

Advances on a computational tool for patient-specific dosimetry in nuclear medicine

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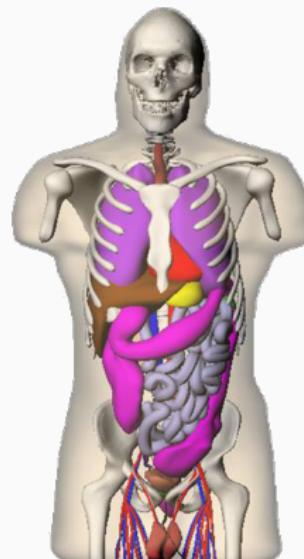
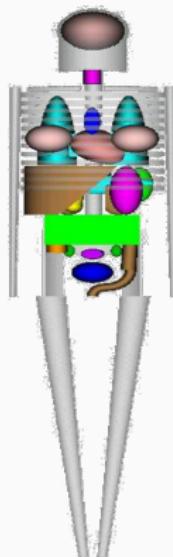
November 7, 2018



***Introduction: the need of a
patient-specific dosimetric calculation at
voxel level in nuclear medicine***

Dosimetry nowadays in clinics

- through virtual mathematical phantoms
- minor corrections on patient characteristics (mass, height, organ size, etc.)



From diagnostic to therapy

New times

- the increasing number of nuclear medicine techniques
- the doses involved in different techniques
- the growth of nuclear medicine use in therapy procedures

Demands

**more accurate dosimetric assessment
both in tumor tissues and organs at risk**

Dosimetric Nuclear Medicine methods

- **S-values**
 - Def: Mean dose per unit cumulated activity
 - Res: Organ, sub-organ, voxel
- **DPK convolution**
 - Def: Radial distribution for mean dose around a point source
 - Res: Voxel
- **Monte Carlo**
 - Def: Monte Carlo radiation transport and delivered energy simulation
 - Res: Organ, sub-organ, voxel

Pros & Cons

- **S-values**
 - Pros: standardized and fast calculation
 - Cons: limited to specified regions, uncertainties can reach 30-40%
- **DPK convolution**
 - Pros: fast calculation
 - Cons: already not established for non-homogeneous media ← working on it!
- **Monte Carlo**
 - Pros: the most accurate calculation and the only one accepted for non-homogeneous media and complex geometries
 - Cons: high computational cost ← working on hacking it!

Patient-specific dosimetry?

- **S-values:** only minor corrections can be made
- “DPK” possible, limited for some regions (where there are no large density changes) and in progress solved when considering DPK performance in non-homogeneous media
- “Monte Carlo,” the most accurate and precise

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- "Monte Carlo": the most accurate and precise

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Organ, sub-organ and voxel level?

In order to asses 3D patient-specific dosimetry it is desired to perform:

- sub-organ and/or voxelized resolution
- consider the actual mass/tissue distribution ← CT, RMN
- take into account patient-specific real activty distribution ← SPECT, PET

The proposal

Design and development of a computational tool devoted to:

- compute dose delivery at voxel (or sub-organ) level with millimetric resolution
- consider the actual tissue patient distribution
- use the actual activity distribution and its time evolution
- integrate parameters for planar dosimetry nowadays in use

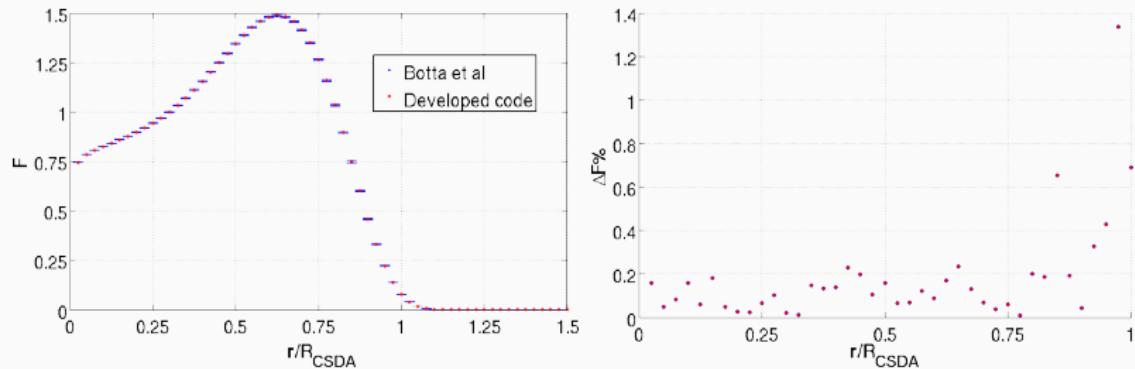
**DOSIS: *an integrated system for
patient-specific dosimetry assessment at
voxel level***

DPK assessment

- performed by Monte Carlo simulations
 - photons, positrons and electrons ← PENELOPE
 - alpha and others ← FLUKA **in progress...**
- a model for estimating electrons DPK for different tissues have been developed¹
- voxelized kernels generated from radial distributions obtained by Monte Carlo simulations
- capable of loading information from dual imaging techniques like PET-CT, SPECT-CT or SPECT-RMN

¹P. Pérez *et al.* Int. Journ. of Nucl. Med. Res. 3:45-55, 2016.

