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

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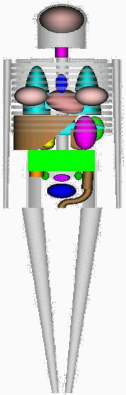
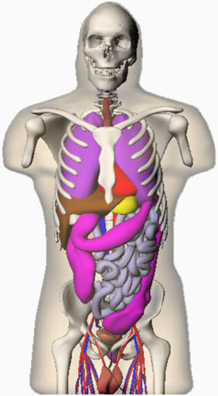
Introduction: ***the need of a patient-specific dosimetric calculation at voxel level in nuclear medicine***

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 stablished 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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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 $\leftarrow$ CT, RMN
- take into account patient-specific real activty distribution $\leftarrow$ 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 avtivity distribution and its time evolution
- integrate parameters for planar dosimetry nowadays in use

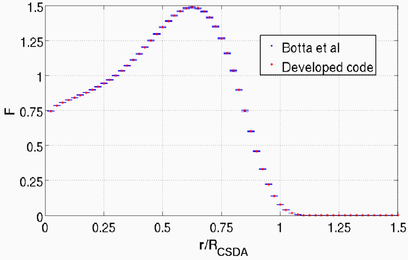
DOSIS: *an integrated system for patient-specific dosimetry assessment at voxel level*

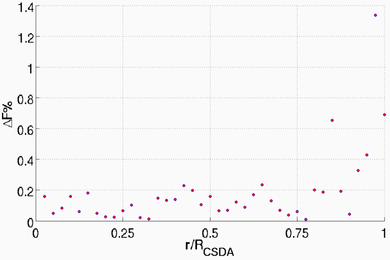
DPK assessment

- performed by Monte Carlo simulations
  - photons, positrons and electrons $\leftarrow$ PENELOPE
  - alpha and others $\leftarrow$ FLUKA in progress...
- a model for estimating electrons DPK for different tissues have been developed[1]
- 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

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

DPK MC results: *validating*

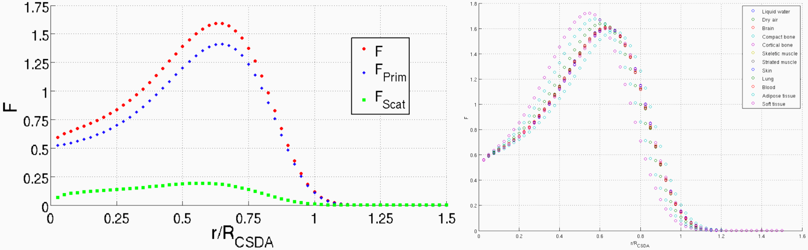




sDPK (F) calculated compared with published data[2] (left) and uncertainties involved (right)

[2]Botta 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

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

Voxelizing

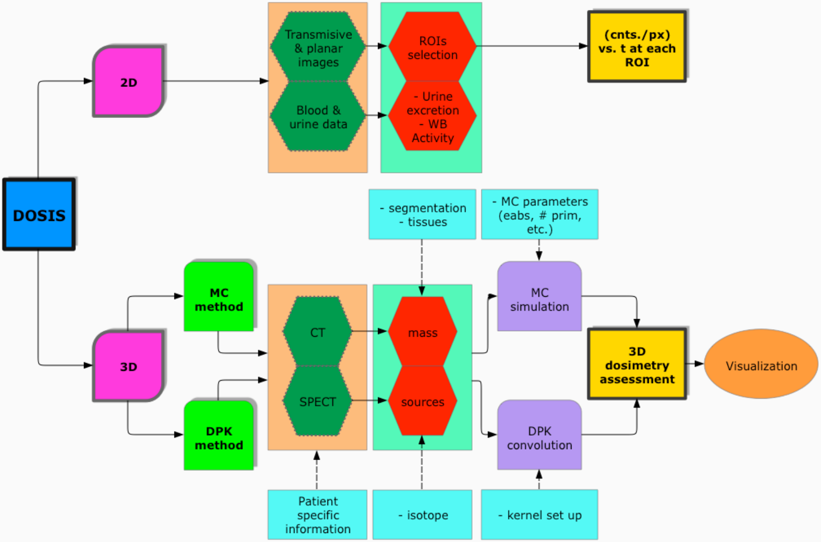
- Defining $\mathcal{K}_D(i,j,k)$ and $\mathcal{A}_{cum}(i,j,k)$ as $\mathbb{K}_D(\vec{r})$ and $\mathbb{A}_{cum}(\vec{r})$ in 3D voxelized geometry
- Using Fourier Transform properties and convolution technique
- Dose $D(\vec{r})$ results

