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Measurement and Comparative Analysis of System (Scintillation Camera) Dead Time using NEMA and AAPM Protocols

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Abstract

Dead time arises because of the multitude of electronic circuits in a nuclear imaging system, each with its own dead time, and the complex interaction between such circuits. Different protocols have been suggested for the evaluation of dead time of scintillation camera. Dead time Of the E. Cam scintillation camera system was calculated by using NEMA [9] (National Electrical Manufacturers Association) and AAPM procedures [1_5] (American Association of Physicist in Medicine). Results thus obtained using the protocols were compared and analyzed. The results obtained for extrinsic paralyzable dead time by the AAPM were within specifications but the intrinsic paralyzable dead time calculated was slightly higher. On the other hand the NEMA protocol was able to calculate exact dead time of the system with a small standard deviation. The extrinsic paralyzable dead time should be measured using AAPM protocol. For the evaluation of intrinsic paralyzable dead time the NEMA protocol can be preferred.

Introduction

The dead time of a nuclear imaging system is the time during which the system processes a single event (i.e., the interaction of a particle or stimulus from a radiation field with the

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system) and is not available to process a succeeding event. It arises because of the multitude of electronic circuits in a nuclear imaging system, each with its own dead time, and the complex interaction between such circuits. Furthermore, the count rate losses of a system are a function of the number of particles produced by the radiation field under investigation, which lie outside the energy window of the single channel analyzer of the system because the interactions of such particles occupy the circuitry of the system while a decision is being reached with regard to further processing. Thus, the dead time of a nuclear imaging system depends on the nature of the system and the type of field interacting therewith.

As a consequence of the dead time phenomenon in nuclear imaging systems, the rate at which events are processed by the system is a non-linear function of the rate of incoming events. For a typical conventional gamma camera, the curve relating events processed to incoming events peaks at about 200,000 counts per second, which defines the so-called fold back point of the curve. At such point, the typical camera processes only about 50% of the incoming events; while at greater counting rates, the efficiency of the camera drops below 50%. Thus, if a radiation field produces particles that interact with the camera at rates in excess of 200,000 per second, less than half of these events will be processed by the camera and appear in a map of the radiation field.

One approach to compensating for the dead time of a gamma camera in order to take into account the dependency of the efficiency of the camera on the rate of incoming events is to assume an analytical approximation of the statistical probability of an event that encounters an electronic component in the camera will be operated on by such component. As indicated previously, dead time is extremely complicated and is dependent not only on the inherent limitations of the camera itself but also on the nuclear

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spectra, which the camera is associated. As a consequence, the use of an analytical function to compensate for dead time yields high error.

It is therefore an object of the present study to provide a the best method of and means for measuring the dead time of a gamma camera, which are less complex than the techniques of the prior art and more likely to produce accurate results.

Materials and Method

Following materials were used during the course of work.

1) Anger type scintillation camera
2) Acquisition and processing computer system
3) Lead Shielding
4) e.soft (computer software)
5) Point source

The following methods were used to determine the dead time of the E.cam Scintillation camera.

In the first protocol (as in AAPM [5]) the following method was adopted to calculate the dead time of the system.

1. A 20% (15%) window symmetrically about the Tc-99m photo peak was used with Collimator removed from the camera and a 15% and 20% window was centered symmetrically about the Tc-99m photo peak a low count rate. A specially made lead masking covering 10% area of crystal will be used. Two sources of Tc-99m were prepared and used as sources; with the sources suspended near the axis of the crystal at a distance greater than one meter so that the required count rate is achieved camera directed horizontally.
2. Following counting procedure was used for counting time of 100 seconds for each step. Maintain the same elapsed time between source measurements in order to cancel the effect of radioactive
    a. Placed source #1 in the scatter phantom and record count. Calculate cps

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b. Added source #2 and measure the combined sources. Calculate cps
c. Removed source #1 and measure source #2only. Calculate cps
d. Above set of measurements were repeated in reverse as a control procedure.

