Comparison of absorbed dose calculation algorithms in

PLANET® Dose and OpenDose3D

Séminaire de Radiothérapie Interne Vectorisé

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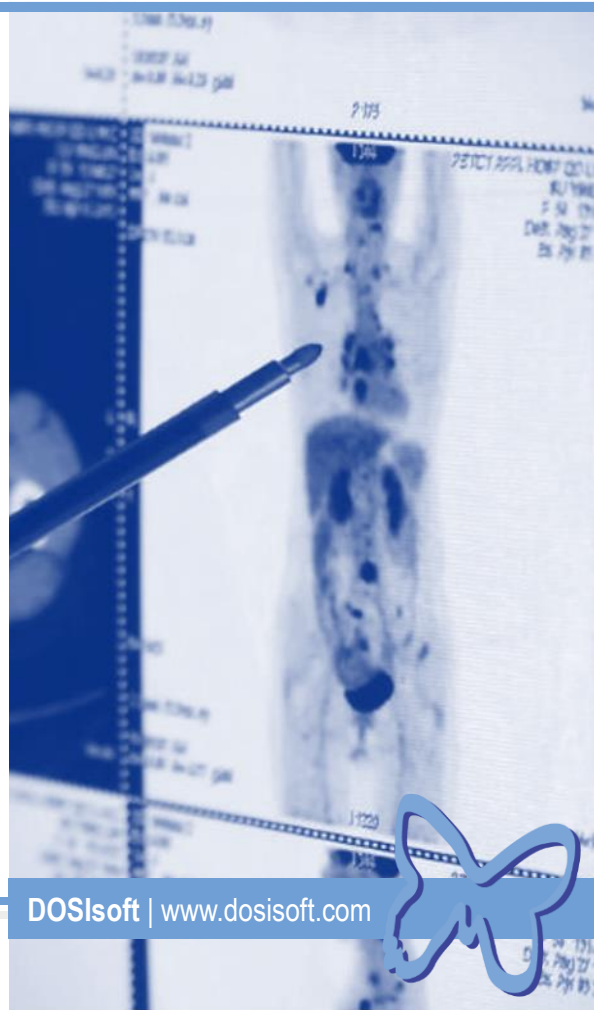
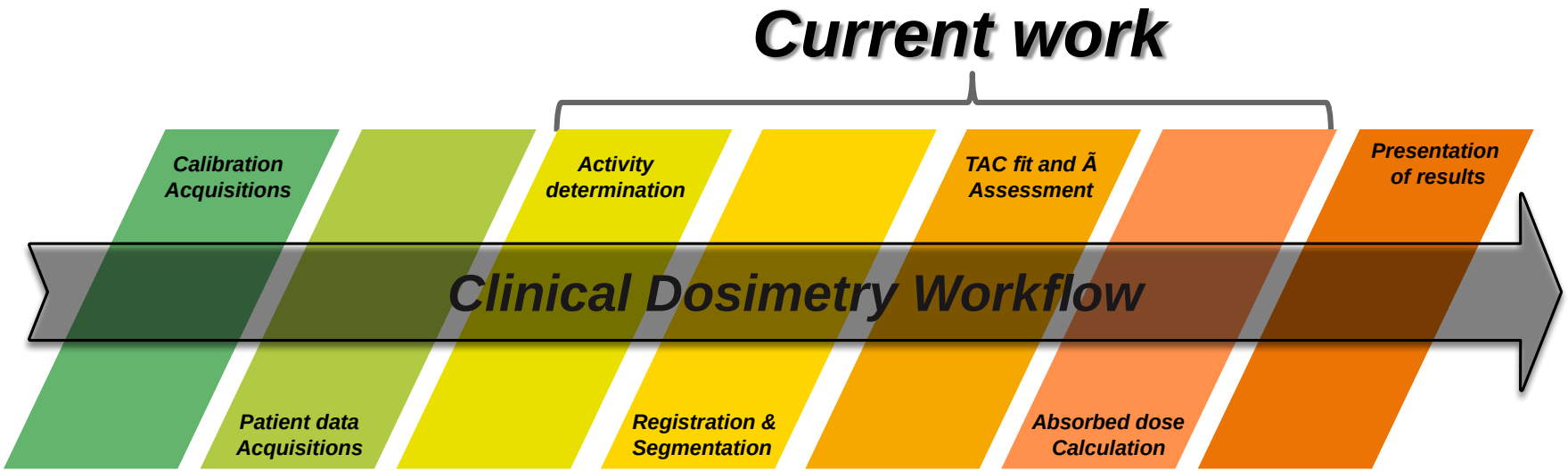
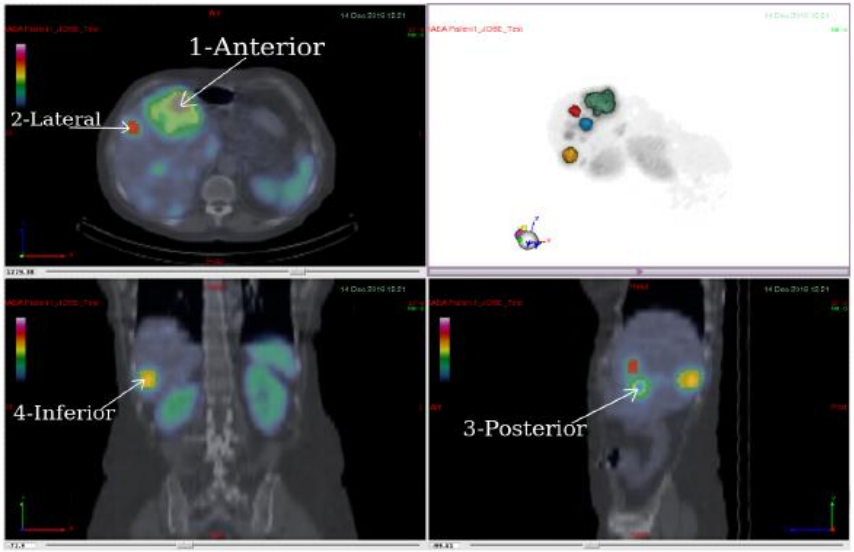


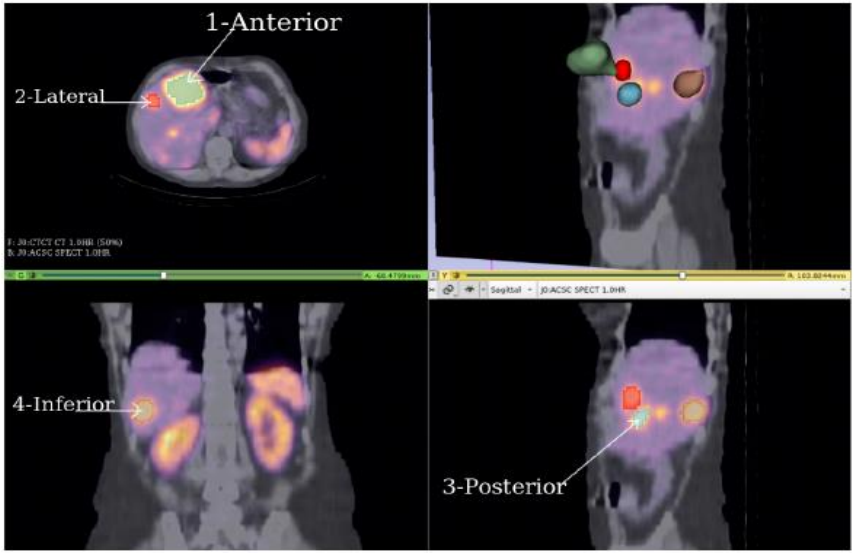
Assessing the accuracy of clinical dosimetry in molecular radiotherapy



IAEA-CRP E23005 project (patient received Lutathera® treatment)



