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Dimensional Comparison of Parallel-Hole type Collimator

Nikhat Shaikh, Jyoti Warrier, Sadhana Bhattacharya

Abstract— Nuclear medicine involves the application of radioactive substances in the diagnosis and treatment of disease. The radiopharmaceutical is administered to the patient and then camera is rotated around the whole body for capturing radiations. The detection of high energy rays such as x-rays or gamma, we need highly precise & efficient detectors so that maximum information can be obtained by either using in vitro radioactive source (as in X-rays) or by in vivo radioactive source (such as in PET, SPCET). There are many studies done for improving the sensitivity and resolution of gamma camera. In this paper, parameters of parallel-hole type collimator (used in gamma camera) are evaluated. The resolution and sensitivity variations are calculated with respect to the dimensional properties of collimator is described. The purpose of this paper is to compare the performance of circular, hexagonal & square holes parallel-type collimators based on various dimensional properties.

Index Terms — Collimators, Efficiency, Gamma Camera, Nuclear Medicine, Nuclear Imaging, PET, SPECT, Radiotracers, Resolution.

1 Introduction

Nuclear imaging provides an efficient tool for internal viewing of organs/ tissues with the help of the radiations emitted by the radiotracers. The radiotracers are engulfed inside and emissions of radiations from them are captured with help of detectors. In Biomedical engineering, the instruments used for imaging purposes are designed for capturing such radiations. The various examples of imaging modalities are PET (Positron Emission Tomography), SPECT(Single Photon Emission Computed Tomography), Hybrid PET-CT, Hybrid SPECT-CT, etc. Before designing any instrument, the various parameters/components are checked, compared individually and best suited for particular application is used [2].

The study of functional as well as structural information of the human body is required for better knowing the internal environment of the body. In this type of imaging, radionuclide is injected into the body for diagnosis and treatment of diseases. For specific organs, a specific radioisotope is used. The radiations emitted by these radiotracers are detected externally by either gamma camera or PET scan or SPECT. So, study of types of detectors becomes very important in order to find precise & clear information of internal body. The detection of radiations depends on how they have interacted with the matter.

In medical imaging, only capturing the information by camera is not enough. But we need to extract the desired information from the images. The gamma camera provides functional imaging by tracing the gamma radiations emitted by the radiotracers. Using the external detectors, we measure the tracer by detecting the particles emitted by the radioisotopes and then develop images by reconstruction algorithms. Hence one has to know how gamma interacts with the matter and how it is detected. The essential components of the scintillators are enlisted and discussed in detail [9].

The purpose of this paper is to compare the performance of circular, hexagonal & square holes parallel-type collimators.

In nuclear radiation imaging, we obtain the image of the spatial distribution of the radiotracer where collimator restricts the gamma rays falling on the detector. Gamma camera is a device in which the gamma rays emitted by radiotracers are detected and image is formed. The quality of image depends on how much the rays reach the detector in specific aligned direction. Collimator determines the spatial resolution and efficiency of the final image. Study highlights variations in dimensional properties of collimators for gamma camera imaging [7]. Using software simulations, various designs of collimator are compared and best suited to specific application are found.

2 Collimator

Collimator is an essential component in gamma camera and the optimized designing of it leads to better quality image of spatial distribution of gamma ray emitting isotope. It works as limiting factor for unwanted gamma rays and thereby, provides less scattering of rays and blurring reduces [3].

In gamma camera, before the detecting scintillating crystal, collimator is placed to direct the rays towards detector edge. The overall system performance depends on the collimator efficiency, resolution and hole shape.

The collimator should be made of high z and high density material in order to improve absorption of scatter gamma rays. The septa wall of collimators is as thin as possible to maximize collimator efficiency, but it must be thick enough to prevent penetration for high energy photons. Analytical computer

- *Nikhat Shaikh is currently Pursuing Master's degree in Biomedical Engineering in MGM College of Engineering & Technology, Mumbai University, India. E-mail: nikhat0904@gmail.com*
- *Jyothi Warrier is working as Assistant Professor in Biomedical engineering department, MGM College of Engineering & Technology, Mumbai University, India.*
- *Sadhana Bhattacharya is working as Scientific Officer, Head of Health Physics Instrumentation, Electronics Division, Bhabha Atomic Research Center, Mumbai, India.*

simulations are done to find the optimum properties of the collimator [4], [5].