3. The dead time was calculated as

$$\tau = \frac{2R_{12}}{(R_1+R_2)^2} \times \ln\left(\frac{R_1+R_2}{R_{12}}\right) \times 10^6$$

Where R_1, counting rates from sources 1, R_2 and R_{12} are the measured net 2 and 1 and 2 combined.

In the second protocol provided by the NEMA [6_9] the following method was used.

1. A 20% (15%) window symmetrically about the Tc-99m photo peak was used with the collimator removed. Two sources of Tc-99m were prepared and used as sources; the activity must be of sufficient activity to produce 20,000 cps each (± 10%) when placed in a scatter phantom. The sources were placed at a distance of 5 times the maximum dimension of the camera detector.
2. With the scintillation camera directed horizontally, a copper strip of width about 2-3mm was placed between the source and the camera.
3. Following counting procedure was used for counting time of 100 seconds for each step. Maintained the same elapsed time between source measurements in order to cancel the effect of radioactive
   a. Placed source #1 in the scatter phantom and recorded count. Calculated cps
   b. Added source #2 and measured the combined sources. Calculated cps
   c. Removed source #1 and measured source #2 only. Calculated cps

   The dead time will be calculated as

$$\tau = \frac{2R_{12}}{(R_1+R_2)^2} \times \ln\left(\frac{R_1+R_2}{R_{12}}\right) \times 10^6$$

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Where R1, counting rates from sources R1, R 2 a n d R1 2 are the measured net 2 and 1 and 2 combined.

Results

Extrinsic Dead Time Measurements

Only AAPM provided protocol for the determination of extrinsic paralyzable dead time. The dead time was calculated for 15% and 20% energy windows separately. Table (a) shows the calculated dead time using the 15% energy window.

Table (a) extrinsic paralyzable dead time calculated using AAPM suggested protocols with 15% energy window.

Sr. No.	Count Rate With S1 = R1 (Cts/sec)	Count Rate With S2 = R2 (Cts/sec)	Count Rate With S1&S2 Combined = R12 (Cts/sec)	Dead Time (μsec)
1	21620	20480	40430	**1.85**
2	21480	20570	40460	**1.76**
3	21540	20390	40315	**1.8**
4	21650	20410	40290	**1.96**

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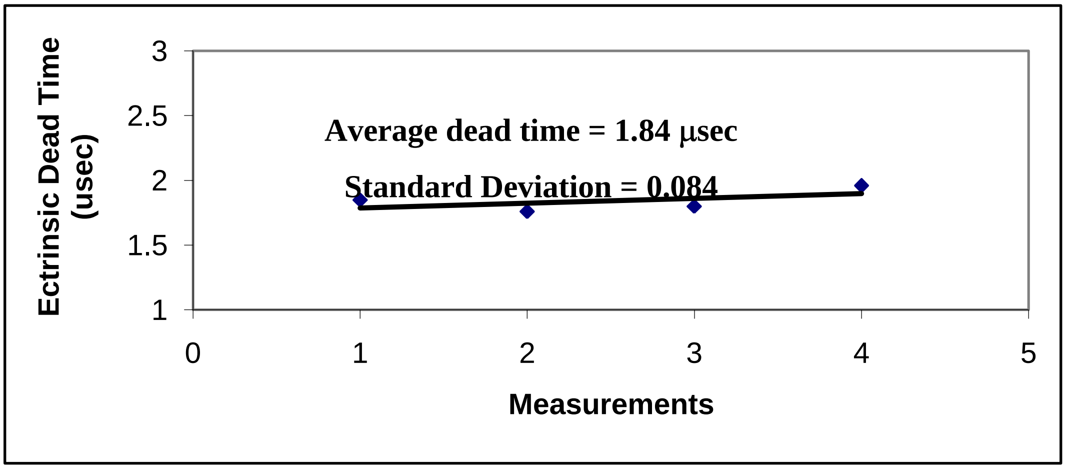

Figure (a) Variation in the values of extrinsic paralyzable dead time using AAPM suggested protocol with 15% energy window.

The results of all measurements vary as depicted by the values in the table. (Small deviation). In Table (b) the dead time calculated using 20% energy window is listed and figure (b) shows the standard deviation and average of the dead time calculated using AAPM protocol.

