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Monte Carlo simulation, GATE, gamma camera model, ^{99m}Tc

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E.CAM DUET GAMMA CAMERA MODEL VALIDATION IN GATE

Monte Carlo simulations are more and more popular trend in nuclear medicine imaging. They were also widely used in radiotherapy and brachytherapy with use of more general simulation software. GATE (Geant4 Application for Tomographic Emission) is a platform developed on general Monte Carlo code designed for simulating and tracking the passage of particles through matter (Geant4) but is specifically designed for nuclear medicine imaging purposes. The aim of this work was to create and validate a model of specific gamma-camera (E.Cam DUET), used in our department, for further use in image analysis and dosimetry field, with GATE simulation platform. We have modeled in first step a point source in the air in three configurations of gamma camera (without collimator, with low-energy high-resolution (LEHR) collimator and with high-energy (HE collimator)), then we have created a phantom with three spherical sources of different sizes but with the same concentration of the radiopharmaceutical. Simulation results were compared to the measured values of the energy spectrum and images obtained on the detectors, and show a good agreement for the point source experiments and revealed some differences for the phantom studies. This results shows that some additional tests and refinements are required but also allows us to study the image degrading quality factors, such as septal penetration and to work towards eliminating them from the pictures.

1. INTRODUCTION

The number of papers treating MC in medicine is increasing which was shown in [5]. Most of them are a general Monte Carlo simulation tool for example MCNP [4], EGS4 [7] or Geant4 [1,2], but also it's possible to find more specialized codes as it takes place in case of GATE (Geant4 Application for Tomographic Emission). This is a platform developed on general Monte Carlo code designed for simulating and tracking the passage of particles through matter (Geant4). It is specifically designed for nuclear medicine imaging purposes, it means for PET and SPECT studies.

Monte Carlo simulations can be used for developing image analysis and correction algorithms, for example for scatter correction [1] or to study an impact on the imaging of the septal penetrations and scattering in the collimator [3]. The simulations can be also very helpful in assisting in the design of new medical imaging devices (for example new collimators design). The optimisation of acquisition protocols and the development or assessment of image reconstruction algorithms and correction techniques are useful as well.

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2. MATERIALS AND METHODS

2.1. MEASUREMENTS

All measurements were performed using Siemens E.Cam DUET dual head gamma-camera with NaI(Tl) scintillation crystal of the 1 inch thickness. Technetium point source was used with 0.7 MBq activities in the first experiment. The source was placed in the center of rotation about 30 cm from the detectors. Energy spectrum was acquired in three configurations: without collimators, witch low-energy high-resolution (LEHR) collimator intended for ^{99m}Tc isotope and with high-energy (HE) intended for ^{131}I. The distances source – detector was 30.9 cm for HE, 33.6 cm for LEHR and 36.3 cm without collimator. Collimators used in the measurements was parallel hole type with hexagon hole shape.

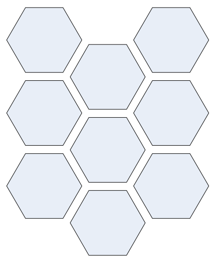

Fig.1. Collimator holes shape and configuration. Diameters of the hexagon and septa thickness depend on the collimator type.

In the second experiment both collimators were used to register SPECT images and acquire an energy spectrum with described earlier configurations. Instead of point source a small plexiglass phantom was used (see Fig 1). In main cylinder three different size spheres was placed in triangle geometry. Volumes of the spheres was 0.4 ml, 2 ml and 5.4 ml and they were filled with a ^{99m}Tc source of activity 0.43 MBq, 1.83 MBq and 5 MBq respectively (approximately constant activity concentration of 0.97 MBq/ml ± 0.1). Main cylinder was filled, in the former experiment, with air and, in the latter experiment, with water as a scattering medium. Using these different phantom and collimators configurations SPECT images were acquired.

