Measurements of dose point kernels using GATE Monte Carlo toolkit for personalized convolution dosimetry

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Outline

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Introduction

- Dose Point Kernels (DPKs):
  - are defined as energy deposition profiles from a point isotropic sources
  - method to compute the absorbed dose from the non-uniform activity or high gradient activity distributions
- Usefulness of kernels?
  - Convolution dosimetry: calculate the dose distributions using the convolution of 3D-dose kernel matrix with cumulated activity map furnished by quantitative SPECT/CT or PET/CT images.
  - Cumulated activity is represented by area under the time activity curve
- Ultimate goal: patient-specific dosimetry

Patient-specific dosimetry:

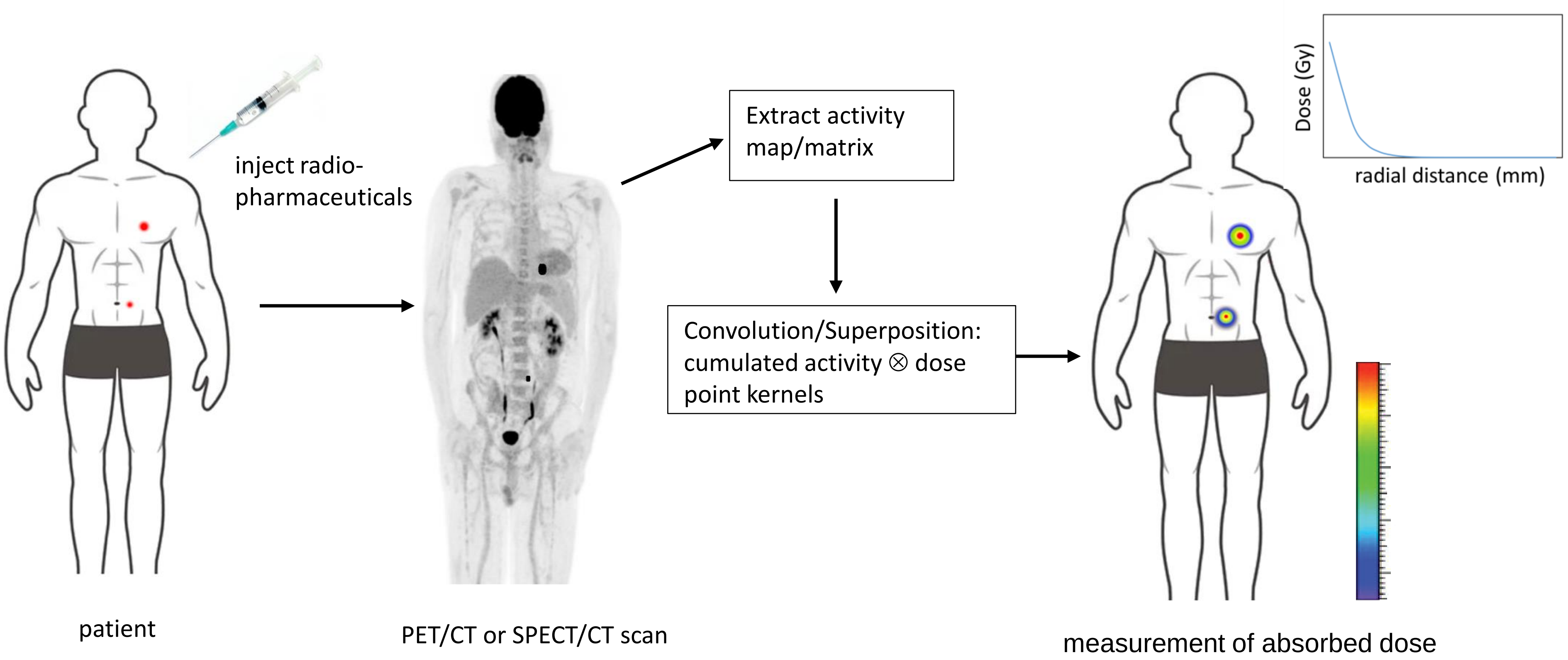


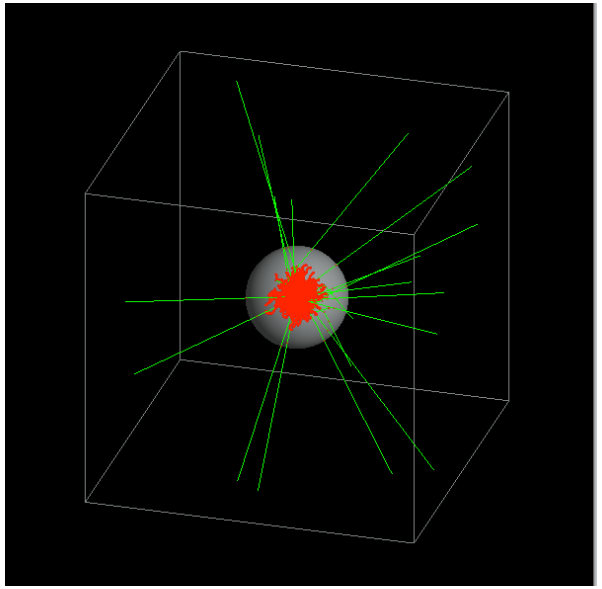
Figure: Schematic representation of the workflow for the patient-specific dosimetry using the Monte Carlo generated dose point kernels and the patient PET/CT scan.

