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Critical Appraisal of Radionuclide Calibrators and Gamma Cameras Prior to Lutetium-177 Internal Dosimetry at Two South African Hospitals

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Abstract

Introduction The functionality of radionuclide dose calibrator and nuclear medicine imaging systems hasa direct effect on the accuracy and preciseness of internal dosimetry evaluations. Our study, therefore, aimed to critically appraise the radionuclide calibrators and gamma cameras prior to Lutetium-177 (^{177}Lu) internal dosimetry in a developing country.

Materials and Methods Two radionuclide calibrators' and three gamma cameras at two South African hospitals were critically appraised in preparation for internal dosimetry of ^{177}Lu. The radionuclide calibrators' accuracy, linearity, and sample volume abilities were appraised. For the three gamma cameras, the uniformity, energy resolution, center of rotation, and collimator sensitivity were appraised. These appraisals were performed between the years 2014 and 2019.

Results The radionuclide calibrators' constancy, accuracy, linearity, and sample volume were within $\pm$5%. We also integrated a ^{177}Lu calibration factor into one radionuclide calibrator's library. The three gamma cameras' uniformity was within 2 to 5%, energy resolution within 11%, center of rotation within 2 mm, and the sensitivity recorded for all low energy high resolution collimator.

Conclusion Our radionuclide calibrators passed the critical appraisal and may be confidently used for assaying ^{177}Lu. All three cameras also passed critical appraisal and may be used to assess organ absorbed dose.

Keywords
- ^{177}Lu
- performance review
- radionuclide calibrator
- gamma camera
- quality control

Introduction

Lutetium-177 (^{177}Lu), with half-life of 6.7 days, is a medium-energy β (β)-emitter of maximum energy of 0.5 MeV and has penetration range of 2 mm in tissue.[1] On decaying, ^{177}Lu emits gamma (γ)-ray energies ranging from 113 to 208 keV with abundance of 10 and 6%, respectively, which allow for post-therapy imaging. The radionuclide ^{177}Lu labeled to a

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bifunctional chelator has been successfully used for therapy in patients with neuroendocrine tumors because of its nuclear decay characteristics and chemical properties.[1]

It is essential to have accurate knowledge of the administered radionuclide in therapeutic and diagnostic nuclear medicine.[2] The levels of activity in radiopharmaceuticals to be administered are governed primarily by the need to balance the effectiveness and safety of the medical procedure. To attain high standards of efficiency and reliability in the practice of ^{177}Lu internal dosimetry, an appropriate quality assurance (QA) program for radionuclide calibrators and gamma cameras (GC) is needed. Quality control (QC) performed on the systems helps to establish and document changes from the initial performance at acceptance testing and ensures the continued accuracy of the dosage assays.[3,4] It also alerts the facility to any malfunctions that could potentially result in maladministration of activity and misdiagnosis. The proper use of radionuclide calibrators and the corresponding measures for determining accuracy and linearity of the system should, therefore, be provided.[5] In South Africa, a medical physicist is to ensure the calibration of radionuclide assaying equipment and GC.[6] Optimum use of the radionuclide calibrator, therefore, requires well-trained personnel and a program for regular QA.

The European Association of Nuclear Medicine advises that all GC types, including details of the manufacturers and model (including year of manufacture), should be listed for any dosimetry.[5] Included should be the number of heads, the crystal thickness, and the collimator type used. The model variant should also be given where applicable, along with any relevant additional hardware used with the system. Information on the acquisition and processing software used such as manufacturer, package, version should also be provided. QC tests performed on dose calibrator include accuracy, linearity, constancy, and geometry, while GC performance is assessed by performing energy resolution, system sensitivity, COR, etc. The aim of our study was to critically appraise the radionuclide calibrators and GC prior to ^{177}Lu internal dosimetry in two nuclear medicine departments in South Africa. The findings of the study may serve as a guide for good practice of clinical dosimetry reporting.

Materials and Methods

Materials and Methods for the Radionuclide Calibrators

We reviewed the performance of radionuclide calibrators; CRC-15R from Capintec, New Jersey, United States, and Curiementor 4 from PTW-Freiburg Germany, for the years 2014 to 2019.

Radionuclide calibrator background, auto zero, system, and data check were performed at the beginning of each working day, prior to measuring any ^{177}Lu sample. These measurements were performed to note any radioactivity leaks or contamination present in the radionuclide calibrator.

Constancy tests were performed with a Cesium-137 (^{137}Cs) radionuclide. The ^{137}Cs used for these tests had a long-lived half-life ($T_{1/2}$) of 30 years and its activity was traceable to a standards laboratory in South Africa. The traceable ^{137}Cs activity recorded was 3.7 MBq manufactured on the 28 September 2004 for one hospital and 7.6 MBq manufactured on the 20 July 2016 for the other hospital. The ^{137}Cs source was measured monthly, and all measurements were background corrected. The *p*-value of the accuracy results was also determined.

