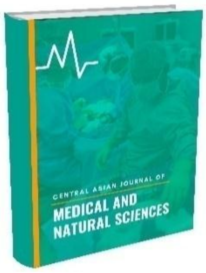
CENTRAL ASIAN JOURNAL OF MEDICAL AND NATURAL SCIENCES



Volume: 04 Issue: 04 | Jul-Aug 2023 ISSN: 2660-4159

http://cajmns.centralasianstudies.org

Role of Gamma Camera Components in Radiological Diagnosis

1. **Numan S. Dawood**
   Ph.D. (Medical Physics)
2. **Nadiya Y Mohammed**
   Ph.D. (Medical Physics)
3. **Dalya A. Ali Mohammed**
   MSc (Medical Physics)
4. **Ramaq G. Al-Qadhi**
   Ph.D. (Medical Physics)
5. **A. H. Ng**
   Ph.D. (Medical Physics)

Received 14th May 2023,
Accepted 15th Jun 2023,
Online 16th Jul 2023

[1, 2, 3, 4] Department of physiology, College of Medicine, University of Baghdad, Baghdad, Iraq
[1] numans@comed.uobaghdad.edu.iq,
[2] nadiyaym@comed.uobaghdad.edu.iq
[3] Dalya.al_eqabi@comed.uobaghdad.edu.iq
[4] ramaqalkadi@comed.uobaghdad.edu.iq

[5] Senior Lecturer, Clinical Oncology Unit, Faculty of Medicine, University of Malaya
ah.ng@um.edu.my

Abstract: The gamma camera, along with SPECT and PET scanners, is one of the main imaging technologies in nuclear medicine. A collimator is typically constructed from tungsten to provide high absorption of gamma photon energies. It has a hole or holes for imaging. Gamma rays from a radioactive source within the body are emitted in all directions, while the photons required constructing an image travel through the hole. A scintillator is the most common material used to convert the high energy of gamma radiation into a low-energy optical photon. These detectors are one of the primary secrets to radio-diagnosis in nuclear medicine. The photomultiplier tube (PMT) is a versatile device with extraordinarily highly sensitivity and response. A typical photomultiplier tube contains a photo emissive cathode (photocathode), focusing electrodes, an electron multiplier, and an electron collector (anode). Conclusion: In the medical imaging area, everyone works to improve the resolution, sensitivity, and size of their devices so that patients can be treated better and diagnoses can be made more accurately. Also, the results of this study suggest that HGC could be a potential way to give better support during surgery.

Key words: Gamma Camera, Collimator, Scintillator, PMT, Radiodiagnosis.

Introduction

The discipline of medical imaging currently employs a variety of image analysis techniques. These techniques provide the radiologist with more information for precise disease analysis and diagnosis. Therefore, the radiologist can now identify abnormalities in the body with significantly greater precision.

The gamma camera, along with SPECT and PET scanners, is the main important part in the imaging technologies of nuclear medicine [1, 2]. Gamma imaging systems have a collimator (pinhole, parallel hole arrays, diverging or converging), a conversion medium (scintillator or semiconductor), Photomultiplier Tubes (PMTs) or semiconductor arrays, and a readout mechanism [3]. Gamma camera designs depend on medical characteristics such FOV, sensitivity, spatial resolution, portability, and cost [4].

Nuclear medicine diagnosis relies on gamma detection and target organ radioactivity. Gamma rays from the accumulating radioisotope region can be detected by a non-imaging gamma probe (GP) during surgery [5] or by SPECT and PET preoperatively.

SPECT/CT, SPECT/ MRI and PET/CT hybrid imaging systems can produce gamma-ray images and provide functional and anatomical information about the target before surgery [6-8]. These systems are too big for the operating room. Several research organisations and manufacturers are aiming towards a portable hybrid system for surgical applications. The Space Research Centre, University of Leicester, created the hybrid gamma camera (HGC) to address this difficulty [9].