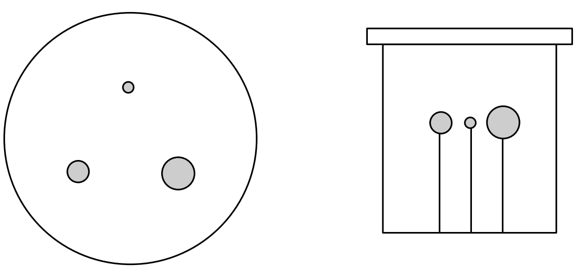

Fig.2. Phantom draft. Left: top view, right: side view. Grey spheres are filled with ^{99m}Tc with constant concentration of the activity.

2.2. SIMULATIONS

For simulations of the E.CAM DUET gamma camera a GATE platform [6] was used. Geometry of our gamma camera is shown on Figure 3. Two heads consist of a few layers: collimator layer (black), crystal layer, back scattering layer and shielding. Collimators were modeled according to system documentation for geometric information of collimator's structure. Simulation time was set to be equal to the appropriate measurements. Phantom was modeled as cylinder with three radioisotope filled spheres of different sizes (described above) and placed on table as it has a place in real measurements

Simulation time for a full SPECT acquisition made on a single Intel Xeon 3.2 GHz computer with 64 frames was about 1000 hours.

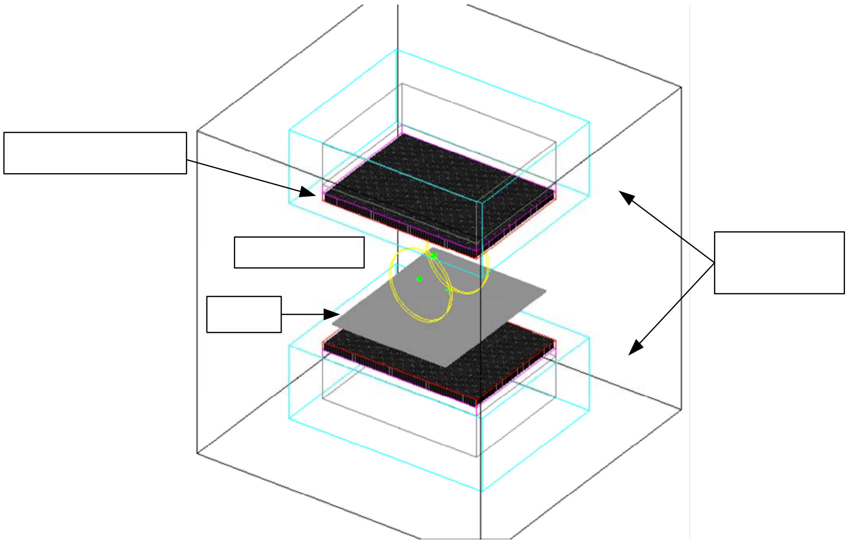

Fig.3. Gamma camera model visualization form GATE platform. Two heads are in starting positions (angle 0° for detector 1 and 180° for detector 2).

3. RESULTS

Figure 4 presents energy spectra both from the experiments (dotted line) and from the simulations (solid line) of a ^{99m}Tc point source without any scattering medium. Results in the case of lack of the collimators are almost identical and are slightly different after the collimators were linked. The source used in the experiments has a single energy line at 140 keV which can be observed as a main photo peak. All peaks for lower energies came from the Compton scattering of the photons on the collimator.

The spectra were normalized in the way that the maximal value was set to be equal 1. The noise in the acquired data comes from the uncertainty of the measured signal itself and the dark current of the photomultipliers. Both compartments of the noise disappear, when high number of counts is reached in the absence of the collimators (Figure 4).

As for Figures 4 (mid), and 4 (down), the collimators restricted the photons to only those perpendiculars to the surface of the detector; this led to decrease in total number of counts in the spectra and revealed the noise. In the case of the HE collimator Compton scattering peak is lower than that peak for the LEHR collimator. It is in agreement with the theory because of the thicker collimator and thicker septa.