Accuracy tests were performed with the same ^{137}Cs radionuclide. The decay constant (λ) of ^{137}Cs was calculated using Eq. 1:

$$\lambda = \frac{Ln\ 2}{T_{\frac{1}{2}}} \quad (1)$$

where; Ln 2 = 0.693, and

$T_{1/2}$ = 30 years.

Using the traceable initial activity of the ^{137}Cs stated above, the final activity was calculated using Eq. (2):

$$A = A_0\, e^{-\lambda t} \quad (2)$$

where; A is the expected or calculated activity,

A_0 is the initial activity at the time of commissioning,

t is time from date of commissioning to the day activity.

This test was performed yearly in the month of September; the ^{137}Cs activity measured (A_{meas}) on radionuclide calibrator was then compared with the calculated activity (A_{cal}). All measurements were background corrected. The percentage difference obtained between the calculated and measured activity was calculated using Eq. (3):

$$\text{Percentage difference} = 100 - \left(100x\frac{A_{meas}}{A_{cal}}\right) \quad (3)$$

Linearity tests were performed with a Technetium-99m (^{99m}Tc) radionuclide. The ^{99m}Tc had a relatively short $T_{1/2}$ of 6 hours and activities of the samples used during this test were similar to maximum assayed in normal use for patients. The linearity tests were performed biannually using the decay method. The ^{99m}Tc source was left to decay for 2, 4, 6, and 24 hours intervals and measurements taken on the radionuclide calibrator. Using Eq. 2, the expected activity of the ^{99m}Tc was then calculated and compared with the measured activity. All measurements were background corrected.

The Curiementor 4 radionuclide calibrator had a factor for ^{177}Lu loaded on its system, but the CRC-15R radionuclide calibrator did not. Using the utility button on the CRC-15R radionuclide calibrator, the ^{177}Lu was added. We entered the name of the radionuclide, $T_{1/2}$ and calibration factor. To determine the calibration factor, our initial starting calibration number was 450.[4] A standard ^{177}Lu source of 7400 MBq was placed in the chamber of our radionuclide calibrator and its activity recorded. Our recorded activity was then compared with standard activity, and was higher than the standard activity. We then increased the calibration number until we measured the same activity as the standard source. Ten different standard sources of ^{177}Lu ordered from a standards laboratory were than measured on the CRC-15R

radionuclide calibrator and the percentage difference calculated using Eq. 3.

Once our calibration factor was established for ^{177}Lu, we performed quarterly sample volume tests on our radionuclide calibrator. Starting with 74 MBq (A_0) ^{177}Lu, a saline solution (0.9% NaCl) was consecutively added to increase the volume to 5 mL (mL) and then to 10 mL. Using Eq. 3 the percentage difference between A_0 and A_{5mL}/A_{10mL} was also calculated. All measurements were background corrected. The *p*-value of the sample volume results was also determined.

Materials and Methods for the Gamma Cameras

We critically appraised three GC, in two nuclear medicine departments in South Africa. The GC types were Philips Marconi Meridian from New York, United States; General Electric (GE) Discovery NM 630 from Boston, United States; and Siemens SymbiaIntevo 16/6/2 from Pennsylvania, United States. The year of manufacturing was 1999, 2011, 2014 for the Philips, GE, and Siemens, respectively. All GCs had double headed crystals with thicknesses of 0.95 cm (cm). Collimators used were "all-purpose parallel-hole" collimators.

All intrinsic flood field uniformity measurements were performed as previously reported by the International Atomic Energy Agency (IAEA) and National Electrical Manufacturers Association (NEMA).[7–9] The integral uniformity was calculated by identifying the maximum and minimum pixel values in the camera's field of view (FOV) and expressing the deviation as the percentage in Eq. 4:

$$\text{Integral uniformity} = \pm 100 \frac{(\max pixel - \min pixel)}{(\max pixel + \min pixel)} \quad (4)$$

Nine-point smoothing function with the pattern of weightings described in ►**Fig. 1** was applied to all uniformity images.

The weighting factor for a pixel outside the analyzed area in the nine-point filter function was zero. All analyses were performed with the manufacturer's software.

All intrinsic energy resolution measurements were performed as previously reported by the IAEA and NEMA.[7–9] The energy resolution was then calculated using Eq. 5:

$$\text{Energy Resolution} = \frac{\text{FWHM(Tc)x18.4}}{140.5} \quad (5)$$

where, FWHM is Full Width at Half Maximum

1	2	1
2	4	2
1	2	1

Fig. 1 Nine-point smoothing function pattern for the uniformity test.