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

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

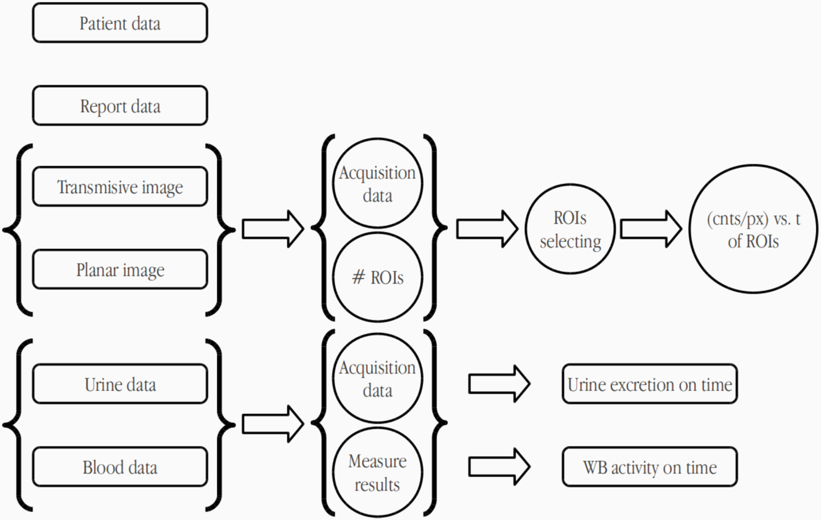
Graphical User Interface

Chartflow

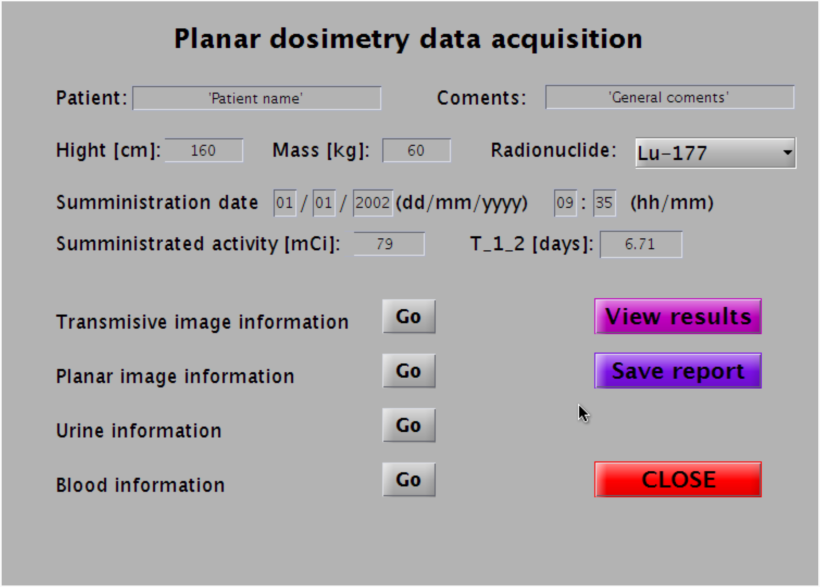


DOSIS
2D
3D
Transmisive & planar images
Blood & urine data
ROIs selection
- Urine excretion - WB Activity
(cnts./px) vs. t at each ROI
MC method
DPK method
CT
SPECT
mass
sources
- segmentation - tissues
- MC parameters (eabs, # prim, etc.)
MC simulation
DPK convolution
3D dosimetry assessment
Visualization
Patient specific information
- isotope
- kernel set up

