote handling device.

The procedure was repeated several times greater than the physical half-life of the radionuclide, sufficient for the source to decay to an activity equal to or less than the lowest activity for which the instrument is to be used [6].

2.3 Background Response Method

Procedure

Operational conditions appropriate to any chosen radionuclide with a low rate of emission of photon energy as evidenced by a low gamma – radiation dose constant was selected. Background reading in activity units of the radionuclide concerned was recorded [7, 9].

2.4 Reproducibility Response Method

Materials

They included Long-lived sealed medium-energy gamma-radiation source, activity about 3.7 MBq {100µci}. Cesium-137 source was available and suitable. Source holder, remote handling device and linear graph paper.

Procedure

The operating conditions appropriate to the radionuclide were selected. The background reading was recorded to be subtracted from the measured activities. The gamma-radiation source was inserted into the source holder by means of the remote handling device and introduced into the dose calibrator. Sufficient time was allowed for the reading to stabilize. The activity was measured, recorded and subtracted from the background reading. The source holder was removed from the dose calibrator and the source was extracted from it by means of the forceps. The procedure was repeated at different heights [7, 9].

3. THEORY

The project was specifically based on the determination of radionuclides activity from the dose calibrator. The radionuclides used in our project were cesium-137, cobalt-57 and technesium-99 respectively. The idea of radioactive decay of radionuclides was much emphasised knowing their half-lives also plays a major role in our project.

3.1 Radioactive decay

Radioactive decay is the process in which an unstable atomic nucleus loses energy by emitting ionizing particles and radiation. This decay, or loss of energy, from the initial atom (Parent atom) results in another atom called the daughter nuclide. The SI unit of radioactive decay is the Becquerel (Bq) and another unit is Curie (Ci). There are three types of

radioactive decay and these are alpha {α} decay, beta {β} decay and gamma {γ} decay respectively [8].

Radioactive Decay Rate {Activity}

The decay rate, or activity, of a radioactive substance is characterized by the following:

Constant Quantities

Half Life - $t_{1/2}$ - the time taken for the activity of a given amount of a radioactive substance to decay to half of its initial value.

$$A(t_{1/2}) = A_o e^{-\lambda / t1/2}$$
$$0.5A_O = A_o e^{-\lambda / t1/2}$$
$$2^{-1} = e^{-\lambda / t1/2}$$
$$In\ 2^{-1} = In\ (e^{-\lambda / t1/2})$$
$$-1In2 = \lambda / t_{1/2}$$

$$\lambda = In2 / t_{1/2} = 0.693 / t_{1/2}$$

Mean Lifetime – τ –the average lifetime of a radioactive particle.

Decay Constant – λ – the inverse of the mean lifetime.

For N radioactive atoms, average decay rate is given by:

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

λ is the decay constant. (If λ = 0.01/s, then 1% of atoms undergo decay each second).

$$\frac{\Delta N}{\Delta t} \lim t - 0 \frac{dN}{dt} = Decay\ rate = Activity$$

Number of particles – N - the total number of particles in the sample.

Decay Timing

The decay of an unstable nucleus is entirely random and it is impossible to predict when a particular atom will decay. However, it is equally likely to decay at any time. Therefore, given a sample of a particular radioisotope, the number of decay events $-dN$ expected to occur in a small interval of time dt is proportional to the number of atoms present. If N is the number of atoms, then the probability of decay ($-dN/N$) is proportional to dt:

Thus,

$$\left(-\frac{dN}{N}\right) = \lambda \cdot dt.$$

Particular radionuclides decay at different rates, each having its own decay constant (λ). The negative sign indicates that N decreases with each decay event. The solution to this first-order differential equation is the following function:

$$N(t) = N_0\, e^{-\lambda t} = N_0\, e^{-t/\tau}.$$

Where N_0 is the amount of N at time zero (t = 0).

The second equation recognizes that the differential decay constant λ has units of 1/time, and can be represented as 1/τ, where τ is a characteristic time for the process.

Given a sample of a particular radionuclide, the half-life is the time taken for half the radionuclide's atoms to decay. The half life is related to the decay constant as follows:

$$t_{1/2} = \frac{\ln 2}{\lambda} = \tau \ln 2.$$

This relationship between the half-life and the decay constant shows that highly radioactive substances are quickly spent, while those that radiate weakly endure longer. Half-lives of known radionuclides vary widely, from more than 10^{19} years (such as for very nearly stable nuclides, e.g. ^{209}Bi), to 10^{-23} seconds for highly unstable ones.