- Because of its complex nature it has not been implemented in clinical settings yet!

Monte Carlo approaches to generate dose point kernels

- approx. solution of transport equations, no exact/non-trivial analytic solutions
- simulation of stochastic process (e^- s and γ-s transport)
- Geant4, GATE, EGS, FLUKA, PENELOPE, ETRAN, MCNP, SMOOPY etc.
- GATE: Geant4 Application for Tomographic Emission
- GATEv8.1and v7.2 were used
- *electronStepLimiter*, production threshold cuts

Simulation mediums



- Dose point kernels algorithms are based on an idea of homogeneous medium
- Human body is composed of different tissues: water, bone, blood, lung, adipose, red marrow …
  - ρ (g/cm^3)
  - elemental composition (Z_{eff})

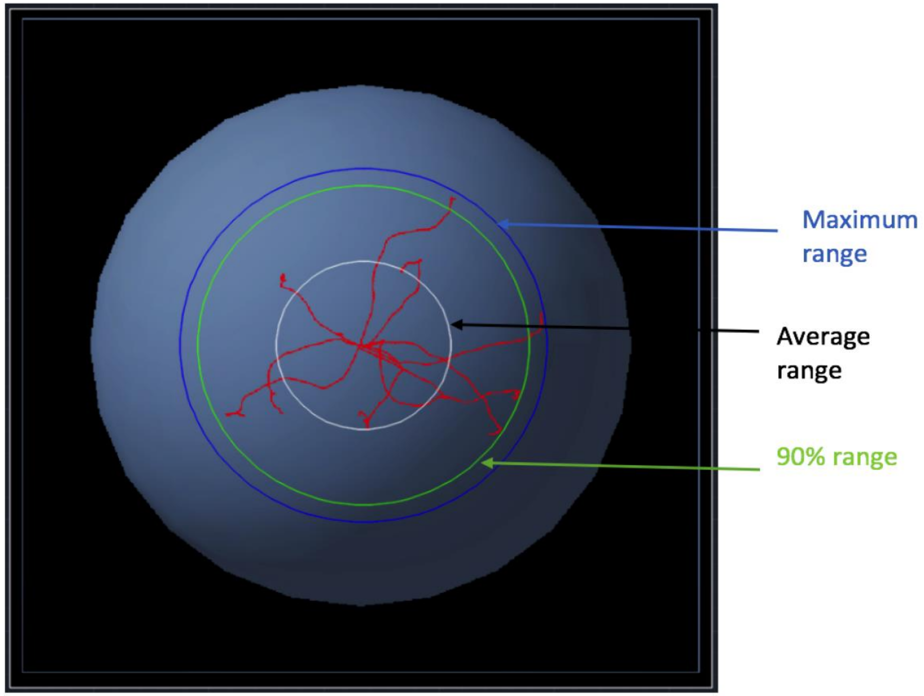
Materials	bone	blood	lung	water	red marrow	adipose
Z_{eff}	11.87	7.78	7.74	7.42	7.21	6.47
ρ (g/cm^3)	1.85	1.06	0.26	1.00	1.03	0.92

We want to have the DPKs for various tissues to find whether it depends on tissue type.