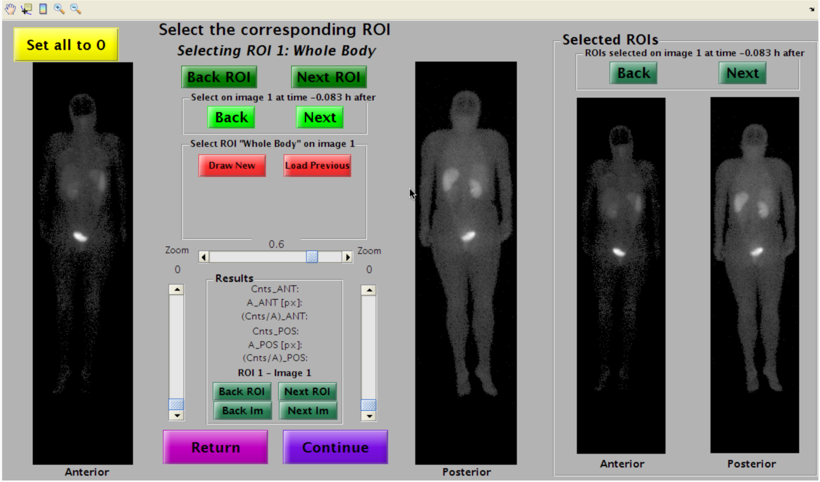
Planar dosimetry chartflow



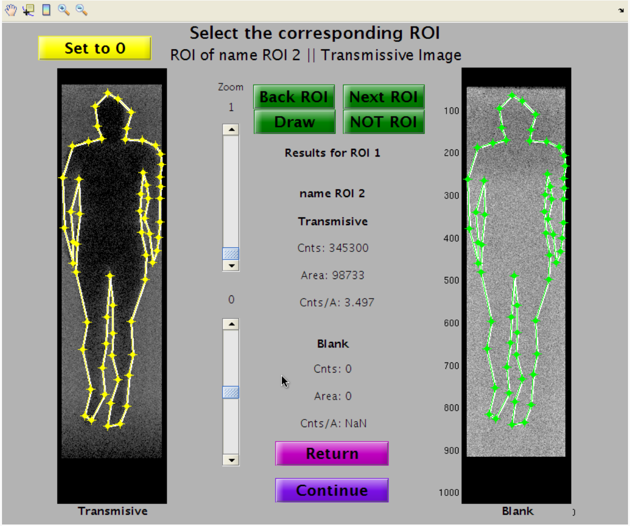
Planar dosimetry GUI: *main*



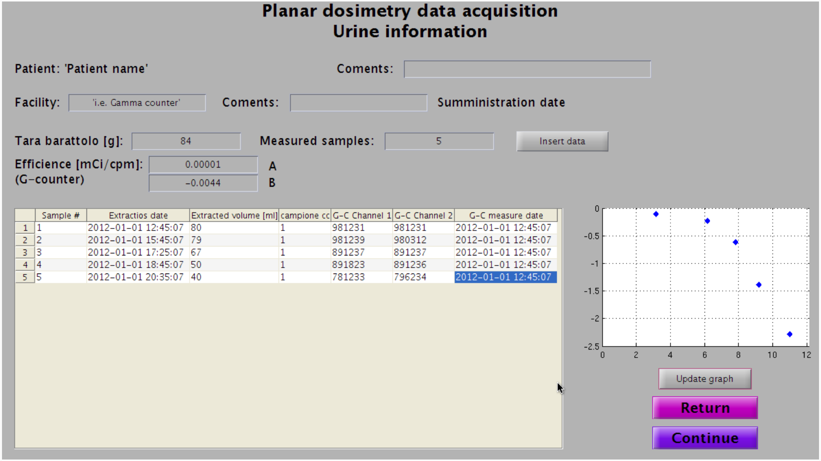
Planar dosimetry GUI: *rois*



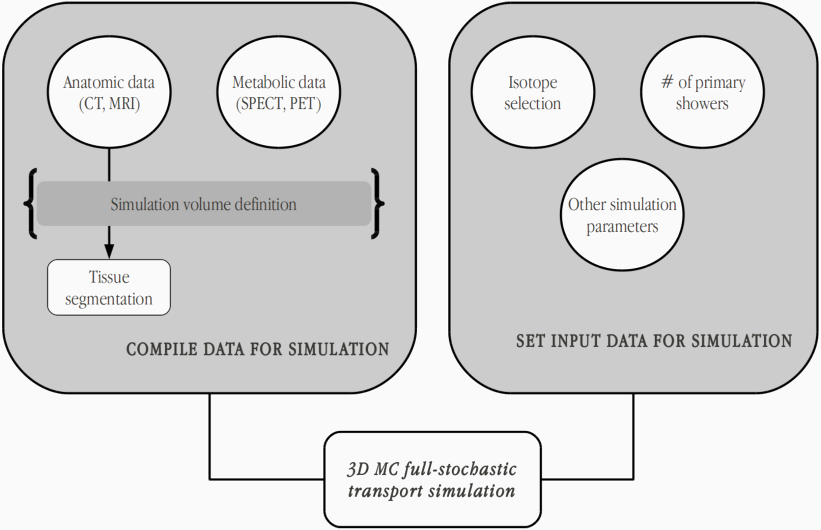
Planar dosimetry GUI: *whole body*



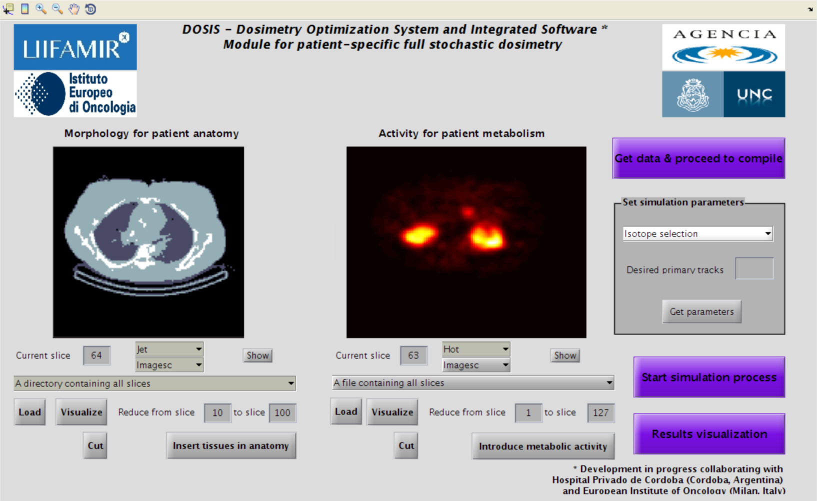
Planar dosimetry GUI: *curves*