The average activity reading for the sources are compared with the decay corrected calibrated activity. The decay equation is used for the correction,

$A_t = A_o\, e^{\wedge} (-0.693t/t_{1/2})$;

A_t is the activity after time t, Ao is the initial activity, t is the elapsed time, and the half life ($t_{1/2}$). The calculated activity and the average activity reading should be within ±5 of each value.

For precision for each source, the percentage difference between the individual measured activities, A_i, and their mean, Ã, is calculated by:

$$\frac{100(Ai - \tilde{A})}{\tilde{A}}\%$$

To assess accuracy for each source, the percentage difference between the mean measured activity, Ã and the

certified activity of the source corrected for radioactive decay to the day of measurement, C is given by:

$$\frac{100(\tilde{A} - C)}{\tilde{A}}\%$$

4. RESULTS AND DISCUSSION

The measured activity increased with increasing depth. This was observed for both Co-57 and Cs-137 sources and both for CRC-25R and VDR-15R dose calibrators (figure 1 and figure 2 respectively). In figure 1 using Co-57 source, for CRC-25R dose calibrator, a polynomial trendline equation with regression of 0.9875 fitting the data was generated as in equation (1)

$y = 0.0026x^4 + 0.0079x^3 - 0.5252x^2 + 3.6502x + 266.04$--(1).

In figure 1, for VDR-15R dose calibrator, a polynomial trendline equation with regression of 0.9774 fitting the data was generated as in equation (2)

$y = 0.0299x^4 - 0.2703x^3 + 0.7909x^2 + 0.9633x + 269.31$—(2)

In figure 2 using Cs-137 source, for CRC-25R dose calibrator, a polynomial trendline equation with regression of 0.9845 fitting the data was generated as in equation (3),

$y = -0.0083x^5 + 0.1555x^4 - 0.944x^3 + 1.7692x^2 + 1.9911x + 233.57$ --- (3)

In figure 2, for VRR-15R dose calibrator, a polynomial trendline equation with regression of 0.9823 fitting the data was generated as in equation (4),

$y = 0.0787x^3 - 0.5769x^2 + 2.1396x + 237.92$ --- (4)

It was realised that the activity reduced with increasing time for both CRC-25R and VDR-15R dose calibrators (figure 3 and figure 4 respectively)

All radionuclide calibrators show some dependence on measurement geometry; this effect deminishes with increasing depth in the well. In general, it was observed that the measured activities for Co-57, Cs-137 and Tc-99m, obtained from the VDR-15R were larger than those from the reference dose calibrator, Capintec CRC-25R.The differences in values is due to the depth of their wells. VDR-15R is an open type calibrator and is dependent on ambient conditions (e.g. temperature, pressure) and had an adjustable zero control, therefore did not give any measurable background response (0 μCi) whilst capintec CRC-25R is a closed type calibrator and did not have any adjustable zero control, giving a measurable background response of 2.39 μCi.

It was found that, the maximum depth of sensitivity in the capintec was 6.8 cm and 5.6 cm for Co-57 and Cs-137.VDR showed a maximum sensitivity depth of 5.2 cm for both Co-57 and Cs-137.

For accuracy and precision, it was observed that , the percentage differences for the reference dose calibrator, Capintec CRC-25R was a little different from that of the VDR-15 but both calibrators were in the range of **±5%** of the mean measured activity, but the main difference was their maximum height of sensitivities with values of 6.8 cm and 5.2 cm for Co-57,for Capintec and VDR-15R respectively and 5.6 cm and 5.2 cm for Cs-137,for Capintec and VDR-15R respectively.

From the linearity test, there were systematic departures of the data points from the fitted straight line in the upper part and lower part and such discrepancies indicated non-linearity. These discrepancies in the upper and lower part were due to impurities (Mo-99 contaminants and Tc-99 contaminants respectively) in the Tc-99m used in the test which revealed itself in apparent levelling out of the activity in the final part and beginning part of the graph. Since most of the points fitted in the straight line, it showed that, all most all the individual activities measured in the test were within the range of ±10% of the values corresponding to the straight line fitted in the data points.

5. CONCLUSION

After performing the quality control tests which included maximum count rate, accuracy, precision, constancy and linearity test on both dose calibrators, it was observed that, the measured activities difference for both calibrators were very small. This was as a result of the differences in depth of their wells.

