Clinical implementation of a Monte Carlo based treatment plan QA platform for validation of Cyberknife and Tomotherapy treatments

A. Wagner[1], Y. Jourani[2], F. Crop[1], T. Lacornerie[1], F. Dubus[1], E. Rault[1], P. Comte[1], R. Cayez[1], C. Boydev[1], T. Sarrazin[1], N. Reynaert[1,2]

[1]Medical Physics department, Centre Oscar Lambret, Lille
[2]Medical Physics department, Institut Jules Bordet, Brussels

Plan

- Introduction (why do we need it ?)
- Moderato system
  - Principles and architecture
  - Machine modelling
  - Interface and practical use
- Clinical applications
  - Comparison with TPS
  - Advanced features : standardized prescription, plan validation, delivered dose reconstruction, MRI-only calculation
- Conclusions and future evolution

1 Introduction

1 Introduction

- Independent MU verification
  - In France there is a legal obligation of independent verification of the monitor units (Critères d'agrément Inca 2008)
  - In practice conformal 3D plans are systematically verified using commercial (eg IMSure) or in-house systems, that provide a single-point verification

But:

- Lack of available and accurate tools for the recalculation of a complete 3D dose distribution of more complex techniques : IMRT, VMAT, SBRT !

1 Introduction

- Aim
  - Develop a powerful and **« clinically usable »** dose verification system for Tomotherapy and Cyberknife
  - No additional tasks shoud be introduced to the dosimetry department !

→ It has to be **user-friendly**, **fast**, and as **automated** as possible

2 Moderato system

2 Accelerator modelling

- Cyberknife
  - The 12 sizes for the fixed and iris collimators were modelled[1]
  - Phase-space files were pre-calculated and stored in Moderato

    → No particle transport in the head : the system reads the phase-space below the chosen collimator

  - More recently the Cyberknife M6 collimator (including a MLC) was modelled as well

[1] Wagner A, Crop F, Lacornerie T, Vandevelde F, Reynaert N. Use of a liquid ionization chamber for stereotactic radiotherapy dosimetry. Phys Med Biol. 2013; 58(8):2445-59

2 Accelerator modelling

- Tomotherapy
  - Double Gaussian spot[2] to obtain agreement between measurements and MC calculations for all field sizes (1.0, 2.5, 5.0 cm)
  - Dynamic Jaws and TomoDirect were included as well
  - Transport in the MLC can be performed using 2 options :
    - **Full MC**
    - **RayTracing** : total distance in tungsten used to calculate an exponential attenuation factor for use in Russian roulette

      → **faster** !

→ Distributions for full MC and RT are almost identical (less scatter due to binary MLC)

[2] Chen Q, Chen Y, Chen M, Chao E, Sterpin E, Lu W. A slit method to determine the focal spot size and shape of TomoTherapy system. Med Phys. 2011; 38(6):2841-9

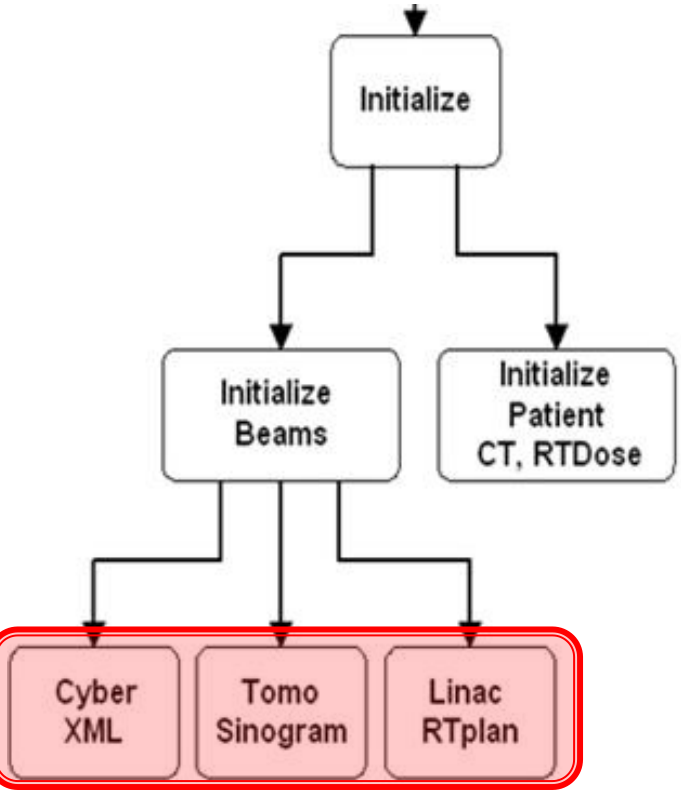
2 Moderato system

- Originally based on *MCDE* *(Monte Carlo Dose Engine)*
  - System developed in Ghent university in 2004[3]
  - Based on BEAMnrc and DOSXYZnrc
  - The phantom (or patient) reprogrammed as a component module (CM) introduced at the bottom of the linac head
  - Slow and not very flexible (QA specific modifications applied inside BEAMnrc/DOSXYZnrc)

[3] Reynaert N, De Smedt B, Coghe M, Paelinck L, Van Duyse B, De Gersem W, De Wagter C, De Neve W, Thierens H. MCDE: a new Monte Carlo dose engine for IMRT. Phys Med Biol. 2004; 49(14):N235-41