Radiopharmaceuticals are an essential component of nuclear imaging techniques, where they serve as chemical carriers of radioactive material to the specific target. For thyroid scintigraphy, radioisotopes such as Technetium-99m pertechnetate (99mTcO4-) are utilised [10]. The most frequently used radionuclide is 99mTc, which can be coupled to a wide variety of pharmaceuticals and is therefore used to diagnose a variety of diseases, and has the optimal gamma energy range around140 keV. The radiopharmaceutical with radioisotope is injected, ingested, or inhaled depending on the nuclear medicine exam. After a period, it will accumulate in the target for investigation. In scintigraphy, a gamma camera detects the radiotracer's gamma rays and creates images of the body's radioisotope distribution and tissue function. For example, a SPECT scan can be used for thyroid scintigraphy 20 minutes after injecting 185 MBq (5 mCi) of 99mTc-pertechnetate since the thyroid uptakes it most between 10 and 20 minutes [11]. The skeletal uptake rate of 99mTc-bisphosphonates is 50–60% of the entire injected amount "it is depended on weight and height of the body [12]", which ranges from 300 to 740 MBq after four hours [13].

The main objective of this article is to explain the role of gamma camera components in radiological diagnosis of various diseases, as well as the impact of gamma camera parts on diagnosis.

Gamma Camera components

Gamma cameras have collimators, scintillation crystals, and PMTs.

Collimator: It is frequently made of tungsten, which has a high atomic number (74) and great attenuation at the 140Kev gamma energy, this provides it with a high amount of absorption. Gamm-rays from radioactive source within the body emitted in all directions, the photons necessary to build the image are passing through the hole. Operating principle: all γ-rays incident on septa of collimator will absorb (inefficient), whereas photons that are passing (in certain directions) through hole will reach the detector. The collimators were used to determine the direction of the gamma ray photons reaching the detector, allowing an image to be created [14]. Gamma camera performance and development, especially spatial resolution, sensitivity, and FOV, depend on collimator properties. Geometry of the apertures' arrangements, the main types of collimators:

Pinhole collimator: Only one collimator hole allows gamma rays to reach the detector. Figure 1 shows a circular knife-edge pinhole collimator. Pinhole collimators enlarge and reduce picture size based on the detector-to-collimator distance, *t*, and the collimator-to-source distance, *h*:

$M = t / h$

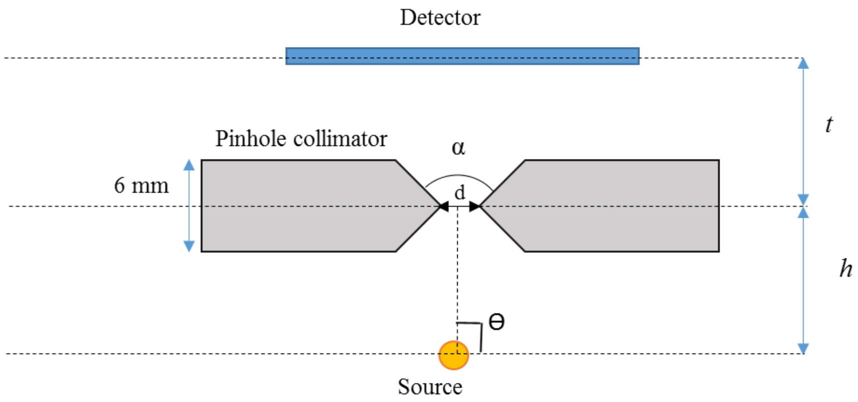


Figure 1: A diagram showing a cross-sectional view of the knife-edge pinhole collimator and *t, h,* acceptance angle, *α,* pinhole diameter, *d,* and source to collimator angle, *Θ* [15].

Pinhole collimator inverts images with changing magnification. Figure 2 shows the pin-hole collimator imaging the thyroid with high spatial resolution but low efficiency. As well as using for imaging small organ.

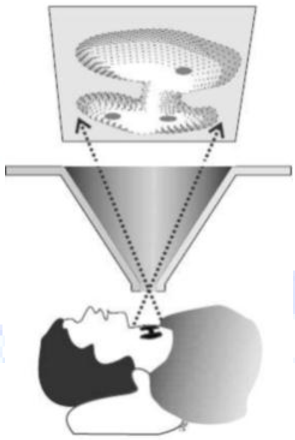


Figure 2: Pinhole Collimator [16].

Parallel-hole collimator: The most typical collimator has all holes perpendicular to the crystal plane and maintains image size and unaffected by the object-to-collimator distance and without inverted image as illustrates in Figure 3. There is a variety of forms depending on hole size, length and septal thickness to match energy of γ-ray.