As we have to design collimator for better quality image, dimensional properties are taken into considerations.

Fig. 1 shows a design of parallel-hole collimator

Where

- Collimator septum's length is L,
- Diameter of holes is d,
- Septal thickness is t,
- Resolution is R and
- Distance from radiating source to collimator end is D

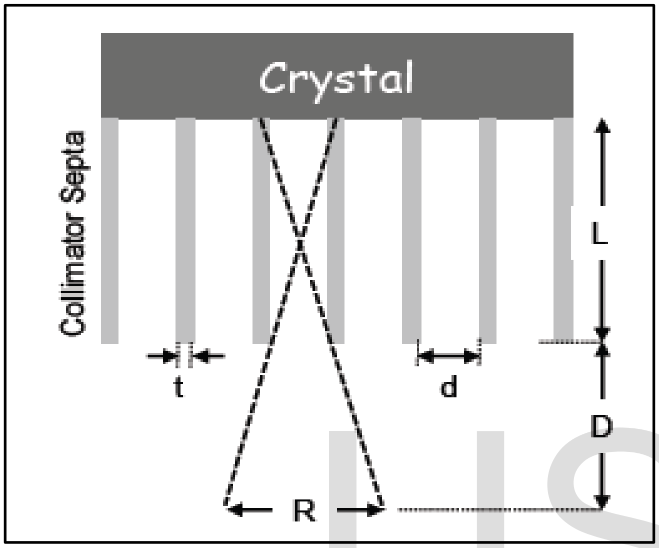

Fig.1. Parallel-hole Collimator with dimensional properties

Parallel-hole Collimators are designed as parallel girds with uniformly distributed holes of equal diameter length and septal thickness. Due to this arrangement, we get uniform image over the entire region of interest [8].

3 Results

Various parameters such as efficiency of collimator, resolution of collimator, etc. were found. Using MATLAB, the results are obtained based on the formulas and equations used for defining the collimator parameters.

Parameters for cylindrical (or round), hexagonal and square hole collimators are calculated for wide range of variations in dimensions of collimators. Collimator Efficiency, Collimator Resolution and Septal Thickness are explained in detail below with graphs obtained in MATLAB.

3.1 Collimator Efficiency

Collimator Efficiency is defined as fraction of gamma rays passing through collimator per gamma ray emitted by the source. Collimator efficiency depends on geometry of the holes (diameter, length) and thickness of the septum [1].

Collimator efficiency g, defined as the fraction of gamma rays passing through the collimator per gamma ray emitted by the source [6].

Collimator efficiency g is given as –

$$g = K^2(d/l)^2[d^2/(d+t)^2] \quad (1)$$

Where t is septal thickness and K is a constant that depends on hole shape

(~0.24 for round holes in a hexagonal array,

~0.26 for hexagonal holes in a hexagonal array,

~0.28 for square holes in a square array).

Efficiency is calculated by changing dimensional properties of collimator. The main three dimensional properties that influence the collimator efficiency are Length(l), diameter and thickness of septum. Results are evaluated by varying one dimensional property keeping other two constant. Also, the shapes of holes affect the efficiency of collimator.

Figure 2 shows the plot of efficiency obtained when length of septum is varied keeping diameter and thickness constant. By changing the length, l from 1 inch to 10 inches with diameter, d=2.54cm (1″) and septal thickenss, t = 0.254cm (0.1″). Efficiency of the collimator decreases as the length of collimator increases. The efficiency is reduced as the rays have to pass through longer paths and most of the rays get absorbed in the collimator itself.

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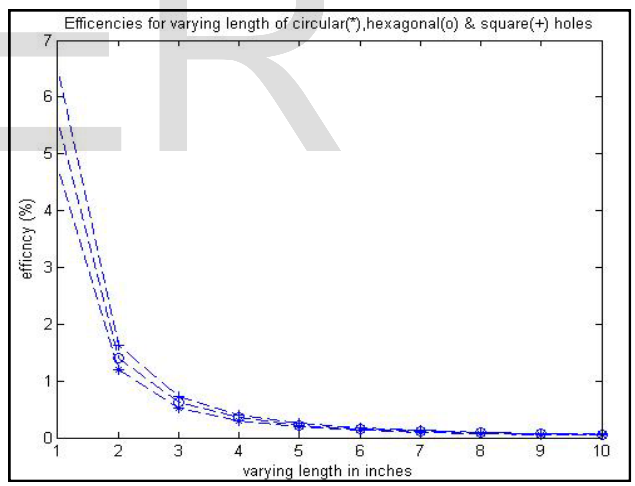

Fig. 2. Efficiencies for varying length of different types of holes Efficiency is plotted on Y-axis with length along X-axis and circular holes is marked as '*', hexagonal 'o' & square '+'.