All analyses were performed with the manufacturer's software.

All COR measurements were performed as previously reported by the IAEA and NEMA.[8,9] The COR was calculated using Eq. 6:

$$\text{COR} = \frac{1}{N} \sum X \quad (6)$$

where, X is average over all views.

All analyses were performed with the manufacturer's software, either demonstrating a Sinus curve or a straight line.

All system sensitivity measurements were performed as previously reported by the IAEA and NEMA.[8,9] The sensitivity (S) was reported in counts/sec/MBq (cnts/s/MBq) and calculated using Eq. 7:

$$S = \frac{Rt_{10}}{A_{cal}} \quad (7)$$

where,

A_{cal} is the calculated activity in the petri dish,

Rt_{10} is the decay corrected count rate at 10 cm and is calculated using Eq. 8:

$$Rt_{10} = C_{10} \times \exp\left(\frac{T_{10} - T_{cal}}{T_{half}} \ln 2\right) \times \left(\frac{\ln 2}{T_{half}}\right) \left(1 - \exp\left(-\frac{T_{acq}}{T_{half}} \ln 2\right)\right)^{-1} \quad (8)$$

C_{10} is the counting rate derived from the reconstructed image (counts/dwell time),

T_{10} is the start time at 10 cm,

T_{acq} is the duration of the acquisition at 10 cm,

T_{cal} is the time of activity calibration,

T_{half} is half-life of Tc-99m.

Results

Results for the Radionuclide Calibrators

Auto zero, system test, and data check results for the radionuclide calibrators were stable. None of the values drifted and was the same as the factory preset. For the years of retrospective analysis, we never repeated any of our auto zero, system of data checks. Background values were below the acceptable value of 3.7 MBq.[10,3,4] Whenever a background measurement was above 3.7 MBq, the reason for the high value was investigated. Our investigations found that other radionuclide sources would be nearby the vicinity of the chamber, or a drop of radionuclide contamination was present in the calibrator. These were corrected by removing all radionuclides from the vicinity of the chamber or washing the radionuclide chamber with Radiowash[a] and repeating all measurements.

[a] Radiowashis a concentrated solution designed to rapidly control radioactive contamination and remove radioactive particles from surfaces [https://m.biodex.com/nuclear-medicine/products/radiopharmacy/decontamination/radiacwash%E2%84%A2-spray-mist]

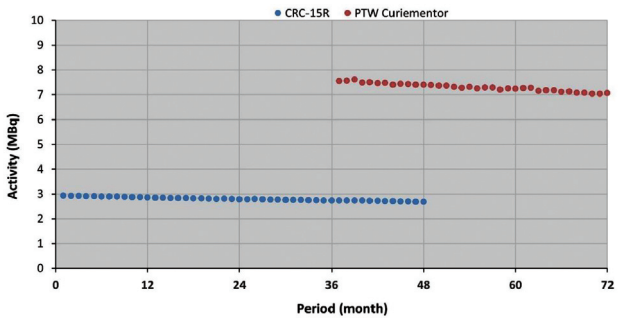

Fig. 2 Constancy results of the CRC-15R and PTW Curiementor 4 radionuclide calibrators using ^{137}Cs sources.

The constancy results for the radionuclide calibrators are given in ►**Fig. 2**. The constancy measurements represented reproducibility in measuring the same source, over period of time, with decay correction. The constancy measurements for CRC-15R and PTW Curiementor 4 calibrators were taken from 2014 to 2017 and 2017 to 2019, respectively. From ►**Fig. 2**, measurements for CRC-15R did not go beyond 2017 because ^{177}Lu was already well establish at the hospital by then. The constancy results for both radionuclide calibrators were linear and did not decay more than the 10% limit as demonstrated in ►**Fig. 2**. The absolute deviation between the measured and calculated monthly constancy was 1.90 and 0.3%for the CRC-15R and PTW Curiementor radionuclides, respectively. These constancy fluctuations were well within the $\pm$10% limit described in literature.[3,4,10] If the measurement exceeded 5% of predicted, investigation into potential sources of error (patients in the area, exposed sources, use of the wrong isotope or setting, etc.) would have applied, while a 10% deviation from predicted would have meant suspension of the use of the dose calibrator and a repair or replacement of it done.