Table (b) Extrinsic paralyzable dead time calculated using AAPM suggested protocols with 20% energy window.

Sr. No.	Count Rate With S1 = R1 (Cts/sec)	Count Rate With S2 = R2 (Cts/sec)	Count Rate With S1&S2 Combined = R12 (Cts/sec)	Dead Time (µsec)
1	21880	20480	41730	**1.70**

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2	21740	20570	41540	**1.89**
3	21810	20390	41780	**1.65**
4	22090	20410	41620	**1.94**

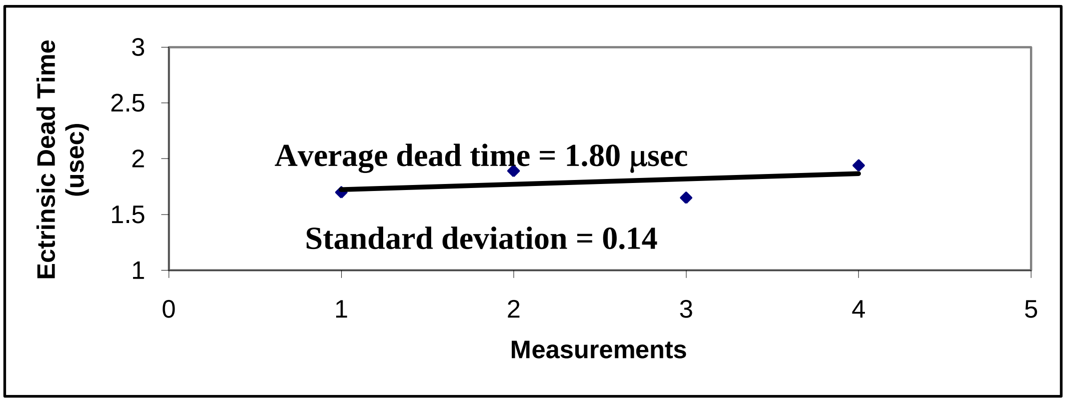

Figure (b) Variation in the values of extrinsic paralyzable dead time using AAPM suggested protocol with 20% energy window.

Intrinsic Dead Time Measurement

In the Tables (c) and (d) the intrinsic calculation using the AAPM protocol are displayed for 15% and 20% energy windows respectively the Figure (c) and (d) show the variation in the dead time measurements using AAPM protocol.

Table (c) Intrinsic paralyzable dead time calculated using AAPM suggested protocols with 15% energy window.

Sr. No.	Count Rate With S1 = R1	Count Rate With S2 = R2	Count Rate With S1&S2 Combined =	Dead Time (μsec)

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	(Cts/sec)	(Cts/sec)	R12 (Cts/sec)	
1	19800	18980	37540	**1.62**
2	19510	18560	37020	**1.43**
3	19650	18470	37010	**1.51**
4	19510	18750	37160	**1.48**

Table (d) Intrinsic paralyzable dead time calculated using AAPM suggested protocols with 20% energy window.

Sr. No.	Count Rate With S1 = R1 (Cts/sec)	Count Rate With S2 = R2 (Cts/sec)	Count Rate With S1&S2 Combined = R12 (Cts/sec)	Dead Time (µsec)
1	20950	18980	38570	**1.68**
2	20860	19460	38940	**1.67**
3	20540	19220	38500	**1.57**
4	20780	19040	38590	**1.53**

