A Dose Kernel Based Analytical Algorithm for Voxel Dose Calculation in Nuclear Medicine

Spiridon V. Spirou[1], PhD
spiridonspirou@yahoo.com
Theodora Kostou[2], MSc
Panagiotis Papadimitroulas[3], PhD

1. Department of Biomedical Engineering, Technological Educational Institute of Athens, Greece
2. Department of Medical Physics, School of Medicine, University of Patras, Greece.
3. BET Solutions, R&D Department, Athens, Greece

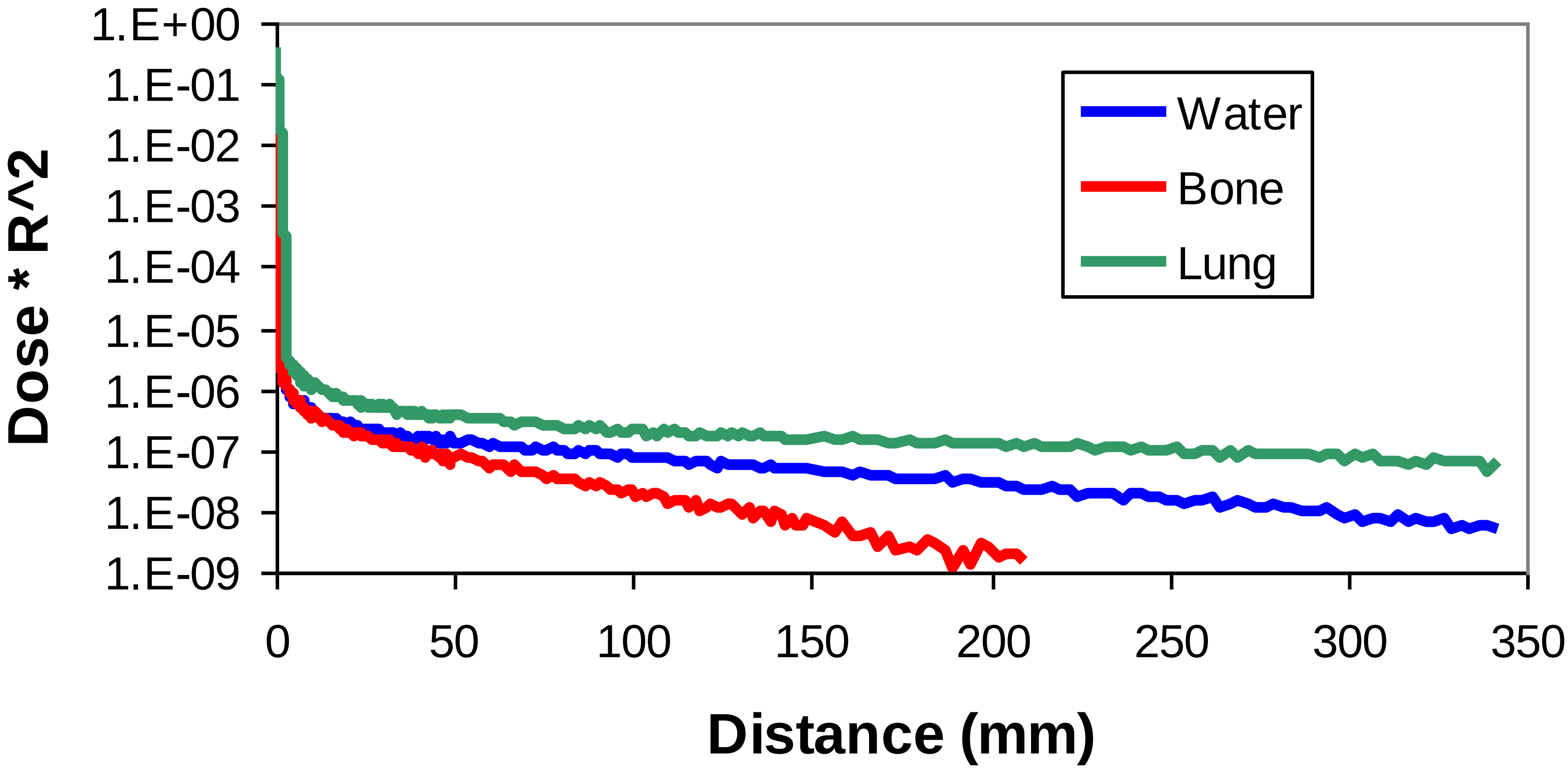
Introduction

- In Nuclear Medicine, absorbed dose is calculated as an average dose to the target organ from the activity in the source organ, using a standard patient (the MIRD approach).
- Dose Point Kernels (DPKs) describe the dose as a function of distance for a given radionuclide and homogeneous phantom.
- In this work, we use the DPKs to calculate dose on a voxel basis in 3D, using the particular patient’s CT.

