DETERMINISTIC 3D RADIATION TRANSPORT SIMULATION FOR DOSE DISTRIBUTION AND ORGAN DOSE EVALUATION IN DIAGNOSTIC CT

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OUTLINE

- Motivation of the work
- Simulation methodology for dose calculations
- PENTRAN and MCNP5 simulations for projected radiography
- MCNP5 modeling of a helical CT scan
- Initial PENTRAN simulation for helical CT
- Future work

Motivation of the Work

- Impressive growth in the number of diagnostic x-ray examinations

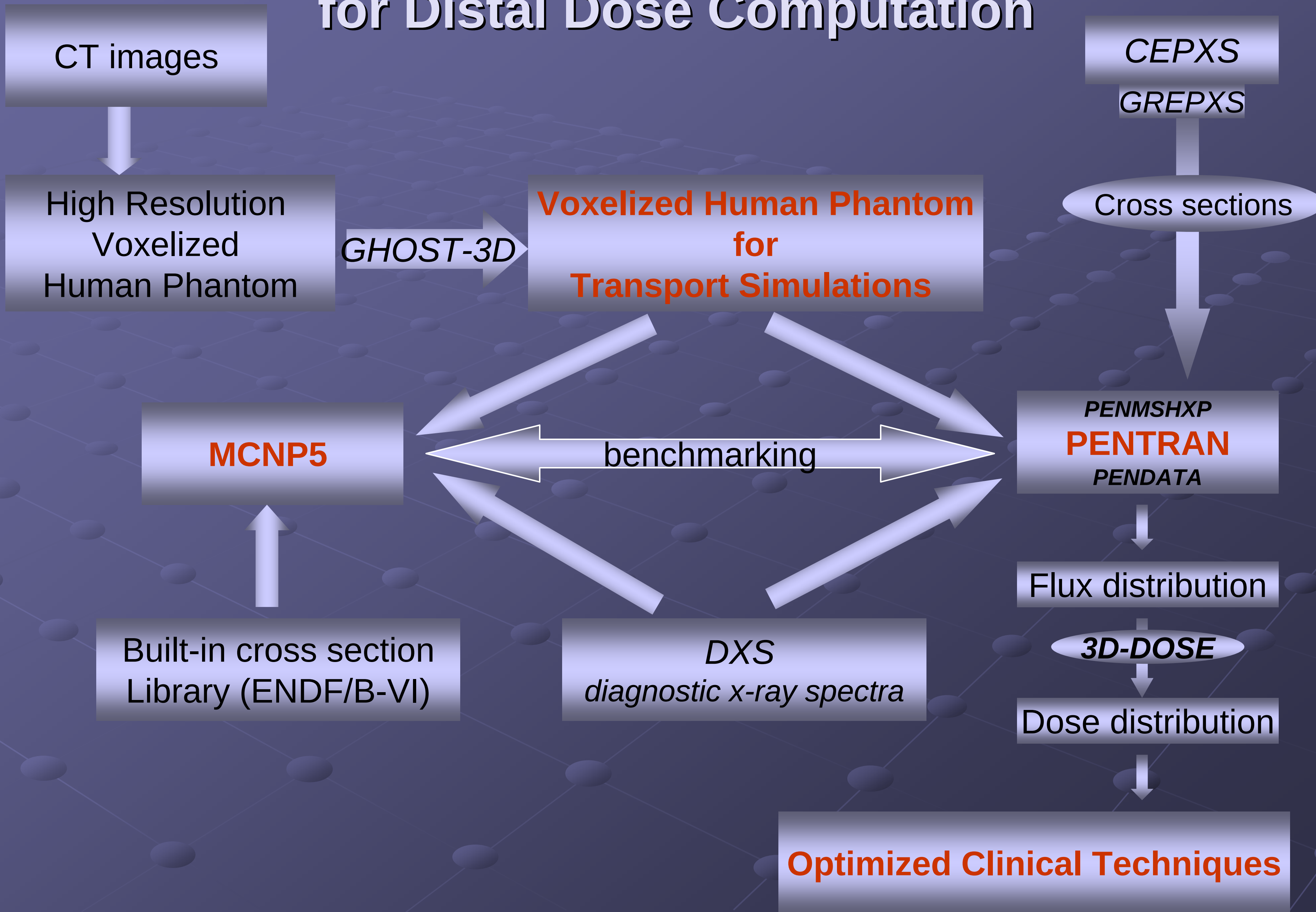
- Introduction of newer, very valuable imaging modalities and equipment