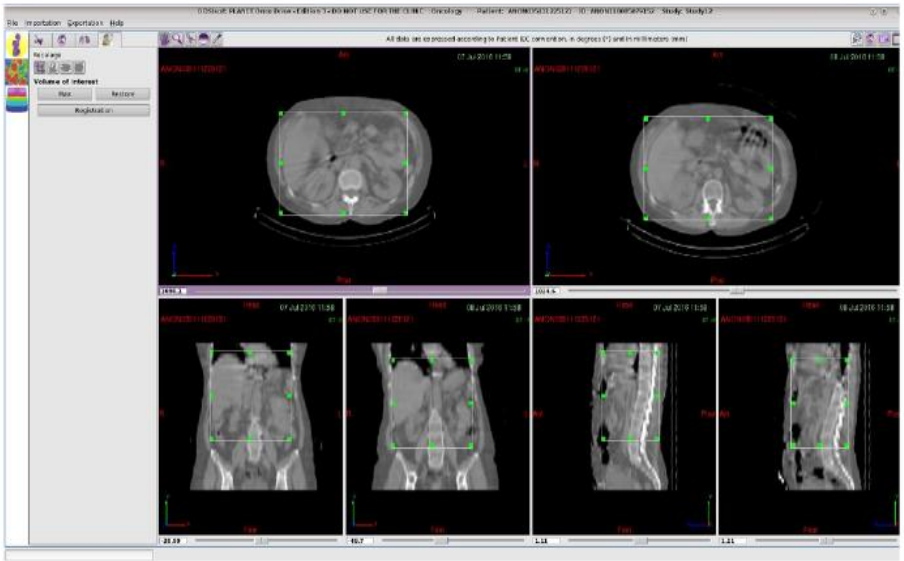
(a) Lesions visualization using PLANET® Dose



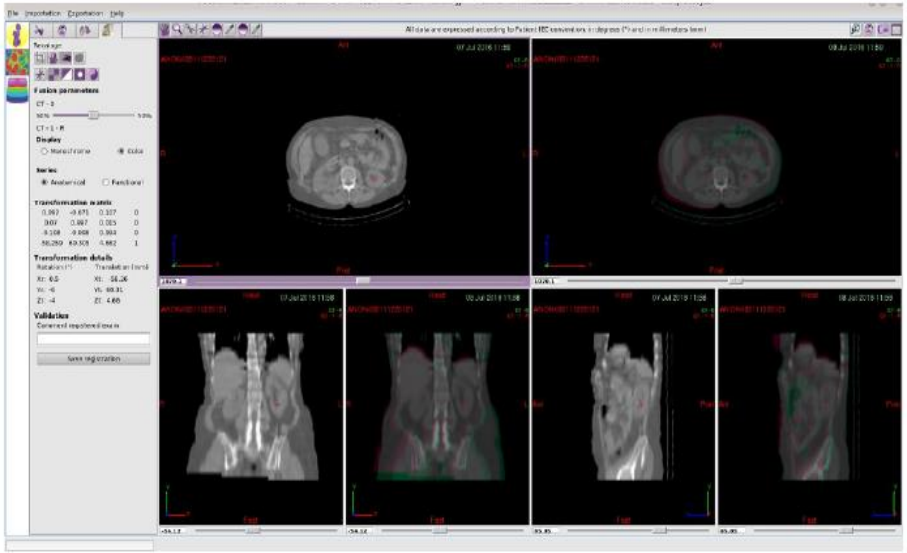
(b) Lesions visualization using OpenDose 3D

Figure 1: Representation of the four marked lesions segmented on patient Cycle3 using PLANET® Dose (a) and OpenDose 3D (b)

Standard Protocol: Registration



(a) Registration Volume Box



(b) Rigid Registration between baseline and T1

Figure 2: Registration procedure in the "*default methodology*" using PLANET® Dose

Standard Protocol: Contouring/Segmentation and Propagation of VOIs

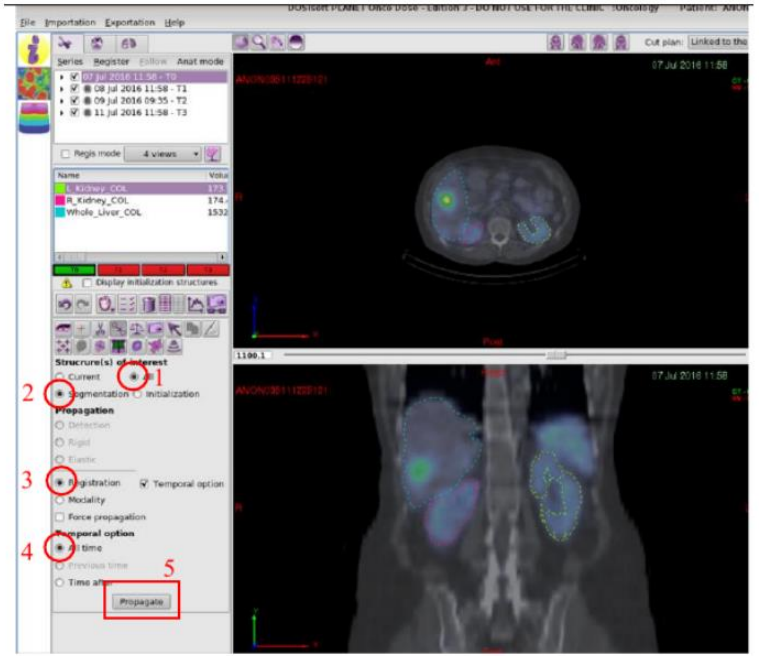
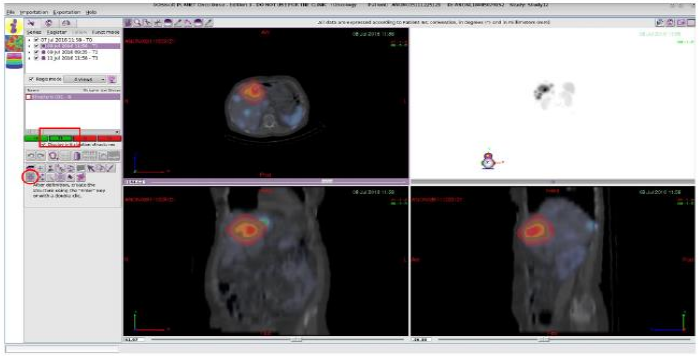
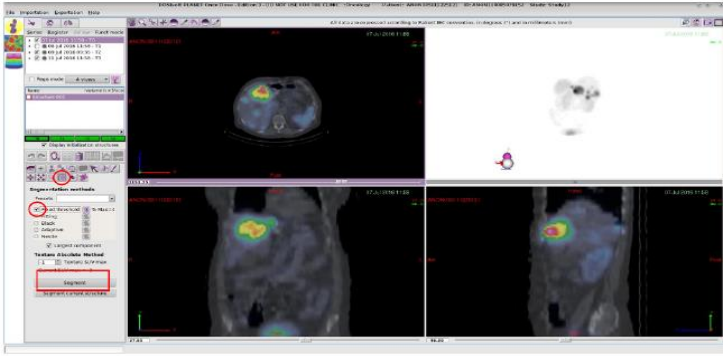


Figure 3: Rigid Propagation for organs segmentation



(a) Definition of Initialization Structure for the 1-Anterior lesion at T1



(b) Segmentation Methods, 40% fixed threshold

Organ Approaches

- ***PL Rigid Propagation***
- ***PL Rigid Propagation (Different Registration Box)***
- ***OD3D Elastic Propagation***