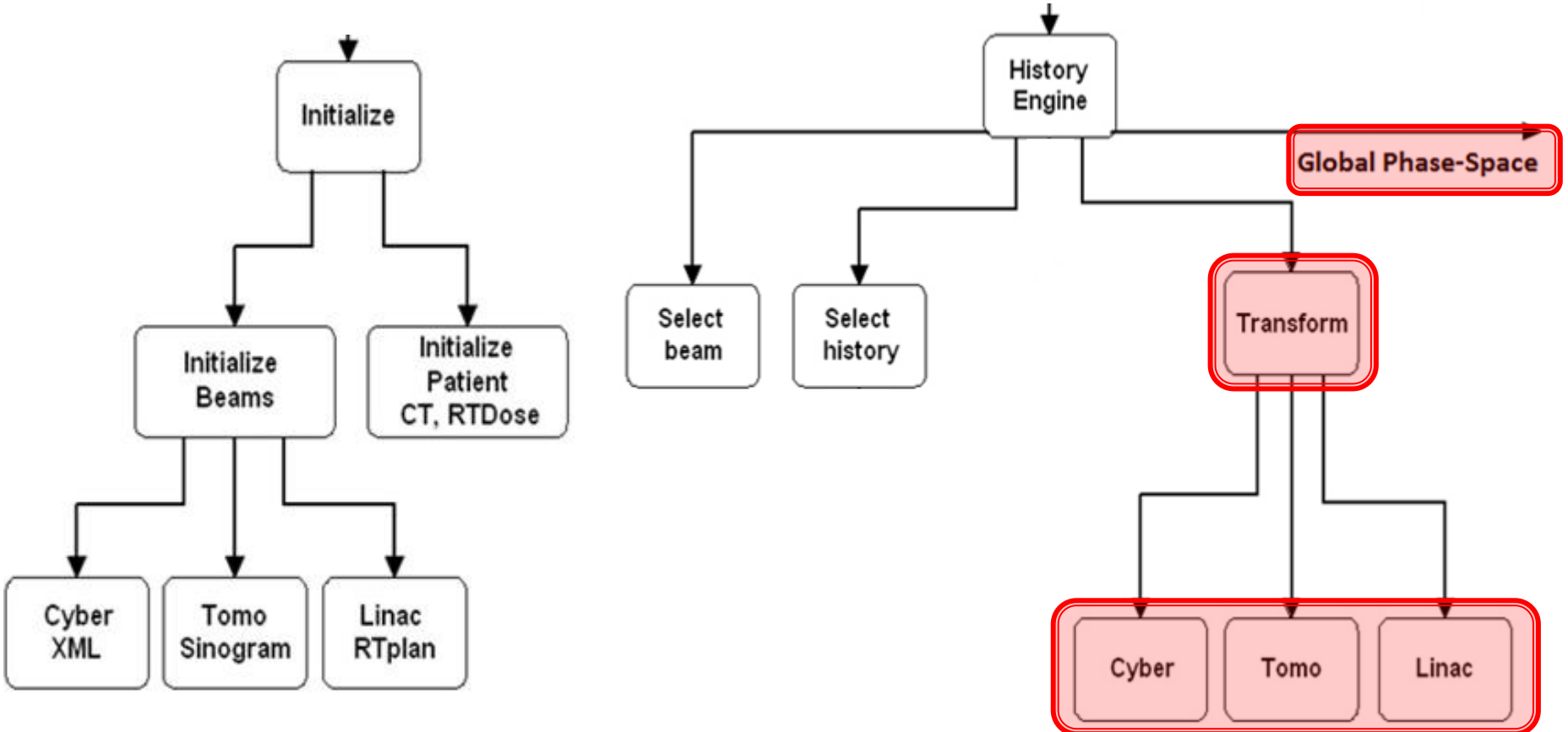
Moderato system : process

- Initialize geometry and BEAMnrc input files using the DicomRT or XML files imported from the TPS



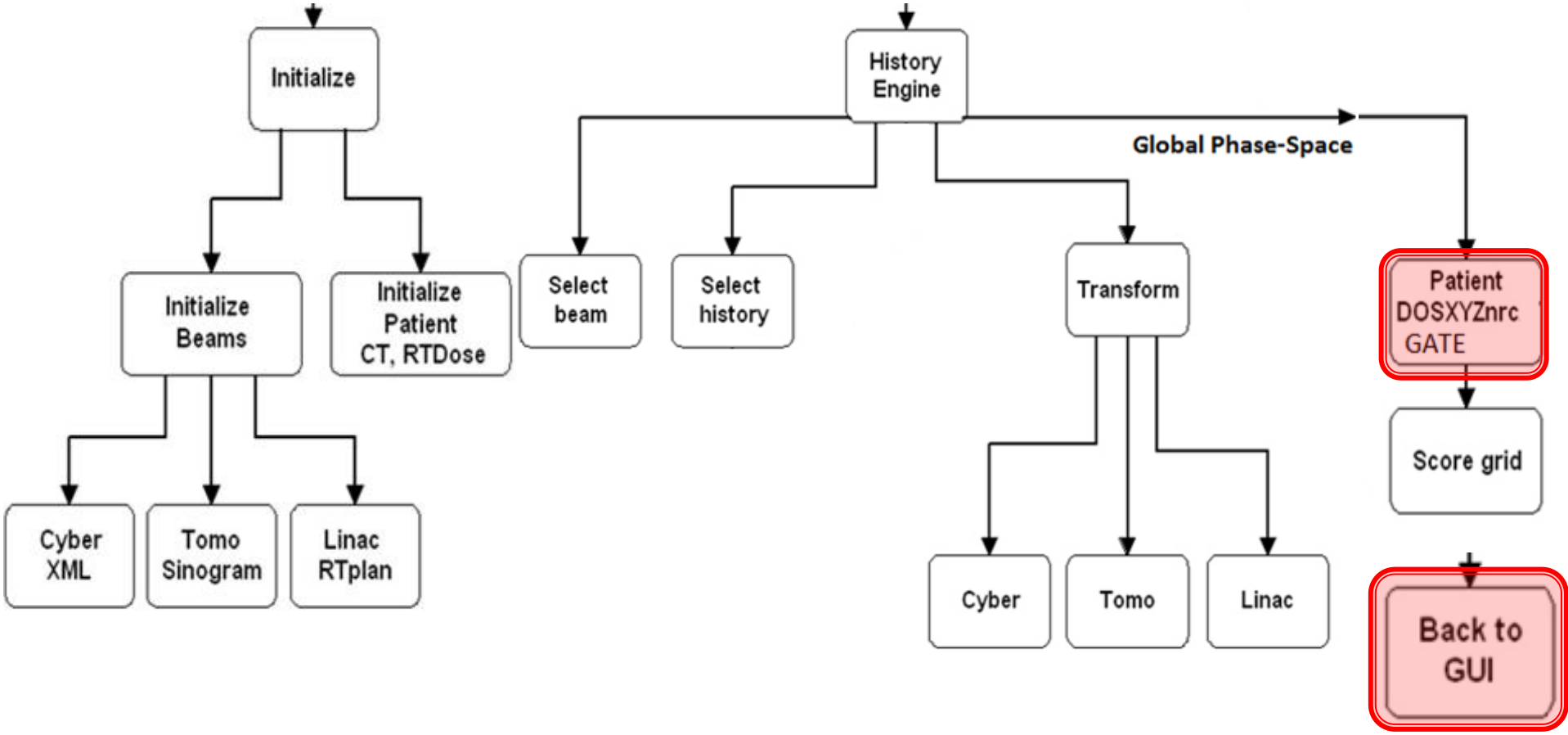
Moderato system : process

- Generate a global phase-space file that combines particles from all beams (cylindrical phase-space surrounding the patient)