- Significant increase in the population's cumulative exposure to ionizing radiation

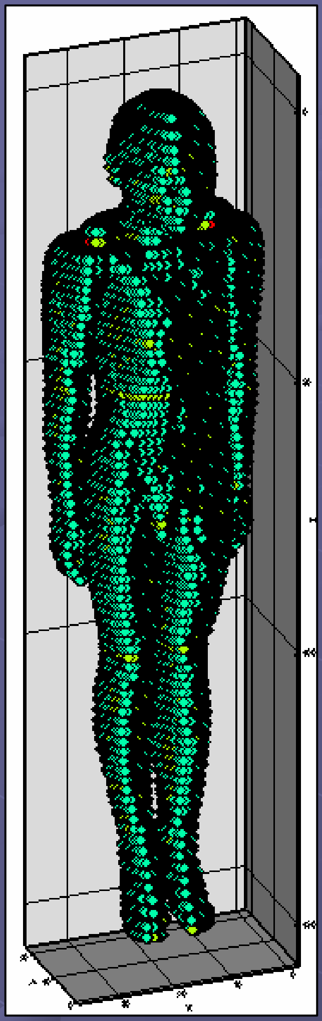
- Demand for fast, accurate, patient-specific dose evaluation methods for diagnostic imaging

Primary concern –> high-dose modalities – fluoroscopy
- CT
-> pediatric patients

Simulation Methodology for Distal Dose Computation

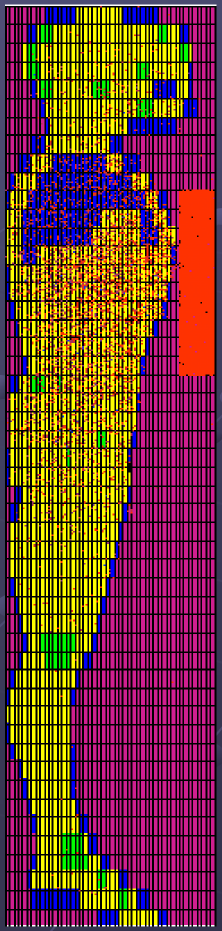


PENTRAN and MCNP5 Simulations for Projected Radiography



- Volumetric source (17.5×3.5×30 cc) over the left side of the phantom chest
- 8 energy groups (10-90 keV)
- 30 coarse meshes (PENTRAN) divided uniformly into 189,600 fine meshes
- Equivalent volumetric mesh-tally (F4) tallies