►**Table 1** gives the results for the accuracy of the two radionuclide calibrators. As demonstrated, results of all accuracy tests performed on the two dose calibrators with ^{137}Cs radionuclide were within the $\pm$5% limit.[3,4,10] The newer radionuclide calibrator, namely PTW Curiementor, had a lower percentage fluctuation. This can be attributed to the older radionuclide calibrator's change of resistance to match the nuclide, whereas newer units use digital conversion factors leading to reduced "response errors."[10] Also, the newer radionuclide calibrator could be said to be more sensitive and precise than the CRC-15R calibrator. The *t*-value for the measured accuracy, when comparing the two radionuclide calibrators, was 0.000212, demonstrating a nonstatistical significance difference between the two radionuclide calibrators accuracy. For error condition within $\pm$5%, no corrective action is required, while error conditions between $\pm$5 and $\pm$10% could trigger an investigation and the equipment used under advice from the manufacturer. In the extreme case of errors above $\pm$10%, equipment usage is halted immediately, and action taken for repairing the dose calibrator.

Linearity results for the two radionuclide calibrators are displayed in ►**Fig. 3**. From the graphs, both calibrators establish linear relationship for the decay of the ^{99m}Tc radionuclide source in log scale. The regression ($R^2 = 1$) in both instances depicts perfect proportionality of the variation of time (t) that is predictable from radionuclide activity (log A).

►**Table 2** demonstrates the linearity deviation between measured and calculated radionuclide activities for the two radionuclide calibrators. The test produced near exactness between the measured and estimated values over the clinical range of use for the radionuclide calibrator. Maximum deviation (0.8%) was observed in CRC-15R calibrator at the 24th-hour decay period. This is 84% less the tolerance limit of $\pm$5%[3,4,10] for linearity test on radionuclide calibrators. Curiementor calibrator, with relatively lesser deviations at 4 and 24 hours, was found to exhibit better linearity among the two systems.

The supplied liner and dipper of the CRC-15R radionuclide calibrator were used to achieve the correct geometry and correct reading for the addition of ^{177}Lu. Replicating the geometry is important because there will be variability depending on its placement within the detector.[10] The calibration setting number found in our study of 450×10 for ^{177}Lu, the syringe uncertainty was 2%, this result compared well with published data within 7%.[4] ►**Table 3** shows

Table 1 Accuracy results of the CRC-15R and PTW Curiementor 4 radionuclide calibrators

CRC-15R				
Date	A_{meas} (MBq)		A_{cal} (MBq)	Percentage difference
09/2014	2.89; 2.88; 2.89	Average = 2.89	2.94	1.70%
09/2015	2.81; 2.81; 2.81	Average = 2.81	2.87	2.09%
09/2016	2.75; 2.75; 2.75	Average = 2.75	2.80	2.10%
09/2017	2.69; 2.70; 2.69	Average = 2.69	2.74	2.01%
PTW Curiementor 4				
Date	A_{meas} (MBq)		A_{cal} (MBq)	Percentage difference
09/2017	7.44; 7.44; 7.44	Average = 7.44	7.44	0.00%
09/2018	7.29; 7.29; 7.29	Average = 7.29	7.27	0.30%
09/2019	7.08; 7.08; 7.08	Average = 7.08	7.11	0.40%