Lesion Approaches

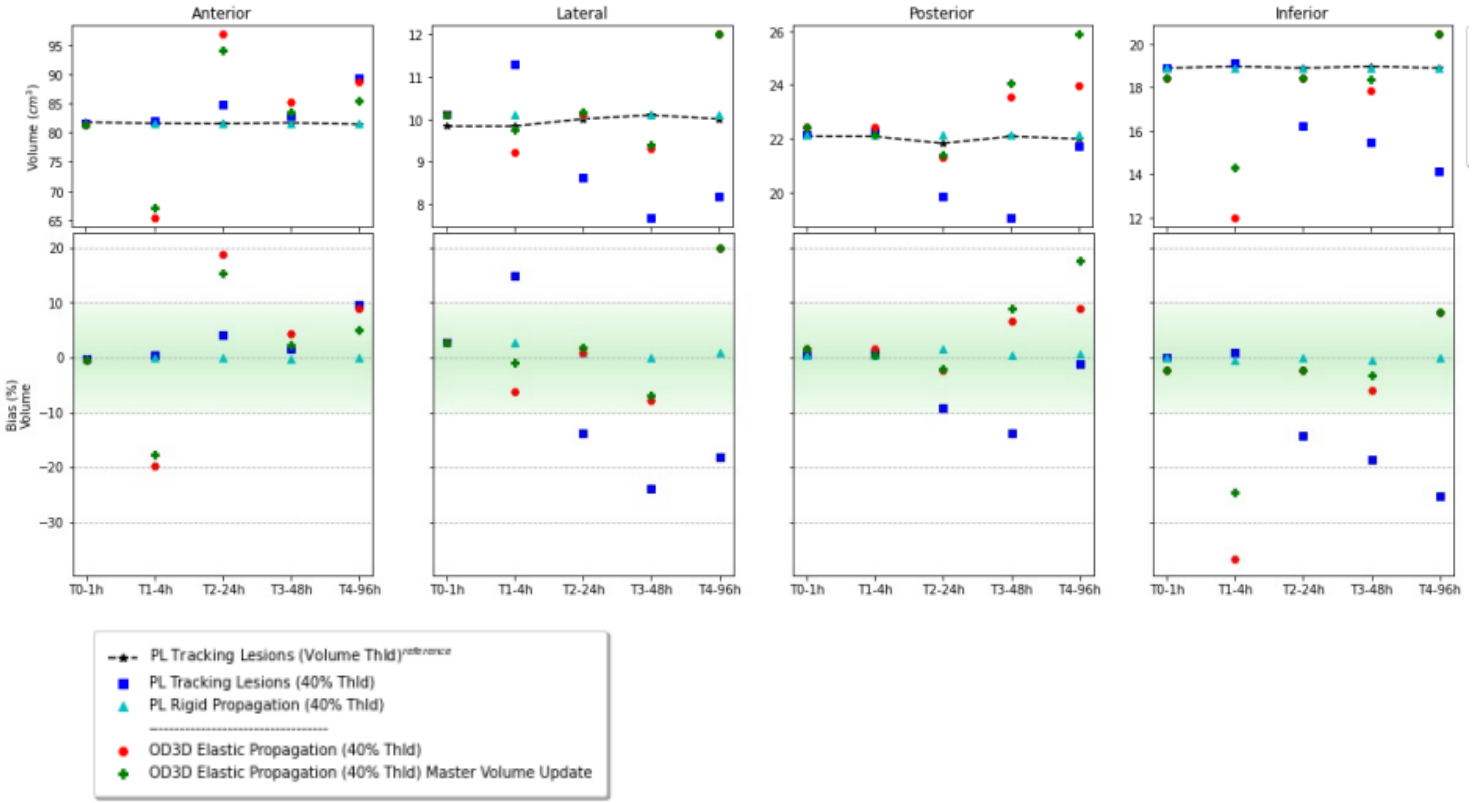
- ***PL Tracking Lesions (Volume Threshold)***
- ***PL Tracking Lesions (40% Threshold)***
- ***PL Rigid Propagation (40% Threshold)***
- ***OD3D Elastic Propagation (40% Threshold)***

Relative Differences (%) on the volume lesions during the Propagation of VOIs

Volume (cm³)

Max ≈ 20%

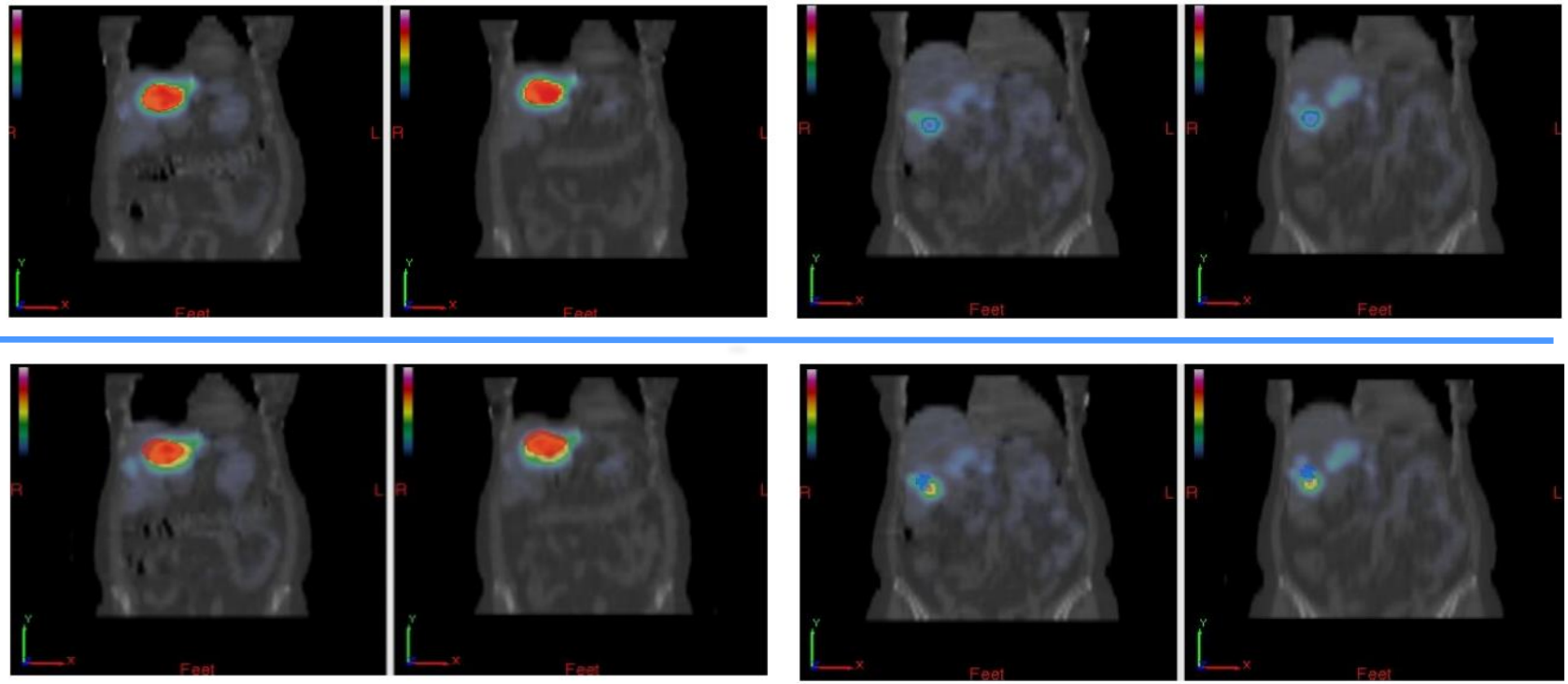
Min ≈ -30%



Difference between Rigid Propagations and Tracking methods

Tracking

Rigid



Same volume

(a) Anterior lesion segmentation using tracking (first row) and rigid propagation (second row) methods

(b) Inferior lesion segmentation using tracking (first row) and rigid propagation (second row) methods