  Tallies were equivalent to the discretized Sn volumes



PENTRAN and MCNP5 Simulations for Projected Radiography

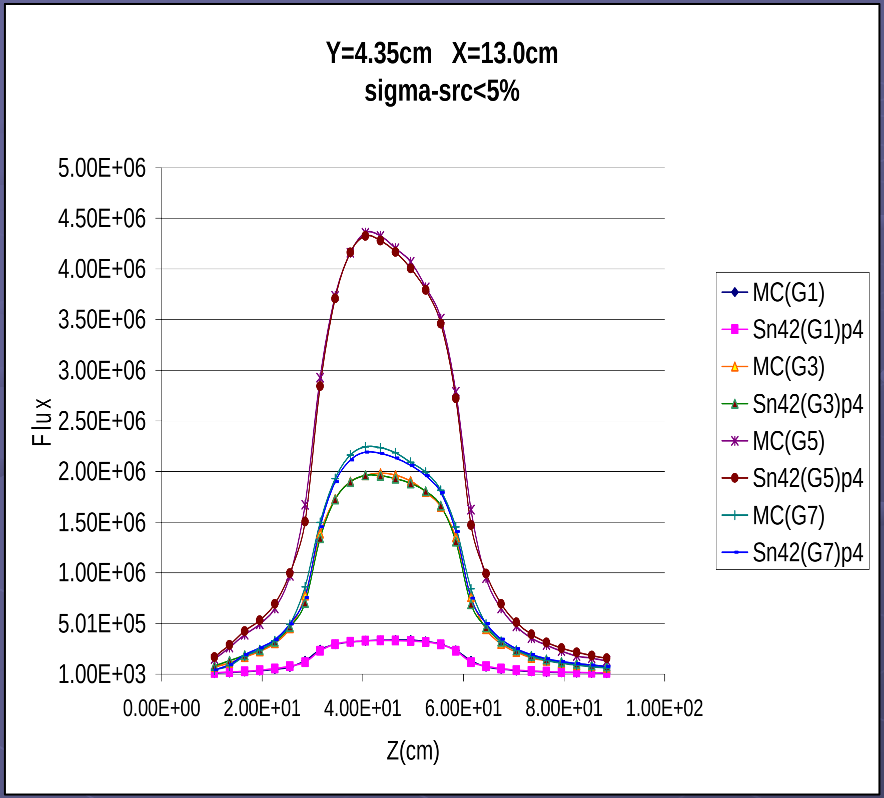


Fig 1

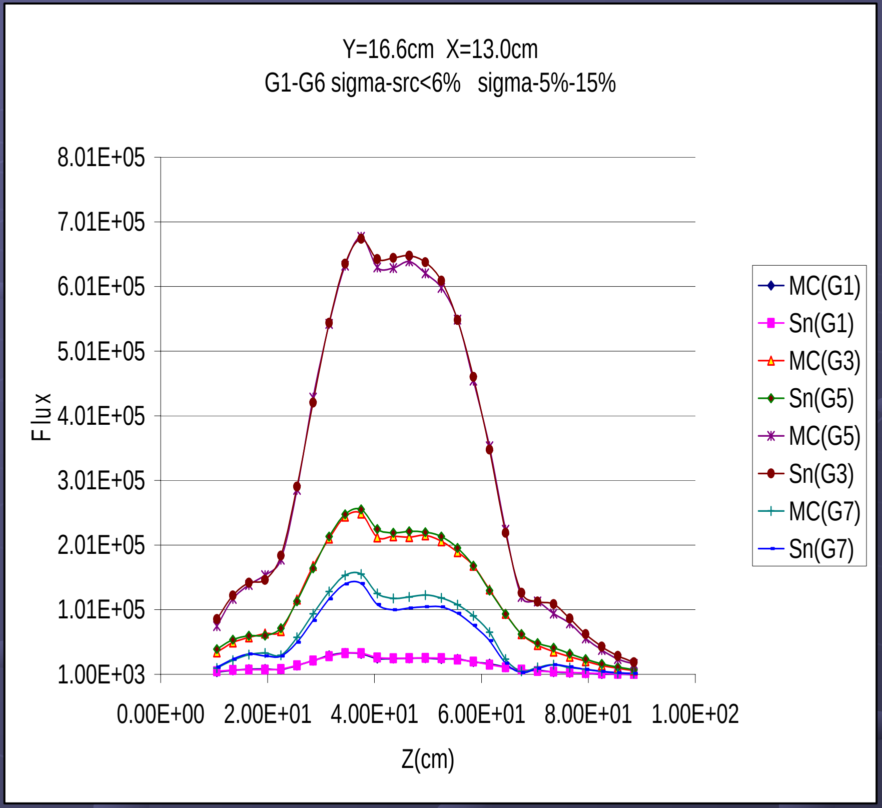
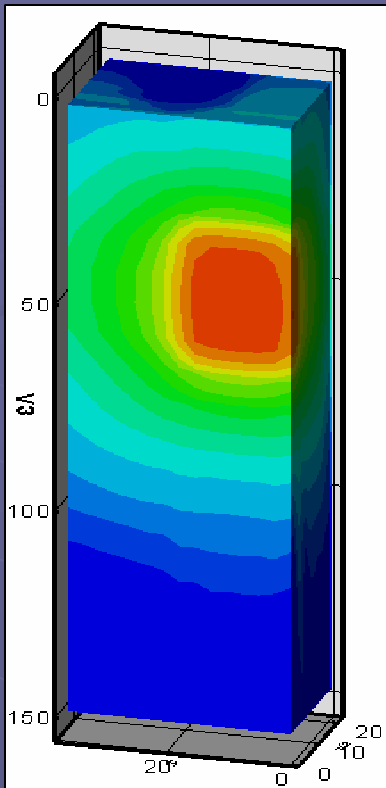