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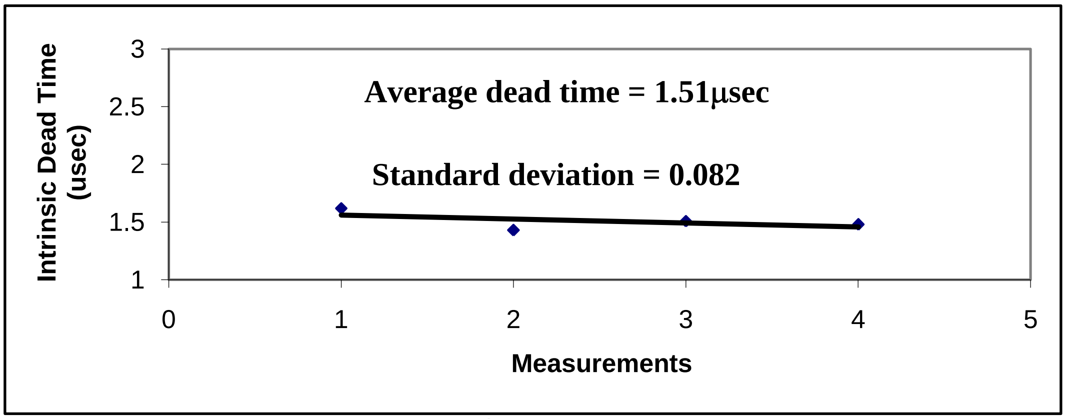

Figure (c) Variation in the values of intrinsic paralyzable dead time using AAPM suggested protocol with 15% energy window

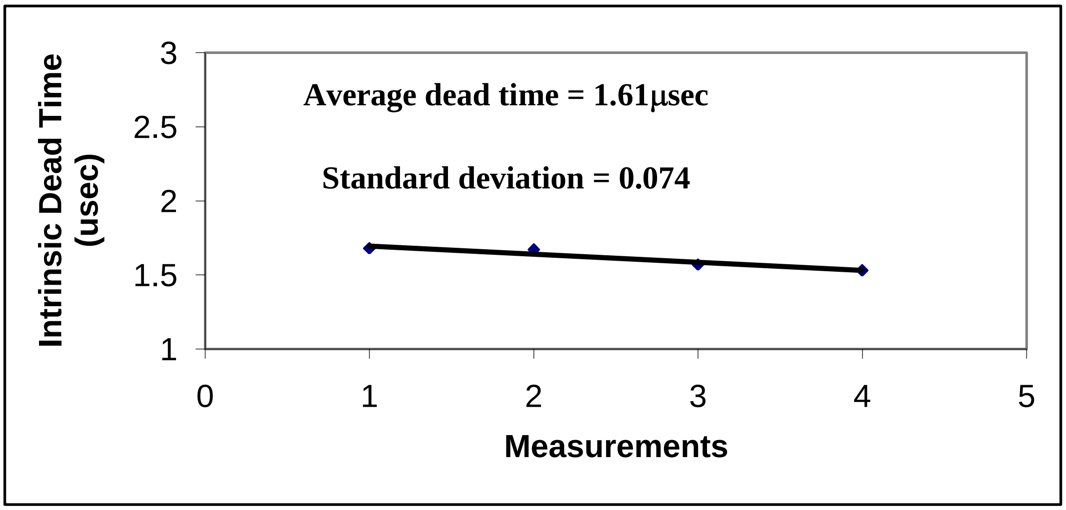

Figure (d) Variation in the values of intrinsic paralyzable dead time using AAPM suggested protocol with 20% energy window

Tables and figure below show the measured dead time and their variation with 15% and 20% energy window.

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Table (e) Intrinsic paralyzable dead time calculated using NEMA suggested protocols with 15% energy window.

Sr. No.	Count Rate With S1 = R1 (Cts/sec)	Count Rate With S2 = R2 (Cts/sec)	Count Rate With S1 +S2 = R12 (Cts/sec)	Dead Time (μsec)
1	21240	19910	39540	**1.86**
2	20870	19770	39020	**1.92**
3	21040	19840	39310	**1.84**
4	21170	20050	39620	**1.85**