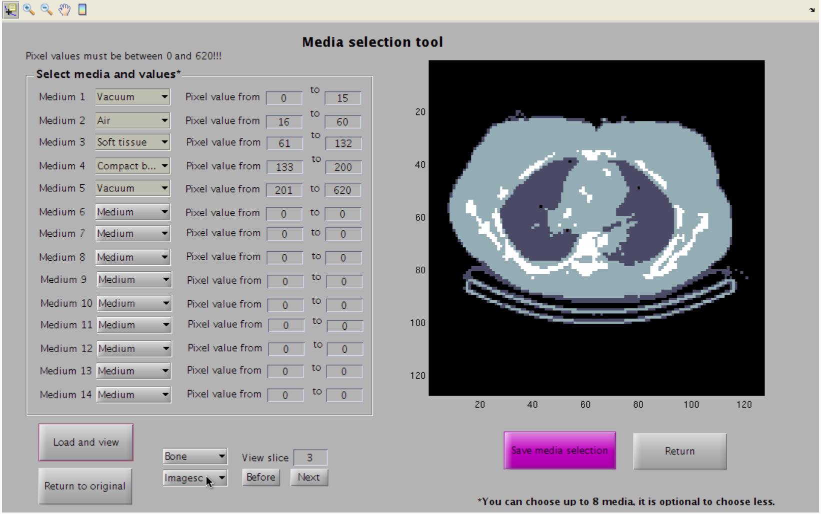
3D dosimetry chartflow



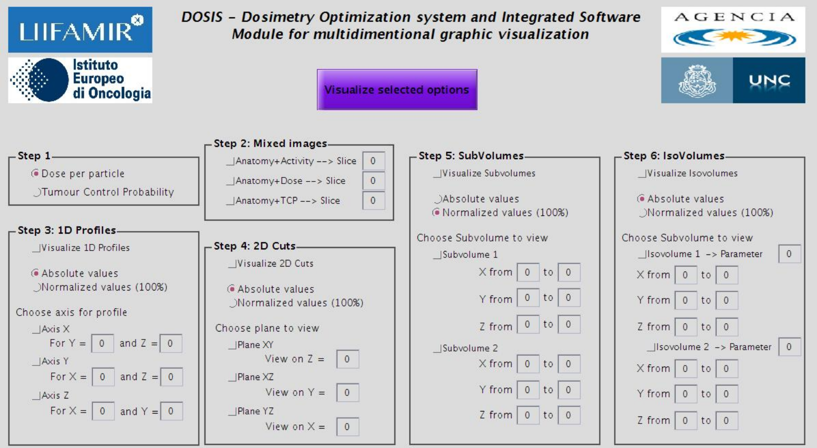
3D dosimetry: *GUI*



3D dosimetry: *segmentation*



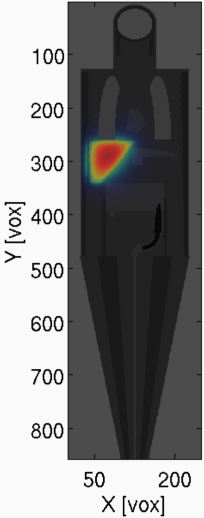
3D dosimetry: *visualization*



Results

Monte Carlo simulations

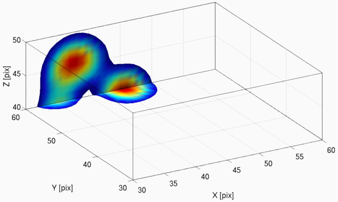
Comparison against bibliography on mathematical phantom

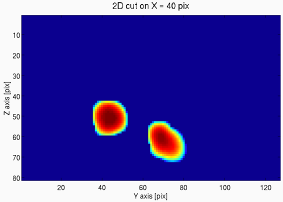


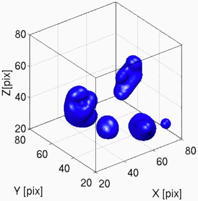
Organ	Reference[a]	DOSIS
Liver	1	1
Adrenals	0.13	0.47
Brain	0.00025	0.00083
Stomach	0.46	0.82
Kidneys	0.09	0.32
Lungs	0.064	0.082
Pancreas	0.12	0.41
Spleen	0.022	0.042

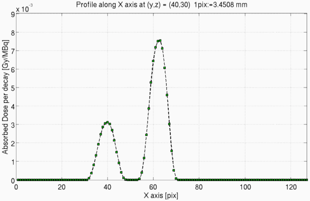
[a] Cherry, Sorenson & Phelps. *Physics in Nuclear Medicine.*

