GEANT4 Simulation of the Gamma-Ray Background in the Images Obtained Using Accelerator-Produced ^{99m}Tc

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INTRODUCTION

The experiments on the accelerator production of ^{99m}Tc via the direct ^{100}Mo(p,2n)^{99m}Tc reaction, along with the separation and extraction procedures set up [1] have already traced the feasibility of such a route as a reliable alternative method for ^{99m}Tc supply. This could be particularly useful for centers where small accelerators for medical purposes have already been built. However, gamma-ray emission analysis of the extracted solutions revealed the presence of very low concentrations of other technetium isotopes, such as ^{93}Tc, ^{94}Tc, ^{95}Tc, ^{95m}Tc and ^{96}Tc [2,3]. The emitted gamma rays from these isotopes, undergoing Compton scattering in the matter, could be detected by the imaging detector, thus resulting in an image background and contrast degradation. Experiment on the assessment of this effect has already been conducted and images concerning the background intensity change have been reported [3]. However, from that experiment it was not possible to assess the individual contribution of each isotope to the image background and thus to make conclusions about the image background behavior as a function of time. In order to meet such requirement we have reproduced the experiment described in [3] using the Geant4 simulation toolkit [4,5].

METHODS

Both the real geometry of the experimental setup described in [3] and the gamma camera dimensions and position have been reproduced for simulation. A schematic diagram of the simulated setup including the water-filled container, the capillary tubes with circulating ^{99m}Tc solution, placed at different depth and the gamma camera are shown in Fig. 1.

The basic elements with exact dimensions inserted in the simulation are the three capillary tubes at different distance from the bottom, the quantity of water in which they are immersed, the width of the container steel walls and the glass layer of the bottom underneath. A simplified version of the collimator of the gamma camera has also been simulated: instead of the real hexagonal shape, the holes are assumed to be regular square-shaped with a basis of 1.7 mm and a septa of 0.2 mm.

The gamma camera sensitive pixels that were simulated had the same width of 0.19 mm as the original ones, but their length was kept equal to the length of the capillary tubes in order to integrate the counts in the resulting image along the direction parallel to the capillary tubes. The number of gamma rays crossing the surface of each pixel is counted, provided that their energy falls within the narrow acceptance window set during image reconstruction. The latter has been assumed to be between 135 keV and 155 keV (±10% of the nominal energy of 140.5 keV of the photon emitted in the decay of ^{99m}Tc).

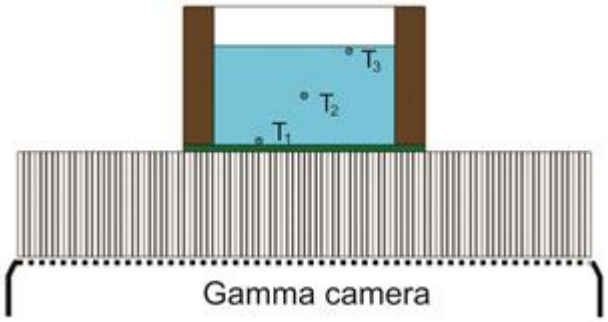

Fig. 1. A cross section sketch of the simulated water-filled container, with the capillary tubes placed on the parallel-hole collimator of the gamma camera positioned underneath. The colors represent the different materials, as defined in the Geant4 material database: water (cyan), air (white), steel (brown), glass (green) and lead of the collimator (dark gray). The capillary tubes with the fluctuating technetium solution are indicated as T_1, T_2 and T_3.

Simulations have been carried out separately for each of the isotopes ^{99m}Tc, ^{93}Tc, ^{94}Tc, ^{95}Tc, ^{95m}Tc and ^{96}Tc, which have then been scaled to the partial activity data from the gamma-spectrometry analysis. Primary ions of a given species were created at a random position, distributed with uniform probability inside the volumes defined by the three capillary tubes, and then decayed at rest. The gamma rays thus produced were followed until they crossed one of the gamma camera pixels (scintillator surface) or until they leave the world volume of the simulation. In order to reduce computing time, electrons and neutrinos, produced by beta decays, were discarded from the simulation stack at the moment of their production. Since Geant4 simulates by default the complete decay chain until a stable species is reached, radioactive daughter ions with a long half-life

(namely, ^{93}Mo and ^{99g}Tc) were also discarded from the stack when they reached the ground state.

A total number of $5 \cdot 10^8$ decay events have been simulated for each species. The number of events obtained for each isotope has then been scaled to the corresponding relative isotope activity obtained from the gamma spectrometry analysis. For each primary ion, the total number of gamma rays in the given energy range that enter each pixel was counted. It was then summed up in a G4THitsMap object which stores the total number of "good" events recorded by each pixel in a given run.