Figure 3 shows the plot of efficiency obtained when diameter of septum is varied keeping length and thickness constant. By changing the diameter, d from 1 inch to 10 inches with length, l=2.54cm (1″) and septal thickness, t = 0.254cm (0.1″). Efficiency of the collimator increases with the increase in diameter of all cylindrical, hexagonal and square holes collimators. The efficiency increases as the rays gets wider path to travel and there is chances of more rays reaching to detector side.

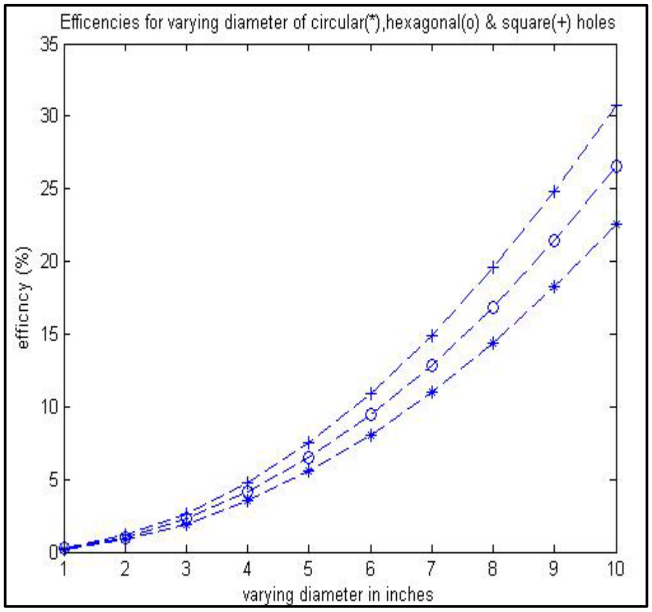

Fig. 3. Efficiencies for varying diameter of different hole- types
Efficiency is plotted on Y-axis with length along X-axis and circular holes is marked as '*', hexagonal 'o' & square '+'.

Figure 4 shows the plot of efficiency obtained when thickness is varied keeping length and diameter of septum constant.
By changing the septal thickness, t from 0.1 inch to 1 inch with length, l=12.7cm (5") and diameter, d= 2.54cm (1"). Efficiency of the collimator decreases as the septal thickness of collimator increases. The efficiency is reduced as most of the rays get absorbed in the collimator itself due to wider septal thickness.

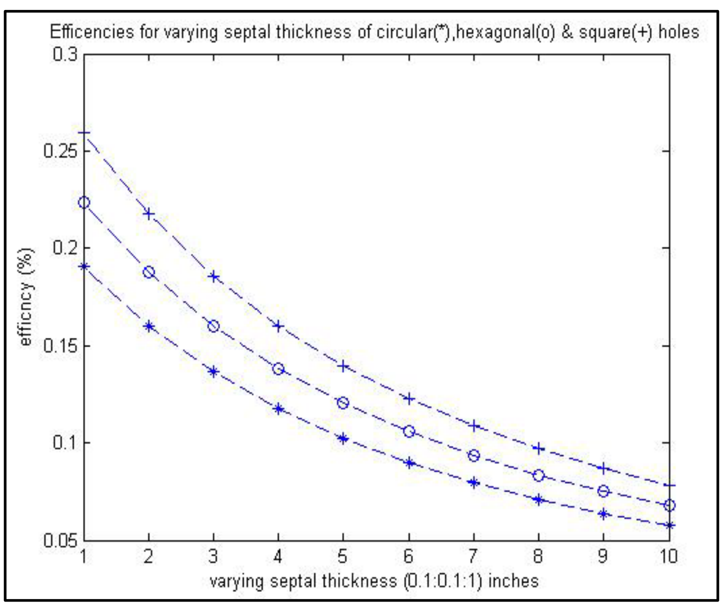

Fig. 4. Efficiencies for varying septal thickness
Efficiency is plotted on Y-axis with length along X-axis and circular holes is marked as '*', hexagonal 'o' & square '+'.

