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Quality Control Procedure of Clinical Nuclear Medicine Instruments and Comparisons with Standard Protocol (At DINAR Cancer Hospital D. I. Khan)

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***Abstract*:** Quality control of clinical Nuclear medicine instruments" i.e. used, used in this research work i.e. radioisotope dose calibrator and SPECT gamma camera is most important for reliable operational characteristics in this research work different tests has been done taking data from " GE- Infinia Hawkeye" SPECT Gamma camera at "DINAR" Cancer hospital D.I.Khan.Auto zero, background, linearity, geometry, constancy and accuracy tests were performed in the case of radioisotopes dose calibrator while tests performed in case of SPECT gamma camera includes background, energy peak, C.O.R and uniformity tests. In conclusion, all the obtained results were within acceptable range stated in operational manual of "GE- Infinia hawk eye" SPECT Gamma Camera and that of radioisotopes dose calibrator was in accordance with IAEA (International atomic energy agency).Thus "Radioisotopes dose calibrator" and "SPECT gamma camera" is in good working condition at DINAR cancer hospital D.I.Khan

***Keywords**: IAEA, DINAR, radioisotope, operational*

Introduction

Clinical Nuclear Medicine Instruments:

In this research work two nuclear medicine instruments are used including radioisotope dose calibrator and gamma camera[1].Radioisotope Dose Calibrator **is** highly pressurized gas filled ionization chamber used to

measure the activities of different types of radioactive sources are called radioisotope dose calibrator[2]. In the field of nuclear medicine radioisotope dose calibrators are used to measure the radiopharmaceutical activities present in vials or syringes before injecting into the patient's body[3]

Components of Radioisotope dose calibrator

The basic components of radioisotope dose calibrator are listed below;

(i) Cylindrical ionization chamber with lead shielding
(ii) Electrometer

Gamma camera is the most widely used device used for imaging purpose in the field of nuclear medicine. This instrument is used for the diagnosis of different types of abnormalities in a patient's body. An advanced version of gamma camera also known as single photon emission computed tomography (SPECT) used to get 3D image of the specific organs [4].The SPECT gamma camera is mainly used for the imaging of kidney, liver, respiratory, cardial system and brain.

Components of gamma camera:

There are many components of gamma camera some of the main components of gamma camera are listed below;

(i) Collimator
(ii) Sodium iodide(NaI) crystal
(iii) Photomultiplier tubes(PMTs)
(iv) Logic circuits
(v) Computer system with a suitable radio-graphical software

Quality Control:

A process that involves the evaluation of instruments in order to make sure that the standard of all the features is acceptable [5]. It is composed of a set of different types of tests in order to check that performed operations are in accordance to the manufacturer standard protocols [6]. The quality control program is necessary after the installation of instruments and prior to daily use of the instrument.

Quality control of Radioisotope dose calibrator:

Quality control tests performed in the case of radioisotope dose calibrator include the following tests

(i) Auto zero test
(ii) Chamber Voltage
(iii) Background test
(iv) Accuracy test
(v) Geometry test
(vi) Linearity test
(vii) Constancy test

[7].After the performance of all of the above stated tests, their results were then compared with standard protocols of IAEA and Capantic-CRC-25R manufacturer manual.

The above stated tests are briefly described below

1. **Auto-zero:**

In order to remove the "internal voltage offset "because of temperature, to get the measurements more accurately the device has a function called Auto zero.

2. **Chamber voltage:**

This test is used to check the chamber voltage required for the correct operation of radioisotope dose calibrator from the voltage supply system [8].

3. **Background test:**

Background test is performed in order to check the presence of radiation source in surroundings of radioisotope dose calibrator by removing all the radiation sources present around dose calibrator [9].

4. **Accuracy test:**

Accuracy test is performed in order to check the closeness of the measured value of activity to the actual stated activity of the radioactive source. Accuracy test is done repeatedly in order to get the "Average value", after getting the required results there may be needed to take the following two steps

(i) Renovate or adjust the radioisotope dose calibrator in case of "percent error of 5.0%"
(ii) In case of $\pm$ 10% of error then, there is need to replace the equipment.