RESULTS

The output image of the simulation with the contribution of ^{99m}Tc is plotted in Fig. 2. The first peak position corresponds to pixels 119 to 122 and represents the emission from the tube situated closer to the gamma camera (at the greatest depth). The second peak position is between pixels 198 and 201 (central tube) and the third is positioned between pixels 277 and 280, corresponding to the least immersed capillary tube. The walls of the container (indicated with grey color) are situated in regions with pixels 0 – 41 and 358 – 399. The fork-shape of the peaks is due to the gamma-ray absorption in the collimator septa positioned there.

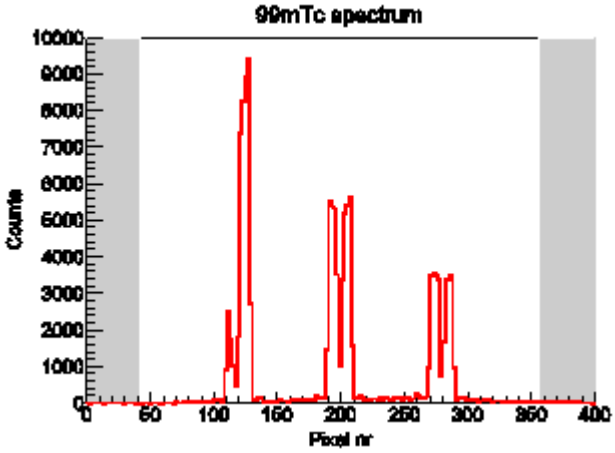

Fig. 2. Simulated output image of ^{99m}Tc without the contribution of the other technetium isotopes.

Fig. 3 shows the simulated cumulative image of the contaminant technetium isotopes (^{93}Tc, ^{94}Tc, ^{95}Tc, ^{95m}Tc and ^{96}Tc), scaled to the relative activities recalculated for 22 hours after target irradiation, when the measurement experiment was performed in [3]. The walls of the container are indicated with grey color. The region between the container walls exhibit a linearly decreasing background similar to the one demonstrated in [3].

Fig. 4 represents the simulated background contribution of each one of the isotopes ^{93}Tc, ^{94}Tc, ^{95}Tc, ^{95m}Tc and ^{96}Tc. However, even in the worst experimental condition (^{99m}Tc photons yield from the deepest position), the maximum overall contribution from background noise may be estimated as 3 – 5%.

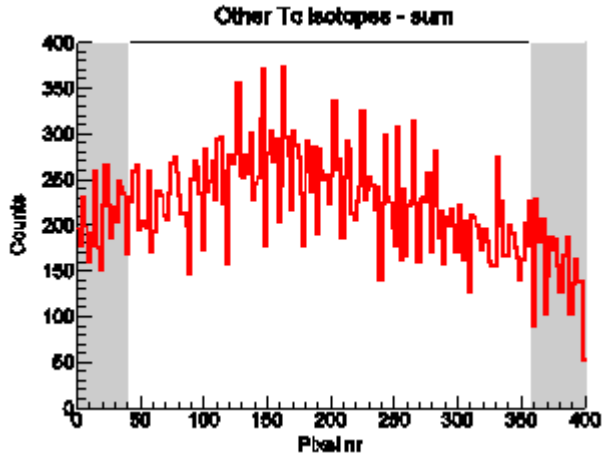

Fig. 3. Simulated output image of the total contribution of the technetium isotopes ^{93}Tc, ^{94}Tc, ^{95}Tc, ^{95m}Tc and ^{96}Tc.

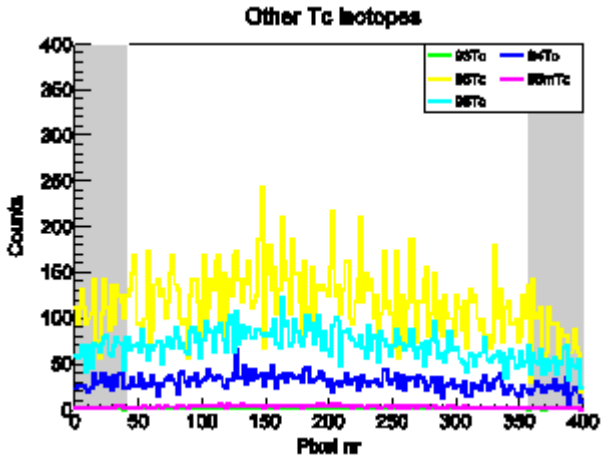

Fig. 4. Simulated output image of the individual contribution of the technetium isotopes ^{93}Tc, ^{94}Tc, ^{95}Tc, ^{95m}Tc and ^{96}Tc.

CONCLUSION

The linear background behavior, seen in the spectra from accelerator-produced ^{99m}Tc, has been well reproduced in the simulated spectra. Figure 4 demonstrates that the greatest part of the background contribution 22 hours after irradiation is due to the Compton scattered gamma-rays emitted by the isotopes ^{95}Tc and ^{96}Tc.

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