Methodologies

- Monoenergetic electron DPKs:

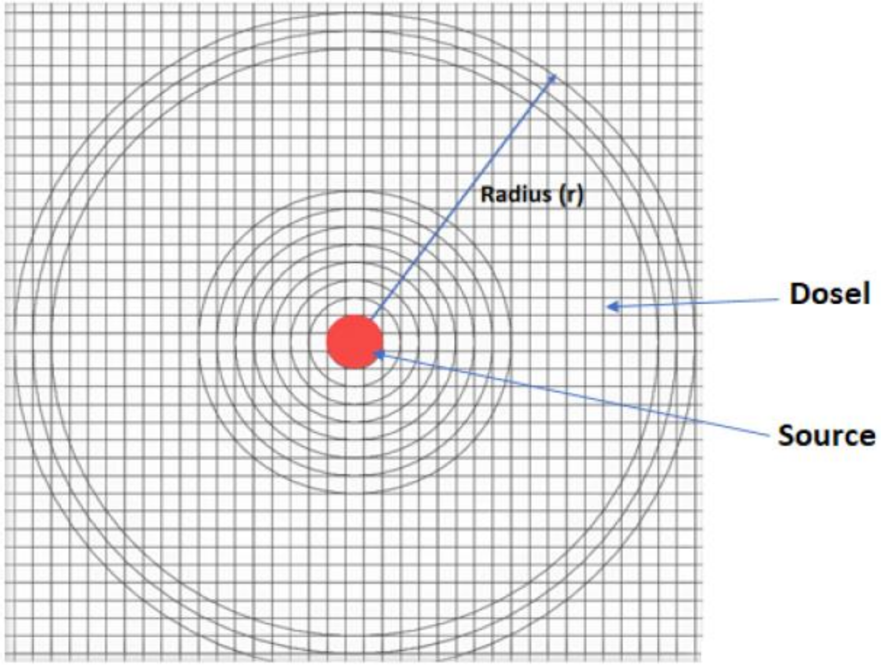
$$J(r/R_{CSDA}) = 4\pi r^2 D(r, E) \frac{R_{CSDA}}{E_0}$$



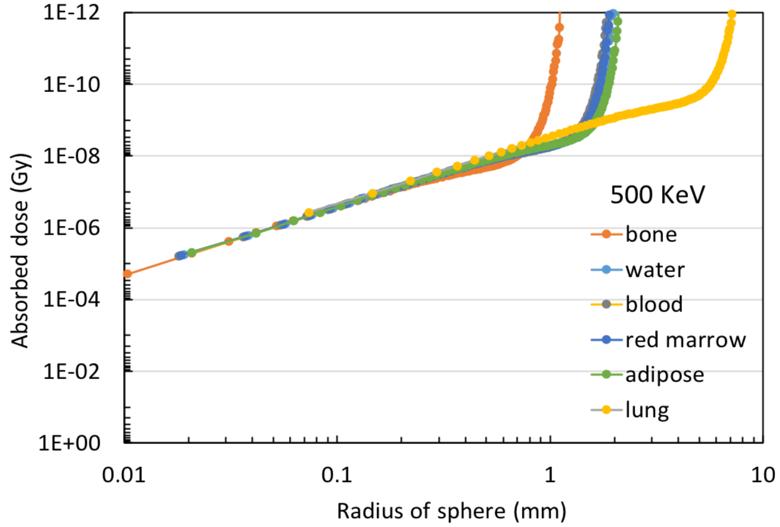
- Beta spectrum DPKs:

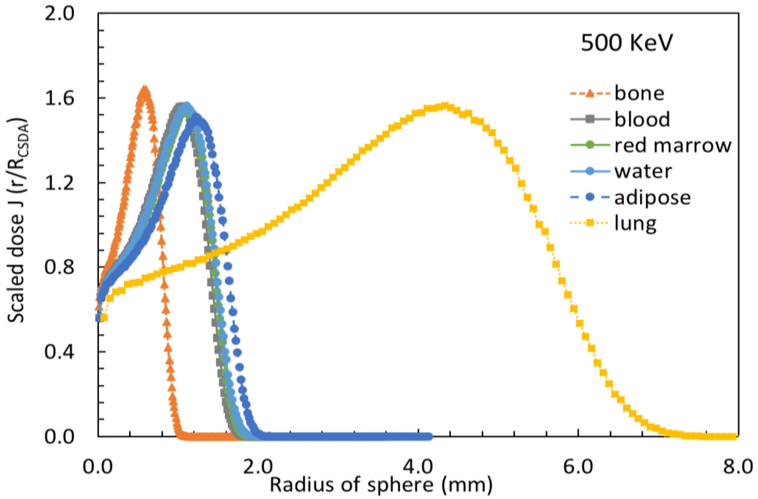
$$J(r/X_{90}) = 4\pi r^2 D(r, E) \frac{X_{90}}{E}$$