5. **Constancy test:**

The constancy test is used to check the closeness of present reading or measurement to the value of measurement done previously on a specific day, limits of acceptability for constancy test is 10% of the "decay corrected reference reading"[10].

6. **Linearity:**

Linearity test is used to check the linear response of the radioisotope dose calibrator at varying values of activities [11].

7. **Geometry test:**

Geometry test is used to check the response of radioisotope dose calibrator at different volumes of the sample or it is used o check that whether the response of dose calibrator is effected or not by varying the geometry of the source [12].

Materials and Methods

Tests performed for the quality control of clinical ionization chamber i.e. radioisotope dose calibrator including auto-zero, background test, accuracy, constancy, linearity and geometry tests by using "CAPANTIC-CRC-25R"at DINAR cancer hospital D.I.Khan, by keeping chamber voltage within the acceptable range given in manual,then auto zero and background tests were performed in the absence of radioactive source in the surroundings of radioisotope dose calibrator.Constancy test was performed by using Cs-137 and CO-57 having following characteristics,

Name	Half life	Energy
Cs-137	30.2years	662Kev
Co-57	270.9 years	122Kev

Linearity test was performed by shield method, using the point source of-
-Tc-99m in a vial of 7 to 10 ml and a calicheck kit as shielding source. Geometry test was performed by using materials including syringe of 7-10ml, radioactive source of 0.5 ml Tc-99m having half-life of 6hours and energy 140Kev and a vial of non-radioactive saline solution or water to raise the volume of sample in syringe, at first activity of 0.5ml Tc-99m was measured and then by gradually increasing the volume of solution by adding water to syringe up to 1ml and so on.
Accuracy test was performed by using radioactive source of Co-57 and Cs-137, the accuracy test was selected from the test menu and measurements were recorded according to the standard given in the manual.

Quality Control of gamma camera:

Quality control tests performed in the case of gamma camera are listed below;

(i) Background test
(ii) Uniformity test
(iii) Energy peaking
(iv) Center of rotation test(C.O.R)

All of the above listed tests are briefly described below

(i) Background Test:

Background test of gamma camera with SPECT system, performed in order to check the presence of any radioactivity in the surroundings
Of "SPECT gamma camera" prior to use of SPECT gamma camera
The radiation source may also be present on the gamma camera, walls or the floor of the room keeping the camera may be contaminated.

(ii) Uniformity Test :

Uniformity of image can be measured either intrinsically or extrinsically, defined as follows

(a) Extrinsic Uniformity

Uniformity measurement done in the presence of collimator is called extrinsic uniformity.

(b) Intrinsic uniformity

Uniformity measurements done without using collimator both at lower and higher counting rates is called intrinsic uniformity test.

Uniformity test of gamma camera with "SPECT system" includes integral uniformity test and differential uniformity test.
Intrinsic uniformity can then be categorized as integral uniformity and differential uniformity, defined below as;

Integral uniformity test:

Integral uniformity is an extensive variable used for the measurement of uniformity in a wide area of the detector, that is represented mathematically as follows,

$$\text{Integral uniformity} = \frac{C_{max} - C_{min}}{C_{max} + C_{min}} \times 100\ \%$$

Where C_{max} = maximum count rate and C_{min} = minimum count rate in a particular pixel of the specific area of the detector.