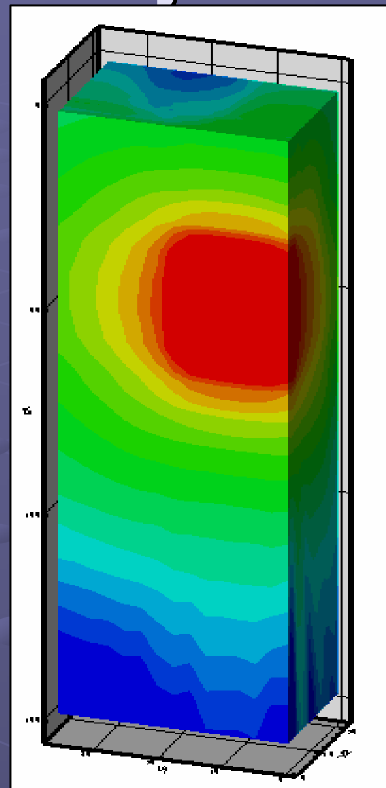
Fig 2

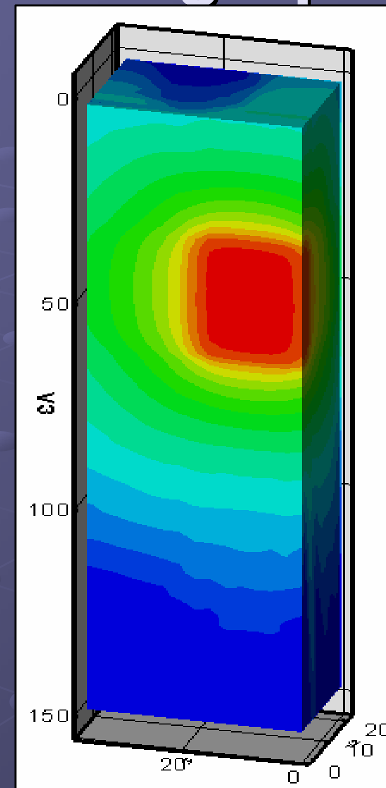
Deterministic vs Monte Carlo results along the Z axis at Y=4.35 cm, X= 13.0 cm (Fig.1) and at Y=16.6 cm, X= 13.0 cm (Fig.2)