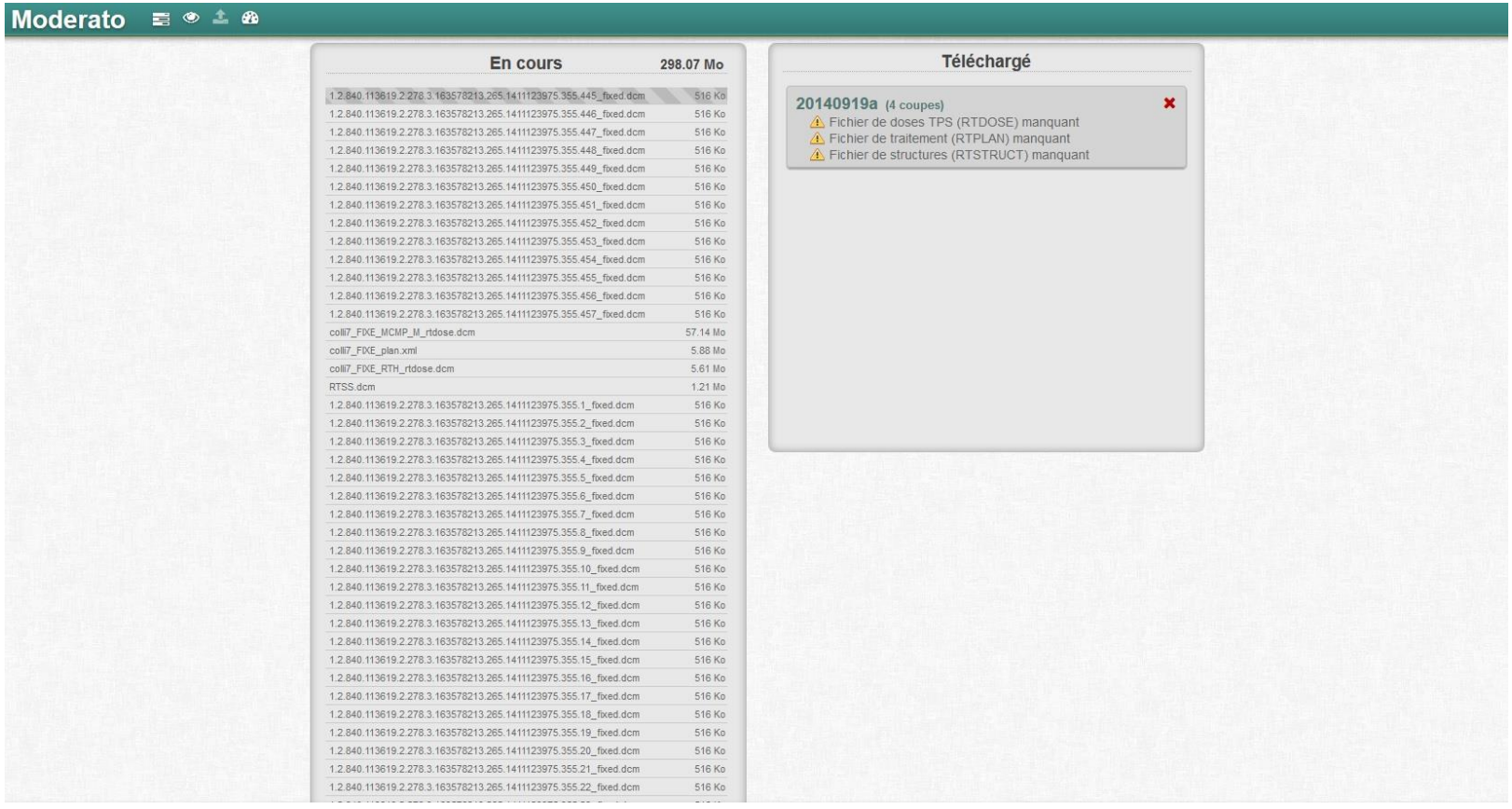
Moderato system : process

- Perform the dose calculation in the patient geometry, combine the obtained dose files and display the results in the GUI



