# Monte Carlo Assessment of Geometric, Scatter and Septal Penetration Components in DST-XLi HEGP Collimator

M. Shafaei[1,3], M.R. Ay[2,3†], D. Sardari[1], N. Dehestani[1,3], H. Zaidi[4]

[1]Islamic Azad University, Science and Research Branch, Faculty of Engineering, Tehran, Iran
[2]Tehran University of Medical Sciences, Department of Medical Physics and Biomedical Engineering, Tehran, Iran
[3]Tehran University of Medical Sciences, Research Center for Science and Technology in Medicine, Tehran, Iran
[4]Geneva University Hospital, Division of Nuclear Medicine, Geneva, Switzerland

*Abstract* — **Image quality and quantitative accuracy in SPECT are affected by collimator penetration and scatter, particularly in high energy imaging. The magnitude of penetrated and scattered photons strongly depends on the photon's energy, object under study and collimator design parameters. Thorough knowledge of penetration and scatter distribution as function of photon's energy is essential for optimization of collimator design, selection of imaging protocols and development of optimum correction algorithms. In this study, the dedicated SIMIND Monte Carlo computer codes was used for calculation of septal penetration and scatter distribution as function of photon's energy and crystal thickness in DST-XLi dual head gamma camera with HEGP collimator. The code was validated through comparison with experimental measurements. The contribution of geometric, scatter and penetration components were quantitatively calculated for energy range of 250 to 450 KeV in DST-XLi HEGP collimator, where the camera equipped with three different crystal thicknesses, 3/8, 4/8 and 5/8 inch, respectively. Another simulation was carried out for a point source of I-131 to evaluate the contribution of scattered and penetrated photons during planar imaging. The point source simulation in 3/8 inch crystal thickness showed 64% of events in the photopeak window are either scatter or penetration from HEGP collimator. This work has demonstrated the relation of geometric, scatter and penetration components as function of photon's energy and crystal thickness in high energy radionuclide imaging. The results can be used for optimal collimator design and development of novel correction strategies.**

*Keywords* — **septal penetration, scatter, HEGP collimator, crystal thickness**

## I. Introduction

Image quality and quantitative accuracy in SPECT are affected by collimator penetration and scatter components [1]. These phenomena highly depend on the collimator characteristic and photon energy. Septal penetration and scatter components are photons that penetrate or scatter in the collimator septa and subsequently detected in the energy window of interest during the data acquisition. The magnitude of both effects is highly important for isotopes that emit high energy photons such as In-111, Ga-67, or I-131[2]. The presence of high levels of penetration and collimator scatter in the projection data complicates the collimator performance and potentially degrades quantitative accuracy. The presence of penetrated and scattered photons from collimator body in SPECT images degrades spatial resolution, contrast and quantification. In addition, image quality and quantification accuracy are affected by these factors [3].

To date there has been no analytic treatment of the septal penetration for multi-hole collimators. Finding these values is even more difficult to treat theoretically, but can also be analyzed using Monte Carlo simulation techniques [2].

Previous works assessing scatter and penetration in high energy imaging are limited and focused on I-131 imaging. Dewajara et al. [3] used Monte Carlo simulations to predict the fraction of scatter and penetration components in the photopeak window. Their results showed that 73% of events in the photopeak window had penetrated or scattered in the collimator [3]. In a recent study, Autret et al. [4] used GATE (Geant4 Application for Tomographic Emission) to predict the mentioned components in the photopeak window for I-131. They showed that 53% of scattered and septal penetration photons are detected in 20% window for I-131 [4]. There are several Monte Carlo codes in literature for assessment of these components in high energy imaging [5].

The limited number of publications assessing the geometric, scatter and septal penetration components in high energy radionuclide imaging as function of photon's energy, spurred the research presented in this paper, where we have tried to find the relation between photon's energy and crystal thickness with mentioned components in order to used the results for optimal collimator design and development of new correction algorithms.