3.2 Collimator Resolution

Collimator resolution, R can be calculated by similar triangles (as shown in figure 1) –

$$R = d * (1 + 2 * D/L) \qquad (2)$$

Where
d is diameter of hole,
D is distance from radiating source to collimator end
L is septal length

Collimator resolution depends on the distance from the radiating source and collimator end 'D'. Also, septal length, changes the resolution of collimator. It is defined as full width at half maximum of the radiation profile from a point source as shown in the figure 5 [1].

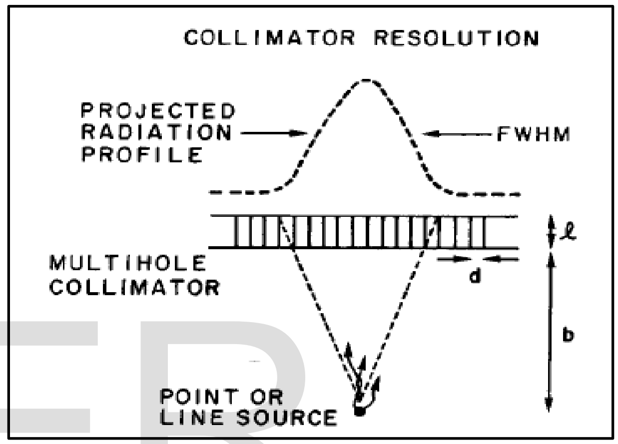

Fig. 5. Radiation profile for parallel-hole collimator

We get sharp radiation profile when the source is near to the collimator end. Spreading of radiation profile occurs as source moves away from the collimator end as shown in figure 6.

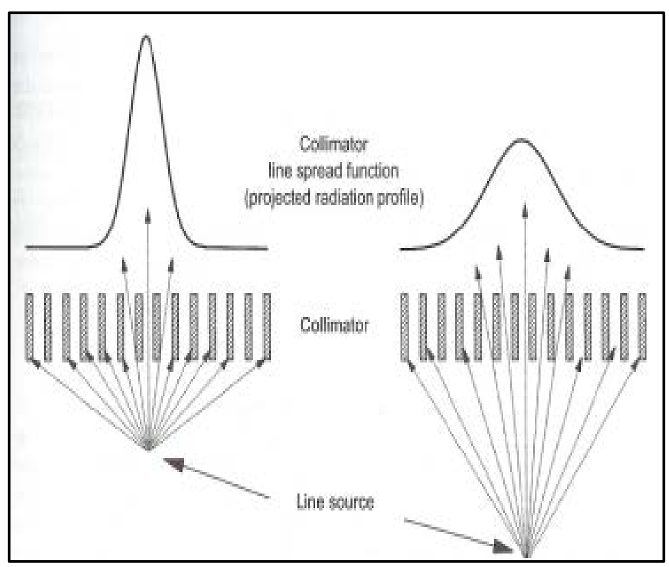

Fig. 6. Radiation profile for parallel-hole collimator source near to collimator end and away from collimator end

Collimator Resolution, R is calculated by changing the

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dimensional parameters of collimator.

Figure 7 shows the graph of Collimator Resolution, R obtained by changing the diameter of holes.

The resolution of the collimator decreases as the value of R becomes large with increase in diameter. More number of gamma rays is allowed to pass through the collimator of larger diameter leading to spread of radiation profile.

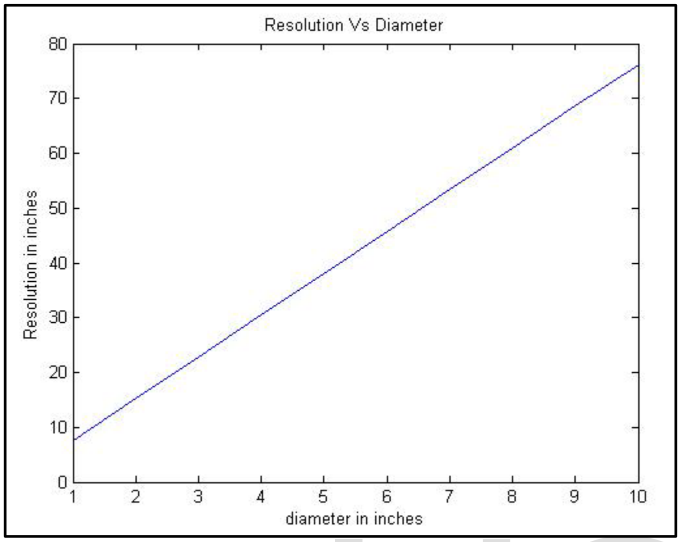

Fig. 7. Resolution, R with respect to variation in diameter, d
Resolution is plotted along Y-axis and d is plotted on X-axis