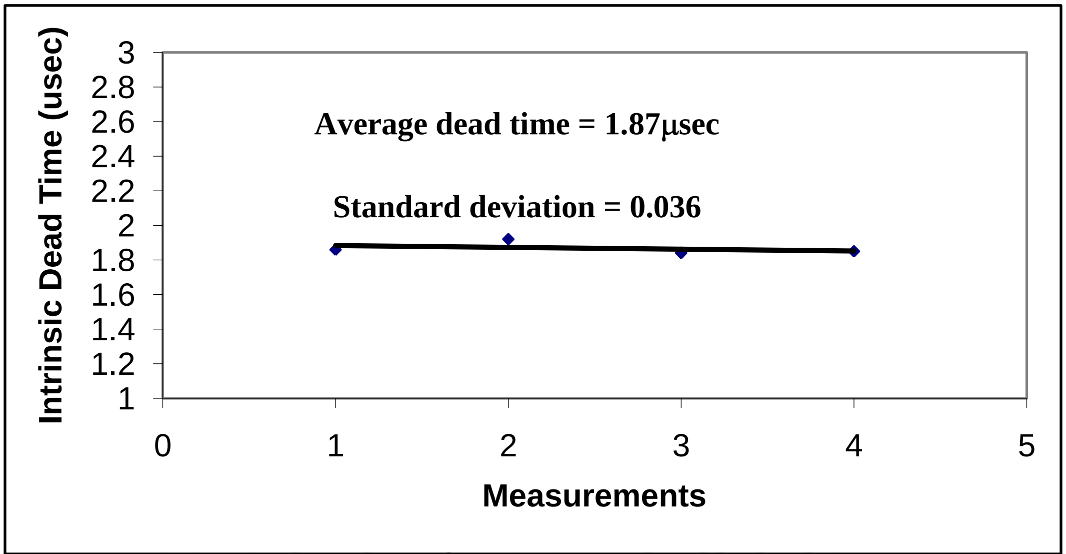

Figure (e) Variation in the values of intrinsic paralyzable dead time using NEMA suggested protocol with 15% energy window

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Table (f) Intrinsic paralyzable dead time calculated using NEMA suggested protocols with 20% energy window.

Sr. No.	Count Rate With S1 = R1 (Cts/sec)	Count Rat With S2 = R2 (Cts/sec)	Count Rate With S1 +S2 = R12 (Cts/sec)	Dead Time (μsec)
1	22770	21370	42280	**1.87**
2	22280	21590	42050	**1.85**
3	22520	21780	42370	**1.92**
4	22490	21630	42360	**1.77**

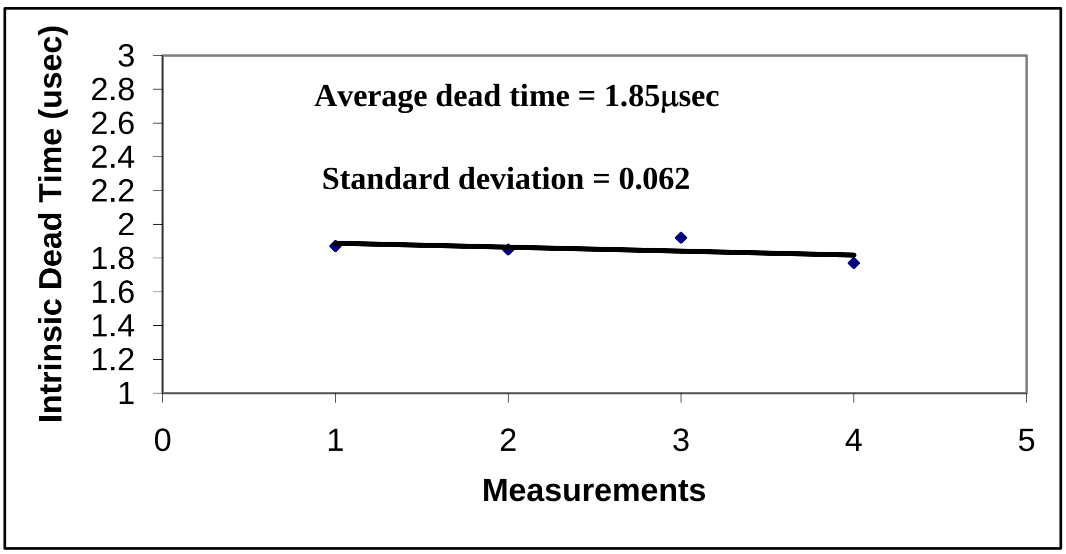

Figure (f) Variation in the values of intrinsic paralyzable dead time using NEMA suggested protocol with 20% energy window

Maximum Count Rate Measurement with 20% Dead time losses

The maximum count rate was measured using both the protocols the results obtained are listed below.