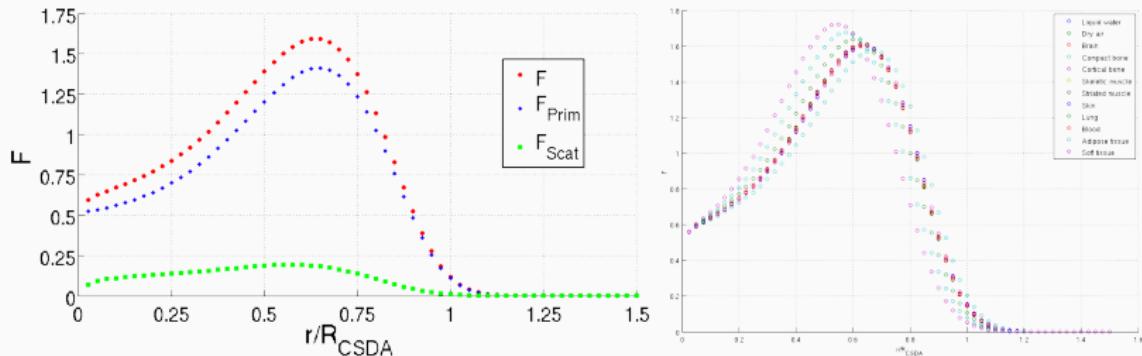
DPK MC results: *validating*



sDPK (F) calculated compared with published data² (left) and uncertainties involved (right)

²Botta et al. Med. Phys. 38(7):3944-3954.

DPK MC results: tissues



sDPK (F) calculated discriminating primary and scattering contributions (left) and for different tissues (right)

Application to internal dosimetry

Voxel level dosimetry with DPK convolution

- Activity distribution can be considered as an array of point sources
- Deposited dose distribution can be calculated by means of integration of all of these sources
- This can be made by the convolution technique

$$D(\vec{r}) = \mathbb{K}_D(\vec{r}) * \mathbb{A}_{cum}(\vec{r}) = \int_{-\infty}^{\infty} \mathbb{K}_D(\vec{r}') \mathbb{A}_{cum}(\vec{r} - \vec{r}') d\vec{r}' \quad (1)$$

Background theory

Voxelizing

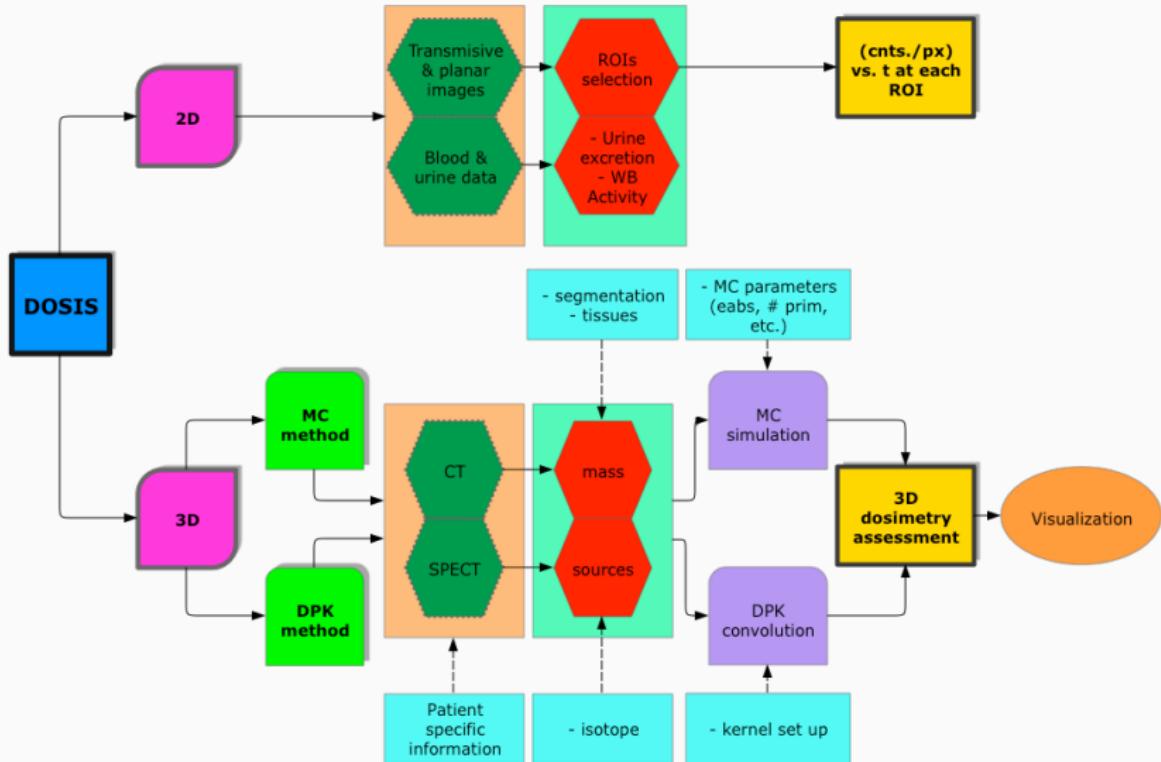
- Defining $\mathcal{K}_D(i, j, k)$ and $\mathcal{A}_{cum}(i, j, k)$ as $\mathbb{K}_D(\vec{r})$ and $\mathbb{A}_{cum}(\vec{r})$ in 3D voxelized geometry
- Using Fourier Transform properties and convolution technique
- Dose $D(\vec{r})$ results

$$D(\vec{r}) = \mathbb{F}^{-1}\{\mathbb{F}\{\mathcal{K}_D(i, j, k)\} \cdot \mathbb{F}\{\mathcal{A}_{cum}(i, j, k)\}\} \quad (2)$$