PENTRAN and MCNP5 Simulations for Projected Radiography

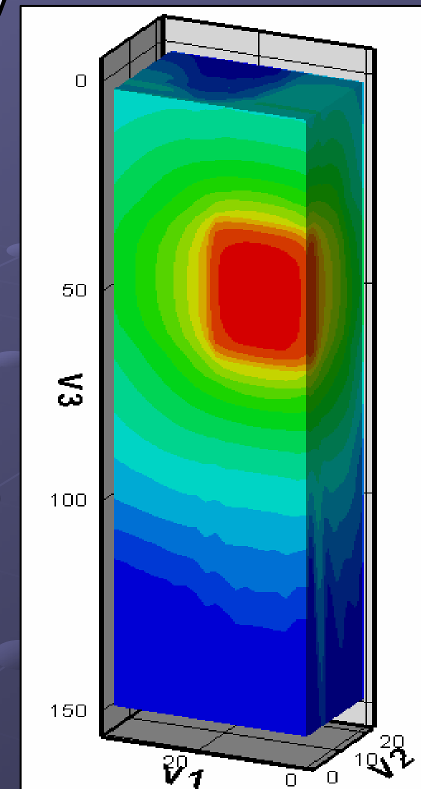


G1 (80-90) keV


G3 (50-60) keV



G5 (30-40) keV

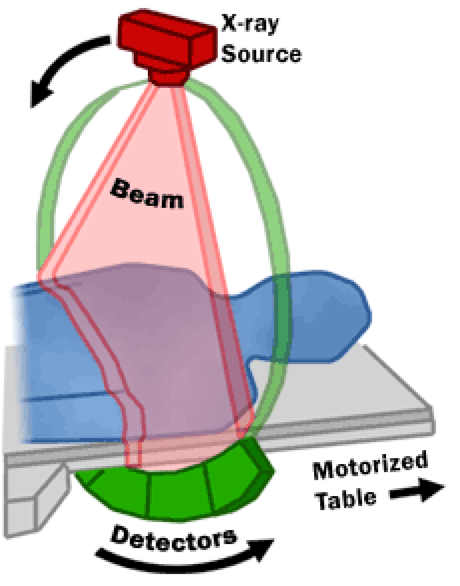


G8 (10-20) keV

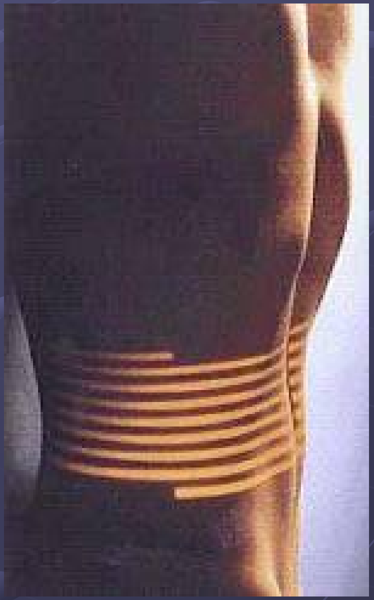
3-D, group 1, 3, 5, and 8 scalar flux distribution computed by PENTRAN with the cepxs cross section library; an S42 angular quadrature (1848 directions) with P3 scattering anisotropy.

MCNP5 Simulations for Helical CT

-x-ray source rotation
-patient table continuously moving



Position of the source on a helix



Edit the source subroutine file (source.f90) in MCNP5 code

MCNP5 Simulations for Helical CT

-position of the source particles randomly sampled over the helix

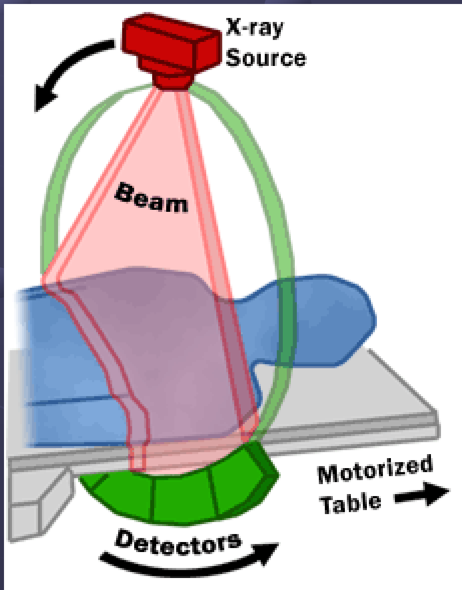
$$z = \eta L + z_C$$

$$x = r \sin \alpha + x_C$$
$$y = r \cos \alpha + y_C$$
$$z = l \alpha$$

$$\alpha = \frac{\eta L - z_C}{l}$$

$$\text{pitch} = \frac{l}{\text{beam width}}$$

L = length of the scan
l = table increment per 360 degrees rotation
r = source to isocentrum distance



MCNP5 Simulations for Helical CT

-direction of the particles randomly sampled within the fan beam

Constraints – polar angle (less than half of beam angle)
- beam width

$$P = \frac{d\Omega}{\Delta\Omega_m}$$

$$d\Omega = d\mu\, d\varphi$$

$$\varphi = 2\pi\eta_2$$

$$\Delta\Omega_m = \int_{\cos\theta_m}^{1} d\mu \int_0^{2\pi} d\varphi = 2\pi(1-\cos\theta_m)$$

Fundamental formulation of Monte Carlo

$$\frac{\int_{-1}^{\mu} d\mu \int_0^{2\pi} d\varphi}{2\pi(1-\cos\theta_m)} = \eta_3$$

$$\Rightarrow$$

$$\theta = \operatorname{acos}\left[\eta_3\left(1-\cos\theta_m\right)-1\right]$$

MCNP5 Simulations for Helical CT

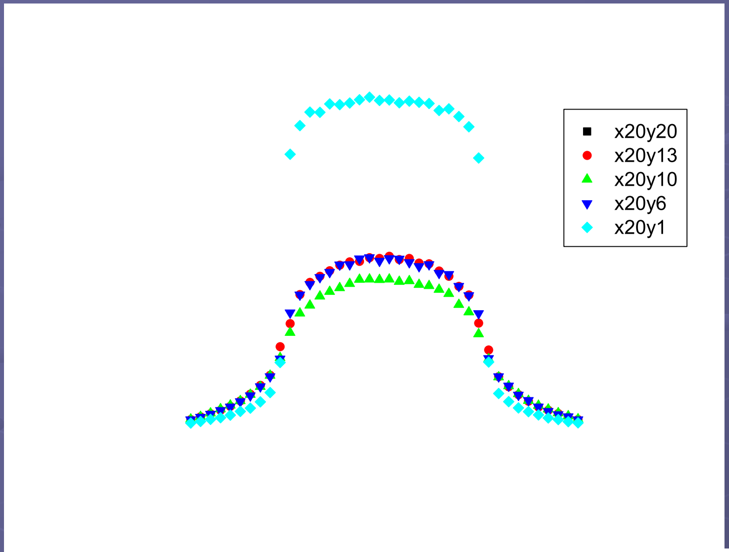
-energy sampled as a look-up table corresponding to the tube potential energy spectrum