AAPM Results

The maximum input count rate, which the camera can detect with a 20% dead time loss was measured using the formula;

$$\mathbf{R\ 20\% = 0.2331/\tau}$$

Where $\tau$the dead time is measured using AAPM protocol with 20% energy window. For intrinsic paralyzable dead time the average value of τ for 20% window was.

$$\textbf{Average value of } \tau = \mathbf{1.59 \times 10^{-6}\ Sec}$$

Putting this value in formula we get

$$\mathbf{R_{max}\ (20\%) = 146.70 Kcts / sec}$$

NEMA Results

The maximum input count rate for 20% loss was measured using the formula;

$$\mathbf{R20\% = 0.1785/T}$$

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Where τ is the dead time measured using NEMA protocol. For intrinsic paralyzable dead time the average value of τ for 20% window was.

Average value of τ = 1.85 x10^{-6} Sec

Putting this value in formula we get

$$\mathbf{R_{max}\ (20\%) = 96.5Kcts\ /\ sec}$$

Discussion

Extrinsic Paralyzable Dead Time for 15% Energy Window:

The calculated average values of extrinsic paralyzable dead time with 15% energy window was found to be 1.84 μsec for four measurements taken using AAPM protocol with a standard deviation 0.0842. To estimate the quality of this result we can use this value of dead time in the formula for the determination of maximum count rate of a gamma camera system suggested by **[13].** they suggest that the dead time of a system can be estimated by using $\boldsymbol{\tau = 1/eR_{max}}$ where e is the base of natural logarithm. The maximum count rate of the system was about 196Kcts/sec putting this value in the above relation we get **τ = 1.88** usec.

Extrinsic Paralyzable Dead Time for 20% Energy Window:

Here again we require that the extrinsic dead time calculated with AAPM with 20% energy window must satisfy dead time calculated using the approximation equation

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mentioned above. The average dead time calculated in the case of 20% energy window was 1.83 μsec with a standard deviation = 0.1436.

Effect of Energy Window on Extrinsic Measurements:

In the protocol suggested by AAPM two energy windows are suggested which are most commonly used for clinical studies. The average value of dead time is 1.84 μsec for a 15% energy discrimination window on the other hand the calculated average value of extrinsic paralyzable dead time for 20% energy window was found to be 1.83μsec which clearly shows that the extrinsic paralyzable dead time calculated with AAPM suggested protocol is within specifications. The increase in the window has caused the dead time to decrease.

Intrinsic Paralyzable Dead Time for 15% Energy Window:

From The average value of intrinsic paralyzable dead time using AAPM protocol equal 1.47μsec with a standard deviation 0.0818 to verify we compare it to the approximate dead time values i.e. $\boldsymbol{\tau = 1.88}$ clearly not in agreement. On the other hand the calculated value of intrinsic paralyzable dead time using the NEMA protocol with a 15% energy window gives a dead time average value of 1.87μsec with a standard deviation of 0.0368 quit close to the expected value ($\boldsymbol{\tau = 1.88}$). Clearly the standard deviation in this case is much smaller than that of AAPM results also putting this value of dead time in the max count rate determination formula we get the result R_{max} (20%) = 95.441 Kcts/sec which agrees with our observations.

Intrinsic Paralyzable Dead Time for 20% Energy Window:

The average dead time calculated using the AAPM suggested protocol equals 1.59μsec with a standard deviation = 0.0739 clearly not within specifications. On the other hand the average dead time calculated using the NEMA protocol with 20% energy window was calculated to be 1.8488μsec with a standard deviation = 0.0627. To verify this result we put it in the formula for maximum count rate determination and calculated value of Rmax (20%) = 96.543 Kcts/sec which agrees very well with the Figure (4.10).

Effect of Energy Window on Intrinsic Measurements:

The result for intrinsic paralyzable dead time using AAPM protocol with a 15% energy window was found to be 1.47μsec on the other hand the intrinsic paralyzable dead time using AAPM protocol with 20% energy window gives a dead time value of 1.59μsec which shows that the dead time has increased with the increasing window width and does not agree with our expected decrease. On the other hand the calculated value of dead time with 15% energy window using the NEMA protocol was 1.87μsec as the window width increases to 20% the value of intrinsic paralyzable dead time becomes 1.85μsec, which is quite in agreement with our expected results.