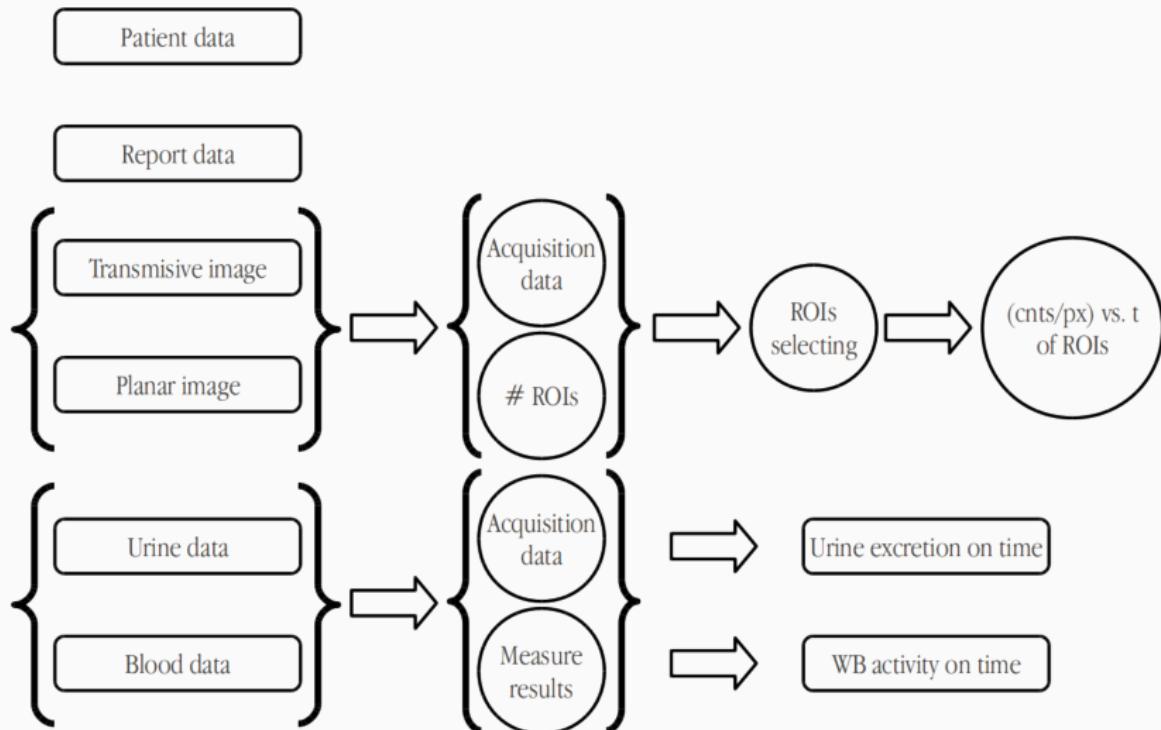
And both Matlab and Python (among others) provide libraries to a fast solve of this equation through Fast Fourier Transform algorithm.

Graphical User Interface

Chartflow



Planar dosimetry chartflow



Planar dosimetry GUI: main

Planar dosimetry data acquisition

Patient: Coments:

Height [cm]: Mass [kg]: Radionuclide:

Sumministration date / / (dd/mm/yyyy) : (hh/mm)

Sumministrated activity [mCi]: T_1_2 [days]:

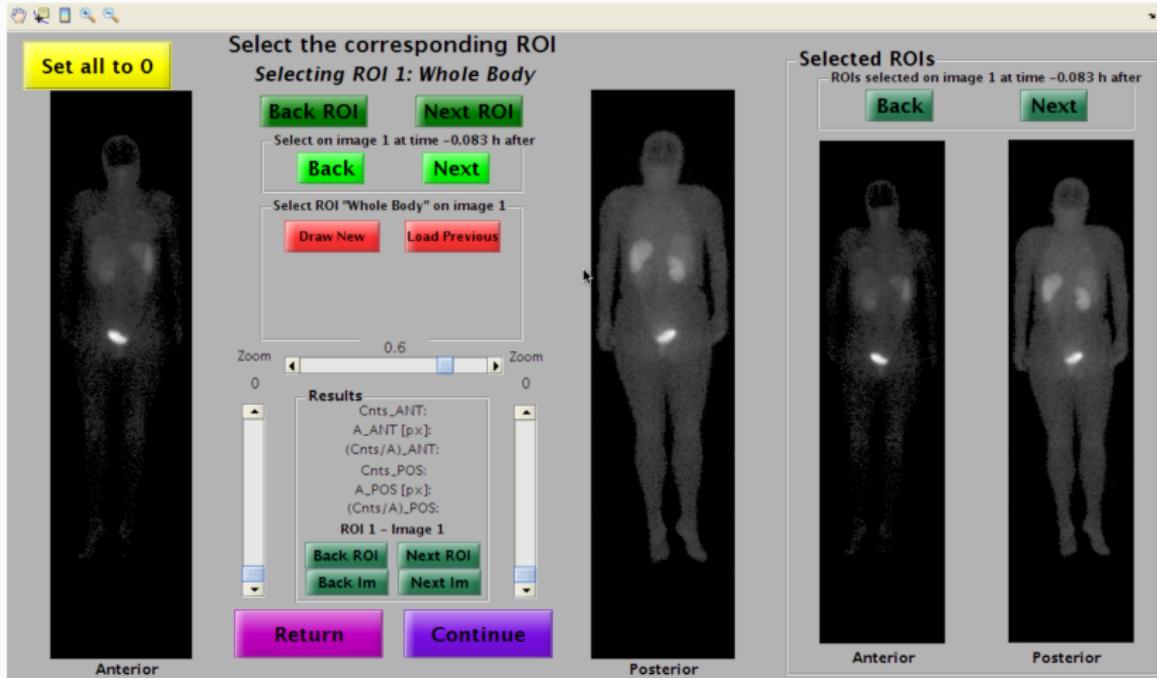
Transmisive image information

Planar image information

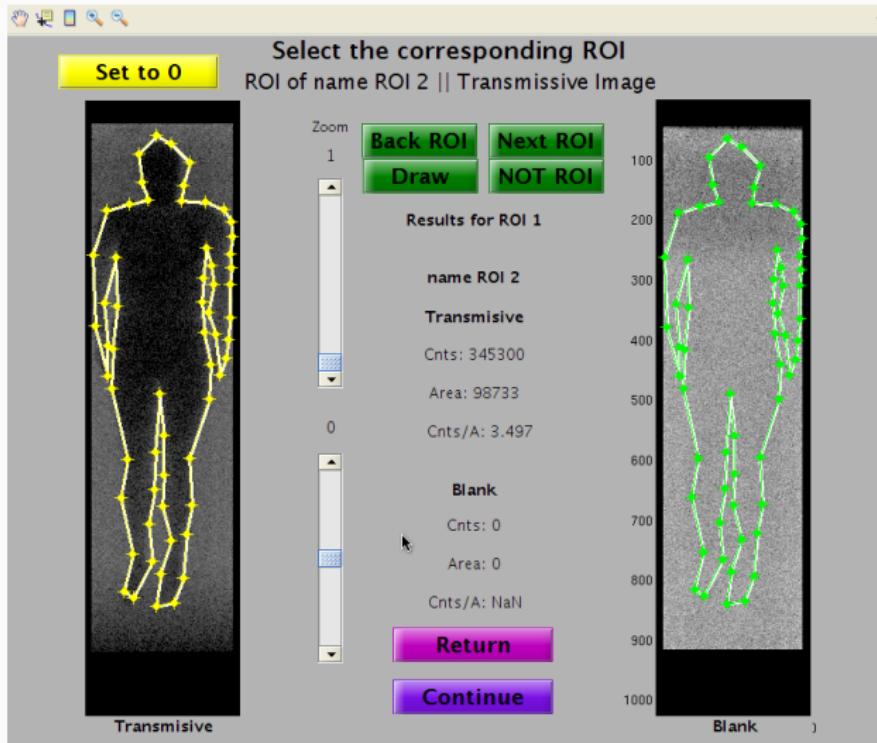
Urine information

Blood information

Planar dosimetry GUI: *rois*



Planar dosimetry GUI: *whole body*



Planar dosimetry GUI: curves

**Planar dosimetry data acquisition
Urine information**

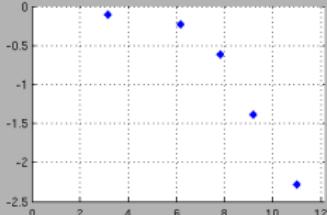
Patient: 'Patient name' Coments:

Facility: 'i.e. Gamma counter' Coments: Sumministration date

Tara barattolo [g]: 84 Measured samples: 5

Efficiency [mCi/cpm]: 0.00001 A
(G-counter) -0.0044 B

	Sample #	Extractios date	Extracted volume [ml]	campione cc	G-C Channel 1	G-C Channel 2	G-C measure date
1	1	2012-01-01 12:45:07	80	1	981231	981231	2012-01-01 12:45:07
2	2	2012-01-01 15:45:07	79	1	981239	980312	2012-01-01 12:45:07
3	3	2012-01-01 17:25:07	67	1	891237	891237	2012-01-01 12:45:07
4	4	2012-01-01 18:45:07	50	1	891823	891236	2012-01-01 12:45:07
5	5	2012-01-01 20:35:07	40	1	781233	796234	2012-01-01 12:45:07