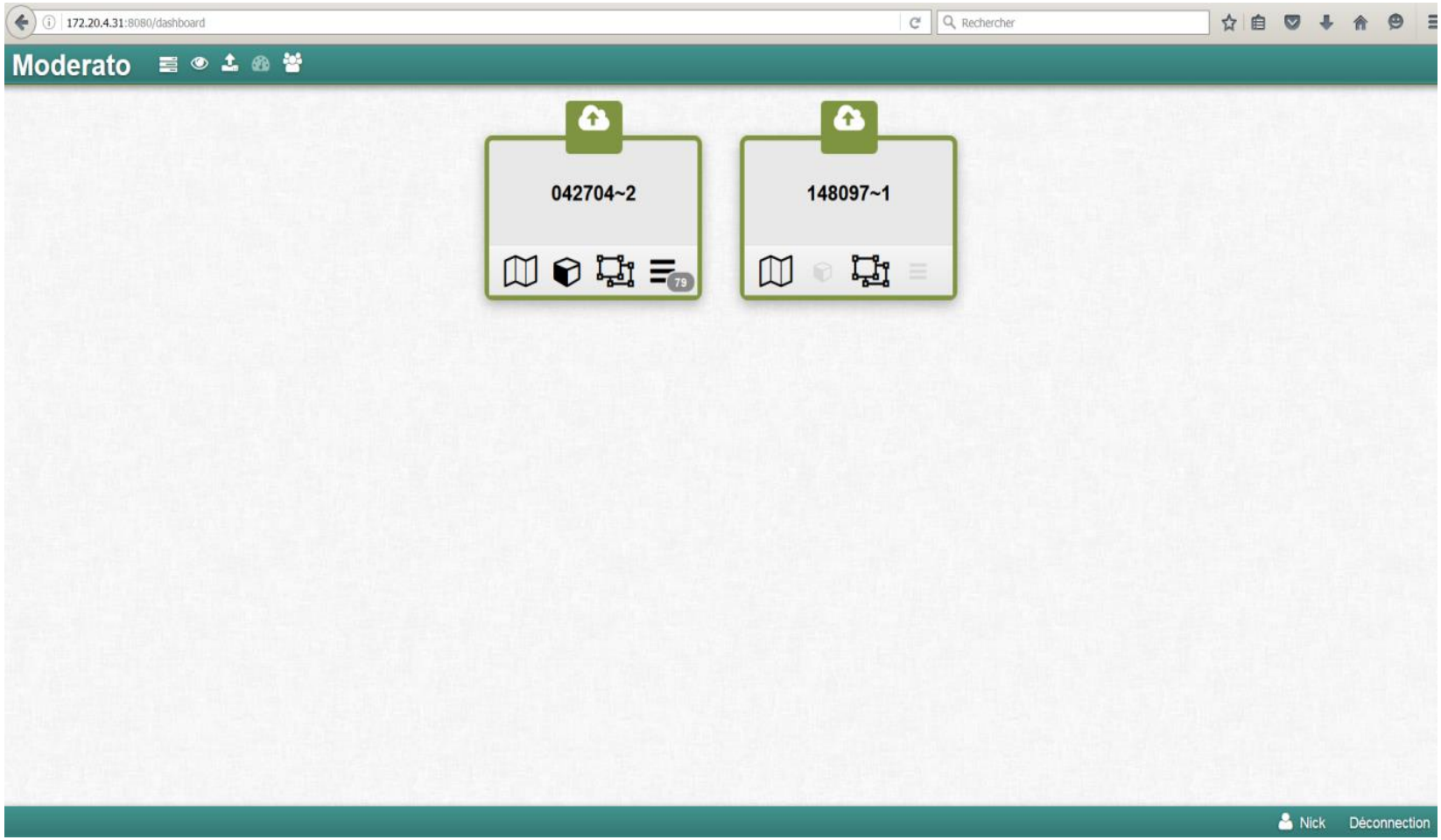
2 Interface and practical use

- Once a plan is finalized, it is exported to Moderato
- The *Dropbox* directory is continuously scanned
- MC calculation automatically launched once all data are present



2 Interface and practical use

- the status of all cases can be visualized in the *Dashboard* (this display also shows if any files are missing)



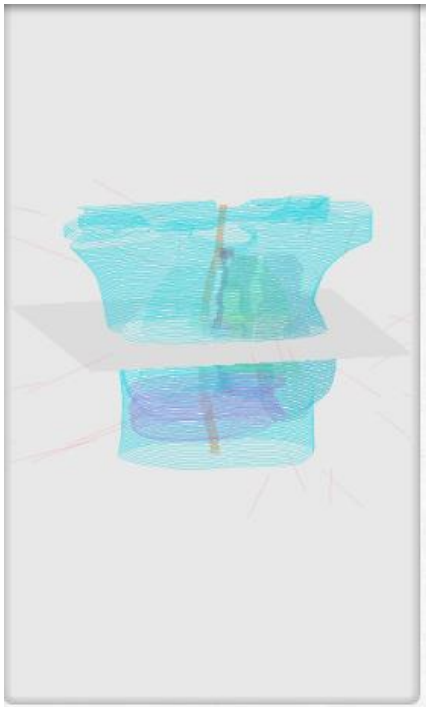
2 Interface and practical use

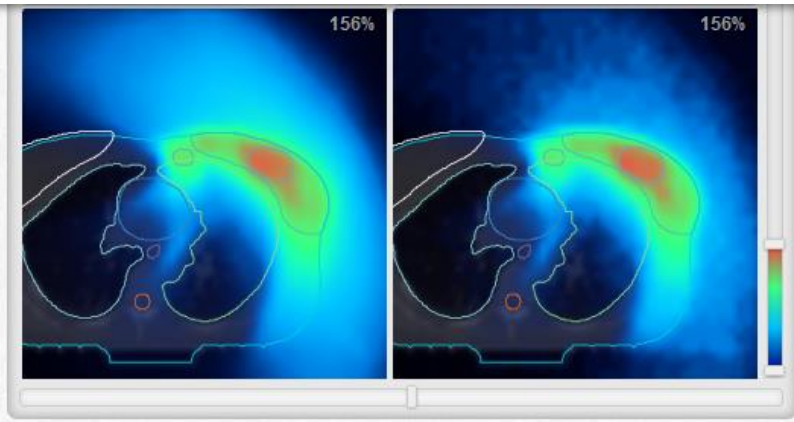
- When calculation is over : patient appears as ready for validation in the patient workflow system (RTFlow ™)

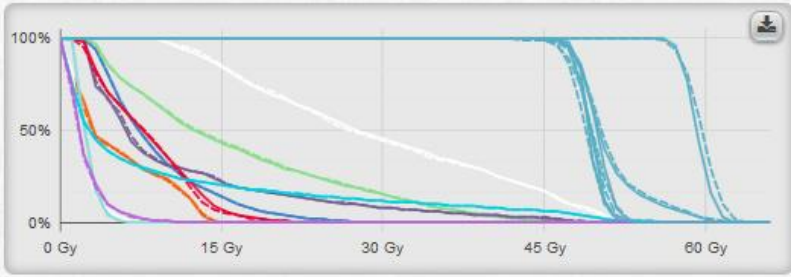
2 Interface and practical use

- The user can visualize the isodoses and DVH data (*Visualization* pane), with a table containing relevant dose points for all organs

- This report is automatically included in the R&V and signed by the physicist and physician