-assign the code's required variables
- directional cosines
- source cell
- surface where the particle starts

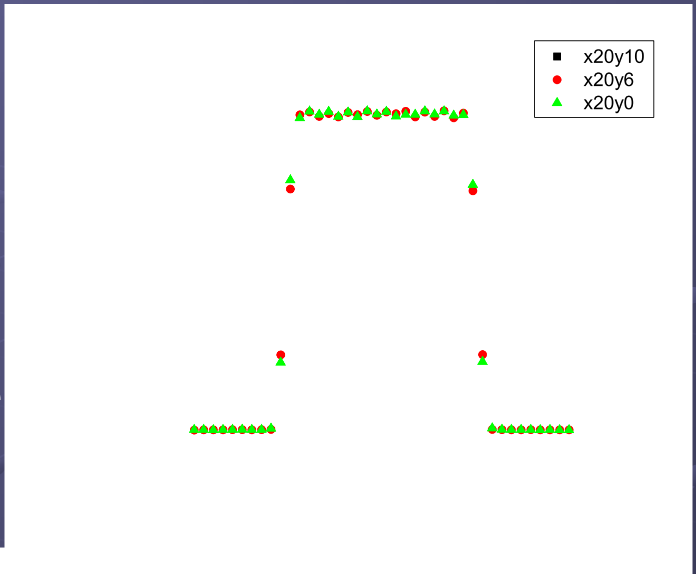
-RDUM card in the input deck – z position of the scan start
- scan length
- beam width
- pitch
- scan radius
- x, y coordinates of the isocenter
- fan beam angle
- source cell number