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## II. Methods and Materials

### A. Monte Carlo Simulation

The SIMIND dedicated Monte Carlo code [6] was used for simulation of DST-XLi (GE Healthcare Technologies, Waukesha, WI, USA) dual head gamma camera with different crystal size and HEGP collimator. The SIMIND Monte Carlo simulation code has been developed by Professor Michael Ljungberg, Medical Radiation Physics, Department of Clinical Sciences, Lund University, Sweden. The entire code is written in FORTRAN- 90. The SIMIND code is designed such that the parameters to be calculated in a particular simulation can be easily changed. This is achieved through a user-written scoring subroutine that is linked to the code. A call to the routine is made at different stages during a photon's history. The SIMIND consist of two main programs, named CHANGE and SIMIND. The CHANGE program provides a menu driven way of defining the system that will be simulated and the radiation transport is performed by SIMIND.The code has been extensively tested by different research groups as a tool for modeling of gamma camera and collimator design. The code is also able to accurately simulate all photon's interaction in collimator. In addition SIMIND can separate the geometric, penetration and scatter components of detected photons in the energy window of interest. Geometric photons are photons which transverse the collimator hole without interaction. Some photons cross at least one septum before being detected by the detector. Penetrated photons contribute to the image and tail a pattern in the image. This pattern is dependent on hole shape of collimator.

Table 1 The design parameters of collimator and gamma camera characteristics

| | |
|---|---|
| Hole length (cm) | 5.4 |
| Septal thickness (cm) | 0.16 |
| FOV (mm$^2$) | 540×400 |
| Crystal Thickness (inch) | 3/8, 4/8, 5/8 |
| Energy resolution | 9.8% at 140 KeV |

### B. DST-XLi Gamma Camera

In this study the DST-XLi dual head gamma camera with its dedicated HEGP collimator accurately modeled using the SIMIND Monte Carlo code. Detailed information about the gamma camera specifications and collimator characteristics are provided by the manufacturer. The DST-XLi gamma camera is commercially available with three different crystal thickness (3/8, 4/8 and 5/8 inch). Table 1 summarizes the scanner design parameters and HEGP collimator characteristic used in this study.

### C. Simulation Setup

After accurate modeling of the geometry of system into the SIMIND the code ran with different setups as follow. In order to separate the contribution of geometric, scatter and penetration components in projection data we simulated a point source in air, 20 cm away from the detector surface at different energies such as 200, 250, 300, 350, 400 and 450 KeV. Individual simulations were carried out with the mentioned energies for different crystal thickness. The impact of different components in projection data were investigated using analysis of pint source planar image. For accurate quantitative analysis of these components the code was set in such way to report the value of each component in individual simulations. In order to investigate the importance of collimator penetration and scatter in a clinical imaging, we simulated I-131 point source, which is one of the most usage isotopes in high energy imaging.

## III. Results

Figure 1 shows the geometric, penetration and scatter fractions of a point source in air in 20% of photopeak widow at different photon's energy in HEGP collimator with 3/8 inch NaI(Tl) crystal thickness.

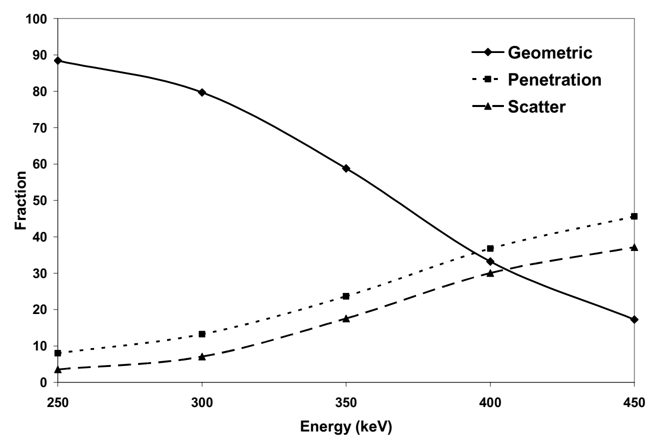



Fig. 1 Geometric, penetration and scatter in collimator for 3/8 inch crystal.

As shown in the figure 1, with increasing the photon's energy the contribution of scattered and penetrated photons increases while the contribution of geometric photons decrease due to the low sensitivity of NaI(Tl) crystal in higher energies. It should be emphasized that although the geometric component in projections is independent from the photon's energy but decreasing the geometric components in figure 1 is due to the decreasing the interaction with crystal with increasing the photon's energy.

Figure 2 shows the impact of using different crystal thickness on the sensitivity of gamma camera. The detector hits in the figure 2 shows the number of photons after collimator and actually is the photons that reach the crystal. But it is well known that the number of photons that stops in the crystal highly depending to the crystal thickness. This behavior clearly shows in figure 2, where the impact of using different photon's energy investigated for different crystal thickness.