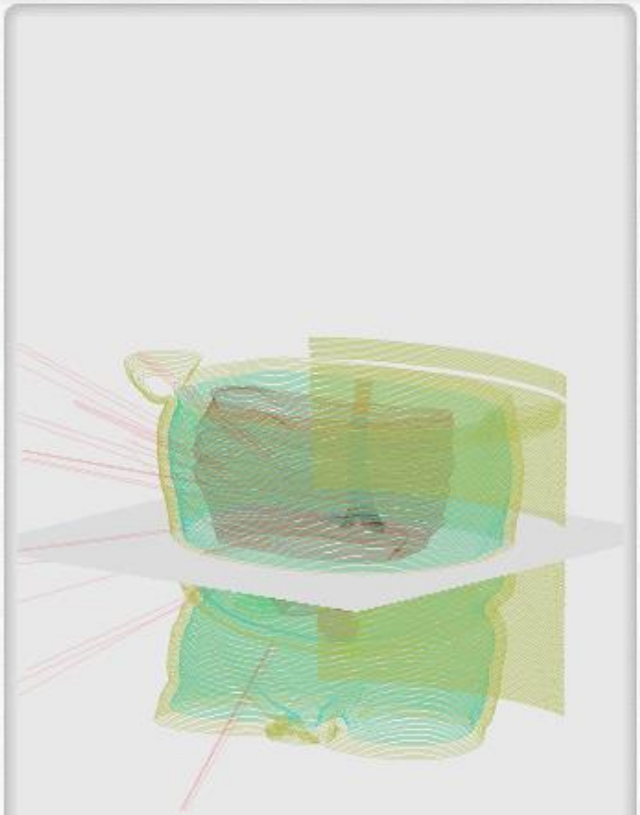
couleur	nom	moy (Gy)		max (Gy)		volume (%)		dose (Gy)	
☑	coeur	8.8		31.8	32.1	100.0	100.0	2.0	2.0
☐	coeur--2cm	20.2	20.3	32.4	32.8	100.0	100.0	9.0	10.0
☐	coeur--5cm	11.2		28.9	29.7	100.0	100.0	2.0	2.0
☐	coeur--ext	5.9	5.8	15.9	16.1	100.0	100.0	2.0	2.0
☐	CTV boost sein G	60.1	60.4	62.8	64.4	100.0	100.0	58.0	56.0
☐	CTV CMI G	50.4	50.3	52.7	54.5	100.0	100.0	48.0	47.0
☐	CTV sein G	50.5	50.3	62.7	65.8	100.0	100.0	40.0	34.0
☐	CTV sousclav G	49.5	49.7	52.9	59.4	100.0	100.0	48.0	46.0
☐	CTV susclav G	49.2	48.9	51.9	52.9	100.0	100.0	46.0	45.0
☐	external	9.5	9.4	61.4	61.2	100.0	100.0	0.0	0.0
☑	foie	2.2	2.1	16.5	16.3	100.0	100.0	0.0	0.0
☑	Internal	9.5		62.0	63.7	100.0	100.0	0.0	0.0

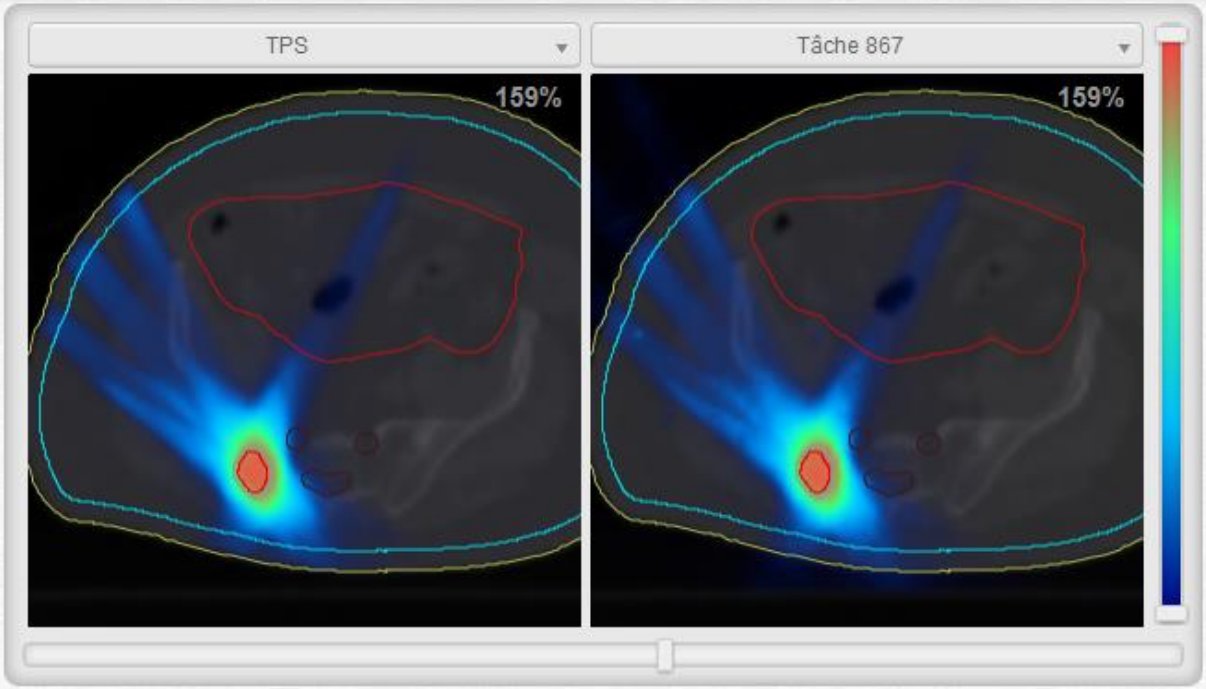
3 Clinical Applications

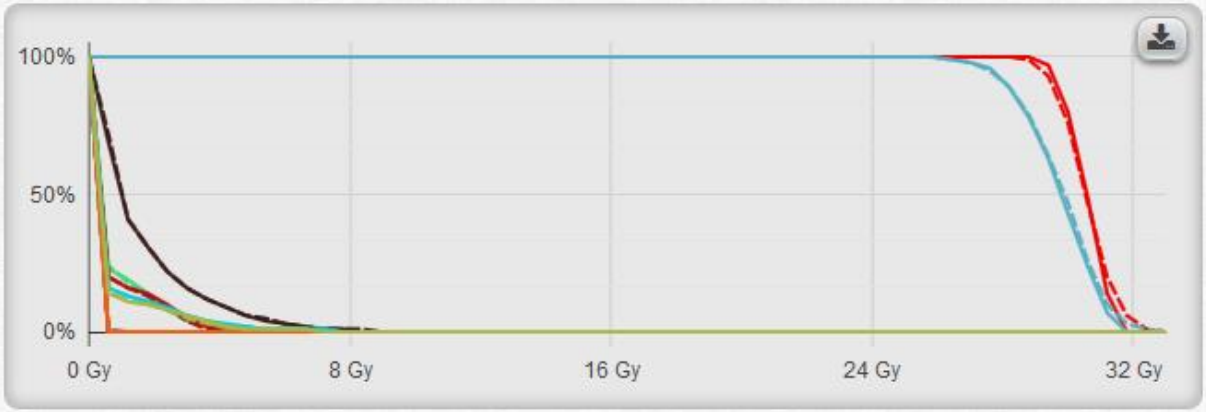
3 Results

- Cyberknife
  - The Cyberknife TPS (Multiplan) includes two different algorithms : RayTracing and Monte Carlo.
  - RT is used for most treatments, except lung
  - Excellent agreement between Multiplan dose distributions and Moderato in most cases