MCNP5 Simulations for Helical CT

Test model – box of air/water 40x20x40 cc centered in the scan field

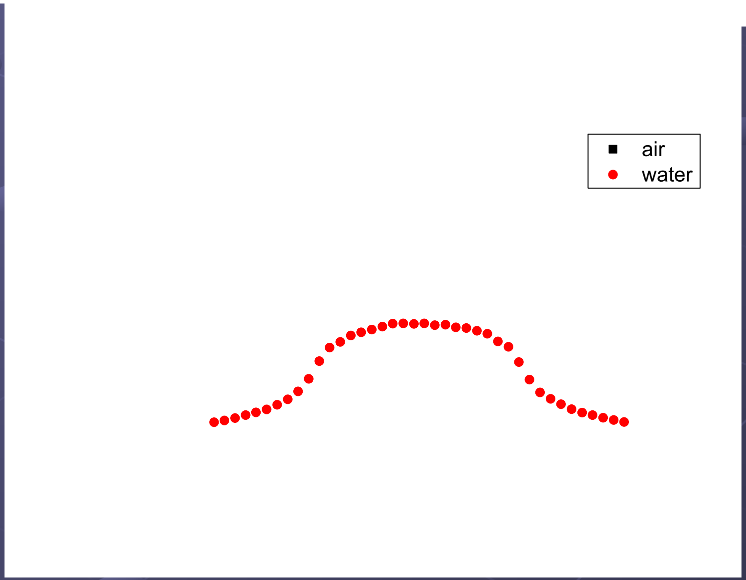


Mid (x,z) plane



water

100 kVp
20 cm scan length
60 cm SID

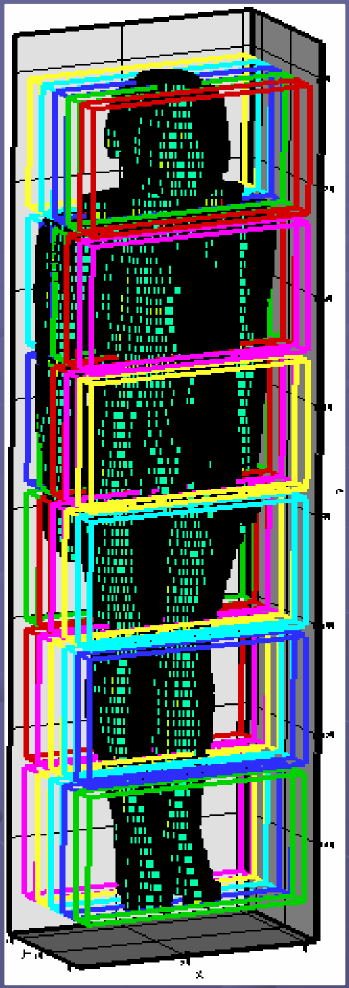


air

Fmesh tally all over the box

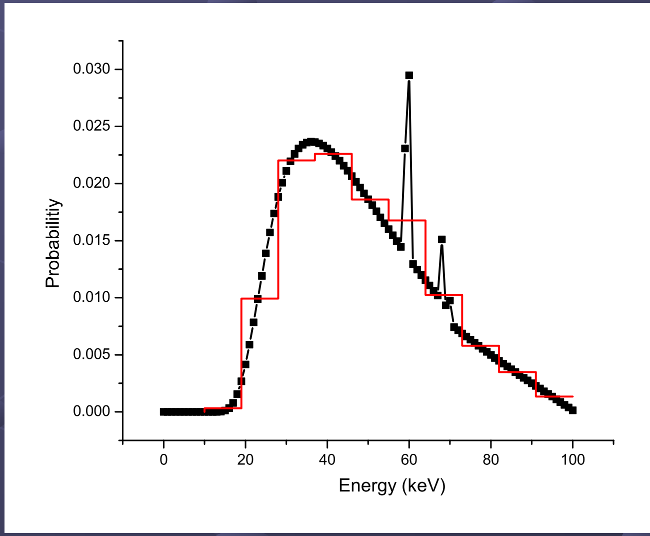
(20,10,20) cm

PENTRAN Simulations for Helical CT



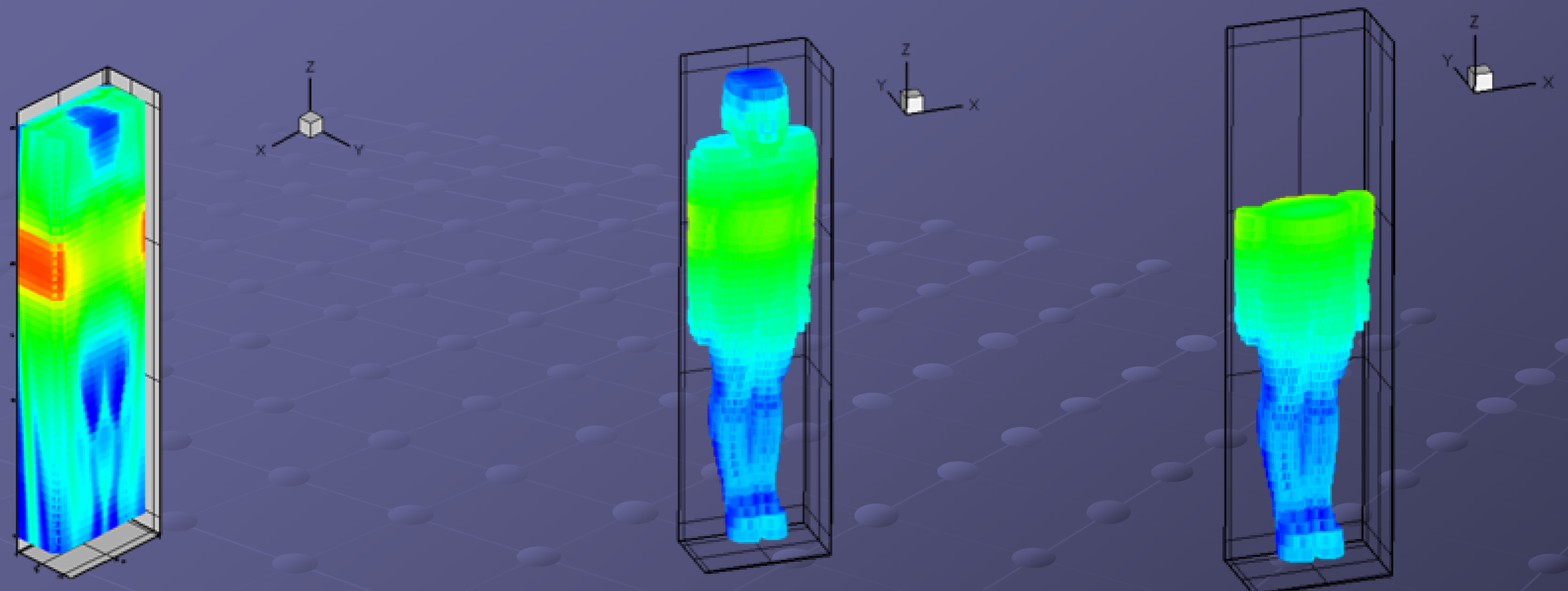
- Collapsed phantom to 79X48X50 meshes
- 10 energy groups
- S32 (1088 directions)