Figure 3 shows the number of detected geometric, penetration and scatter components in projection data from a point source of I-131 positioned 20 cm from detector surface when using different crystal thickness. Although these components are not function of crystal thickness, but increasing the crystal thickness increases the number of detected photons belong to these components.

Figure 4 illustrates the contributions of geometric, penetration and scattered components in the planar image of an I-131 point source in air and 20 cm away from detector surface for different crystal thickness. The results show that 64%, 61% and 59% of the events in photopeak have even penetrated or scattered in the collimator for 3/8, 4/8 and 5/8 inch crystal thickness, respectively.

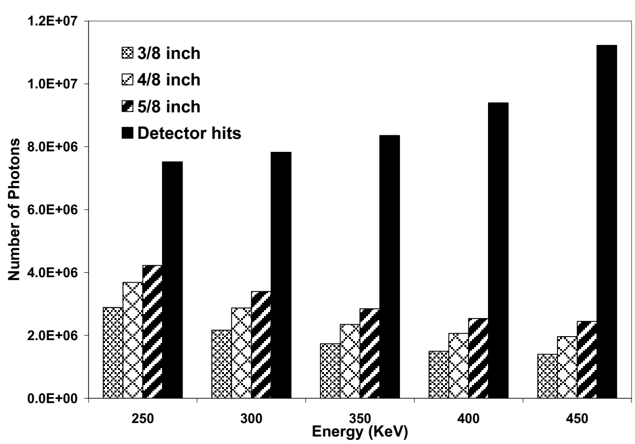



Fig. 2 Detector hits and number of detected photons in photopeak window for different crystal thicknesses.

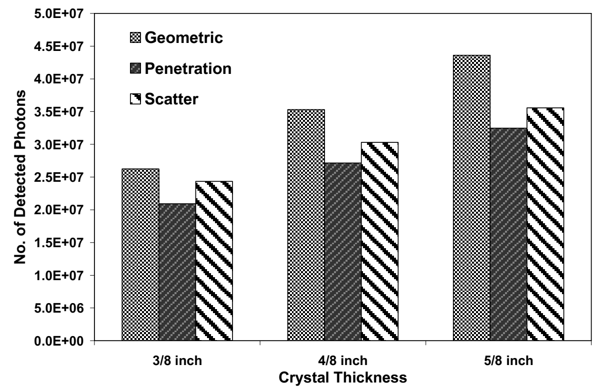



Fig. 3 Comparison of the number of geometric, penetration and scatter photons for different crystal thicknesses for a point source of I-131 situated 20 cm from detector surface.

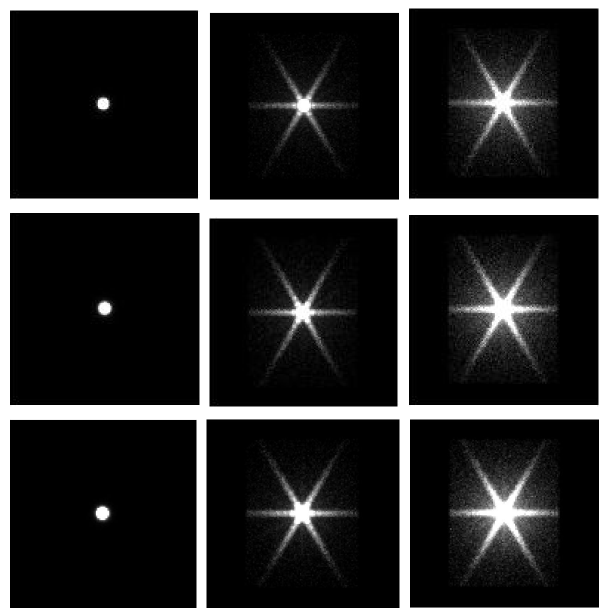
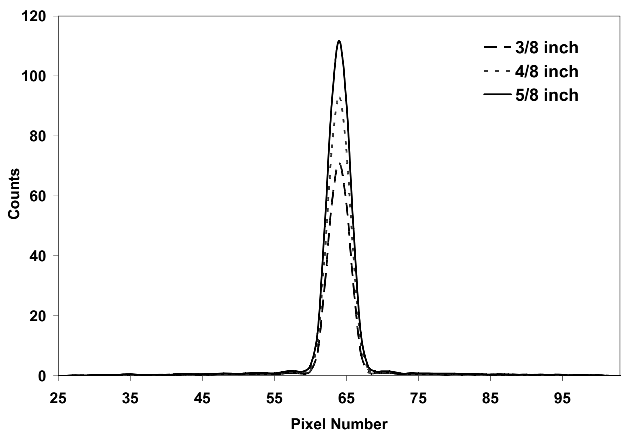
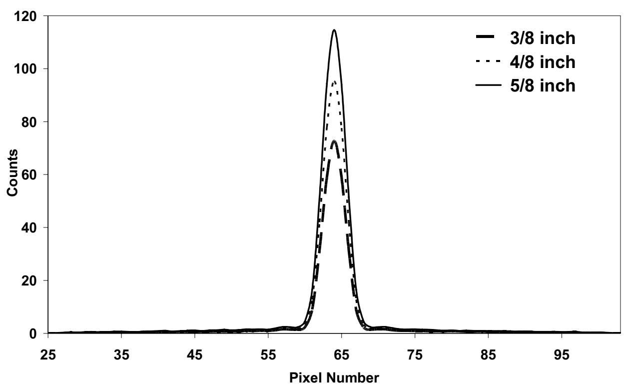