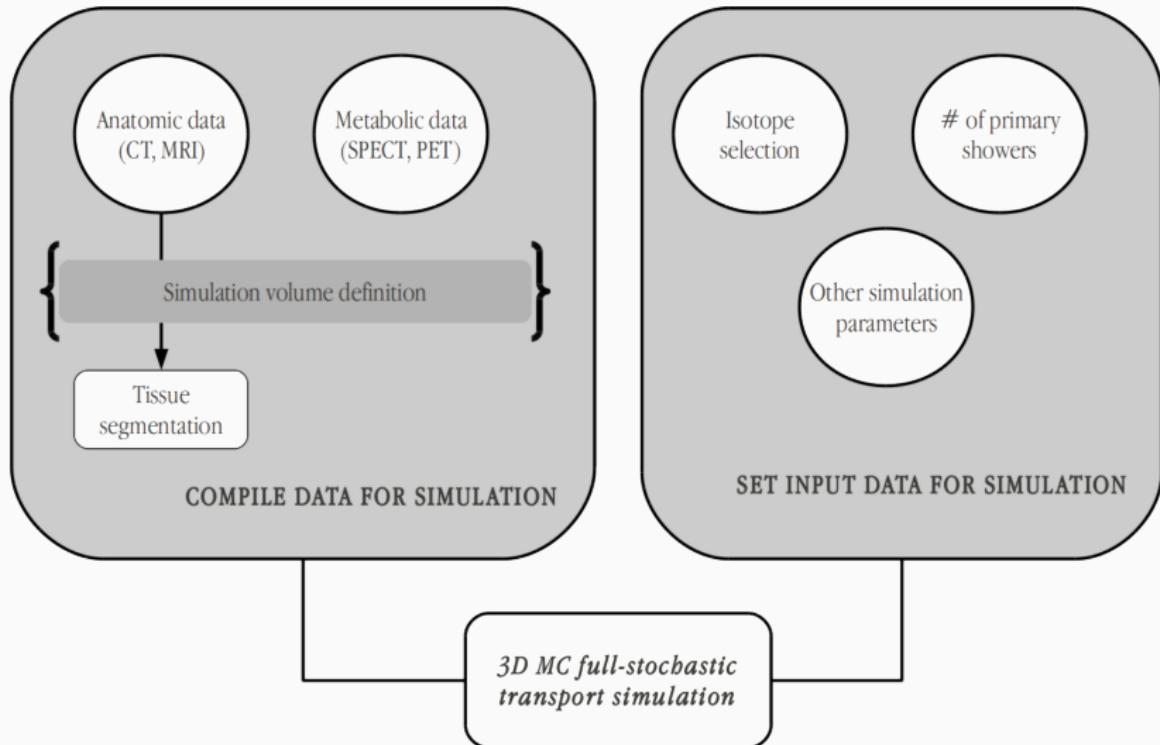


Update graph

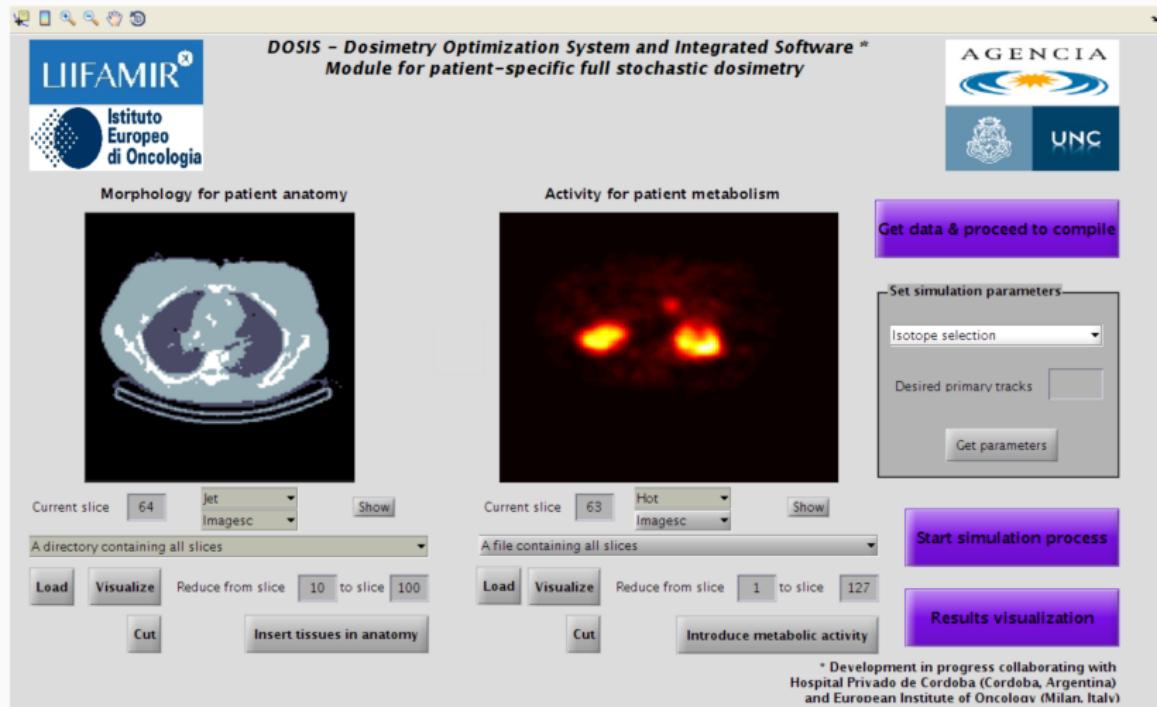
Return

Continue

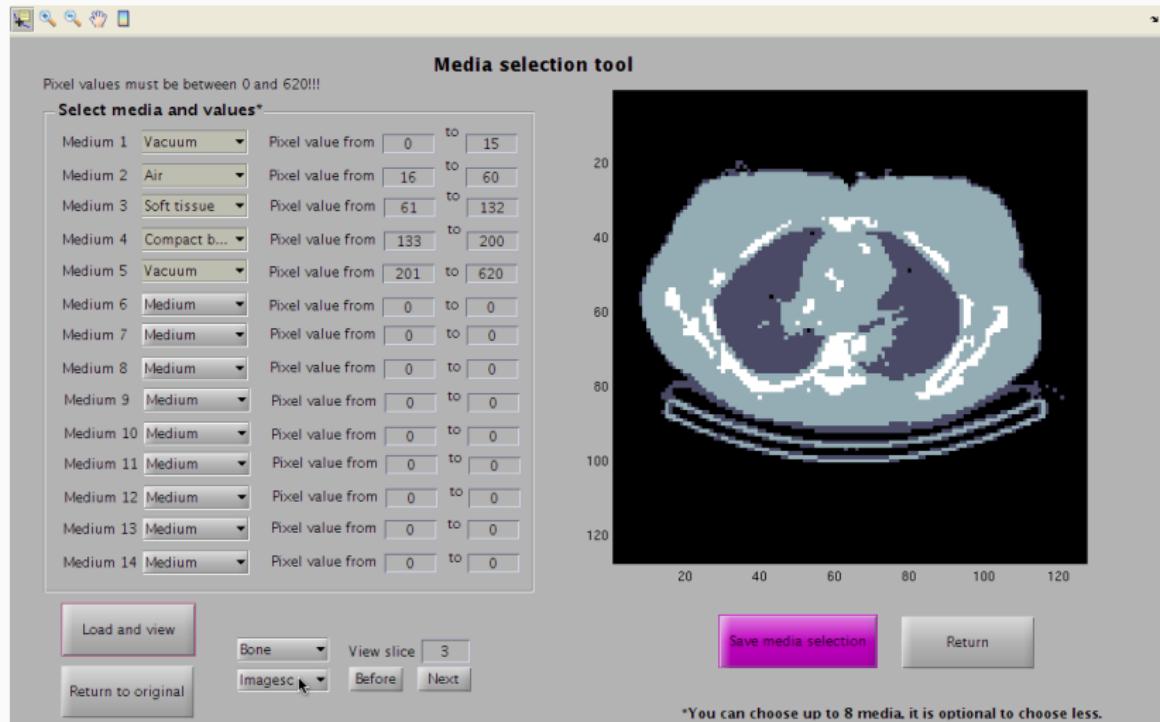
3D dosimetry chartflow



3D dosimetry: GUI



3D dosimetry: *segmentation*



3D dosimetry: visualization



DOSIS – Dosimetry Optimization system and Integrated Software
Module for multidimensional graphic visualization



Visualize selected options

Step 1

- Dose per particle
- Tumour Control Probability

Step 2: Mixed images

- Anatomy+Activity --> Slice
- Anatomy+Dose --> Slice
- Anatomy+TCP --> Slice

Step 3: 1D Profiles

- Visualize 1D Profiles
- Absolute values
- Normalized values (100%)

Choose axis for profile

- Axis X
For Y = and Z =
- Axis Y