- MCNP5 simulation to obtain a projected source onto the phantom -> source spatial distribution in PENTRAN
  - Void inside the box corresponding to the phantom
  - Fmesh tally in 4 rectangles surrounding the box; energy tallies corresponding to the Sn group structure

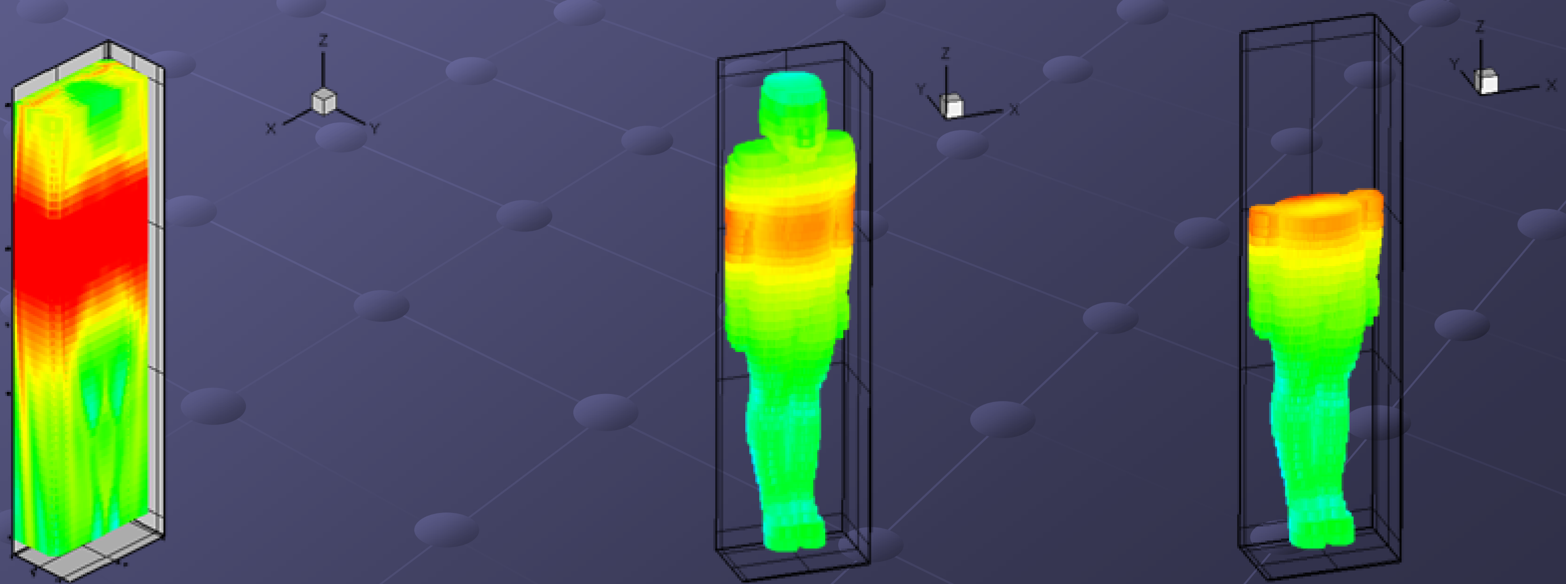


PENTRAN Simulations for Helical CT

Group 1



Group 5



Conclusions and Future Work

- Deterministic Sn calculations may be a convenient alternative to the Monte Carlo methods, especially for global dose distribution and doses to organs outside the radiation field

- CT applications pose big challenges to deterministic calculations due to an adequate source representation

- Need to validate the source representation (angular dependence of source distribution)

- Proper normalization of the source intensity based on clinical measurements