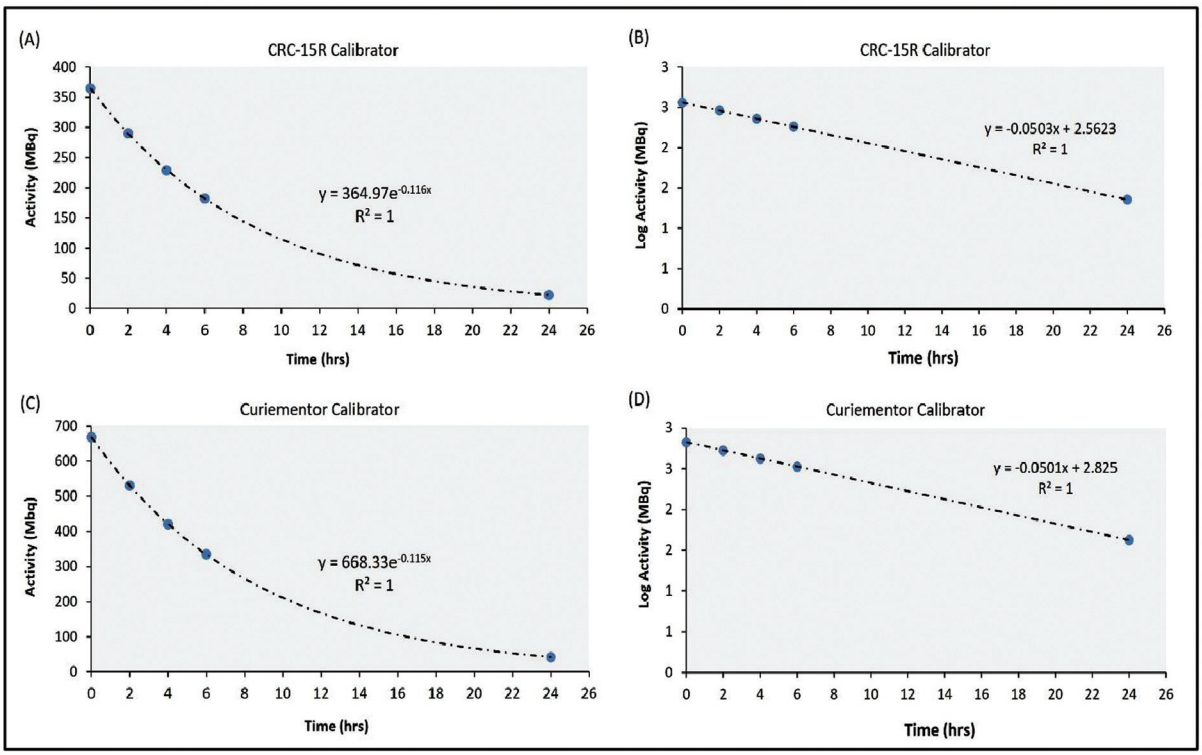

Fig. 3 Tc-99m decay curves (A&C) and linearity graphs (B&D) from CRC-15R and Curiementor radionuclide calibrators.

Table 2 Percentage differences between the calculated and measured linearity results for CRC-15R and Curiementor radionuclide calibrator

	Maximum deviation (%)		Tolerance limit	Action limit
Time (h)	CRC-15R	Curiementor		
2	0.1	0.1	± 5%	± 10%
4	0.7	0.3		
6	0.1	0.1		
24	0.8	0.5		

the results of the measured ^{177}Lu on the CRC-15R radionuclide calibrator compared with the standard laboratory's measurement. For series of 10 measurements performed, the deviation between standard laboratory measured data and average activity measurement from the CRC-15R radionuclide calibrator was estimated to be 1.3%.

Results for the sample (source) volume geometry test performed are presented in ►**Fig. 4**. In general, as the source volume is increased the relative efficiency of the radionuclide calibrator decreases but should not exceed 5% if the test is performed within 10-minute period.[11] The radionuclide calibrator measured the activity quiet accurately even with the volume of saline solution increased to 5 and 10 mL. This was due to the syringe volumes being normalized based on the liquid column height, which resulted in a predictable efficiency observed across syringes sized 5 and 10 mL. Volume correction factors of 0.98, 0.99 and 1.03 were estimated for the 1, 5, and 10 mL volumes, respectively. There is, therefore, no need for application of volume correction to measurements on the CRC-15R calibrator since all correction factors fell within the range of 0.95 to 1.05.

Quarterly ^{177}Lu geometry tests at volumes of 1 mL, 5 mL, and 10 mL, as indicated from ►**Table 4**, showed percentage deviations within ± 10%[3,4,10] for the radionuclide calibrator. The *t*-test value when comparing the initial activity to sample volume activities of 5 and 10 mL were 0.000122 and 3.32E-07, respectively, demonstrating a statistically nonsignificant difference.

Results for the Gamma Cameras Tests

The "all-purpose parallel-hole" collimator sensitivities for this study were 65, 52, and 45 cnts/s/MBq for the Philips Marconi Meridian, GE Discovery NM 630, and Siemens

Table 3 Measured ^{177}Lu on the CRC-15R radionuclide calibrator compared with standard laboratory measurements

No. of measurements (N)	Standard laboratory measured activity (MBq)	CRC-15R measured activity (MBq)			Percentage difference
		Min.	Max.	Ave.	
10	7,400	7,260	7,370	7,305 ± 37	1.3%