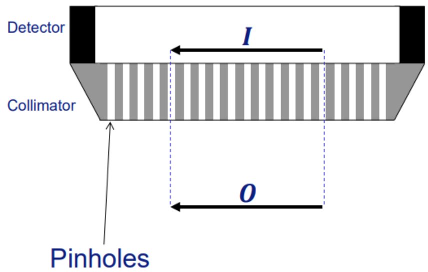


Figure 3: Parallel hole collimator [17]

Diverging collimator: Multiple holes which are diverging off-center, giving a miniature image. and non-inverted image as shown in Figure 4. The detector further away from the imaging source will allow further increase area of acquisition. Diverging collimators are used for whole-body imaging to provide a wider field of vision. Simultaneously, it has lesser resolution and efficiency than parallel-hole collimators [17].

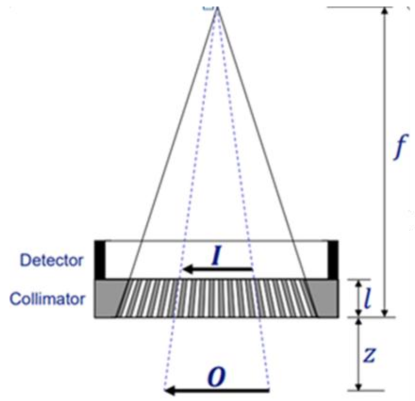


Figure 4: Diverging collimator [17]

Converging collimator: Multiple holes which fan toward the center illustrate in Figure 5, which is providing magnified, non-inverted images of small objects and are more efficient and more precise than parallel-hole collimators. Some collimators may be flipped, allowing a technician to switch from converging to diverging collimation [18].

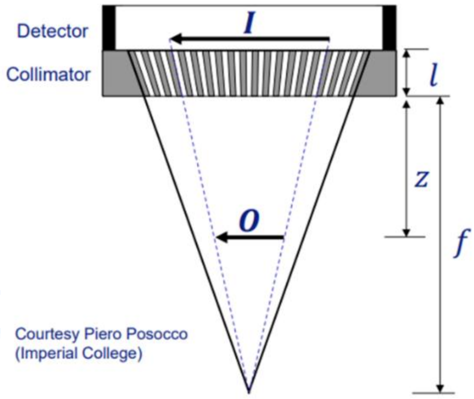


Figure 5: Converging collimator [18]

Other collimators include slant-hole and fan-beam. Slant-hole collimators are slanted to the crystal plane, while fan-beam collimators are converging over the transaxial direction and parallel over the rotation angle [18]. Both are utilised in SPECT. [17].

Scintillator crystal:

Scintillator is a detector which is the predominant material for converting the high energy of gamma rays into a low energy optical photon. These detectors represent one of the main keys of nuclear medicine technology for radiodiagnosis. Inorganic scintillators have several advantages encourage their use in gamma cameras such as the maximum gamma-stopping power and optical photon output, this match well with photomultiplier tube (PMTs) absorption spectra and charge coupled device (CCD), and are inexpensive to manufacture.

Inorganic scintillation crystals have an electronic band structure that controls the energy states in their lattice. When gamma photons are absorbed by an inorganic crystal, the electrons are moved to the conduction band. However, this is inefficient for producing light and, as a result; the emitted light is low-quality. An increase in impurity concentration can enhance luminescence efficiency and the emission wavelength. This effect is achieved by transferring the energy from the impurity centers to the energy levels in the crystal lattice.

Thallium doped Sodium Iodide (NaI(Tl)), Thallium doped cesium iodide (CsI(Tl)) or CsI(Na) crystals are most commonly used in gamma cameras. To prevent damage from moisture and dust, NaI(Tl) and CsI(Tl) must be encapsulated in aluminium and transparent glass [19]. The probabilities of the interaction of gamma photons which are passed through collimating holes with crystal depends on the gamma energy and crystal thickness, some of these photons are absorbed in the crystal whereas some of the photons scatter or pass through crystal without interaction. In gamma camera, the thickness of the crystal takes into account because it has a high impact on the ability to detection gamma photons, spatial resolution of the camera and to determine depth of radioactive material accumulated within human body [20, 21]. For example, CsI (TI) has numerous properties that enable it to detect gamma radiation, including an optical photon output of 54 photons per KeV, a Z efficacy is 54, and an intensity of approximately 4.5 g/cm3. The maximal wavelength of scintillation photons is 565 nm. This wavelength of the CsI (TI) crystal corresponds well with the detector's (CCD) response and has an efficiency of greater than 90% for gamma photon detection. [22].