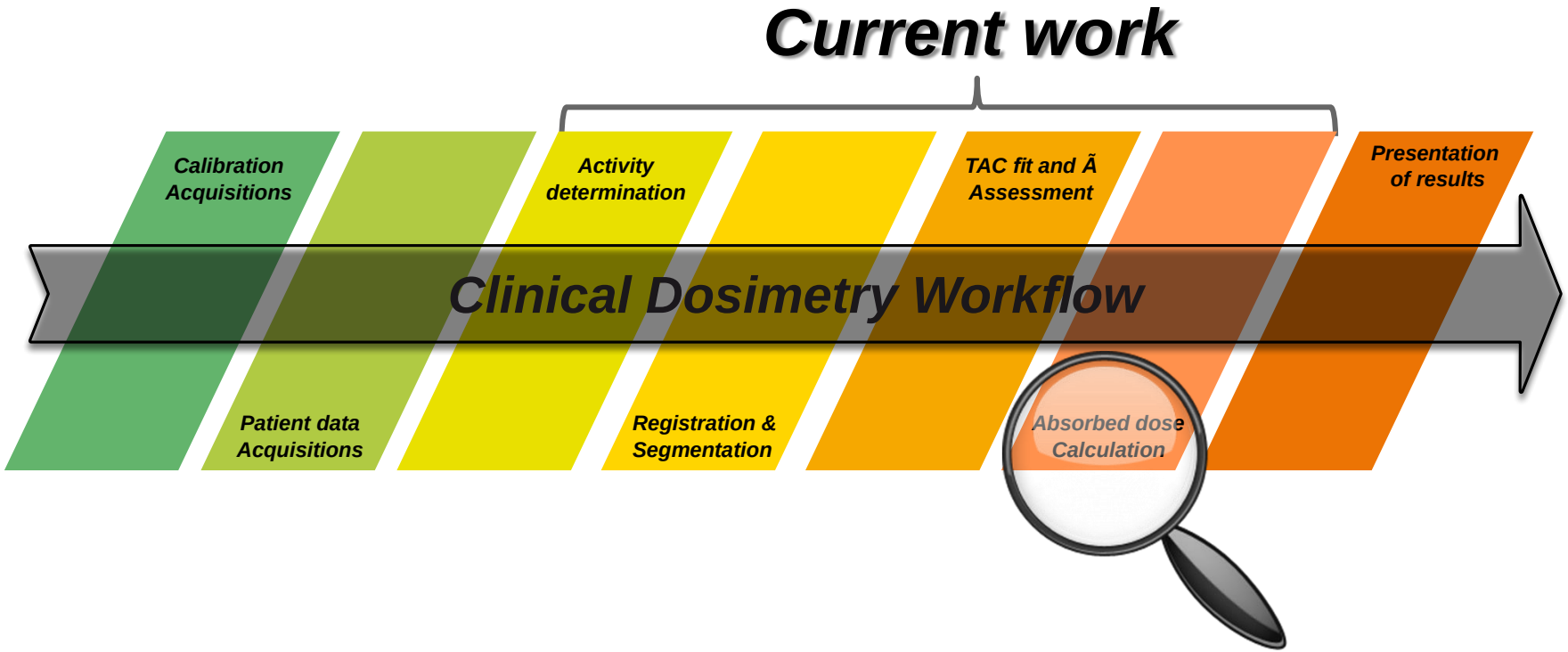
Relative Differences (%) for Absorbed Dose Values

- Organ approaches sorted into Relative Difference (%) computed from Absorbed Dose

Approach	Max Relative Diff (%)
PL Rigid Propagation (Different Registration Box)	2 %
OD3D Elastic Propagation	20 %

- Lesion approaches sorted into Relative Difference (%) computed from Absorbed Dose

Approach	Max Relative Diff (%)
PL Tracking Lesions (40% Thld)	13 %
OD3D Elastic Propagation (40% Thld)	36 %
PL Rigid Propagation (40% Thld)	52 %

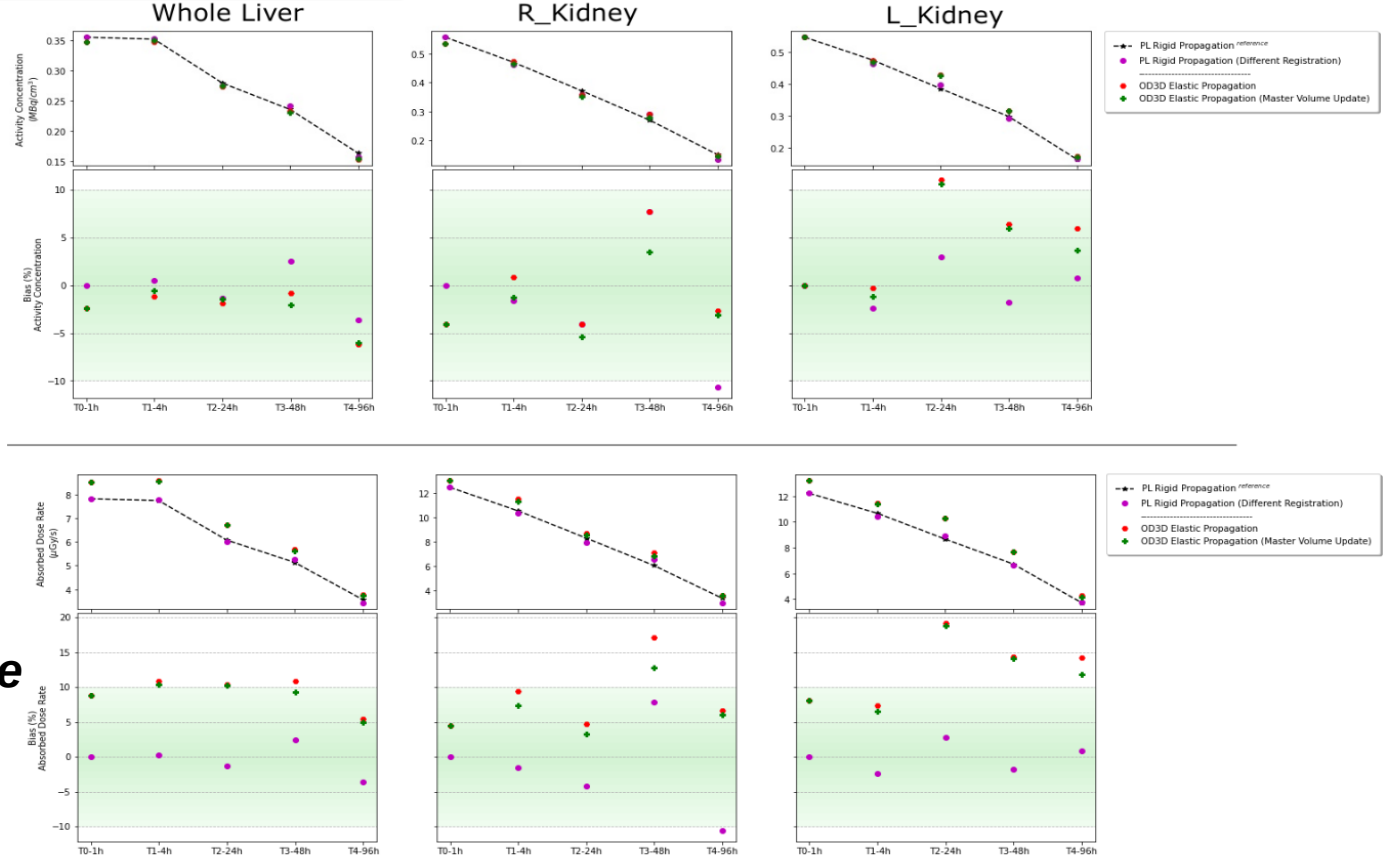

Current work
Calibration Acquisitions
Activity determination
TAC fit and Ã Assessment
Presentation of results
Clinical Dosimetry Workflow
Patient data Acquisitions
Registration & Segmentation
Absorbed dose Calculation

Analysis of the relative difference between *Activity Concentration* and *Absorbed Dose Rate* (DVK Convolution with density correction)

Activity Concentration
(MBq/cm³)

≈ **11%**

Absorbed Dose Rate
(µGy/s)



Comparison of absorbed dose calculation algorithms

ADR relative difference using local energy deposition (*LED*) algorithm

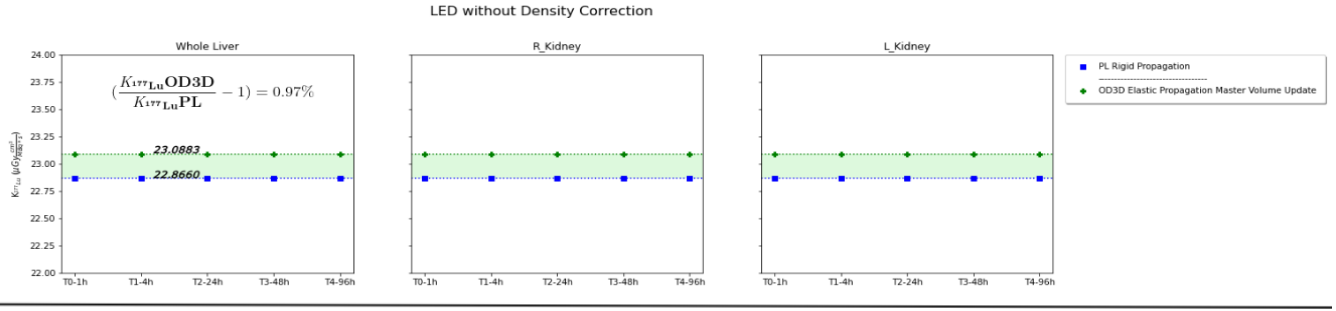
LED without Density Correction

1%

PLANET (177Lu)		
2.352E-14	J/(Bq*s)	
1.0286	g/cm3	
2.287E-14	J/(Bq*s) (cm3/g)	J/g * cm3/(Bq*s)
2.287E-11	Gy *cm3/(Bq*s)	J/kg * cm3/(Bq*s)
2.287E-05	uGy * cm3/(Bq*s)	
22.8660	uGy * cm3/(MBq*s)	