Effect of Source Strength on Dead Time Measurements:

The American association of Physicist in Medicine has suggested two sources of activity about 0.1 mCi the intrinsic paralyzable dead time calculated with there suggested protocol give an average dead time value of 1.47μsec and 1.59μsec for 15% and 20% energy windows which do not satisfy Figure (4.10) on the other hand NEMA has suggested two source of approximately 1.1mCi placed behind a copper strip such that they produce a count rate of 20 Kcts/sec the calculated dead time values for there suggested protocol for 15% and 20% energy windows were 1.870263μsec and 1.85μsec respectively which agree very well with the Figure (4.13) this suggests that the dead time calculation can be improved by using a larger source.

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Effect of Source Distance on Dead Time Measurements:

The AAPM suggested source to camera distance is 1.5 m which is nearly equal 4feet but the results obtained using this distance in the AAPM protocol does not give satisfactory results as earlier researches has shown that a small source to camera distance effects the counting efficiency of the system because the gamma flux is not uniform. On the other hand the NEMA suggested source to camera distance is approximately 10feet the results obtained with this distance that is with the NEMA protocol are satisfactory and clearly give it another advantage on the AAPM protocol.

Effect of Camera Orientation on Dead Time Measurements:

According to AAPM the camera face must be horizontal that means that the plane of the camera crystal is horizontally aligned with the floor of the gamma camera room. But using this orientation (i.e. with AAPM suggested protocol) did not give satisfactory results. In the NEMA protocol it has been suggested that the camera face be orientated perpendicular to the floor of the gamma camera room. Using this orientation the camera showed good results. But orientating the camera face perpendicular to the floor of the room is very risky and cause damage to the gantry and also irreparable camera crystal which is a disadvantage of NEMA protocol but gives good results in this orientation.

Effect of Scatter Material on Dead Time Measurements:

For the extrinsic measurements the American Association of Physicist in Medicine has suggested a scatter phantom to be placed between the source and the camera face for calculating system dead time this is done to achieve scattering of the gamma radiations such that they can cause pile up in the system and help calculate the dead time. AAPM report dose not suggest introducing a scatter material between the source and the camera face for intrinsic measurements so as to make the radiation scatter

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and cause pile up in the camera system. The results, as we know, with AAPM protocol did not show reliability. On the other hand by introducing a copper strip of 2-3mm thick between the camera face and source gave excellent results. [10_13]

References

[1] R Adams "The measurement of resolving time of scintillation cameras" 1992 Phys Med. *Biol.* **17** 867.

[2] Zasadny KR, Koral KF, Swailem FM. *"Dead time of an anger camera in dual-energy-window-acquisition mode."* Med Phys. 1993 Jul-Aug;20(4):1115-20.

[3] Alexander *"Method of and means for compensating for the dead time of a gamma camera"* 1996 Phy. Med Biol 45 657.

[4] Koral KF, Zasadny KR, Ackermann RJ, Ficaro EP. *"Deadtime correction for two multihead Anger cameras in 131I dual-energy-window-acquisition mode.*" Internal Medicine, Division of Nuclear Medicine, The University of Michigan Medical

Center, Ann Arbor 48109, USA.1998.

[5] Report. aapm-6; "Scintillation Camera Acceptance Testing and Performance Evaluation" Published by American Institute of Physics for American Association of Physicist in Medicine.

[6] Inoue Y, Ohtake T, Oritate T, Nishikawa J, Yoshikawa K, Sasaki Y. **"***Effect of the distribution of radioactive sources on deadtime loss in a single-crystal gamma camera."* Department of Radiology, Institute of Medical Science, University of Tokyo, Japan. Radiat Med. 1998 Mar-Apr;16(2):149-52.

[7] Woldeselassie T. *"Modeling of scintillation camera systems.".* Faculties of Technology and Medicine, Addis Ababa University, Ethiopia. Med Phys. 1999 Jul;26(7):1375-81.