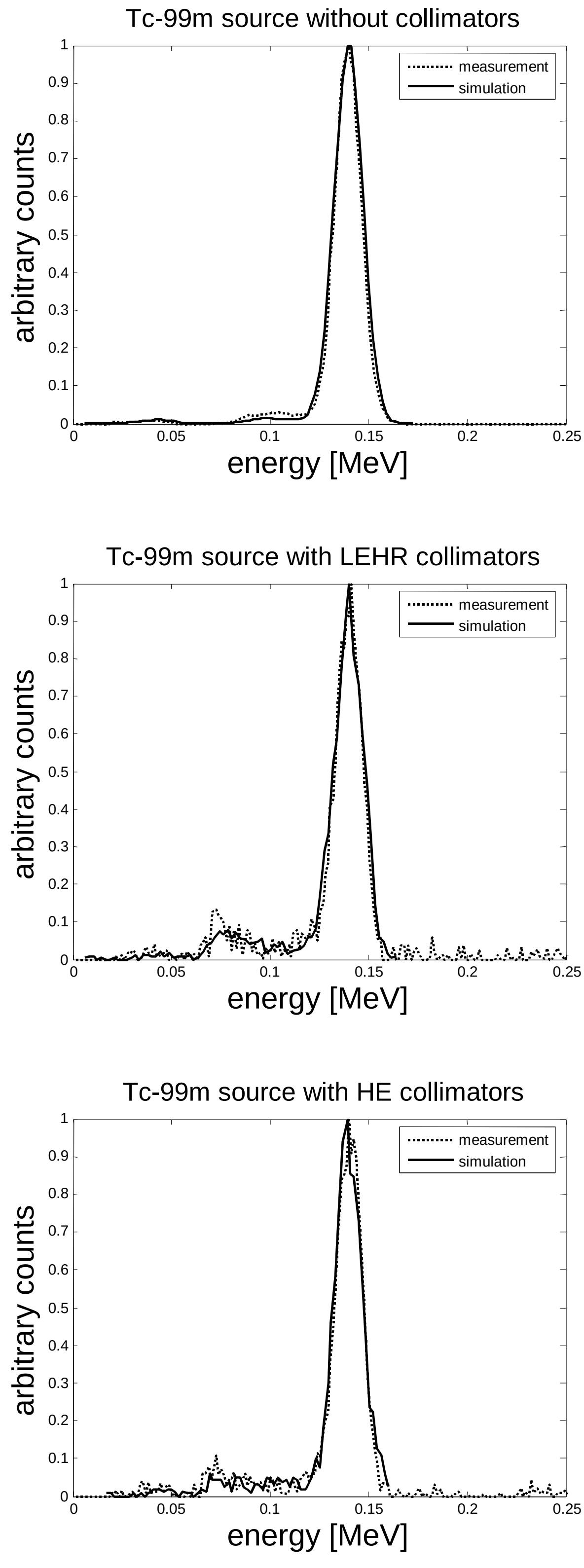

Fig.4. Simulated and experimental spectra of 99mTc source in three configurations of the system: without collimators (up), with LEHR collimators (middle), with HE collimators (down).

There where differences between measurements and simulations observed in phantom with high activity, complex geometry in medium (Fig. 5, Fig. 6). For the configuration with the LEHR collimators measured Compton photo peak is higher and is placed in about 30 keV lower energies in opposite to the simulations in the situation when main photo peak is well located. When the collimators are absent the location of the photo peaks have a better energetic localization agreement. The spectra height differences in the Compton range were observed on normalized plots. This results from differences in Compton-to-Photopeak ratios between measurement and simulation. In this case a large dead time parameters of the detectors have its impact, which wasn’t seen earlier in the point source energy spectrum (Fig. 4 up) as only main photo peak was registered due to lack of the scattering medias.