The effective and most sensitive depth for VDR-15R was therefore detected and appropriate jig was designed for the effective use of this dose calibrator. Calibration curve was plotted for the VDR-15R dose calibrator.

In order to maintain the effective use of the VDR-15R calibrator, an evaluation criterion should be done which include a daily constancy check, an annual accuracy check and a quarterly linearity test of the VDR-15R dose calibrator.

6. RECOMMENDATION

In order to maintain the effective use of the VDR-15R calibrator, an evaluation criterion should be done which will include a daily constancy check, an annual accuracy check and a quarterly linearity test of the VDR-15R dose calibrator.

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APPENDIX

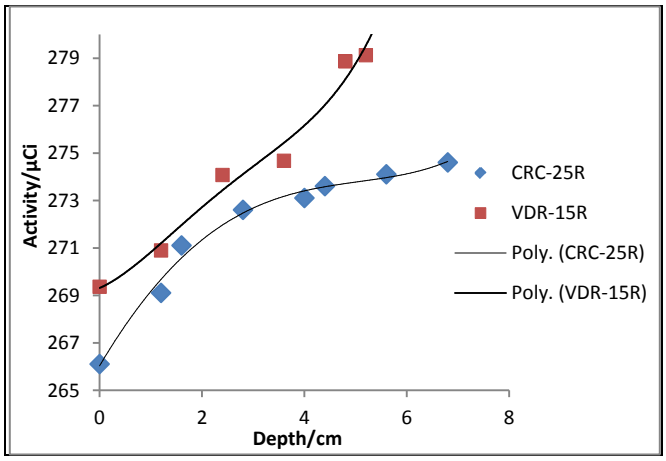

Figure 1: A graph of Activity (mCi) against Depth (cm) in the Well -Chamber using the CRC-25R and VDR-15R calibrators

The Depth Zero (0) cm represents the initial activity recorded.

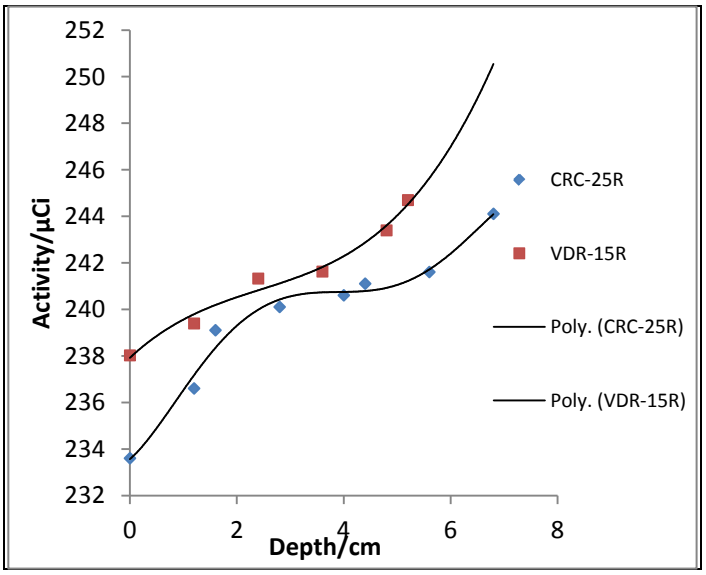

Figure 2: A graph of Activity (mCi) against Depth (cm) in the Well – Chamber using the CRC-25R and VDR-15R dose calibrators

The Depth Zero (0) cm represents the initial activity recorded.

Test of Linearity of Activity Response (Decaying Source Method)

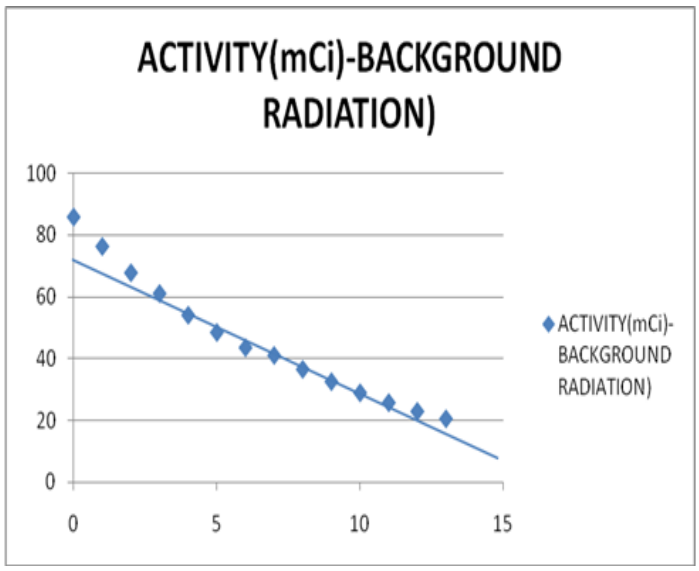

Figure 3: Graphs for Activity (mCi) against Time (hrs) *Calibrator:* Capintec (CRC-25R)