Figure 8 shows the graph of Collimator Resolution, R obtained by changing the distance between collimator end and source. The resolution of the collimator decreases as the value of R becomes large with increase in distance between collimator end and source. Scattered rays are tends to be pass through the collimator and radiation profile spreads.

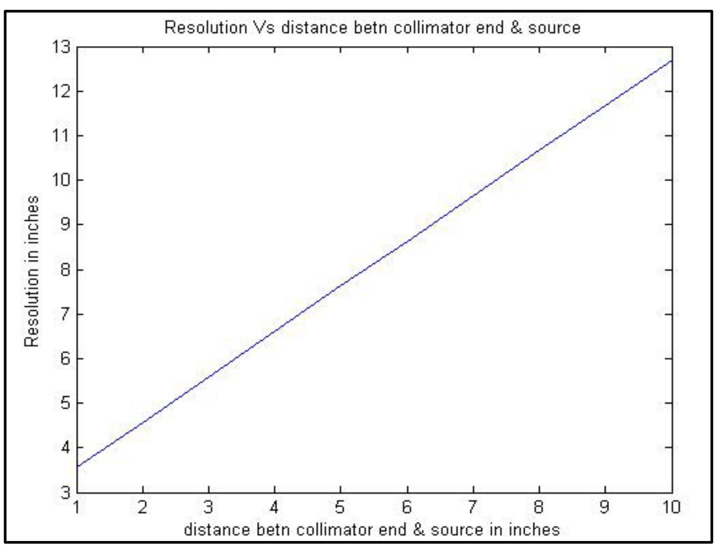

Fig. 8. Resolution, R with respect to variation in distance between collimator end and source, D
Resolution is plotted along Y-axis and D is plotted on X-axis

Figure 9 shows the graph of Collimator Resolution, R obtained by changing the length of septum.

The resolution of the collimator increases as the value of R becomes small with increase in length. Most of the gamma rays get absorbed within the collimator and very few reach towards the detector leading to sharp radiation profile.

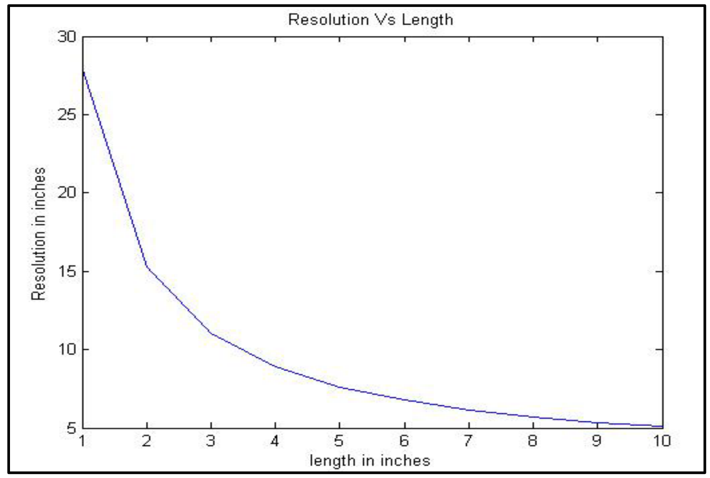

Fig. 9. Resolution, R with respect to variation in length, L
Resolution is plotted along Y-axis and L is plotted on X-axis

3.3 Collimator Septal Thickness

Septal penetration must be least so that maximum rays should be passed towards the detector so as to get better image. But, the septal thickness must be optimum so that only some gamma rays gets absorbed and still we get good quality image of desired area.

Normally, 5% absorption can be allowed for obtaining the optimum septal thickness. Septal thickness, t is given as –

$$t > \frac{\frac{6d}{\mu}}{L - \left(\frac{3}{\mu}\right)} \qquad (3)$$

Where
μ is linear attenuation coefficient of material
d is diameter of septum/hole
L is septal length

The linear attenuation coefficient, μ changes with the material and also with the energy of gamma rays.