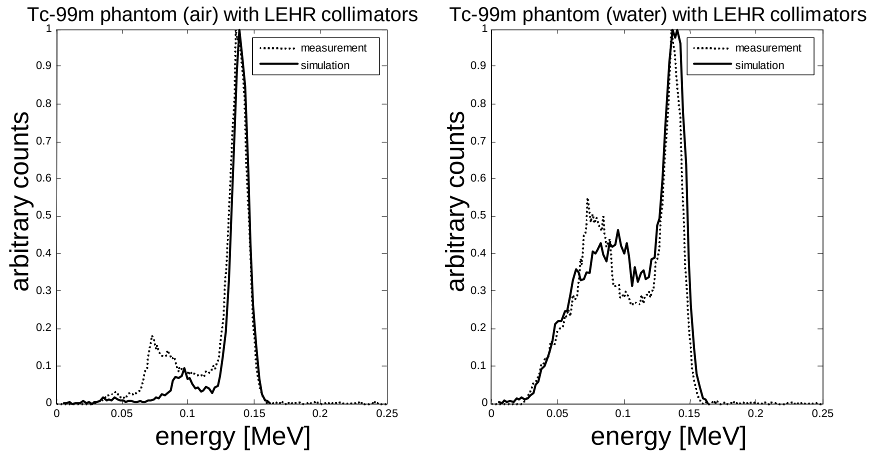

Fig.5. Simulated and experimental spectra of ^{99m}Tc phantom with air and water filling and with LEHR collimators.

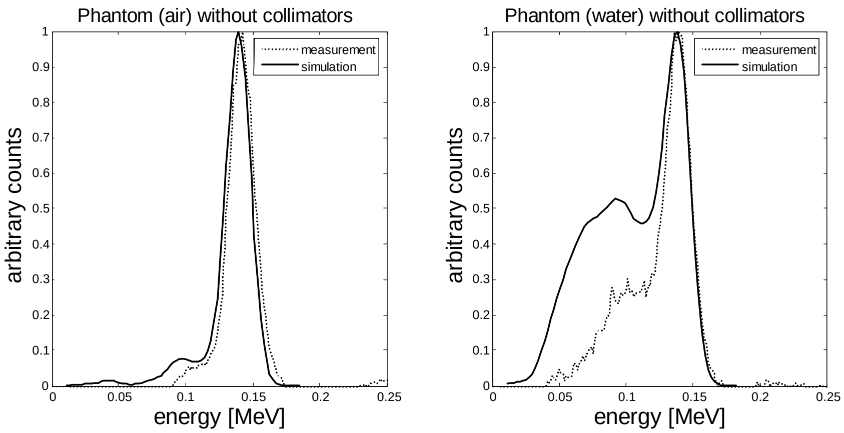

Fig.6. Simulated and experimental spectra of ^{99m}Tc phantom with air and water filling and without collimators.

Figures 7 to 9 presents’ examples of the images obtained in the gamma camera and form the simulations in a few configurations. Left side of the figures contain a plot of a count profile in the maximum count place. It correspond to the three different activity of the spheres. In the presence of the scattering medium (water) the smallest is almost lost.