Fig. 4 The planar image of an I-131 point source in air including the geometric components (left column), sum of geometric and penetration (middle column) and sum of geometric, penetration and scatter (right column) for different crystal thickness, 3/8 inch (top row), 4/8 inch (middle row) and 5/8 inch (bottom row).

The results in this study are in good agreement with the pervious publications [3,4]. The small discrepancies between the results are due to the minor difference in the camera and collimator specifications simulated in these studies.




**(a)**




**(b)**

Fig. 5 Horizontal profile from the center of images shown in Fig. 4, (a) sum of geometric and penetration components (b) sum of geometric, penetration and scatter

## IV. Conclusion

The geometric, penetration and scatter components for the DST-XLi HEGP collimator at different range of energies and different crystal thickness was modeled using the SIMIND Monte Carlo code. It was observed that the penetration and scatter components increase by increasing the photon's energy, while the detected geometric components in the crystal decrease by increasing energy. It was concluded by increasing the crystal thickness the number detected photons categorized in all three mentioned components increase due to increasing the probability of photon absorption in the crystal. The results of this study also showed collimator penetration and scatter in HEGP collimator have major contribution on radionuclide imaging when using high energy emitter radio isotops. We showed fractions of scatter and penetration quantitatively for different crystal thicknesses. The results in this study can be used for development of new techniques and evaluation of existing techniques that are used for scatter and penetration correction in high energy SPECT imaging such as I-131 SPECT. Our results, consistent with the reported data by Dewajara and Autret show high energy collimators are not well adapted to I-131 imaging; in addition we have reported an energy dependent function for geometric, penetration and scatter components.

## References

1. X. He, E. C. Frey, J. M. Links, X. Song, and B. M. W. Tsui (2005) Comparison of penetration and scatter effects on defect contrast for GE and Siemens LEHR collimator in myocardial perfusion SPECT-A simulation study. IEEE Trans Nucl Sci 52: 59–64
2. H. Zaidi, Quantitative Analysis in Nuclear Imaging, Springer, Singapore, 2006
3. Y.K. Dewajara, M. Ljungberg, K.F. Karol (2000) Characterization of scatter and penetration using Monte Carlo simulation in I-131 imaging. J Nucl Med 41: 123–130
4. D. Aurtret, A. Bitar, L. Ferrer, A. Lisbona, and M. Bardies (2005) Monte Carlo modeling of gamma camera for I-131 imaging in targeted radiotherapy. Cancer Biotherapy & Radiopharmaceuticals. 20:77–84
5. I. Buvat, I. Castiglioni,(2002) Monte Carlo simulation in SPET and PET. Q J Nucl Med 46: 48–61
6. SIMIND Version 4.5. The SIMIND Monte Carlo program, M. Ljungberg Online]http://www.radfys.lu.se

† Corresponding Author: Mohammad Reza Ay
Institute: Tehran University of Medical Sciences
Street: Pour Sina
City: Tehran
Country: Iran
Email: mohammadreza_ay@tums.ac.ir