MC results on patient images

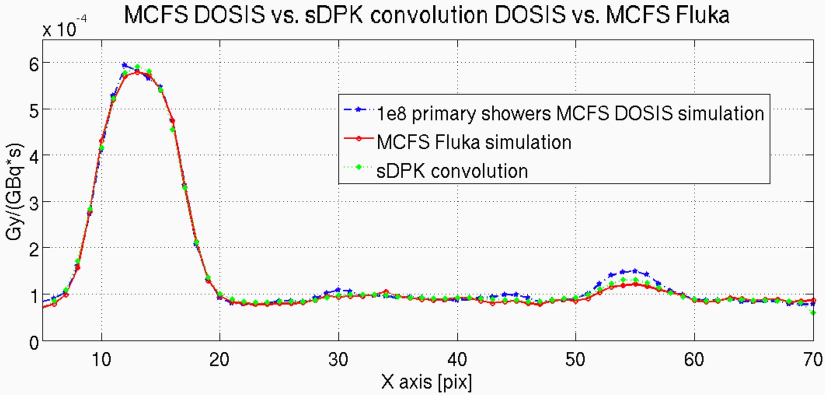








DOSIS results



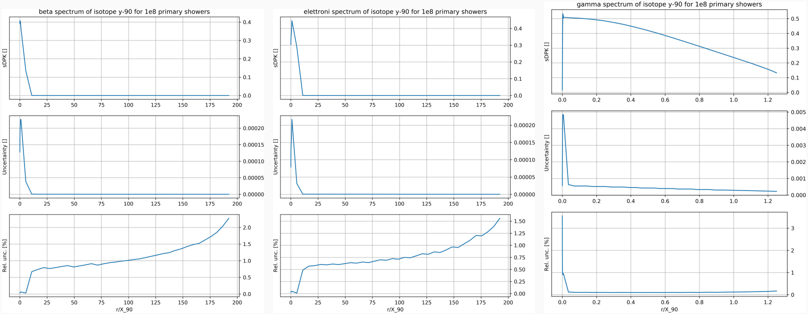
Final considerations

DOSIS today

- The developed tool is capable of perfoming 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 in testing process for different situations with colleagues from IEO (Milán) and University of Lund (Sweeden)
    - analyzing effects of DPK convolutions when changing voxel size and activity distribution
    - both DPK[3] and MC calculations are being performed by DOSIS
    - results are expected to be sent for publication by the end of the year

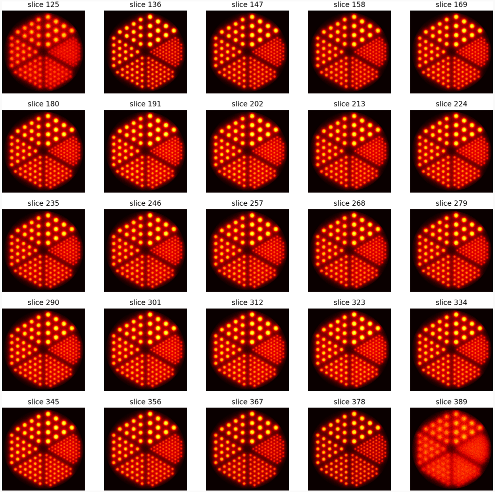
[3] Not yet implemented in GUI.

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
- develope 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!

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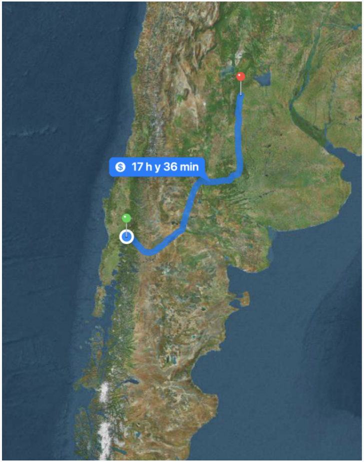

Thanks for all!

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