Photomultiplier tubes (PMT):

In the previous century, a scintillation mechanism was first used to quantify radiation. It uses a light detector to convert the scintillation light emitted into a quantifiable electrical signal that can be expressed as charge, voltage, or current. According to the literature, photomultiplier tubes are the most common photodetectors in use today [22].

The photomultiplier tube (PMT) is a multifunctional device with extraordinarily high sensitivity and rapid response. A photomultiplier tube contains a photocathode, focusing electrodes, an electron multiplier, and an anode housed in a vacuum tube as illustrated in Figure 6.

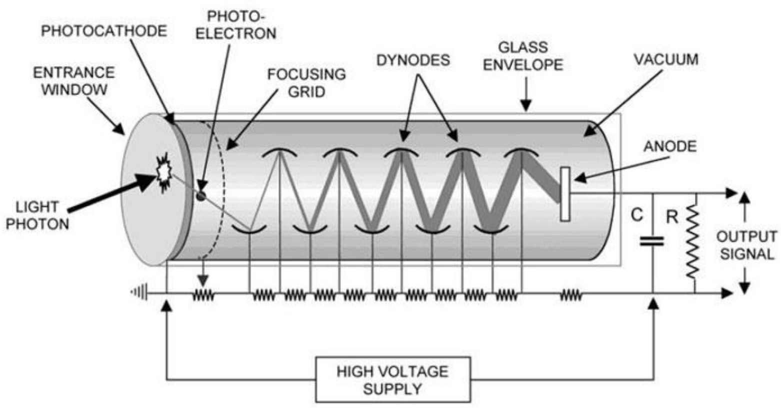


Figure 6: Cross-section of PMT tube [23]

Incident photons hit the photocathode, on the device's entry window. The photoelectric effect causes electrons to be ejected from the surface. The focusing electrode directs these electrons toward the electrodes called dynodes, each dynode is held at a higher positive potential than the one before it, by about 100 volts. The electrons are multiplied via the secondary emission process [24].

Although the PMT is a reliable device with a large intrinsic gain (on the order of 106-107), its performance is restricted by its low quantum efficiency of ≈ 25%. They're also expensive, bulky, fragile, and sensitive to magnetic fields, requiring successive dynodes with increasingly large positive bias potentials [25].

Conclusion

1. Using high amount activities of Tc-99m lead to an increase in the count rate response by the gamma camera, which will provide a distinct image.
2. Different collimations that can be used to produce the best image depending on the distances between detector collimator and between collimator and source.
3. To enhance patient management and diagnosis, all medical imaging gadget designers and manufacturers increase resolution, sensitivity, and size.
4. The hybrid gamma camera (HGC) could be used to estimate the depth of radiolabeled tissue within a patient by combining optical and gamma imaging intraoperatively.
5. Finally, the findings of this investigation suggest HGC could be a promising technique for providing superior surgical support.

References:

1. Moshe Bocher, et al., A fast cardiac gamma camera with dynamic SPECT capabilities: design, system validation and future potential. Eur J Nucl Med Mol Imaging, 2010. 37(10): p. 1887–1902.
2. Cherry, S.R., The 2006 Henry N. Wagner Lecture: Of Mice and Men (and Positrons)—Advances in PET Imaging Technology. J Nucl Med November 2006. 42(11): p. 1735-1745).
3. Lees JE, et al., A Multimodality Hybrid Gamma-Optical Camera for Intraoperative Imaging. Sensors. 2017; 17(3): p.554-566
4. Krings, T., et al., A numerical method to improve the reconstruction of the activity content in homogeneous radioactive waste drums. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometer, Detectors and Associated Equipment, 2013. 701: p. 262-267.
5. Povoski, S.P., et al., A comprehensive overview of radioguided surgery using gamma detection probe technology. World J Surg Oncol, 2009. 7(11): p. 1-63.
6. Alqahtani F. F. (2023). SPECT/CT and PET/CT, related radiopharmaceuticals, and areas of application and comparison. Saudi pharmaceutical journal : SPJ : the official publication of the Saudi Pharmaceutical Society, 31(2), p.312–328.
7. Hasan,M.H., Hussain, H.S., Hasan, A.M., MRI Brain Scans Classification Using Bi-directional Modified Gray Level Co-occurrence Matrix and Long Short-Term Memory, NeuroQuantology, 2020, 18 (9), 54.
8. Hasan, M. R. ., Kadam, S. M. ., & Essa, S. I. Diffuse Thyroid Uptake in FDG PET/ CT Scan cCan Predict Subclinical Thyroid Disorders. Iraqi Journal of Science, 2022, 63(5), 2000–2005
9. Lees, J.E., et al., A Hybrid Camera for simultaneous imaging of gamma and optical photons. Journal of Instrumentation, 2012. 7(6): p. 1-11.
10. Burke, G., et al., Comparative thyroid uptake studies with ^{131}I and ^{99m}TcO4^{-}. The Journal of Clinical Endocrinology and Metabolism, 1972. 34(4): p. 630-637.
11. Zhao, L., et al., 99mTc-pertechnetate thyroid scintigraphy predicts clinical outcomes in personalized radioiodine treatment for Graves' disease.Revista espanola de medicina nuclear e imagen molecular,2018. 37(6), p. 349–353.

12. Dawood, N.S., Mussttaf, R.A., AL-Sahlanee, M.H.R. Model for Prediction of the Weight and Height Measurements of Patients with Disabilities for Diagnosis and Therapy. International Journal Bioautomation, 2021, 25(4), pp. 343–352.

13. Van den Wyngaert, T., et al., The EANM practice guidelines for bone scintigraphy. European journal of nuclear medicine and molecular imaging, 2016. 43(9): p. 1723-1738.7.

14. Lawson, R.S., in The Gamma Camera: A comprehensive guide. Institute of Physics and Engineering in Medicine: Manchester, England.2013. p. 80-82.

15. Bugby, S.L., Development of a hybrid portable medical gamma camera, in Physics Department. 2015, University of Leicester: Leicester, UK.

16. Ali, W.M., 2015. Development of Prototype Quality Control Phantom for Gamma Camera and SPECT System.2015, Sudan University of Science and Technology: Sudan..

17. Van Audenhaege, K et al., Review of SPECT collimator selection, optimization, and fabrication for clinical and preclinical imaging. Medical physics, 2015. 42(8), 4796–4813.

18. Dong-Hee Han, et al., Development of a diverging collimator for environmental radiation monitoring in the industrial field: Nuclear Engineering and Technology,2022. 54(12), p. 4679-4683.

19. Roncali, E., Mosleh-Shirazi, M. A., and Badano, A., Modelling the transport of optical photons in scintillation detectors for diagnostic and radiotherapy imaging. Physics in medicine and biology, 2017. 62(20), p.207–235.

20. Numan S. Dawood, A method for source – depth estimation using a Hybrid Optical / Gamma Camera, in Physics Department. 2018, University of Leicester: Leicester, UK.

21. Hasan, R. H., Essa, S. I., & AL-Naqqash, M. A. Depth dose measurement in water phantom for two X-ray energies (6MeV and 10MeV) in comparison with actual planning. Iraqi Journal of Science,,2019, 60(8), p.1689–1693.

22. Lees, J.E., et al., A high resolution Small Field Of View (SFOV) gamma camera: a columnar scintillator coated CCD imager for medical applications. Journal of Instrumentation, 2011. 6(12): p. 1-12.

23. Moses W. W., Photodetectors for Nuclear Medical Imaging. Nuclear instruments and methods in physics research. Section A, Accelerators, spectrometers, detectors and associated equipment, 2009. 610(1), p. 11–15.

24. https://www.sense-pro.org/lll-sensors/pmt

25. Park, H., Yi, M. and Lee, J.S. Silicon photomultiplier signal readout and multiplexing techniques for positron emission tomography: a review. Biomed. Eng. Lett, 2022. 12, p. 263–283.