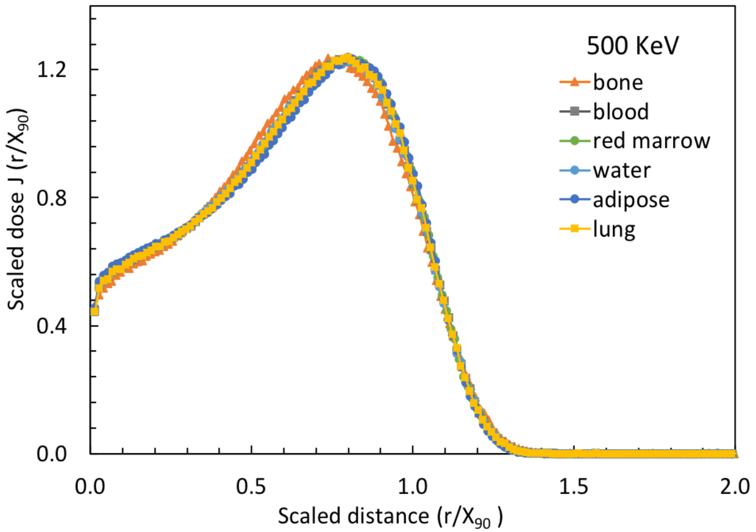
$$X_{90} = 4\pi\rho \int_0^{X_{90}} r^2 \Phi(r, E) dr = 0.90$$