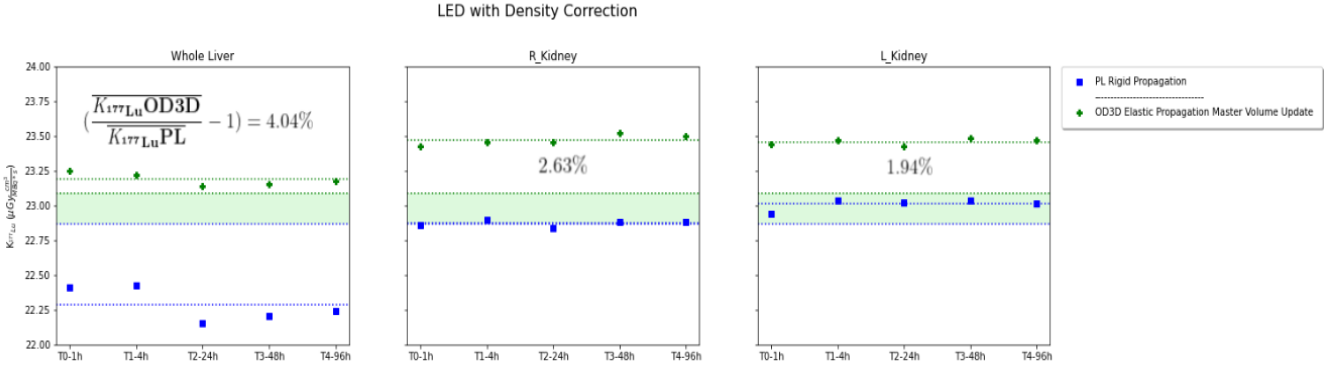
$$K_{^{177}Lu}(\mu Gy \times \frac{cm^3}{MBq * s}) = \frac{LED_{(\mu Gy/s)}}{A_{0(MBq/cm^3)}}$$

OD3D (177Lu)		
0.085495	mJ/(MBq*h)	
2.375E-14	J/(Bq*s)	
1.0286	g/cm3	
2.309E-14	J/(Bq*s) (cm3/g)	J/g * cm3/(Bq*s)
2.309E-11	Gy *cm3/(Bq*s)	J/kg * cm3/(Bq*s)
2.309E-05	uGy * cm3/(Bq*s)	
23.0883	uGy * cm3/(MBq*s)	



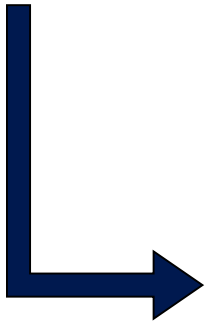
LED with Density Correction

4%

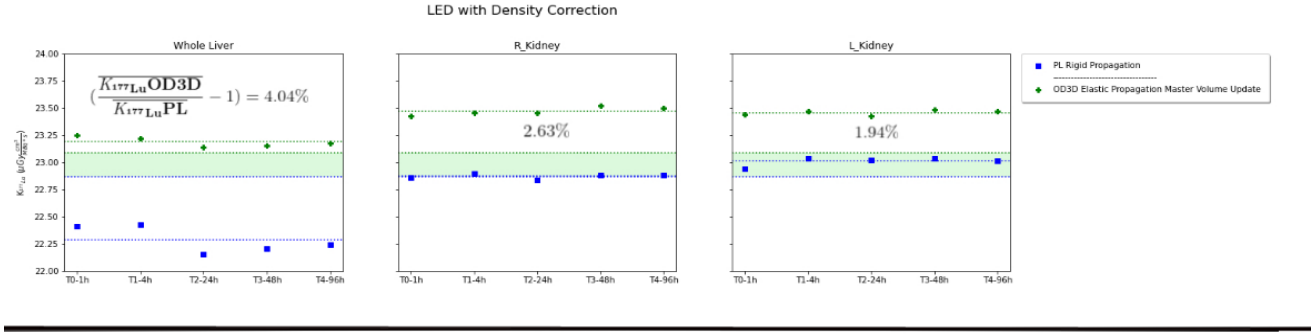


Calibration Function of Hounsfield units

4%



2 fitting segments



OpenDose3DLogic.py

```
159 if self.calibrationFile.exists():
160     with self.calibrationFile.open('r') as f:
161         self.calibration = json.load(f)
162 else:
163     self.calibration = {
164         "CTCalibration": {
165             "a0": 0.001, "b0": 1, "a1": 0.0005116346986394071, "b1": 1},
166         "SPECTSensitivity": {"Value": 122.6, "Units": "counts/MBqs", "Time": 1800},
167         "SPECTRecovery": {}
168     }
```

The calibration of CT Hounsfield units for radiotherapy treatment planning

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Received 23 February 1995

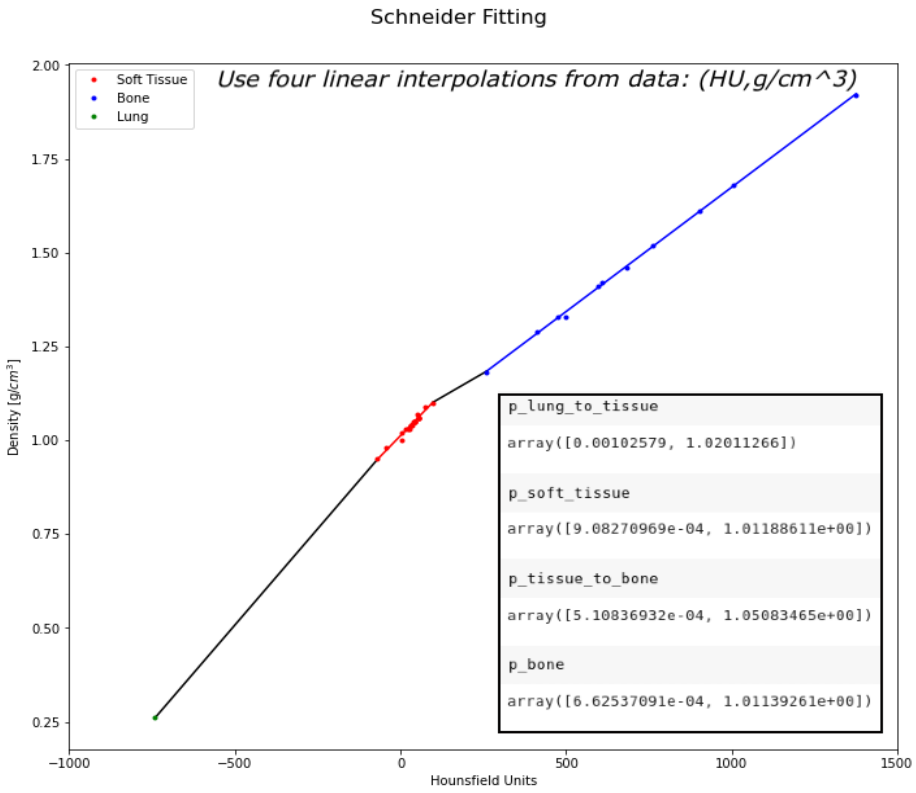
Calibration of CT units for radiotherapy