For X = and Z =
- Axis Z
For X = and Y =

Step 4: 2D Cuts

- Visualize 2D Cuts
- Absolute values
- Normalized values (100%)

Choose plane to view

- Plane XY
View on Z =
- Plane XZ
View on Y =
- Plane YZ
View on X =

Step 5: SubVolumes

- Visualize Subvolumes
- Absolute values
- Normalized values (100%)

Choose Subvolume to view

- Subvolume 1
 - X from to
 - Y from to
 - Z from to
- Subvolume 2
 - X from to
 - Y from to
 - Z from to

Step 6: IsoVolumes

- Visualize Isovolumes
- Absolute values
- Normalized values (100%)

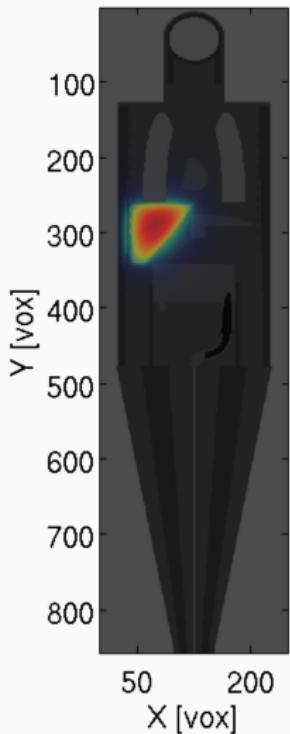
Choose Subvolume to view

- Isovolume 1 -> Parameter
 - X from to
 - Y from to
 - Z from to
- Isovolume 2 -> Parameter
 - X from to
 - Y from to
 - Z from to