Differential uniformity:

The differential uniformity parameter is used to measure the detector's uniformity in a small portion of the detector area i.e. ~5 pixels either in "X" or "Y" position.
After finding the high and low values of determined difference, mathematically differential uniformity can be written as follows;

$$Du\% = \frac{[\text{High value} - \text{Low values}]}{[\text{High value} + \text{Low Values}]} \times 100\ \%$$

Energy peaking (photo peak) and energy resolution:

The capability of gamma camera detector to accurately calculate the energy of the striking radiations is called its energy resolution. It is the
Predominant factor in finding the general working of the SPECT gamma camera, as due to this factor (energy resolution) the gamma camera is able to distinguish between the primary radiations and the scattered radiations "(Compton scattering)",energy resolution in terms of percents can be written as

$$\text{Energy resolution \%} = \frac{\text{FWHM}}{\text{Photo peak}} \times 100\%$$

Where

FWHM = "full width at half maximum" and photo peak can be defined as the peak of the energy distribution graph, on which the maximum energy of the striking radiations was deposited on the detector's surface.

Center of rotation (C.O.R):

Among the other factors one of the major parameter that can cause remarkable distortion in the in the image reconstruction in the case of SPECT gamma camera is the center of rotation. Therefore, it is necessary for all of the images constructed by gamma camera to have recognizable center of rotation of gamma camera with SPECT system. Background test of SPECT gamma camera was performed by using the materials including collimators (LEHR, i.e. low energy high resolution with energy $\leq$ 200kev for radioactive source of Tc-99m), computer having suitable nuclear medicine software and SPECT gamma camera. Then after having all required materials, first of all the radioactive sources were removed from the vicinity of gamma camera and background test settings were selected by selecting the time of 60 seconds (standard given by the manufacturer) and then after the passage of selected time for each detector i.e. "D_1" and "D_2" the results in the form of image and numerical values were displayed on the computer screen. Energy peaking and energy resolution tests were performed by using the following materials,

(i) Point source of Tc-99m
(ii) SPECT gamma camera with computer

As in this test Tc-99m radioactive source is used for which the suitable energy window setting of 9-10% was selected by putting point source of Tc-99m at distance of "5UFOV" from the gamma camera detector and then after the passage of sufficient time of 2-3 seconds the photo peak was check the energy resolution of gamma camera. Uniformity test was done according to the standards given by National electric manufacturer association and the obtained results were then noted & compared with standards, by using the point source of 1 milli curie of Tc-99m at distance of "5ufov"from detector in order to get the uniform distribution of radiations. Then by removing collimators from both detectors and selecting 3000kcts rate of counting, the qualitative results were displayed on the computer screen and noted. For the quantitative assessment of SPECT gamma camera the values of Integral and differential uniformity were recorded by selecting the additional Settings of "64 by 64" matrix size .Then the percent values of IU and DU were observed and recorded from the computer screen. C.O.R, center of rotation test was performed for the SPECT gamma camera in order to check the correct position of center of rotation in image acquired with the help of SPECT gamma camera by using the appropriate apparatus, i.e. radio-active source of 1milli curie Tc-99m, LEHR collimator and suitable computer software with the setting of radiation free background, both detectors were selected from detector selection menu and then C.O.R tests were performed by using H-mode and L-mode at the count rate of 6000kcts and energy window settings of 140 Kev for the radioactive source of Tc-99m.The matrix size of "256 X 256" at zooming of 1.0. Then the images were observed for any artifacts due to misalignment of the detectors "D_1" and "D_2" of the SPECT gamma camera during its rotation.

Results and Discussion

Table 1:Daily QC of Dose Calibrator

S.NO	Auto-Zero	BKG (µCi)	Chamber Voltage (V)	Accuracy (%age deviation For Cs-137)	Constancy (Cs-137) (µCi)	Remarks
1	0.02	17.57	155.0	-6.0	160	Ok
2	0.02	15.58	155.0	-4.2	163	Ok

3	0.02	13.96	155.0	-3.4	159	Ok
4	0.03	3	155.0	-6.3	160	Ok
5	0.03	19.37	155.0	-5.6	164	Ok
6	0.03	16.3	155.0	-3.6	165	Ok
7	0.03	17.58	155.0	-2.2	166	Ok
8	0.03	6.33	155.0	-2.2	171	Ok
9	0.02	7.75	155.0	0.6	175	Ok
10	0.02	1.31	155.0	3.2	175	Ok
11	0.02	1.55	155.0	3.4	174	Ok
12	0.02	1.53	155.0	2.8	173	Ok