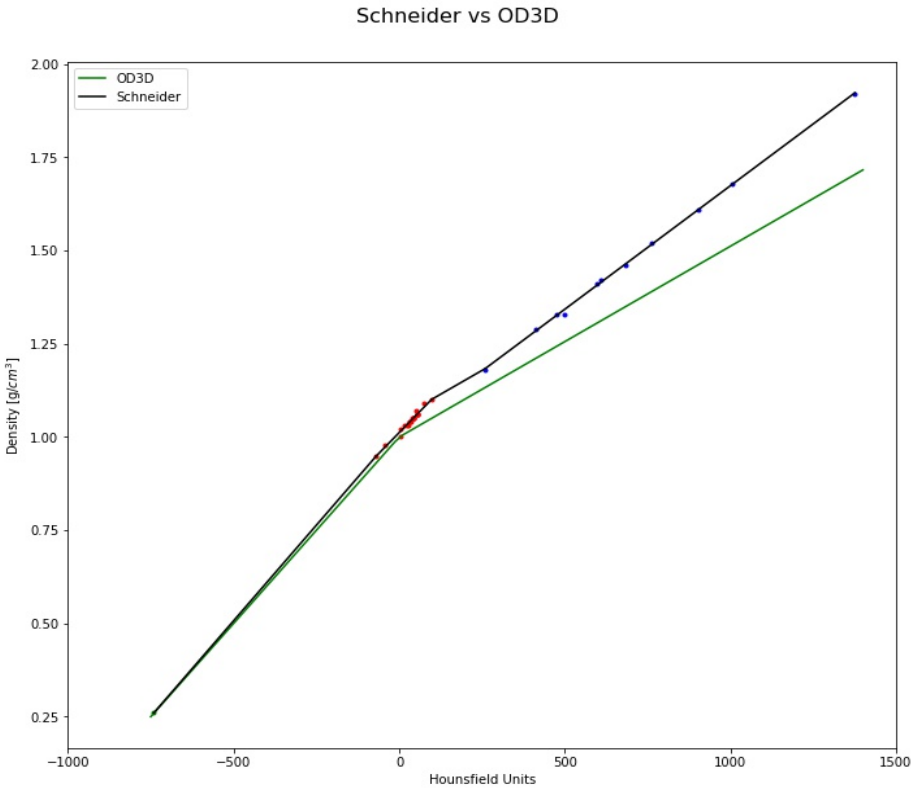
4 fitting segments

Table 4. Chemical composition as percentages, density ρ (taken from ICRP 1975) and calculated Hounsfield numbers, relative electron densities ρ_e and relative proton stopping powers ρ_s for various tissue descriptions.

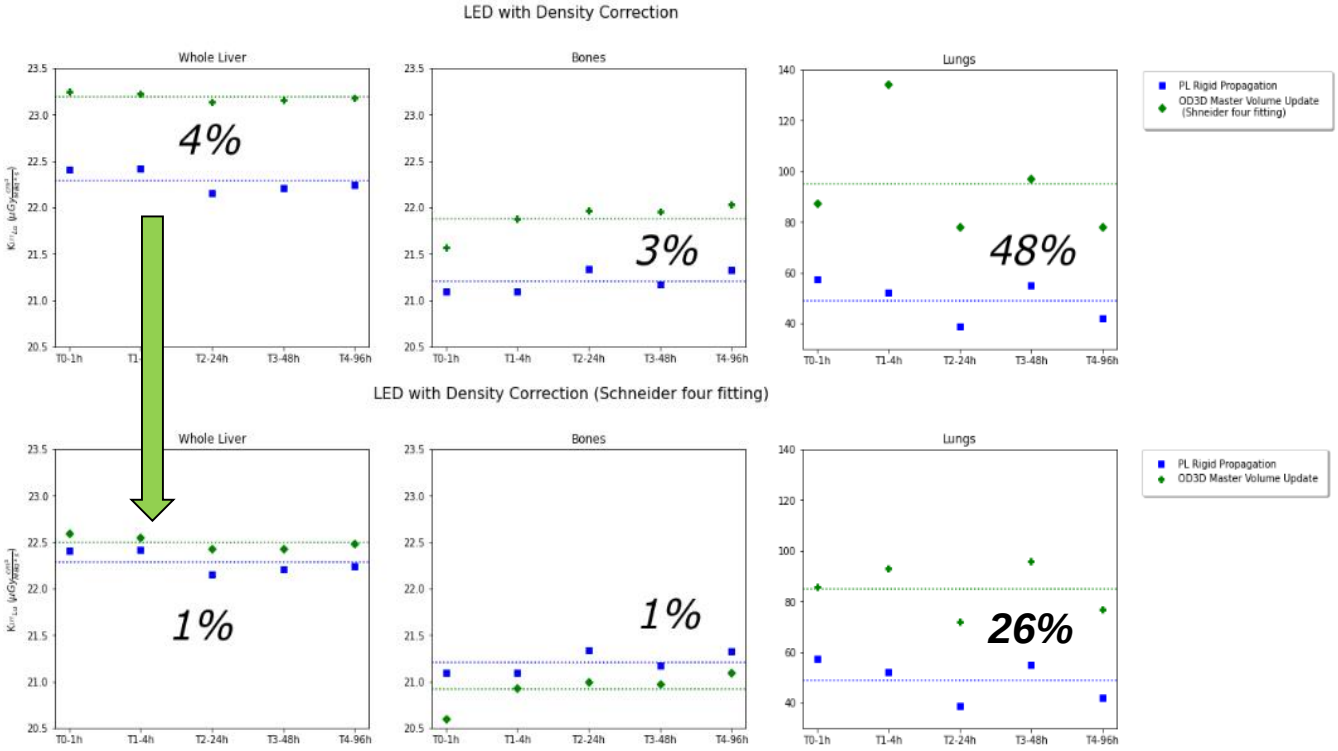
	H	C	N	O	Ca	P	Na	Mg	S	Cl	K	Fe	I	ρ	H	ρ_e	ρ_s
	11.4	59.8	0.7	27.8			0.1		0.1	0.1				0.95	930	0.951	0.979
	10.2	11.0	3.3	74.5		0.1	0.1		0.2	0.3	0.2	0.1		1.06	1055	1.050	1.053
Brain	10.7	14.5	2.2	71.2		0.4	0.2		0.2	0.3	0.3			1.04	1037	1.035	1.040
Breast	10.6	33.2	3.0	52.7		0.1	0.1		0.2	0.1				1.02	1003	1.014	1.029
Cell nucleus	10.6	9.0	3.2	74.2		2.6			0.4					1.00	1003	0.994	0.996
Eye lens	9.6	19.5	5.7	64.6		0.1	0.1		0.3	0.1				1.07	1050	1.055	1.060
GI tract	10.6	11.5	2.2	75.1		0.1	0.1		0.1	0.2	0.1			1.03	1023	1.024	1.028
Heart	10.3	12.1	3.2	73.4		0.1	0.1		0.2	0.3	0.2	0.1		1.06	1055	1.051	1.054
Kidney	10.3	13.2	3.0	72.4	0.1	0.2	0.2		0.2	0.2	0.2			1.05	1043	1.041	1.045
Liver	10.2	13.9	3.0	71.6		0.3	0.2		0.3	0.2	0.3			1.06	1053	1.050	1.054
Lung (deflated)	10.3	10.5	3.1	74.9		0.2	0.2		0.3	0.3	0.2			1.05	1044	1.041	1.044
Lung (inflated)														0.26	259	0.258	0.258
Lymph	10.8	4.1	1.1	83.2			0.3		0.1	0.4				1.03	1028	1.026	1.027
Muscle	10.2	14.3	3.4	71.0		0.2	0.1		0.3	0.1	0.4			1.05	1042	1.040	1.044
Ovary	10.5	9.3	2.4	76.8		0.2	0.2		0.2	0.2	0.2			1.05	1045	1.043	1.046
Pancreas	10.6	16.9	2.2	69.4		0.2	0.2		0.1	0.2	0.2			1.04	1032	1.034	1.041
Cartilage	9.6	9.9	2.2	74.4		2.2	0.5		0.9	0.3				1.10	1098	1.083	1.081
Red marrow	10.5	41.4	3.4	43.9		0.1			0.2	0.2	0.2	0.1		1.03	1014	1.023	1.041
Spongiosa	8.5	40.4	2.8	36.7	7.4	3.4	0.1	0.1	0.2	0.2	0.1	0.1		1.18	1260	1.150	1.156
Yellow marrow	11.5	64.4	0.7	23.1			0.1		0.1	0.1				0.98	958	0.982	1.013
Skin	10.0	20.4	4.2	64.5		0.1	0.2		0.2	0.3	0.1			1.09	1075	1.078	1.084
Spleen	10.3	11.3	3.2	74.1		0.3	0.1		0.2	0.2	0.3			1.06	1054	1.051	1.054
Testis	10.6	9.9	2.0	76.6		0.1	0.2		0.2	0.2	0.2			1.04	1032	1.032	1.035
Thyroid	10.4	11.9	2.4	74.5		0.1	0.2		0.1	0.2	0.1		0.1	1.05	1040	1.041	1.045
Skeleton—cortical bone	3.4	15.5	4.2	43.5	22.5	10.3	0.1	0.2	0.3					1.92	2376	1.781	1.714
Skeleton—cranium	5.0	21.2	4.0	43.5	17.6	8.1	0.1	0.2	0.3					1.61	1903	1.517	1.480
Skeleton—femur	7.0	34.5	2.8	36.8	12.9	5.5	0.1	0.1	0.2	0.1				1.33	1499	1.278	1.269
Skeleton—humerus	6.0	31.4	3.1	36.9	15.2	7.0	0.1	0.1	0.2					1.46	1683	1.389	1.370
Skeleton—mandible	4.6	19.9	4.1	43.5	18.7	8.6	0.1	0.2	0.3					1.68	2006	1.577	1.534
Skeleton—ribs (2nd, 6th)	6.4	26.3	3.9	43.6	13.1	6.0	0.1	0.1	0.3	0.1	0.1			1.41	1595	1.347	1.329
Skeleton—ribs (10th)	5.6	23.5	4.0	43.4	15.6	7.2	0.1	0.1	0.3	0.1	0.1			1.52	1763	1.441	1.413
Skeleton—sacrum	7.4	30.2	3.7	43.8	9.8	4.5		0.1	0.2	0.1	0.1	0.1		1.29	1413	1.244	1.238
Skeleton—spongiosa	8.5	40.4	2.8	36.7	7.4	3.4	0.1	0.1	0.2	0.2	0.1	0.1		1.18	1260	1.150	1.156
Skeleton—vertebral column (C4)	6.3	26.1	3.9	43.6	13.3	6.1	0.1	0.1	0.3	0.1	0.1	0.1		1.42	1609	1.355	1.337
Skeleton—vertebral column (D6, L3)	7.0	28.7	3.8	43.7	11.1	5.1		0.1	0.2	0.1	0.1	0.1		1.33	1477	1.278	1.267