Calculation of the DPKs

- The DPKs were calculated using the GATE Monte Carlo toolkit, v6.1
  - Papadimitroulas *et al*, Med. Phys. 39, 5238 (2012); doi: 10.1118/1.4737096.
- Spherical geometry:
  - Homogeneous medium (water, bone, lung, and soft tissue)
  - Radionuclide at center
  - Concentric shells for 3D dose calculation
  - Smaller dose-scoring voxel sizes in inner shells for higher accuracy

Example: DPK for ^{99m}Tc

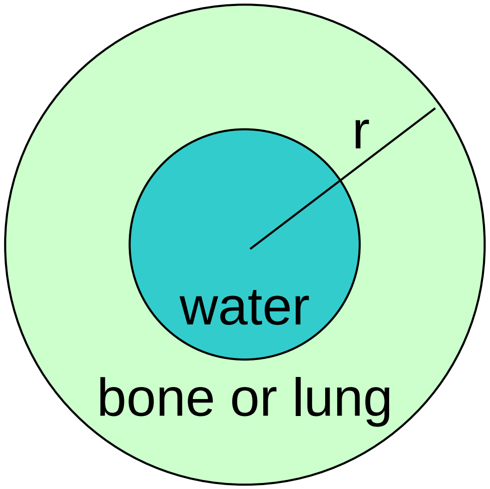


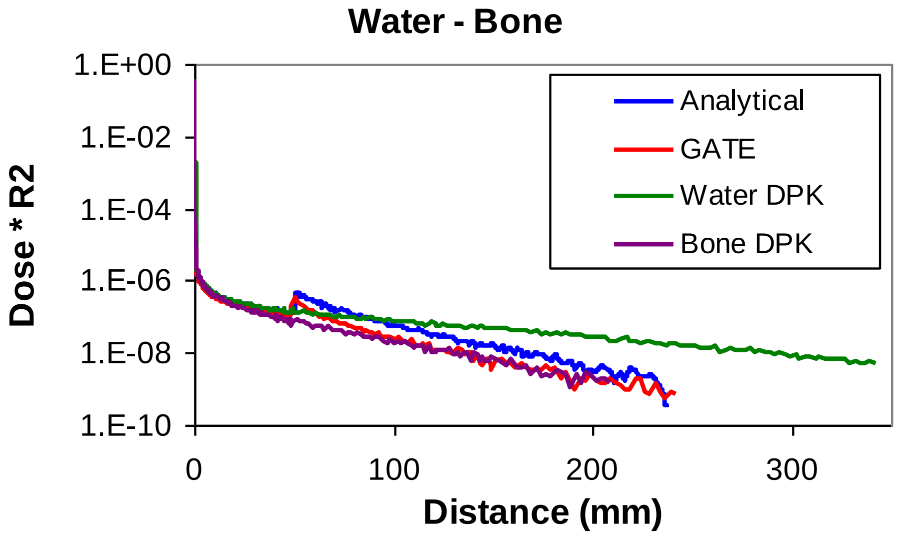
Calculation of absorbed dose

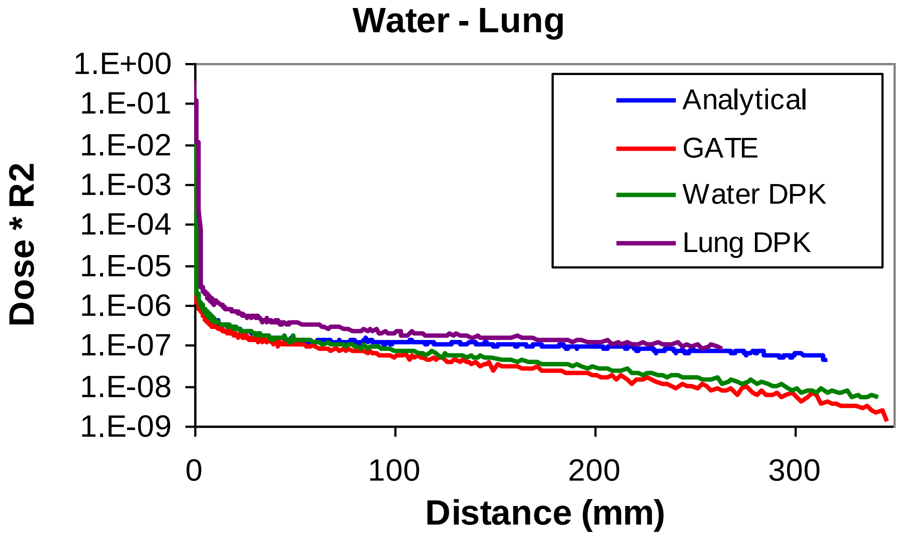
- The path from the source voxel to the target voxel was calculated in 3D
  - The path is a list of materials traversed and the distance in each material
- Using the DPK, the total energy absorbed in the first material, E_1, was calculated.
- The position r_2 in the second material where the total energy absorbed is equal to E_1 was calculated.
- The DPK in the second material was read, beginning at r_2.
- The total energy absorbed in the second material, E_2, was calculated
- The position r_3 in the third material where the total energy absorbed is equal to E_1+E_2 was calculated.
- The DPK in the third material was read, beginning at r_3.
- The process was repeated until the target voxel

Case 1: Two-component phantom

- Spherical geometry, same as in calculating the DPKs
- Inner material is water ($r \leq 50.25$ mm), outer material is either bone or lung ($50.25 < r \leq 349.5$ mm).
- Radionuclide is ^{99m}Tc