Table 2: Linearity test (Shield Method)

S.NO	Attenuator combination	Measured activity(mCi)	Calibration factor	Corrected Activity
1	Black	71.6	1	71.6
2	Black +Red	42.1	1.71	71.991
3	Black + Orange	21.1	3.42	72.162
4	Black + Yellow	6.34	11.31	72.2709
5	Black + Green	1.704	43.41	73.97064
6	Black + Blue	0.43	167.61	72.0723
7	Black +Purple	0.17	427.2	72.624
8	Black+ Purple+ Red	0.088	780.7	68.7016
9	Black+Purple+Orange	0.046	1517.05	69.7843

Average Activity (mCi) = 71.68630444

Upper limit (+5%) = 75.27061967

Lower Limit (-5%) = 68.10198922

Graph 1 ,Linearity Test

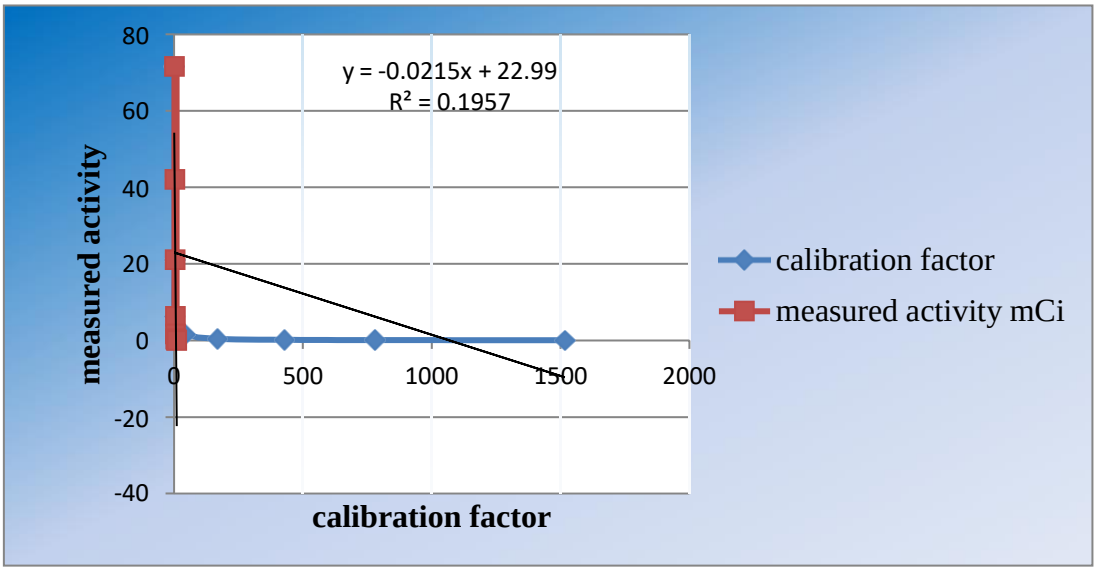


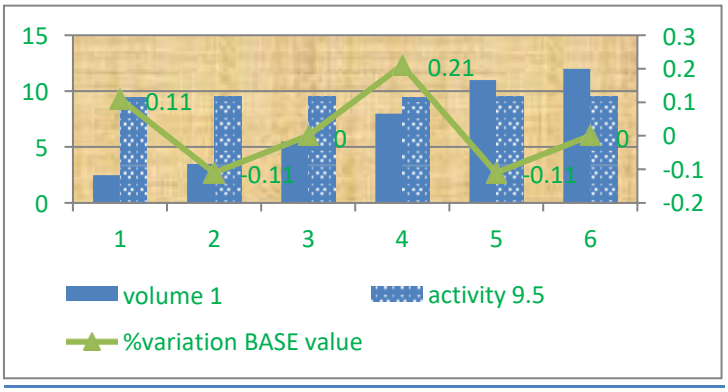
Table 3: Accuracy Test

S.NO	Radionuclide	%Variation	Remarks
1	Cs^{137}	2.6	Ok
2	Co^{57}	-2.6	Ok

Table 4: Geometry test Results

S.NO	Measured Activity(mCi)	Volume (ml)	%Variation
1	9.5	1	Base value
2	9.49	2.5	0.11
3	9.51	3.5	-0.11
4	9.5	5.5	0
5	9.48	8	0.21
6	9.51	11	-0.11
7	9.5	12	0