Results

Monte Carlo simulations

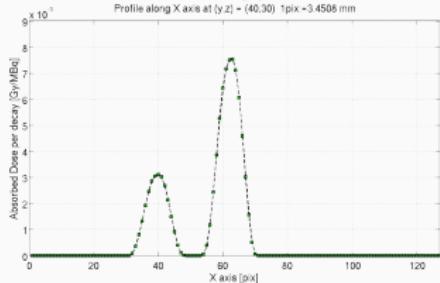
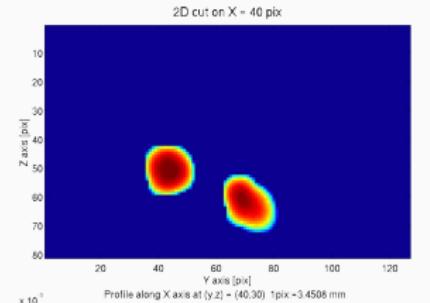
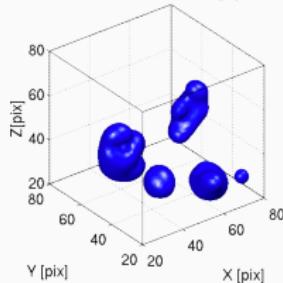
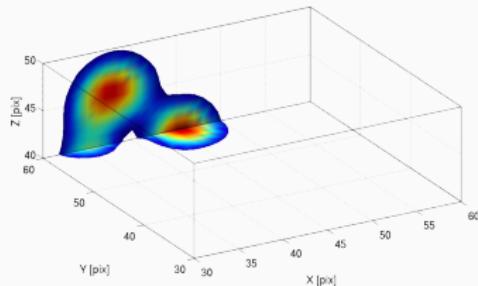
Comparison against bibliography on mathematical phantom



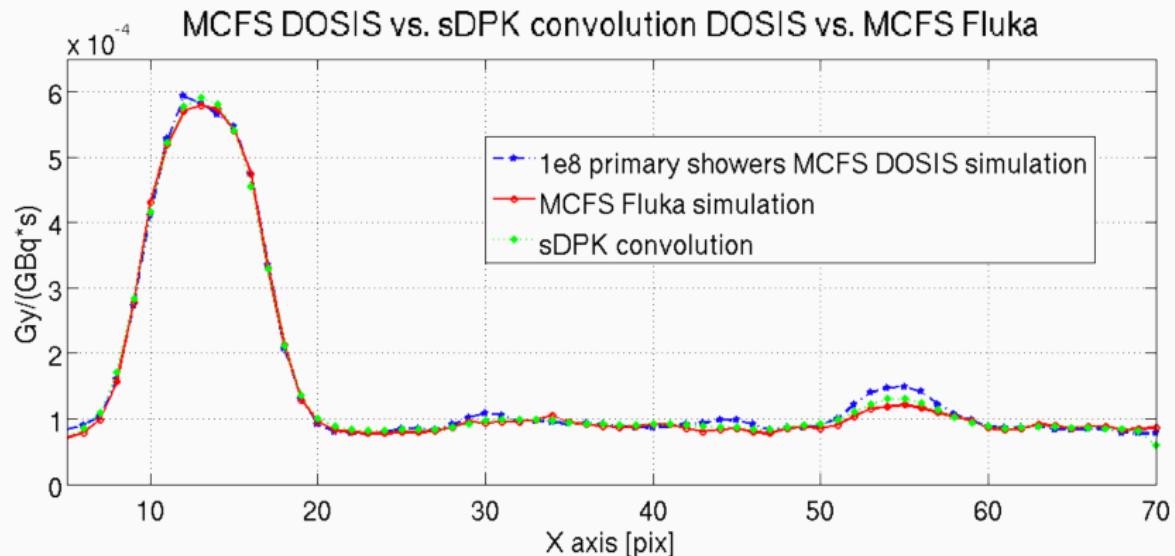
Organ	Reference ^a	DOSIS
Liver	1	1
Adrenals	0.13	0.47
Brain	0.00025	0.00083
Stomach	0.46	0.82
Kidneys	0.09	0.32
Lungs	0.064	0.082
Pancreas	0.12	0.41
Spleen	0.022	0.042

^aCherry, Sorenson & Phelps. *Physics in Nuclear Medicine*.