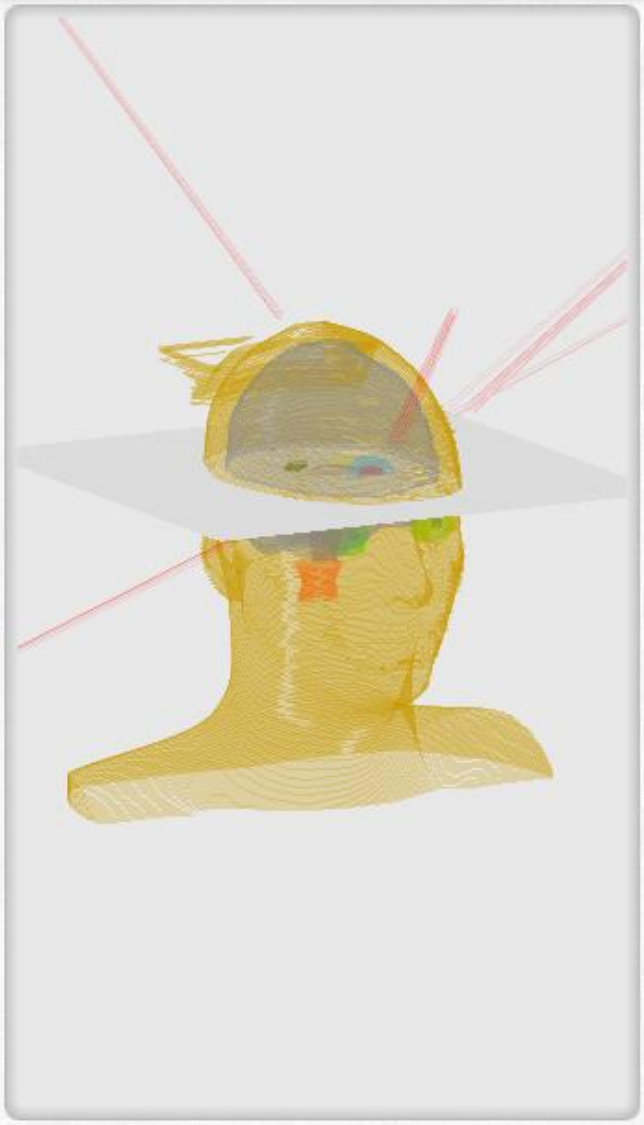
3 Results

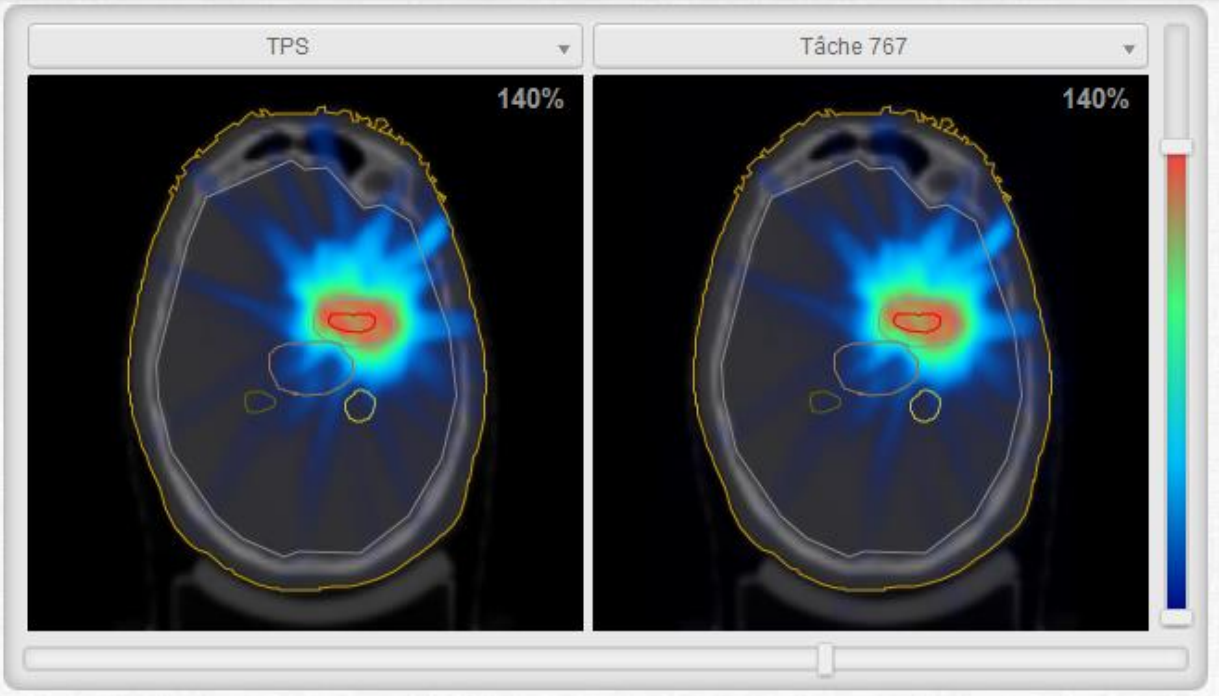


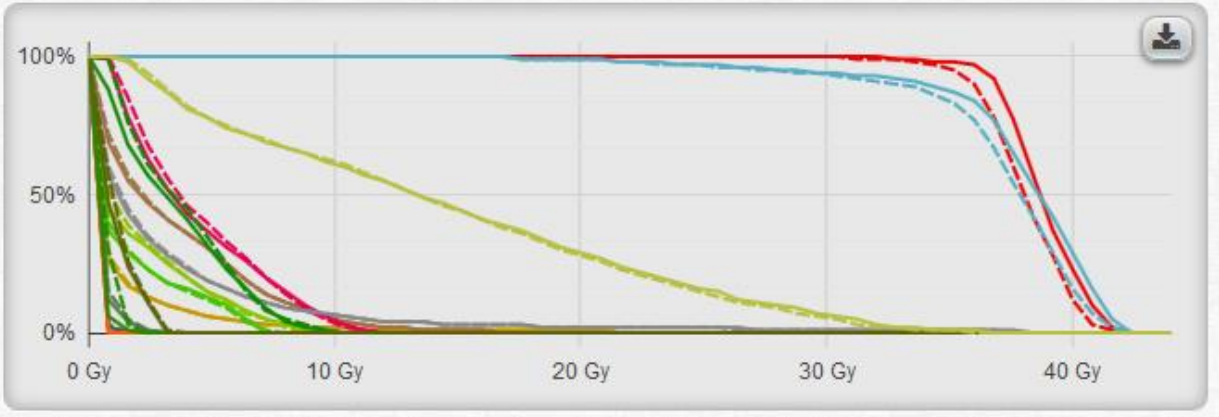




3 Results