Graph 2: Geometry test



Gamma Camera:

Table 5: Detector#1 daily QC tests

S.NO	Test	Source	BKG ≤ 2.5kcts	Energy peak(140±3.0) Kev	FWHM ±11.0%	Uniformity ≤5.0	Count rate(≤40)
1	Daily QC	Tc^{99m}	2.1	138.6	9.6	1.84	31.9
2	Daily QC	Tc^{99m}	2.1	137.9	9.7	2.36	30.8
3	Daily QC	Tc^{99m}	2.1	137.5	9.7	2.64	34.9
4	Daily QC	Tc^{99m}	2.1	139.4	9.8	1.89	34.1
5	Daily QC	Tc^{99m}	2.1	137.5	9.7	2.52	25.7
6	Daily QC	Tc^{99m}	0.2	121.1	10.7	2.58	4.6
7	Daily QC	Tc^{99m}	2.2	139.1	9.8	1.84	34.8
8	Daily QC	Tc^{99m}	2.2	139.2	9.7	2.73	40.4
9	Daily QC	Tc^{99m}	2.0	141.6	9.6	1.85	24.5
10	Daily QC	Tc^{99m}	2.0	140	9.7	2.89	28.0
11	Daily QC	Tc^{99m}	2.2	140	9.3	1.964	31.6
12	Daily QC	Tc^{99m}	2.2	140	9.3	2.051	38.8

Table 6: Detector #2 daily QC test

S.NO	Test	Source	BKG ≤ 2.5kcts	Energy peak(140±3.0) Kev	FWHM ±11.0%	Uniformity ≤5.0	Count rate(≤40)
1	Daily QC	Tc^{99m}	2.0	140.2	9.3	1.93	32.9
2			2.0	139.5	9.2	2.12	32.0
3			2.2	139.2	9.3	2.61	36.0
4			2.2	140.4	9.4	2.37	34.8
5			2.2	139.7	9.3	2.26	26.6
6			0.2	123.0	10.1	3.19	4.6
7			2.2	141.0	9.5	2.32	35.8
8			2.4	138.5	9.3	2.39	41.7
9			2.0	140.4	9.5	2.11	25.2
10			2.4	139.8	9.3	1.822	28.8
11			2.3	139.3	9.8	2.715	30.8
12			2.3	141.5	9.4	2.685	39.8