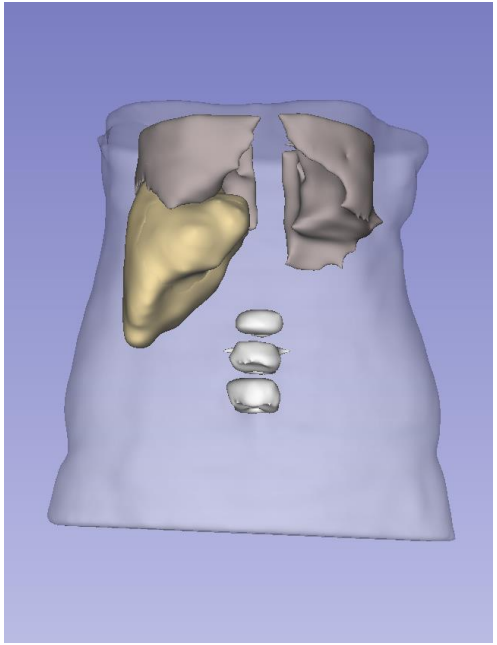
Comparison of Calibration Functions





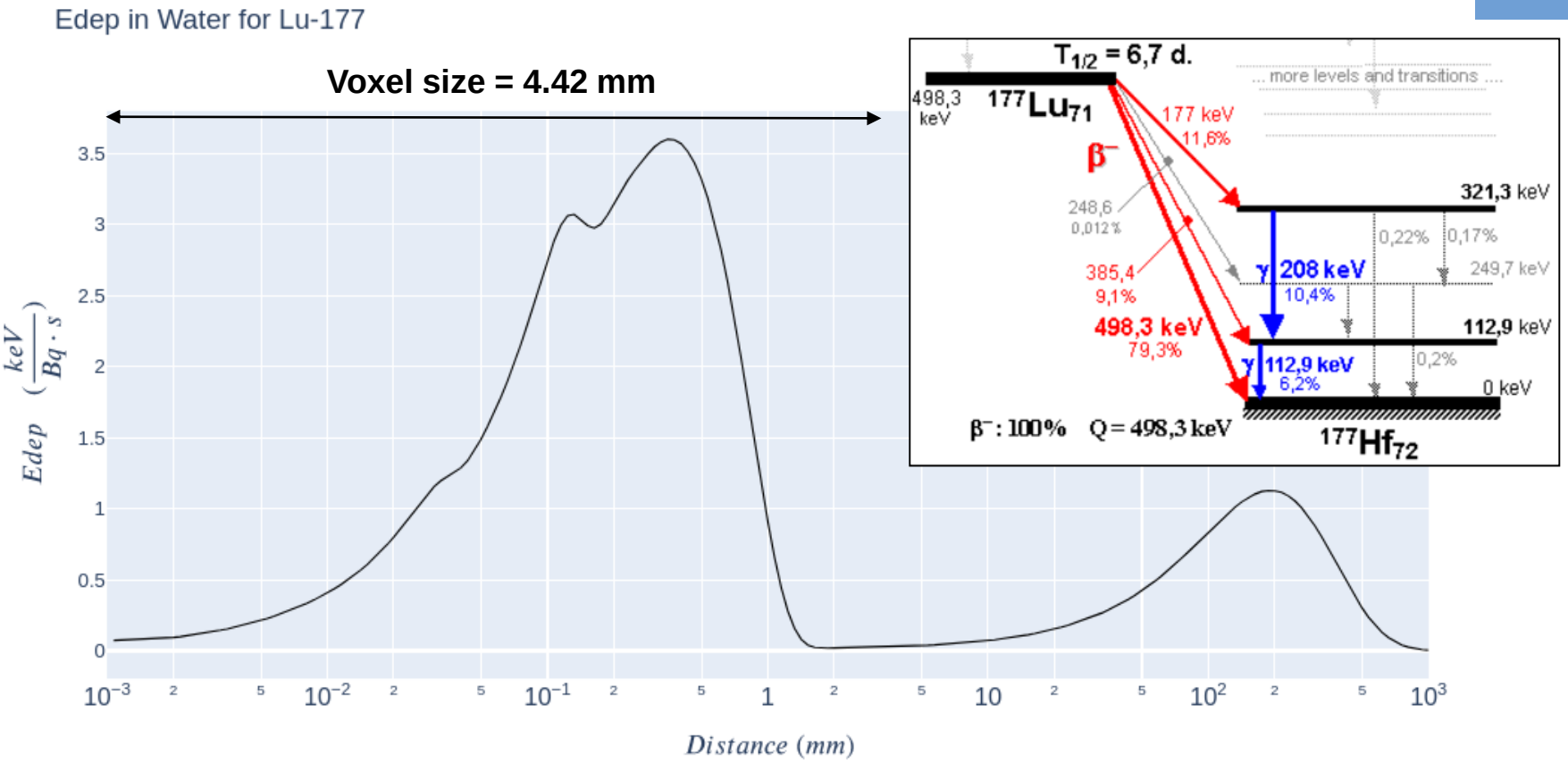
ADR relative difference for *LED* using *Schneider Calibrator Function*