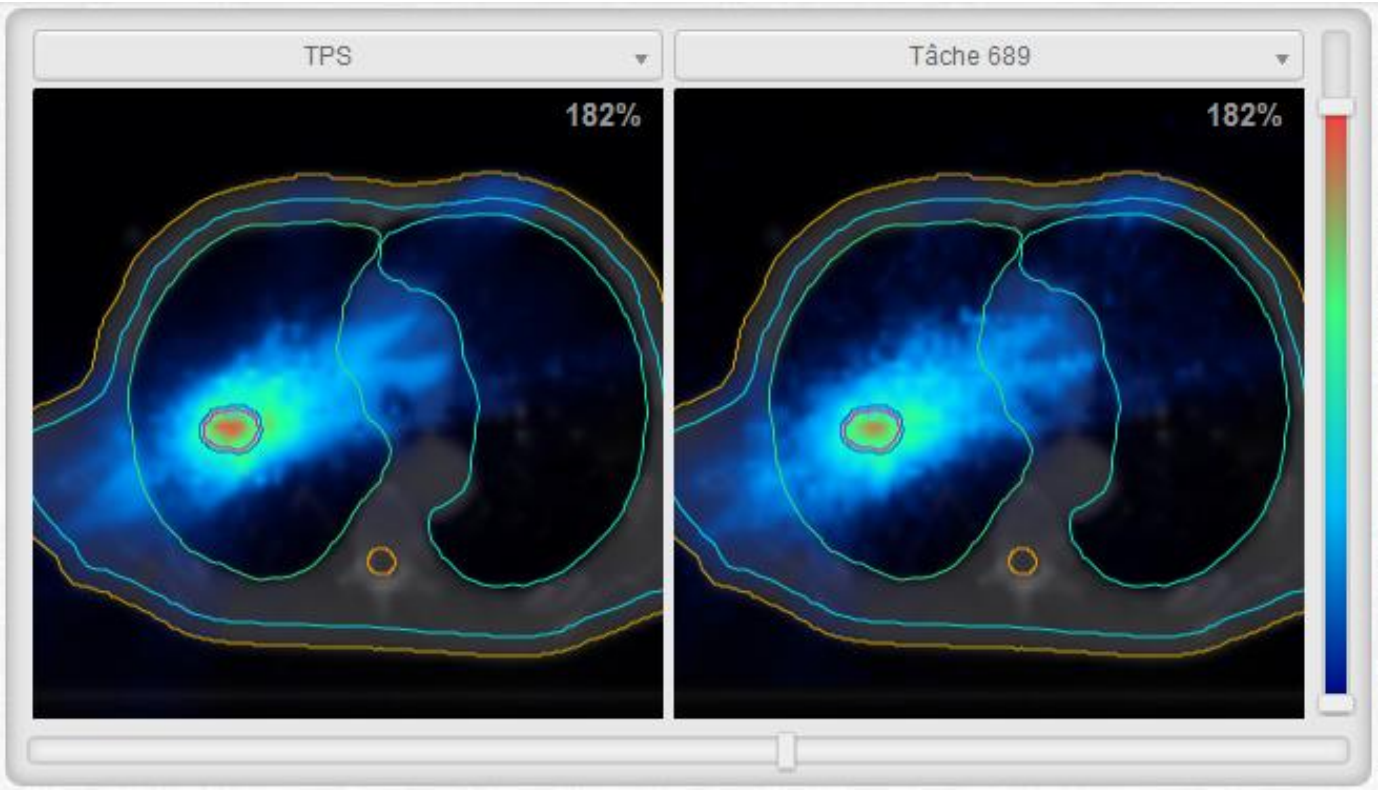


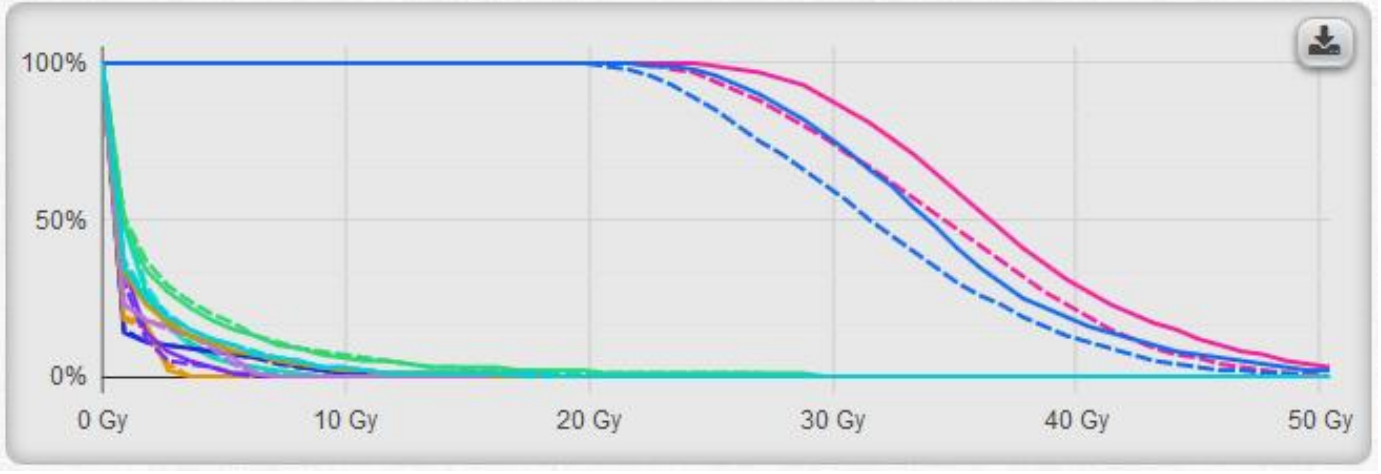




3 Results

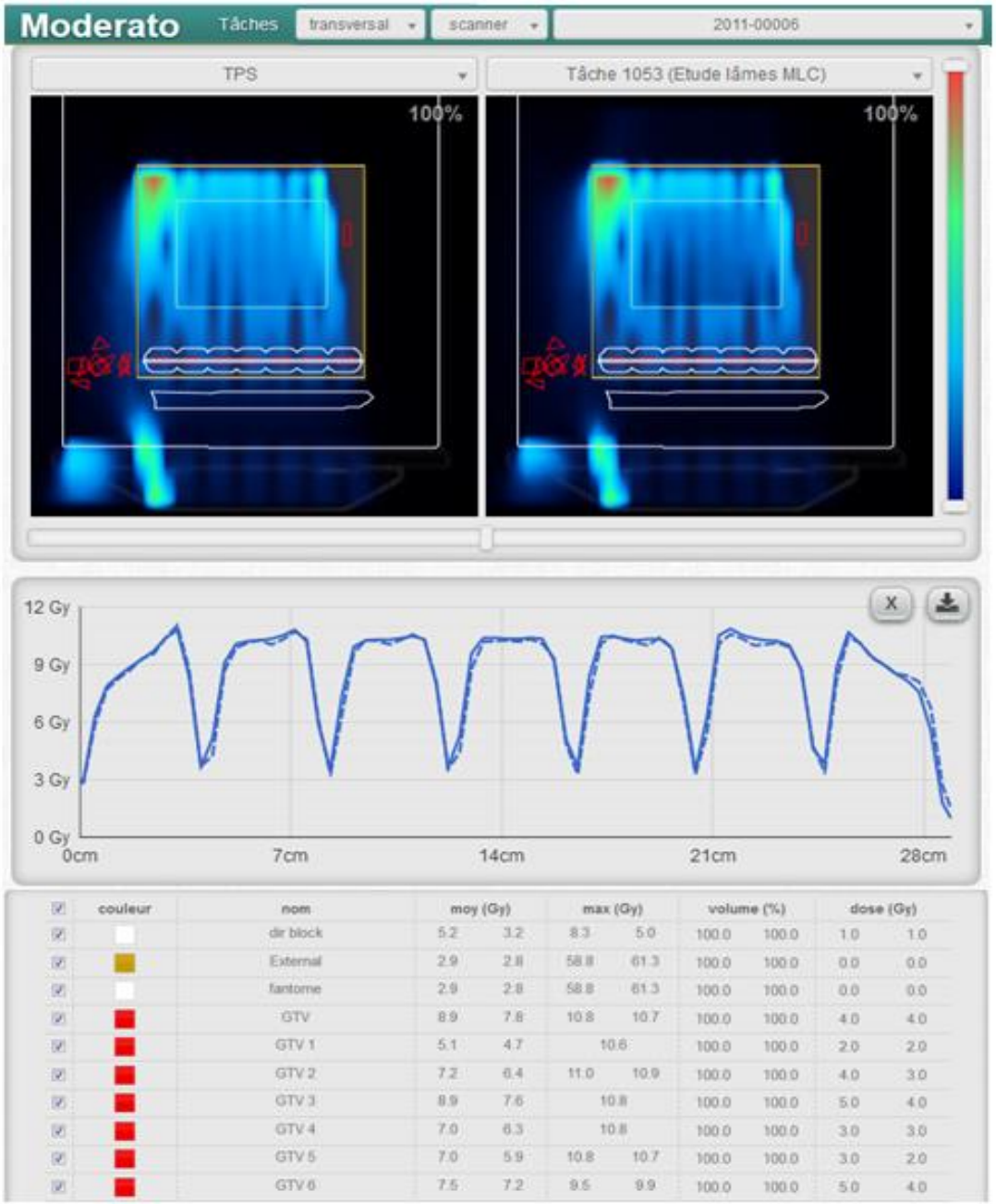
- small lung tumors surrounded