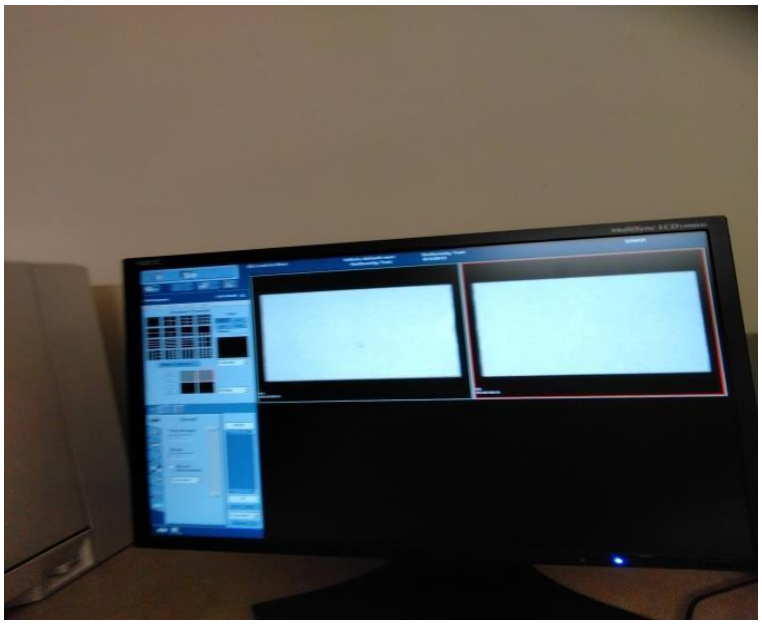


Figure 1: Gamma Camera Background test

Table 7: Uniformity Test

Detector #1

S.NO	Source	FWHM ≤ 11%	CFOV IU% ≤3.0%	CFOV X-DU% ≤2.1%	CFOV Y-DU% ≤2.1%	UFOV IU% ≤ 4.5%	UFOV X-DU% ≤ 2.5%	UFOV Y-DU% ≤ 2.5
1	Tc^{99m}	9.6	2.54	2.18	2.053	2.72	2.18	2.49
2		9.52	1.19	1.571	1.883	2.794	1.847	2.318
3		9.58	2.145	1.846	1.787	3.309	2.159	2.552
4		9.63	0.5987	0.4619	0.5277	1.117	0.7033	0.610
5		9.655	0.571	0.439	0.398	0.988	0.646	0.761
6		9.613	0.772	0.441	0.535	2.363	1.235	1.383
7		9.706	0.806	0.585	0.543	1.858	0.986	1.131
8		9.681	1.317	1.173	0.872	1.760	1.236	1.227
9		9.581	1.026	0.703	0.886	2.861	2.193	2.277
10		9.725	1.671	1.072	1.512	2.610	1.932	1.809
11		9.61	1.28	0.774	1.108	1.85	0.94	1.16

Table 8: Uniformity test: Detector #2

S.NO	Source	FWHM ≤ 11%	CFOV IU% ≤3.0%	CFOV X-DU% ≤2.1%	CFOV Y-DU% ≤2.1%	UFOV IU% ≤ 4.5%	UFOV X-DU% ≤ 2.5%	UFOV Y-DU% ≤ 2.5
1	Tc^{99m}	9.2	2.15	1.60	1.48	2.68	2.18	1.67
2	Tc^{99m}	9.25	1.576	1.157	1.329	1.753	1.157	1.329
3	Tc^{99m}	9.25	0.6892	0.452	0.5175	0.9818	0.6038	0.6149
4	Tc^{99m}	9.318	1.789	1.059	0.5176	0.859	2.197	1.345
5	Tc^{99m}	9.232	1.366	0.933	1.030	1.876	1.407	1.195
6	Tc^{99m}	9.352	1.168	1.012	1.510	1.788	1.067	1.510
7	Tc^{99m}	9.316	1.788	0.7479	0.7881	1.298	1.130	0.879
8	Tc^{99m}	9.223	1.1946	1.321	1.513	2.171	1.746	1.232
9	Tc^{99m}	9.441	2.012	0.8677	0.9299	1.5215	1.3301	1.082
10	Tc^{99m}	9.270	1.54	0.73	1.02	1.84	1.37	1.28
11	Tc^{99m}	9.61	2.334	1.185	1.460	5.15	2.476	3.14