[8] Woldeselassie T. *"Decaying source method for scintillation camera resolving times."* Med Phys. 2001 Nov;28(11):2336-43.

[9] Standards Publication, NEMA; **"Performance Measurements of Scintillation Camera"** Washington, DC; National Electrical Manufacturers Association.

[10] Delpon G, Ferrer L, Lisbona A, Bardies M. *"Correction of count losses due to deadtime on a DST-XLi (SmVi-GE) camera during dosimetric studies in patients injected with iodine-131."* Unite INSERM 463, Nantes, France.Phys Med Biol. 2002 Apr 7;47(7):N79-90.

[11] Woldeselassie T. *"Modeling of scintillation camera systems."*. Faculties of Technology and Medicine, Addis Ababa University, Ethiopia. Med Phys. 1999 Jul;26(7):1375-81.

[12] Woldeselassie T. *"Decaying source method for scintillation camera resolving times."* Med Phys. 2001 Nov;28(11):2336-43.

(13) Cherry R Simon Physics in Nuclear Medicine third edition, 179, 2003

Author,s Profile.

Dr Khan has received his M.Phil Degree in Solid State Physics from CSSP (PU) Lahore Pakistan with research project entitled "Radioactive Pollution and its Health Hazards, a Study by SSNTDs and XRD analysis" and Master Degree in Physics with specialization in "Advance Electronics" from G.T.I.College (new Campus) Rabwah, PAKISTAN affiliated with PU, Lahore. Recently has completed his PhD Degree with project in Solid State Physics entitled "A Comprehensive Investigation of Solid Aerosols Using XRD and ASS Techniques" He has completed other relevant Post graduate training courses as participant, presenter and as a faculty member in his areas of specialization from PINUM, NIAB, PNRA, NIFA, EPD etc the well reputed institutions of Pakistan Atomic Energy Commission and Environmental Protection Department along with his Professional in service training. Recently He is working as Associate Professor of Physics in the Department of Physics GCU (UDC/CC) Faisalabad. As for as his research Experience is concerned it is multidimensional, He has more than 30 years of academic and research experience at graduation and post graduation level, his areas of interest are Solid state Physics, Surface Physics, Aerosol

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Physics, Thin Film Technology, Crystal Growth, Cloud Nucleation Theory, Nano Physics Atomic and Nuclear Physics, Health and Medical Physics, Radiation Physics, Radiography and Medical Imaging Geo Physics, Soil Physics, Climatology and Meteorology, X-ray Crystallography etc. More than 95 Research Projects have been completed under his supervision with breakup as Atomic and Environmental research Project Physics (33), Health and Medical Physics (12), Radiation Physics and Dosimetery (33), Solid State Physics " Electronics and Electrical Instrumentation (09), Soil and Geo Physics (05), Laser and Plasma Physics (03) respectively and have 95 research publications along with 20 manuscripts in progress and expected to be published very soon in well reputed journals in his credit, He is Ex. Pakistan Nuclear Regularity Authority (PNRA) certified Health Physicist RPO, RSO (PAEC) as attachment with atomic and Nuclear Physics research lab. Editor ,executive editor ,associate editor Active member of advisory boards, Editorial Committee and reviewer/ referee in above said areas of interest for more than 15 national international journals .HE has also honored to be a member of world class societies, institutes, webs, organizations and important links related to his areas of specialization like Prof. Abdul Salam Physics Society, Pakistan Institute of Physics (PIP), Physics web (the community websites of Institute of Physics), Nanotech web org. (the community websites of Institute of Physics), Medical Physics web (the community websites of Institute of Physics), Optics org. (The community websites of Institute of Physics), PASTIC. (Pakistan Science Foundation), the Aerosol Society" the science of airborne particles, USA. American Association of Physics Teachers (AAPT). American Physics Society (APS), Particle and High energy physics, global research and consulting network, Radiation protection and Dosimetry (RPD), Saudi medical physics society (SMPS), African Physical society (AFPS), American Association of Physicist in medicine (AAPM),