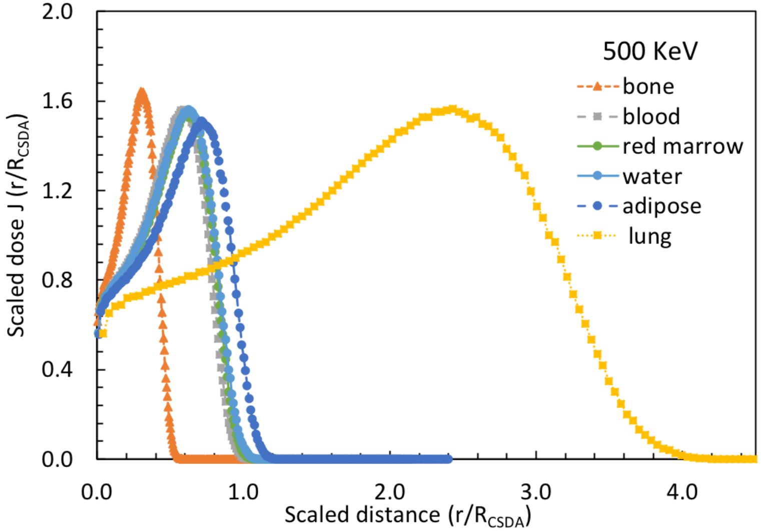


Results: (i) Monoenergetic electrons dose point kernels: 500 KeV

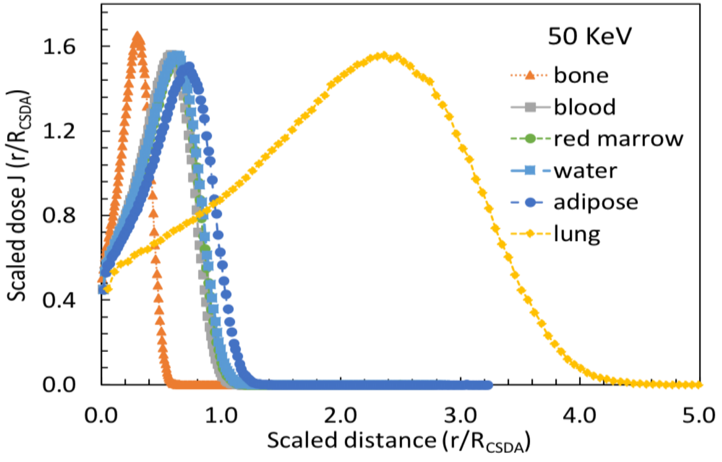


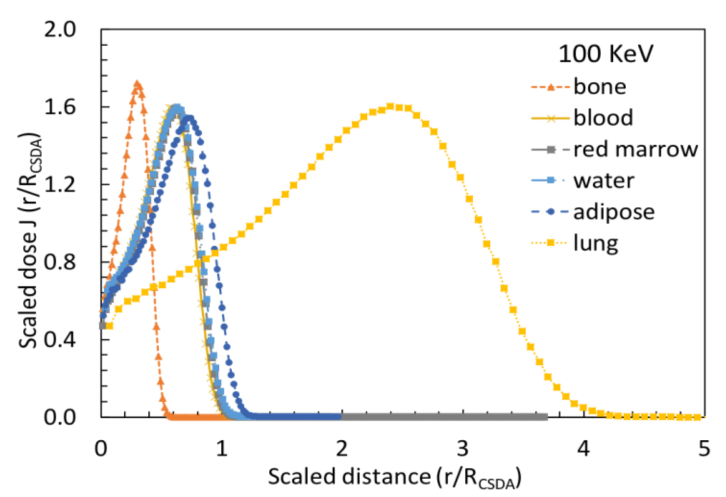


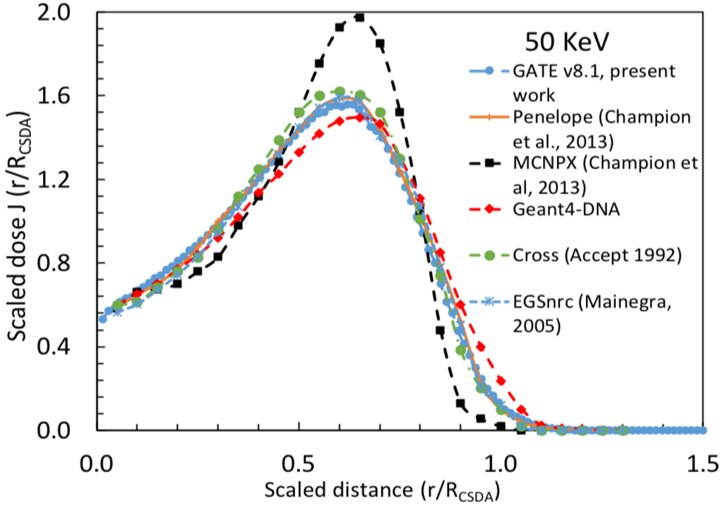


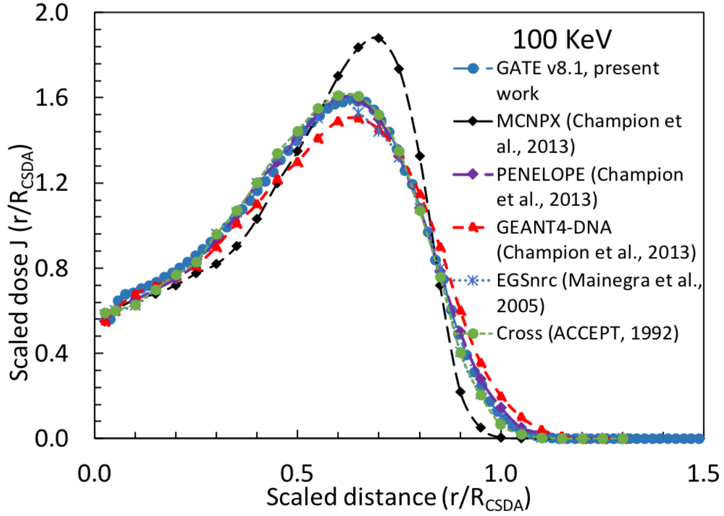


Comparison of monoenergetic electrons dose point kernels:

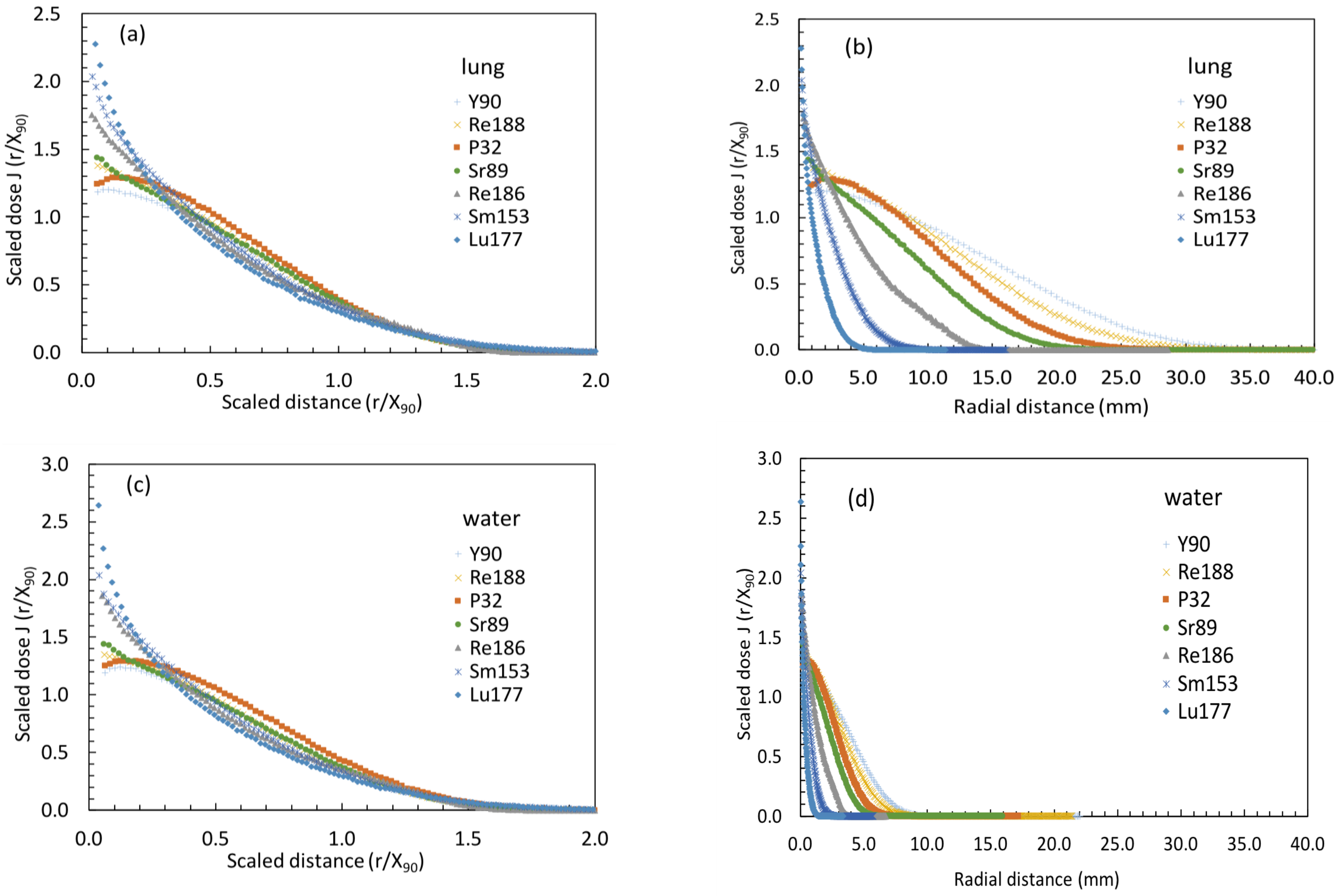




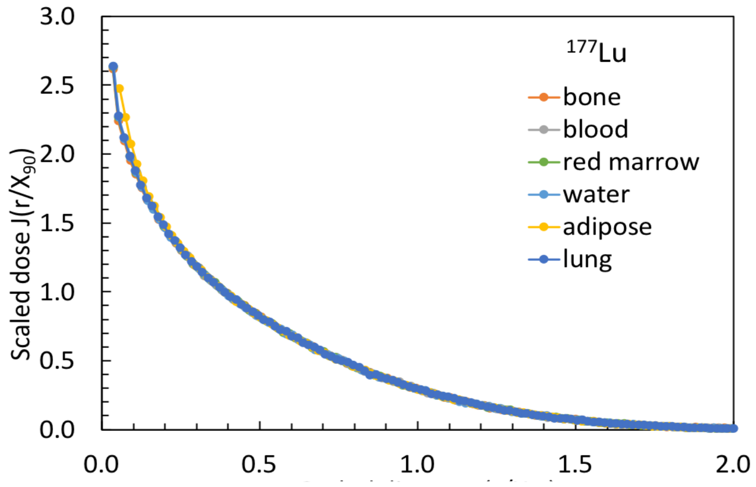


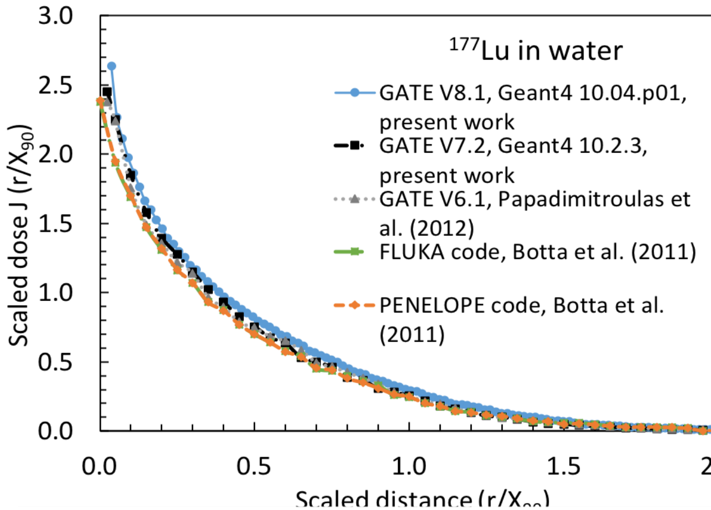


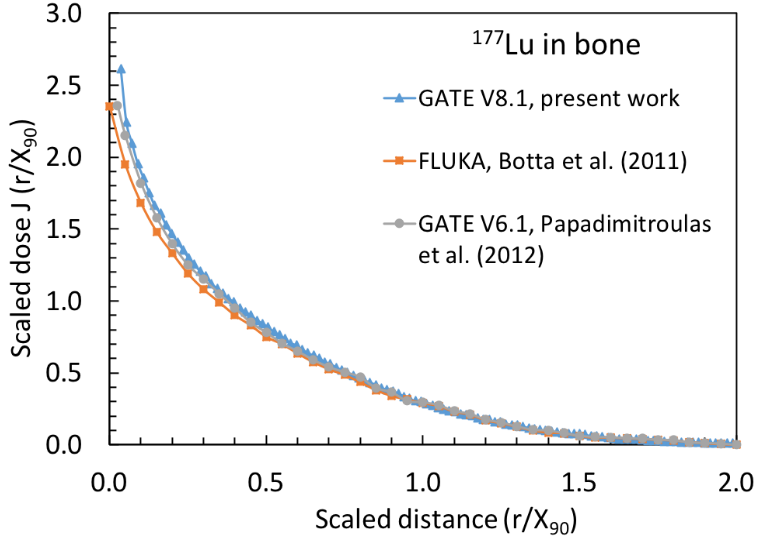
Results: (ii) beta radionuclides dose point kernels

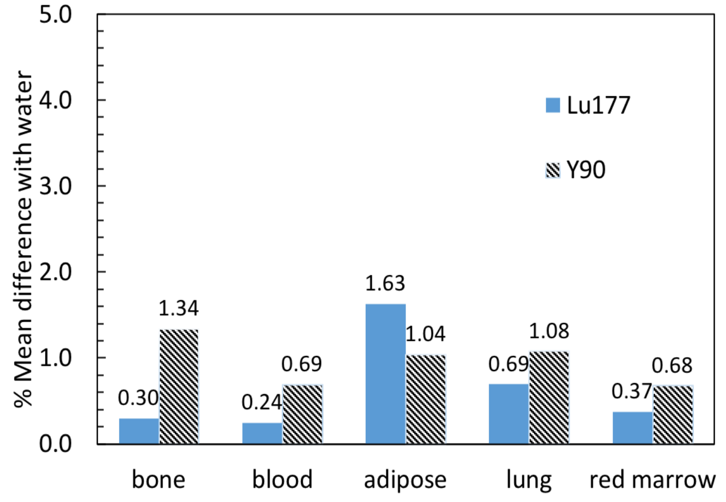


Impact of tissue type on dose point kernels?