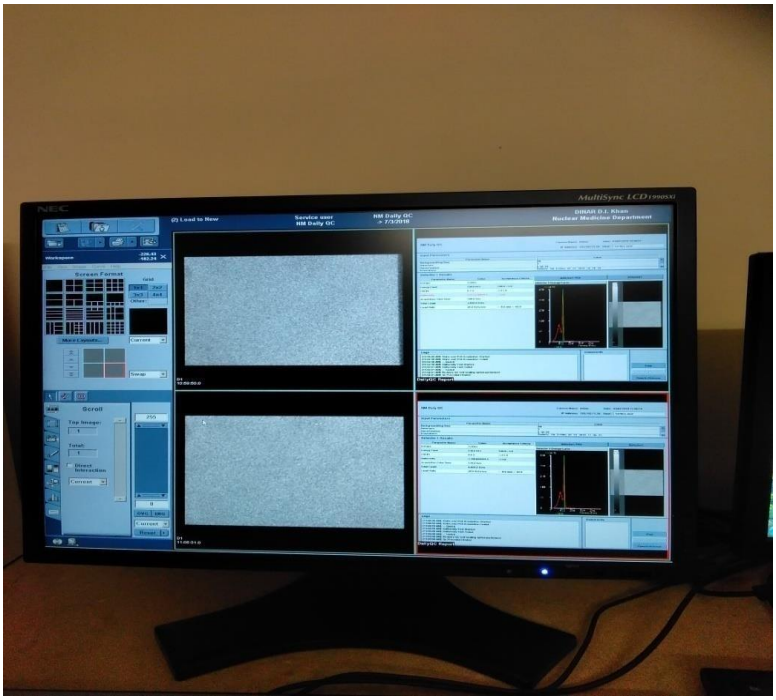


Figure 2: Uniformity test of gamma camera detectors

Table 9: Results obtained in C.O.R test:

S.NO	Mode H/L mode	Delta X D_1 ≤ 0.5	Delta X D_2 ≤ 0.5	Delta Y D_1 ≤ 0.5	Delta Y D_2 ≤ 0.5
1	L-mode	0.48	-0.205	0	-0.199
2	H-mode	-0.15	0.221	0	-0.027
3	L-mode	-0.05	0.05	0	-0.041
4	H-mode	-0.099	0.132	0	0.046
5	L-mode	-0.096	-0.033	0	0.018
6	H-mode	-0.164	0.18	0	0.029
7	L-mode	0.013	-0.081	0	0.116
8	H-mode	-0.041	0.1729	0	-0.035
9	L-mode	-0.032	0.0204	0	-0.101
10	H-mode	0.011	0.0420	0	-0.0414
11	H-mode	-0.099	-0.0355	0	-0.154
12	L-mode	-0.149	0.0934	0	0.121
13	H-mode	-0.0441	0.0208	0	0.120

Average value of delta X for D1 = -0.5792

Average value of delta X for D2 = 0.70524

Average value of delta Y for D1 = 0

Average value of delta Y for D2= -0.1157

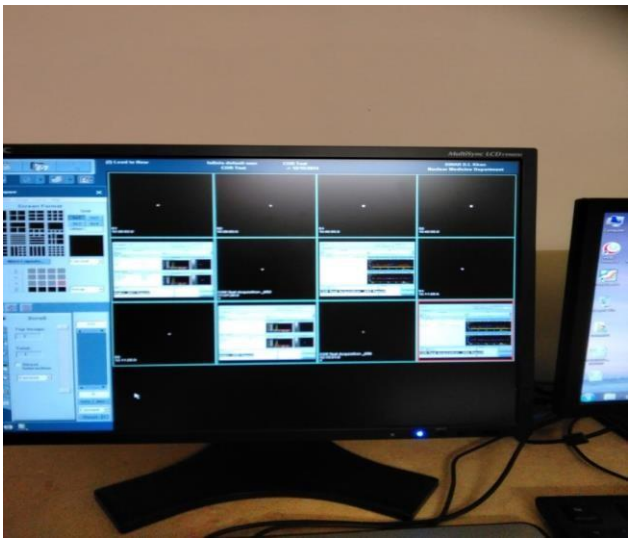


Figure 3 C.O.R test

Results and Discussion

As this research work has been carried out on the clinical nuclear medicine equipments, some of the nuclear medicine are used for the diagnosis and some are for the treatment purposes, hence it is of utmost importance to have equipments with a good standard to get reliable and better quality results. Therefore quality control tests

performed for the radioisotope dose calibrator and SPECT gamma camera at DINAR cancer hospital D.I.Khan. The tests performed with the acceptable range of values given by NEMA, IAEA and manufacturer are listed below,