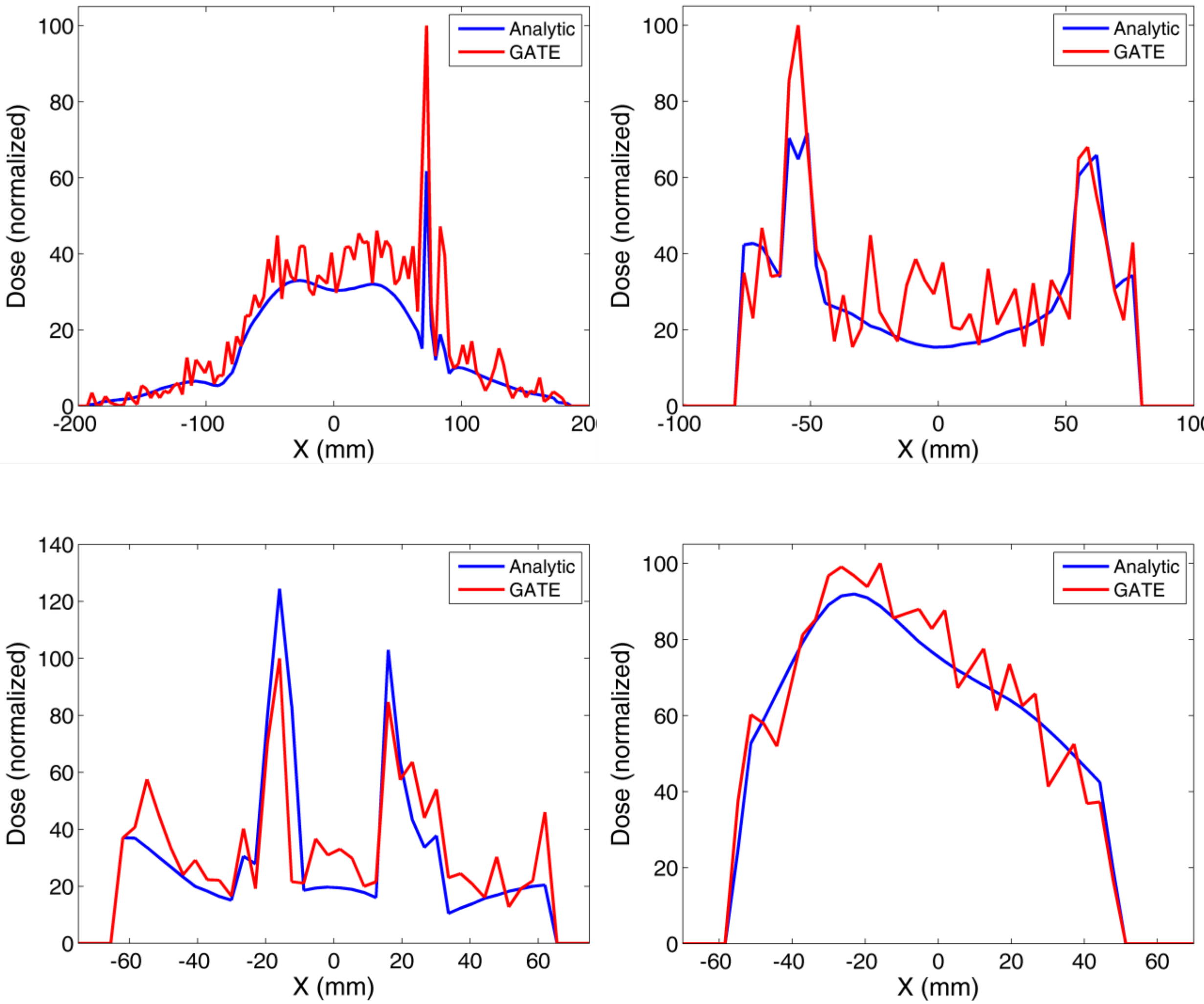




Case 2: XCAT

- XCAT computational anthropomorphic model used to generate patient CT
- 100 slices, from top of head to diaphragm
- Slice dimensions are 128 x 128 pixels
- Voxel size is 3.54 x 3.54 x 3.54 mm^3
- Radionuclide (^{99m}Tc) placed in different organs to assess effects of geometry and inhomogeneities.
- 10^{10} particles simulated for improved statistics

Case 2: XCAT



- Dose profiles in patient Left-Right direction
- Dose has been normalized so that Dmax of GATE profile = 100%

Conclusion

- An analytical algorithm for 3D voxel dose calculation, that is based on radionuclide dose point kernels, has been implemented
- Agreement with Monte Carlo is good in relatively homogeneous geometries, worse when inhomogeneities are present.
- This is due to known shortcomings of the DPKs:
  - The DPKs have been calculated in homogeneous media
  - Scatter (both radial and lateral) between different media is not accounted for
  - Spectral changes in different media are not accounted for
  - The DPKs have been calculated for a single type of “bone”, whereas GATE recognizes different types of bone, with different compositions, densities etc.