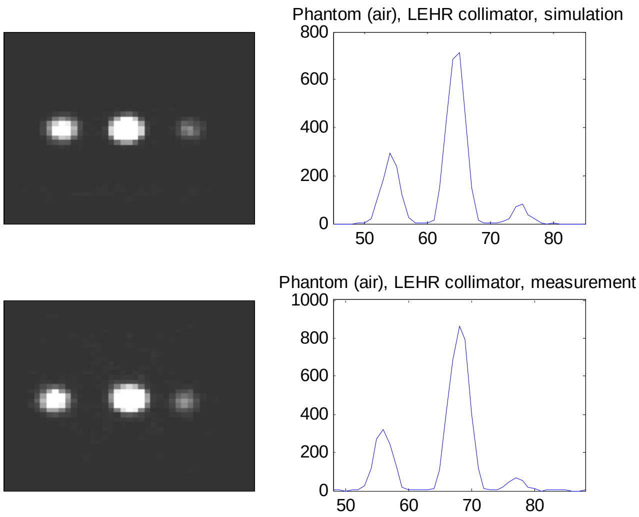

Fig.7. Phantom filled with air results for LEHR collimator. Up – simulation, down – experiment. Left: images obtained from the detector. Right: Profiles of the pixel intensity acquired for the spheres filled with the ^{99m}Tc (x axis - pixel number, y axis - counts).

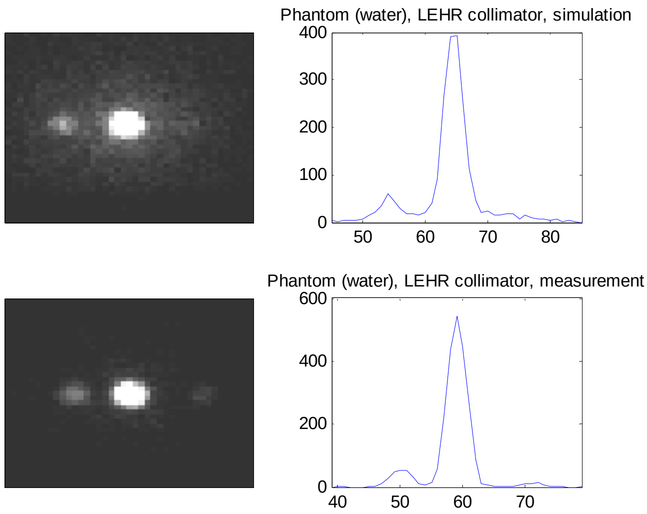

Fig.8. Phantom filled with water results for LEHR collimator. Up – simulation, down – experiment. Left: images obtained from the detector. Right: Profiles of the pixel intensity acquired for the spheres filled with the ^{99m}Tc.

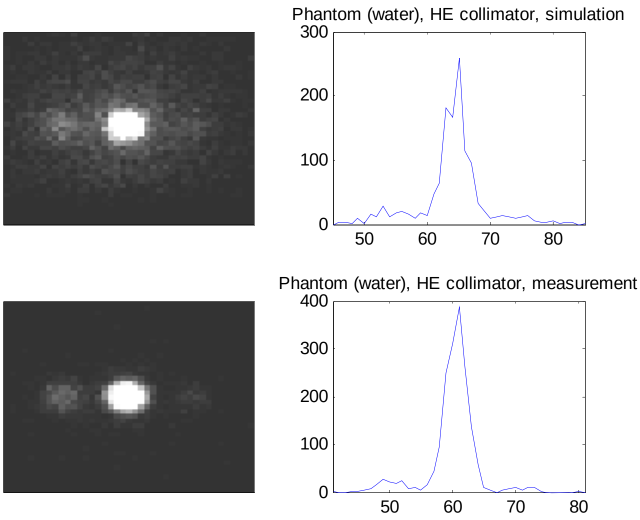

Fig.9. Phantom with water results for HE collimator. Up – simulation, down – experiment. Left: images obtained from the detector. Right: Profiles of the pixel intensity acquired for the spheres filled with the ^{99m}Tc.

4. DISCUSSION

Simulation results of the gamma camera using GATE package were compared to the measured values of the energy spectrum and images obtained on the detectors, and show a good agreement for the point source experiments. In the presence of higher activity and more complex geometry in scattering medium as for the phantom studies energy spectra reveal differences in scatter photo peaks localizations. These results suggest that new tests towards more precise energetic calibration, efficiency calibration and the dependence of detector response on source volume are needed. The simulation model has to be constantly refined.

However this primary result allows us to consider Monte Carlo simulations, in this case in the form of GATE package, as a very helpful tool in nuclear medicine images analysis.

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