Quality control tests for dose calibrator

(i) Auto zero (± 0.3 V)
(ii) Background (≤ 20%)
(iii) Chamber voltage (155.0 V)
(iv) Accuracy (± 10%)
(v) Linearity test
(vi) Geometry test
(vii) Constancy test

Quality control tests for gamma camera

(i) Background test (≤ 2.5kcts)
(ii) Energy peak (140 ± 3.0) Kev for Tc-99m
(iii) FWHM (±11%)
(iv) Uniformity (≤ 5.0)
(v) Count rate (≤ 40)
(vi) C.O.R (delta X = 0.5 ,delta Y =0.5 for both the detectors)

Hence after the performance of all the quality control tests for clinical nuclear medicine equipments the acquired values were compared with the limits given by NEMA, IAEA and manufacturer manuals, and all of the obtained values were in accordance to the given limits.

Conclusion

This research work was carried out at DINAR cancer hospital D.I.Khan in order to ensure the better quality of results obtained in the case of radioisotope dose calibrator and SPECT gamma camera. In this research study the "Quality control " procedures were done by performing different types of tests ,whose recorded values were compared with standard protocols and it is concluded that the clinical nuclear medicine equipments i.e. dose calibrator and SPECT gamma camera are in good operational conditions to be used for diagnostic and treatment purposes at DINAR cancer hospital D.I.Khan.

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References

[1] Laura, H.B. (2018, June). An Introduction to the Physics of Nuclear .Retrieved
[2] from http://iopscience.iop.org/book/978-1-6432-7034-0
[3] Allied academics (2018, May 14-15).YEAST-BASED DRUG DISCOVERY
[4] |Global|USA|Europe|Middle East Asia Pacific. Retrieved from yeast. Allied
[5] academies.com/events-list/yeast-based-drug-discovery
[6] Anne,M.H.(2018, April 13).Why Does Radioactive Decay Occur? Retrieved from
[7] https://www.thoughtco.com/why-radioactive-decay-occurs-608649
[8] Biodex (2018).Dose Calibrator Vial Reference sources-sources-Nuclear Medicine|
[9] Biodex. Retrieved from m.biodex.com/nuclear-medicine/products/sources/dose
[10] -calibrator-vial-reference-sources.
[11] Biodex (2018).Liner. Retrieved from m.biodex.com/nuclear-medicine/products/
[12] Dose-calibrator-accessories/well-insert
[13] 6.Biodex(n.d).InMed-Product.Retrieved from https://inmed.com.au/product/113/Surgical-

[14] Forceps.Canadian Nuclear Safety Commission. (2012, December 1). Introduction to Radiation. Retrieved from https://nuclearsafety.gc.ca /eng/pdfs/.../ radiation/Introduction-to- Radiation -eng . Desertvapes. (2018). Diy-e-liquid supplies10 ml Syringe Retrieved from https://desertvapes.com/e-juice-syringes-10
[15] Dotmed.com, Inc (2001-2018).Chamber dose calibrator. Retrieved from https:
[16] //m.dotmed.com/listening/dose-calibrator/capintec/crc-15r-w-chamber/1771809
[17] EKO-TEKNIK (2008). Calicheck Linearity Test Kit. Retrieved from eko- teknik.com/
[18] V4/product/calicheck-linearity-test-kit/.
[19] Electromagnetic waves.(BBC 2014).Retrieved from www.bbc.co.uk/ schools/
[20] gcsebitesize/science/edexcelelectromagnetic-spectrumrev5.shtm.
[21] 11.Gopal,B.S.(2018) Performance Parameters of Gamma Cameras. Retrieved from
[22] https://link.springer.com/chapter/10.1007/978-1-4614-4012-3-10.
[23] 12. Hermen,C etal.(2008 Aug 01).Introduction to Health Physics, Fourth Edition 4th Edition.Retrieved from https://www.amazon.com/Introduction-Health-Physics- Herman Cember/dp/007142308715