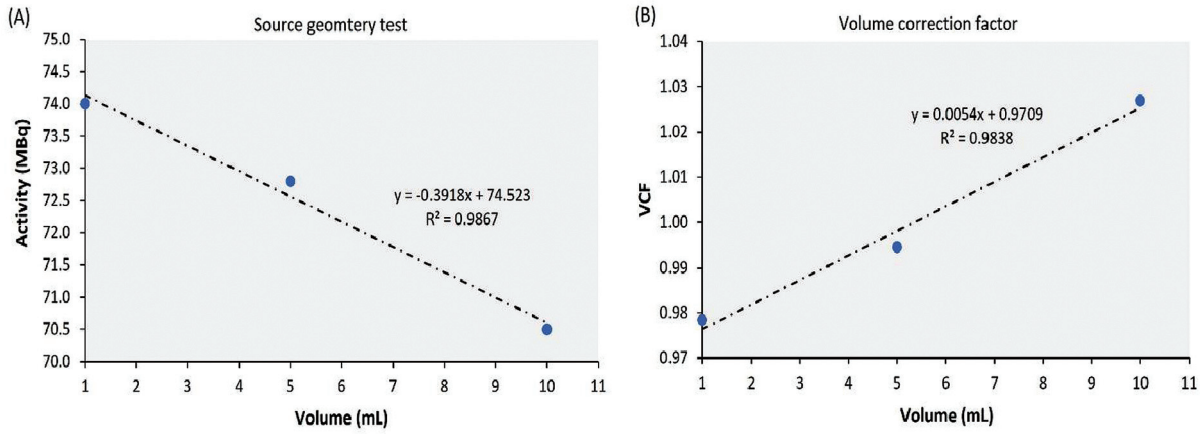

Fig. 4 Source volume geometry and volume correction factor for CRC-15R calibrator.

Table 4 Percentage differences between radionuclide activities at different volumes

Date	Activity (MBq)			Percentage difference (%)	
	Initial (A_{1mL})	At 5 mL (A_{5mL})	At 10 mL (A_{10mL})	A_{1mL}& A_{5mL}	A_{1mL}& A_{10mL}
Jan-18	74.0	73.0	71.0	1.4	4.1
Apr-18	74.0	72.0	70.0	2.7	5.4
Jul-18	74.0	73.0	70.0	1.4	5.4
Oct-18	74.0	73.0	70.0	1.4	5.4
Jan-19	74.0	73.0	71.0	1.4	4.1
Apr-19	74.0	72.0	71.0	2.7	4.1
Jul-19	74.0	73.0	70.0	1.4	5.4
Oct-19	74.0	73.0	71.0	1.4	4.1

SymbiaIntevo 16/6/2 GC systems, respectively. Similar to published literature, our sensitivity varied from collimator to collimator.[12–15] ►**Table 5** shows results for the three systems performed over the period of 2015 to 2019.

Average uniformities for the central and useful fields of view (CFOVs, UFOVs estimated for the Philips Marconi Meridian camera were found to range between 3.19 to 3.60% and 3.39 to 3.61%, respectively. Deviation in uniformities between the two detectors (D1 and D2) form this GC was found to be quite close, indicating similar uniformity performance. Similar trends were observed for the GE discovery and Siemens SymbiaGC systems. While GE recorded average CFOV and UFOV of 3.17 to 3.63% and 3.75 to 4.47%, Siemens recorded 2.67 to 3.07% and 2.76 to 3.31%, respectively. Within the period of study, the Siemens system could be said to have produced better image uniformity comparatively. However, uniformities for all the system were within the limit of ± 5% required.

Energy resolution measurements performed for all three systems were found to within the recommended limit of ± 11%.[3,4,10] Energy resolution assessed for the two detectors indicates that Siemens, with average resolutions of 8.2% (D1) and 8.4% (D2), will have better ability to resolve energies of radionuclide sources during clinical applications. Average energy resolution estimated for the Philips system was 9.0% (D1) and 9.2% (D2), while GE was 8.9% (D1) and 9.1%. Likewise for the uniformity and energy resolution tests, all measurements of the COR were within the recommended limit of ± 2 mm.[3,4,10] The GE system recorded the least deviation, indicating its superior ability to produce precise (circular) rotation around fixed central point and less artifact in reconstructed transverse slices. It is worth noting that the performance measures of the imaging systems could be age dependent. The Siemens system was manufactured in 2014 and may comparatively have better specifications than the Philips and GE cameras that were produced in 1999 and 2011, respectively.

Discussion

The radionuclide calibrators' constancy, accuracy, linearity, and sample volume were within the limits described in literature.[3,4,10] The absolute percentage difference of the CRC-15R radionuclide calibrator ^{177}Lu measurement when compared with the standard's laboratory measurement was 1.2%, after the calibration factor was loaded. Both the CRC-15R and PTW Curiementor 4 radionuclide calibrators were, therefore, validated for clinical dosimetry. A properly calibrated radionuclide calibrator is critical to good clinical dosimetry.[5] The stochastic nature of radioactivity gives rise to intrinsic errors; it is, therefore, critical that QC be done for therapeutic isotopes to mitigate error in measurements.