Here, we have kept 'Lead' as collimator material and energy is changed.

For E = 150KeV, the linear attenuation coefficient is 21.43. The diameter of the collimator is changed keeping length constant and vice versa. Thus, an optimum septal thickness is obtained for low energy collimator. In low energy gamma ray imaging, septal thickness must be less enough, so that most of the low energy gamma rays reach the detector as shown in figure 10.

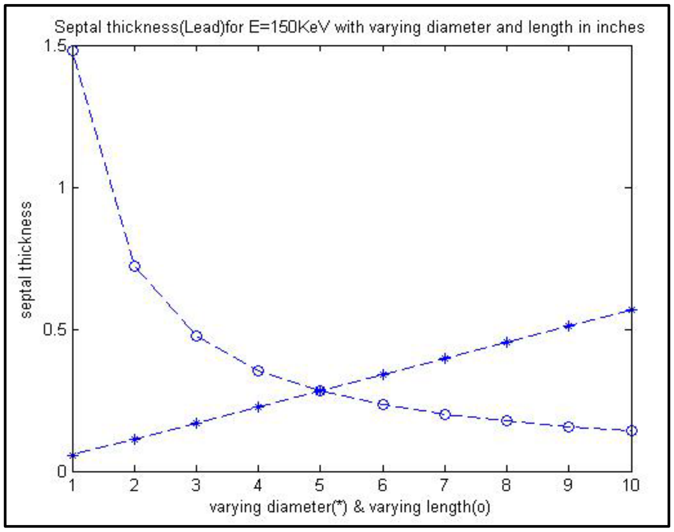

Fig. 10. Septal Thickness,t for Lead at E=150 KeV
Septal Thickness is plotted along Y-axis and diameter is marked as '*' with length marked as 'o' along the X-axis

For E = 400 KeV, the linear attenuation coefficient is 2.49. The diameter of the collimator is changed keeping length constant and vice versa. Thus, an optimum septal thickness is obtained for medium energy collimator. In medium energy gamma ray imaging, septal thickness must be sufficiently wider than low energy collimator so that most of the gamma rays gets absorbed and desired aligned gamma rays reaches towards the detector as shown in figure 11.

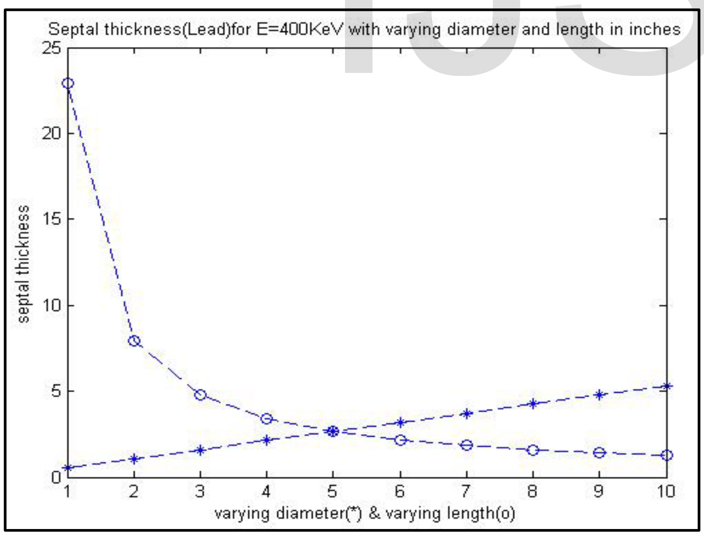

Fig. 11. Septal Thickness,t for Lead at E=150 KeV
Septal Thickness is plotted along Y-axis and diameter is marked as '*' with length marked as 'o' along the X-axis

4 Conclusion

Designing collimator for Medical Imaging devices is a very active discipline. By simulating collimator, accuracy for manufacturing of desired dimension collimator can be increased and collimator with better features can be designed. Comparison is done for the performance of circular, hexagonal and square holes lead parallel-hole collimators based on efficiency and resolution. Efficiency of collimator increases with the increase in diameter in all 3 hole-types of collimator, with more in square type. Resolution is best when the distance between source and collimator is least.

Modeling collimator provides an efficient way to study effects of dimensional changes with respect to collimator's resolution, efficiency and septal thickness. Manufacturing of collimators is done in better way by knowing the desired configurations and their simulated outputs.

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