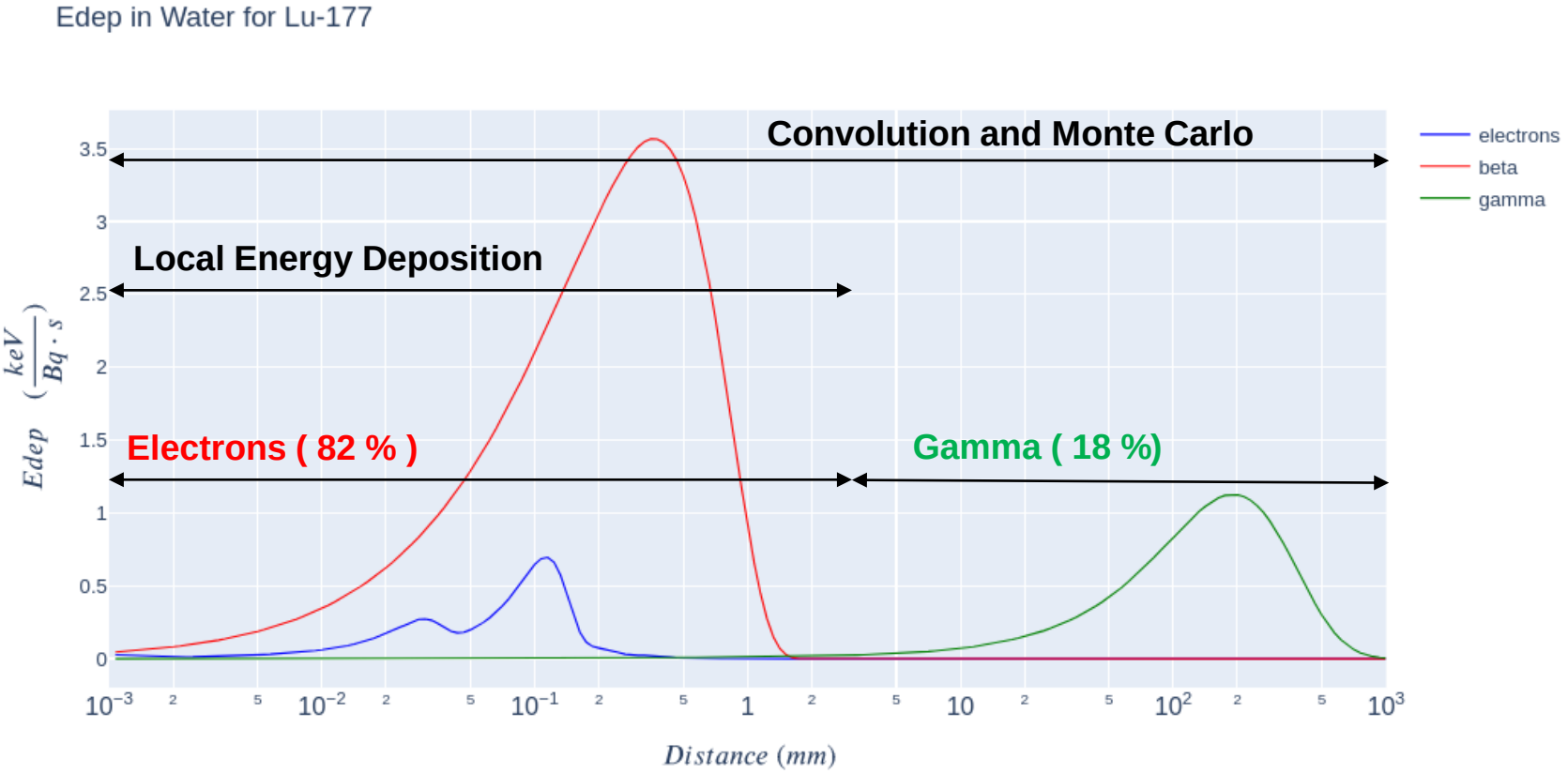


Monte Carlo Comparisons

DPK calculations, 177Lu scheme



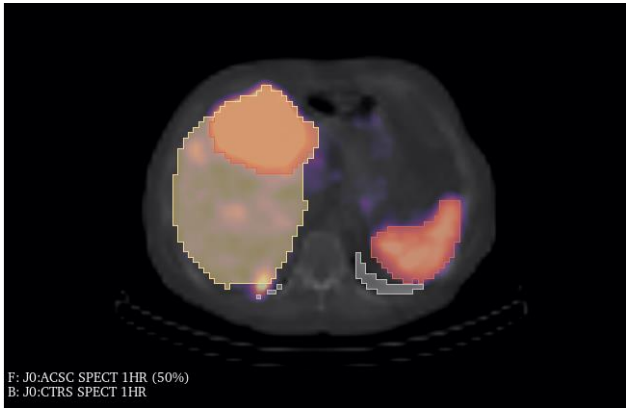
DPK divided contributions



Monte Carlo Comparisons

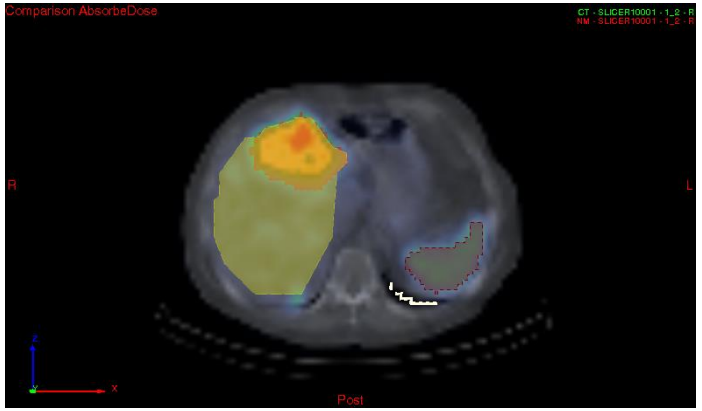
- *Share VOIs segmentations*

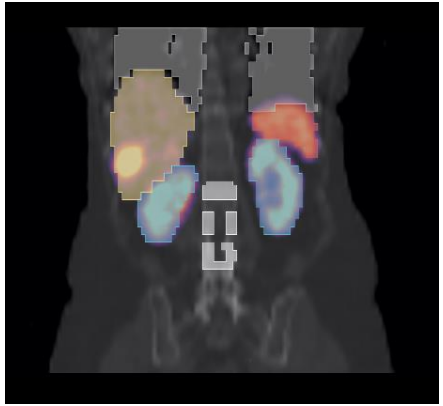
Segmentations Share improvement between OD3D and PLANET® Dose



Share VOIs

- ✓ Same volume
- ✓ One time point
- ✓ No Registration
- ✓ No Propagation of VOIs
- ✓ No Time integration



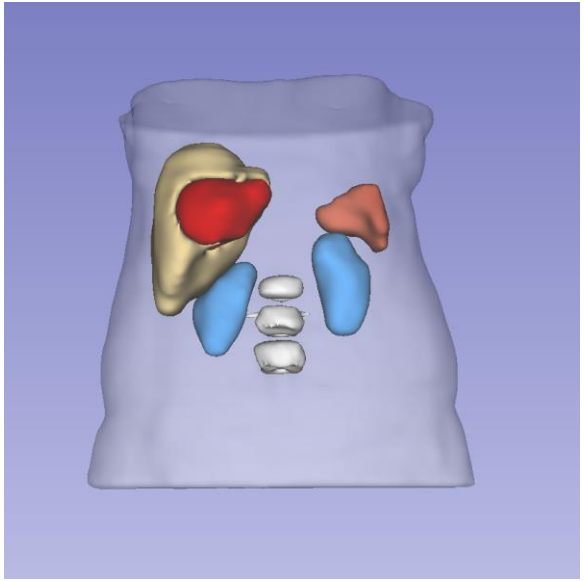


	VOIs	Total activity (MBq)	Activity Concentration (MBq/cm3)
Self irradiation	Healthy Liver	331.64	0.25
	Spleen	62.01	0.48
	Kidney	188.51	0.50
	Anterior Lesion	224.91	0.93
Cross irradiation	Bone Marrow	8.19	0.05

Comparison of Average ADR results for DVK Convolution and Monte Carlo

VOIs	Activity Concentration (MBq/cm3)	Relative Difference %	
Monte Carlo		***LED***	***DVK Convolution***
Soft Tissue	0.25 – 0.93	-5%	-2%
Bone Marrow	0.05	-25%	-11%

VOIs	Activity Concentration (MBq/cm3)	Relative Difference %	
		DVK Convolution	
Monte Carlo		***PLANET® Dose***	***OpenDose3D***
Soft Tissue	0.25 – 0.93	-2%	-1%
Bone Marrow	0.05	-10%	-11%



VOIs	Volume [cm3]	Average absorbed dose rate (mGy/h)
Monte Carlo		
Spleen	128.06	41.6
Bone Marrow	155.48	5.3

Conclusions

- Using Schneider calibration function the observed differences were reduced. The difference for LED with media density correction decreased from 4% to 1%.
- In the final comparison of convolution vs. direct Monte Carlo simulations, a good agreement was obtained for soft tissues (around 2% of difference at maximum).
- In bone marrow (one of the most complex case: mainly cross-irradiation contribution and higher impact of densities) a larger difference was expected and noted (about 11%).
  ➔ Evaluation of increasing the kernel size and optimization/other way to deal with density management (tradeoff between accuracy/computation time for clinical use).
- This work validates the absorbed dose computation approaches implemented in the 2 software in the context of ^{177}Lu-based radiopharmaceutical therapies.
- It will be further extended to other isotopes (e.g. ^{131}I), and the accuracy of other steps of the CDW will also be evaluated.

www.dosisoft.com