Table 5 Measurements for uniformity, energy resolution and center of rotation tests on GC systems

GC system	Year	Detector	Integral uniformity (%)				Energy resolution (%)		Centre of rotation (mm)	
			CFOV		UFOV					
			Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.
Philips Marconi Meridian	2015	D1	2.86–4.21	3.37	2.90–4.21	3.47	8.92–9.11	8.99	1.09–1.81	1.47
		D2	2.76–4.50	3.19	3.09–4.50	3.39	9.05–9.36	9.18	1.56–1.99	1.82
	2016	D1	2.68–3.56	3.22	3.16–4.06	3.53	8.87–8.97	8.91	1.20–1.78	1.53
		D2	2.73–4.32	3.41	3.03–4.45	3.61	9.00–9.03	9.02	1.01–1.95	1.69
	2017	D1	3.26–4.01	3.60	3.26–4.01	3.60	9.00–9.12	9.06	1.01–1.85	1.49
		D2	2.98–3.95	3.53	3.01–3.98	3.57	9.15–9.38	9.30	1.01–1.99	1.60
GE Discovery NM 630	2018	D1	2.31–3.71	3.17	2.47–4.19	3.75	8.92–9.11	8.99	0.18–0.35	0.29
		D2	2.27–3.86	3.21	2.27–4.45	3.84	9.05–9.36	9.18	0.15–0.37	0.30
	2019	D1	3.23–3.78	3.54	4.08–4.19	4.15	8.87–8.97	8.91	0.31–0.36	0.34
		D2	3.16–3.91	3.63	4.25–4.78	4.47	9.00–9.03	9.02	0.33–0.38	0.36
Siemens SymbiaIntevo 16/6/2	2017	D1	2.07–3.73	2.76	2.10–4.76	3.06	8.21–8.26	8.24	0.78–1.18	0.98
		D2	2.22–2.76	2.67	2.05–3.84	2.85	8.31–8.42	8.38	0.39–0.58	0.50
	2018	D1	2.07–3.37	3.01	2.15–4.71	3.31	8.22–8.24	8.23	0.75–1.19	0.97
		D2	2.16–3.88	2.78	2.08–4.38	2.76	8.36–8.39	8.38	0.41–0.60	0.52
	2019	D1	2.46–3.92	3.07	2.10–4.28	3.29	8.20–8.25	8.23	0.72–1.23	1.01
		D2	2.55–3.51	2.89	2.07–3.57	2.77	8.32–8.42	8.37	0.21–0.53	0.43
Tolerance limit			IU = ± 5%				ER = ± 11%		COR = ± 2 mm	

Abbreviations: COR, center of rotation; CFOV, central field of view; ER, energy resolution; GC, gamma camera; IU, integral uniformity; UFOV, useful field of view.

The integral uniformity, energy resolution, and COR results for all three GCs were within the limits described in literature[3,8,9,12,16–19] and was therefore validated for clinical dosimetry. The lowest average integral uniformity was displayed by the Siemens SymbiaIntevo 16/6/2 with 2.94 and 3.21% for the CFOV and UFOV, respectively. However, this GC also displayed the largest *range* when compared with the others, with a *range* of 2.07 to 3.96% and 2.04 to 4.76% for the CFOV and UFOV, respectively. The large *range* was attributed to slight changes in the source distance from the crystal, radiation source shifts from the center of the detector, or different source volumes during preparation. Hence, monitoring fluctuations in uniformity that are within prescribed limits is important. Regular analysis of integral uniformity can facilitate detection of gradual deterioration prior to any visible change.[17,20] Saad, 2013[17], similar to our study demonstrated that performing the intrinsic uniformity requires special attention to the physical and geometric adjustments, which can affect the results. The importance of energy resolution and uniformity to assess the state of the tuning of the photomultiplier tubes is stressed by the authors of this paper. The correct and stable energy window settings are crucial for good data acquisition. Smaller detector energy resolution will result in narrower window settings and achieve better image quality, which plays a crucial role in dosimetry. Impaired energy resolution or an incorrect energy calibration of the pulse height analyzer could also indicate changes in GC sensitivity.[12–15,18] The sensitivity results also depend on the accuracy of the radionuclide calibrator used. Accuracy of ± 5% obtained on the radionuclide calibrators in this study was sufficient to indicate that the sensitivities obtained are comparable to the manufacturer's specifications. Image degradation can also result from COR offset, with large image degradation experienced with larger offsets. An offset in COR would have a profound effect on single-photon emission computed tomography dosimetry results. A COR offset is difficult to ascertain in clinical images and is often overlooked.[18] The COR of this study was well within limits.