MC results on patient images



DOSIS results



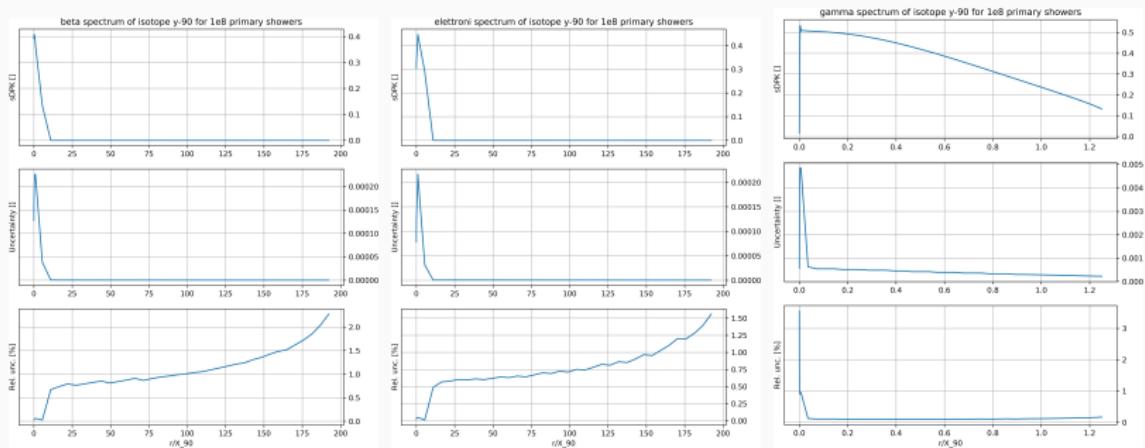
Final considerations

DOSIS today

- The developed tool is capable of performing planar dosimetry
- DOSIS is capable of assessing patient-specific 3D dosimetry at voxel level by means of MC simulations and DPK convolution
- The tool is now being implemented for different situations with colleagues from IEO (Milan) and University of Lund (Sweden)
 - analyzing the effects of DPK convolutions when changing voxel size and activity distribution in image resolution
 - both DPK³ and MC calculations are being performed by DOSIS
 - results are expected to be sent for publication by the end of the year

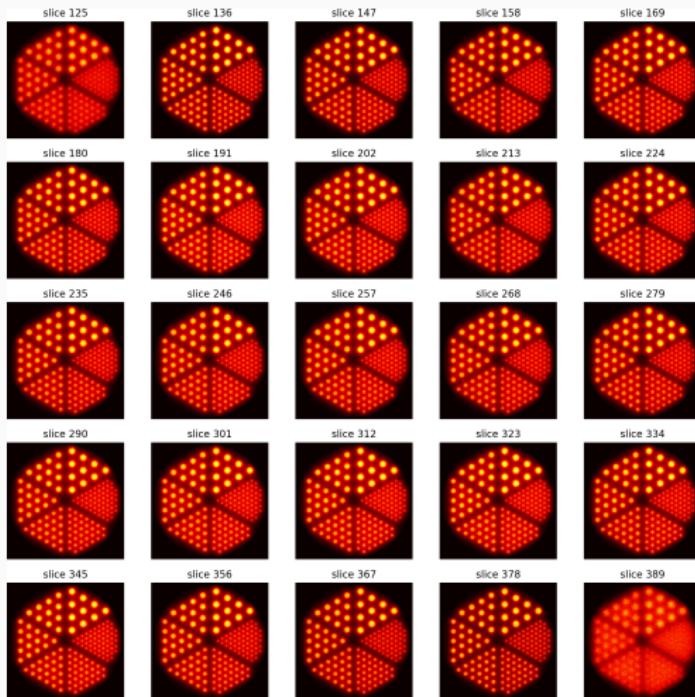
³Not yet implemented in GUI.

Uses: DPK



radioisotopes of ^{90}Y , ^{131}I and ^{177}Lu

Uses: MC



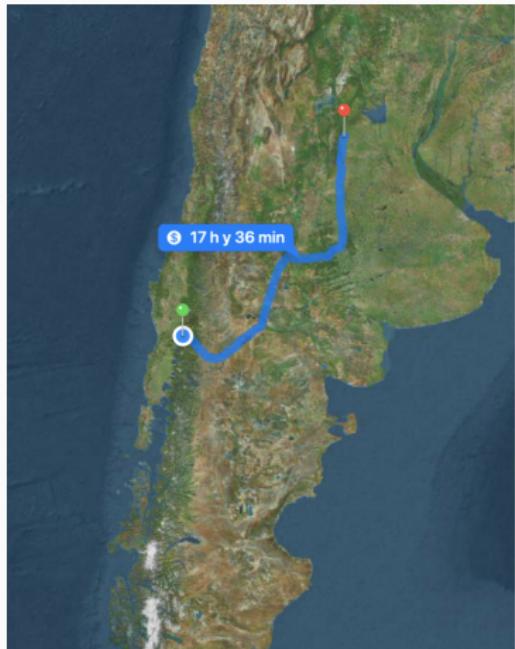
3D enegy delivering on phantom

Next Work

- move to free languages like Python
- improve GUI and segmentation modules
- develop FLUKA implementation in order to add alpha emitters
- test the DOSIS with measurements and other calculation softwares
- include machine learning and deep learning techniques for supporting in segmentation and visualization

Thanks!

Visit us in Córdoba!



Thanks for all!



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www.famaf.unc.edu.ar/~pperez1

download this presentation from: github.com/pap84/oral-jfmf2018