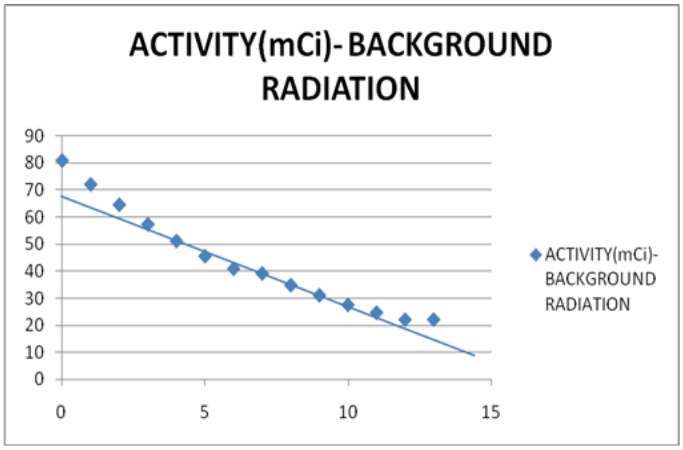

Figure 4: A Graph of Activity (mCi) against Time (hrs) Calibrator: VDR-15R

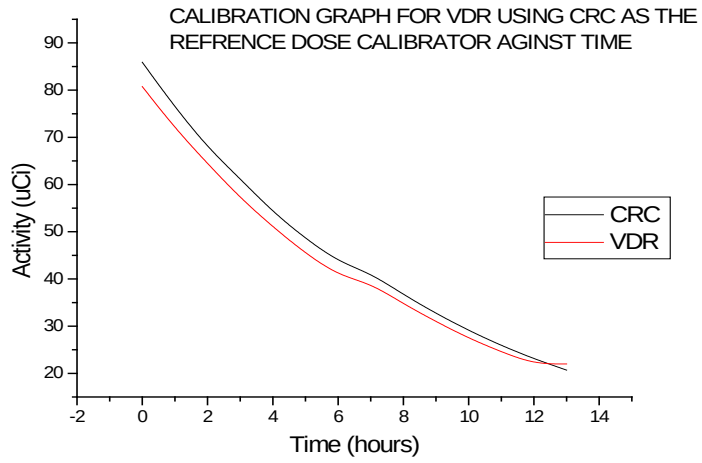

Figure 5: Calibration Graph for VDR-15R using CRC-25R as the Reference Dose Calibrator against Time

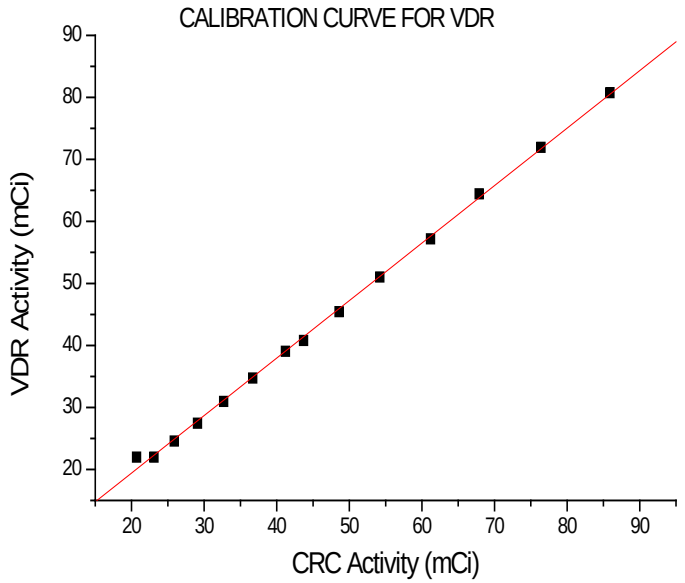

Figure 6: A Calibration Graph for VDR-15R Dose Calibrator