Conclusion

- Dose point kernels of monoenergetic electrons (0.015-10) MeV and radionuclides beta emitters has been simulated
- Minimal discrepancies are observed between water and other tissues kernels when scaled with X_{90} for all simulated isotopes
- Impact of tissue type has been found to be minimal for purposes of dosimetry
- Use of single kernel generated in water may be sufficient for 3D dose calculations
- Future work is targeting experimental validation of dose point kernels

Experimental validation

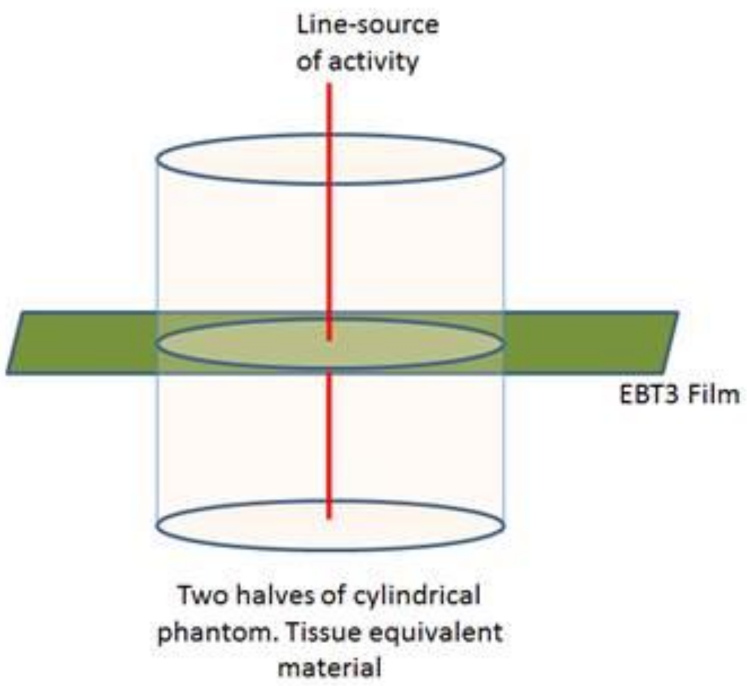


Fig 1: detector geometry with Gafchromic films

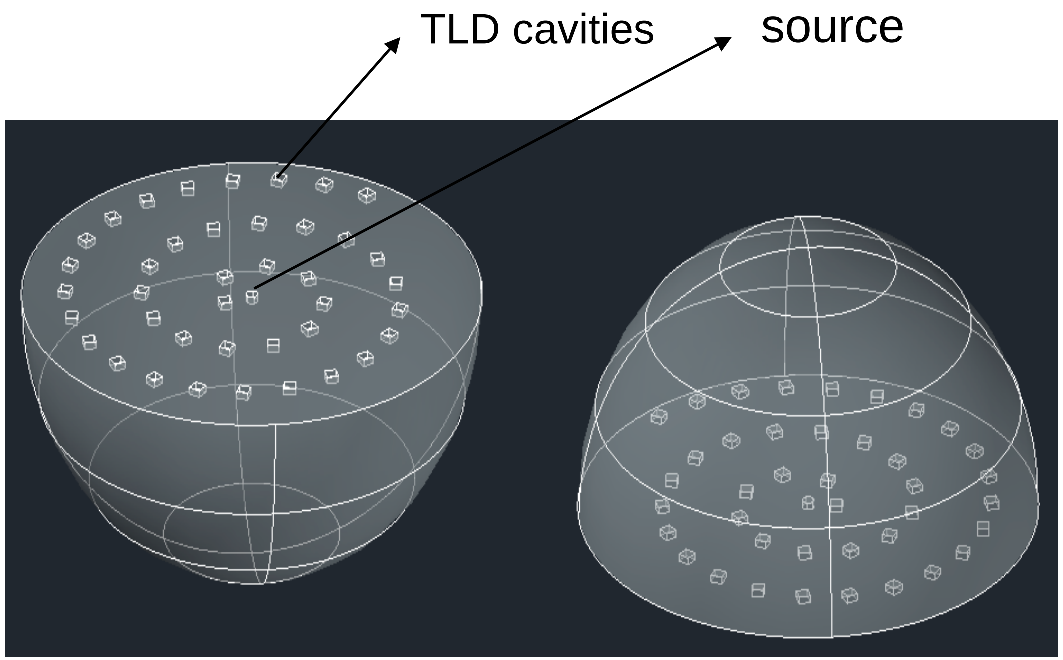


Fig 2: detector geometry equipped with TLDs