A limitation of our study is that validation using ^{177}Lu for linearity, uniformity, and sensitivity tests was not done. Authors selected to use ^{99m}Tc instead of ^{177}Lu for these tests as the measurement accuracy of these nuclides should not differ intrinsically or extrinsically, due to ^{177}Lu not being a pure β emitter. Only linear or uniform response of the devices was assessed; hence, this was the justification for the methods and results in this study. The use of "expensive" radionuclide such as ^{177}Lu for QC is also limited in a developing country. The authors, however, recommend that ^{177}Lu be used for sensitivity tests, as this would affect dosimetry results.[5]

Conclusion

Our study successfully appraised existing radionuclide calibrators and GC systems meant to be deployed for performance of ^{177}Lu internal dosimetry in two nuclear medicine

centers in South Africa. Owing to satisfactory results, the hospitals are in position to deliver this specialized treatment procedure, which is highly dependent on sound performance of the two named detectors.

Ethical Approval

Sefako Makgatho Health Sciences University Research Ethics Committee approved this study, SMUREC Ethics Reference Number: SMUREC//M/114/2018: PG
University of Kwazulu-Natal Biomedical Research Ethics Committee approved this study, BREC Ethics Reference Number: BE693/18.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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References

1 Kwekkeboom DJ, Krenning EP. Peptide receptor radionuclide therapy in the treatment of neuroendocrine tumors. Hematol Oncol Clin North Am 2016;30(01):179–191
2 Bailey D, Humm J, Todd-Pokropek A, van Aswegen A. IAEA. Nuclear Medicine Physics: A Handbook for Teachers and Students. Vienna: International Atomic Energy Agency; 2014:621–640
3 https://www.aapm.org/pubs/reports/RPT_181The selection, use, calibration, and quality assurance of radionuclide calibrators used in nuclear medicine: AAPM report No.181pp.1–13. Accessed March 13, 2022
4 http://www.gammadata.se/assets/Uploads/CRC-15R-Manual-9250-0038-Rev-W-F18CRC-15R radioisotope dose calibrator owner's manual. Manual stock no. 9250–0038 Accessed March 13, 2022
5 Lassmann M, Chiesa C, Flux G, Bardiès M. EANM Dosimetry Committee guidance document: good practice of clinical dosimetry reporting. Eur J Nucl Med Mol Imaging 2010
6 https://www.hpcsa.co.za/Uploads/Legal/legislation/health_professions_ct_56_1974Health professions act 56 of 1974. Regulations defining the scope of the profession of medical physicist. Government notice R310 in regulation gazette 4179 Accessed March 13, 2022
7 Bailey D, Humm J, Todd-Pokropek A, van Aswegen A. Nuclear Medicine Physics: A Handbook for Teachers and Students. Vienna: International Atomic Energy Agency; 2014:235–248
8 Human Health Series No. 6. Quality Assurance for SPECT Systems. Vienna: International Atomic Energy Agency; 2009
9 National Electrical Manufacturers Association (NEMA). Performance measurements of scintillation cameras. NEMA NU-1 2001. Accessed March 15, 2022 at: http://www.nema.org/stds/nu1.cfm
10 https://pharmacyce.unm.edu/nuclear_program/freelessonfiles/vol15lesson4.pdfThe Science of Measurement: A Primer on Radioactivity Dose Calibrators. Accessed March 13, 2022
11 Santos JAM, Carrasco MF, Lencart J, Bastos AL. Syringe shape and positioning relative to efficiency volume inside dose calibrators and its role in nuclear medicine quality assurance programs. Appl RadiatIsot 2009;67(06):1104–1109
12 IAEA-TECDOC-602. Quality Control of Nuclear Medicine Instruments 1991. Vienna: International Atomic Energy Agency; 1991
13 Ballani N, Doughherty G. Simple Method to Measure Gamma Camera Energy Resolution. Elsevier Ltd; 2015:172–175
14 Quality Assurance for Radioactivity Measurement in Nuclear Medicine, Technical Reports Series No. 454. Vienna: International Atomic Energy Agency; 2006
15 National electrical Manufacturers Association (NEMA). Digital imaging and communications in medicine. DICOM PS 3.1. Accessed March 15, 2022 at: https://dicom.nema.org/dicom/2004/04_01pu.pdf
16 Cherry S, Sorenson J, Phelps M. Physics in Nuclear Medicine. 4th edition. Philadelphia: Saunders/Elsevier; 2012:209–231;683
17 Saad IE. Analysis of the geometrical and physical fluctuations while performing intrinsic uniformity test for Philips Forte gamma camera. International Journal of Recent Research and Applied Studies 2013;15(03):269–279
18 Quality Control Atlas for Scintillation Camera Systems. Vienna: International Atomic Energy Agency; 2003
19 Blust J. Gamma camera acceptance testing: the first quality control. J Nucl Med Technol 1994;22:58–60
20 Sorenson J, Phelps M. Physics in Nuclear Medicine. 2nd edition. Philadelphia, PA: W.B. Saunders Co.; 1987:252–259,387–390