by low density lung tissue
- due to different energy cut-off value for the secondary electron transport





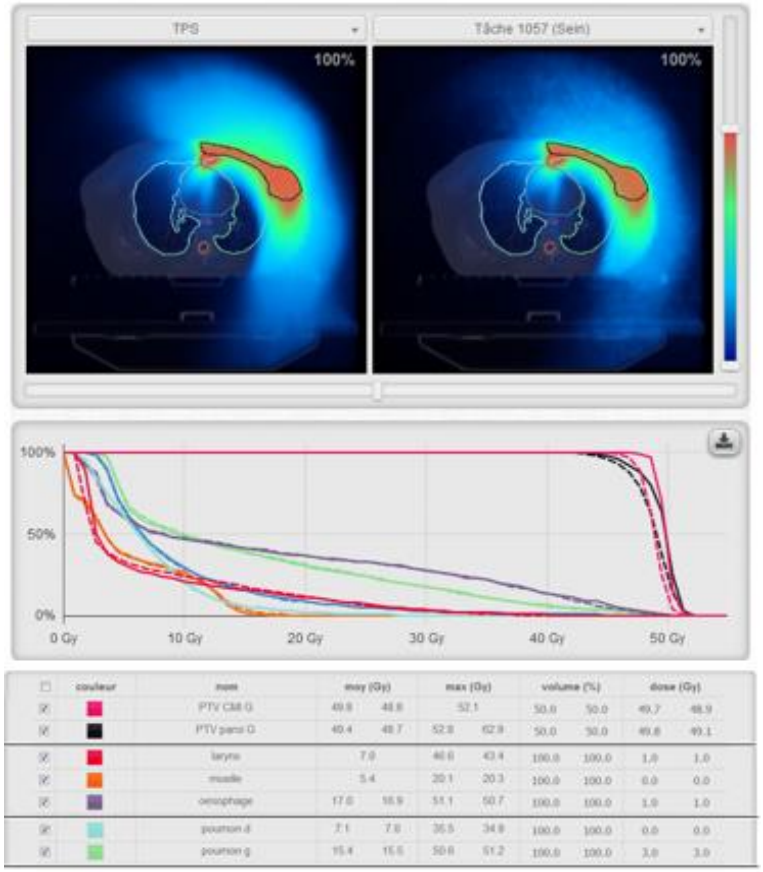
3 Results

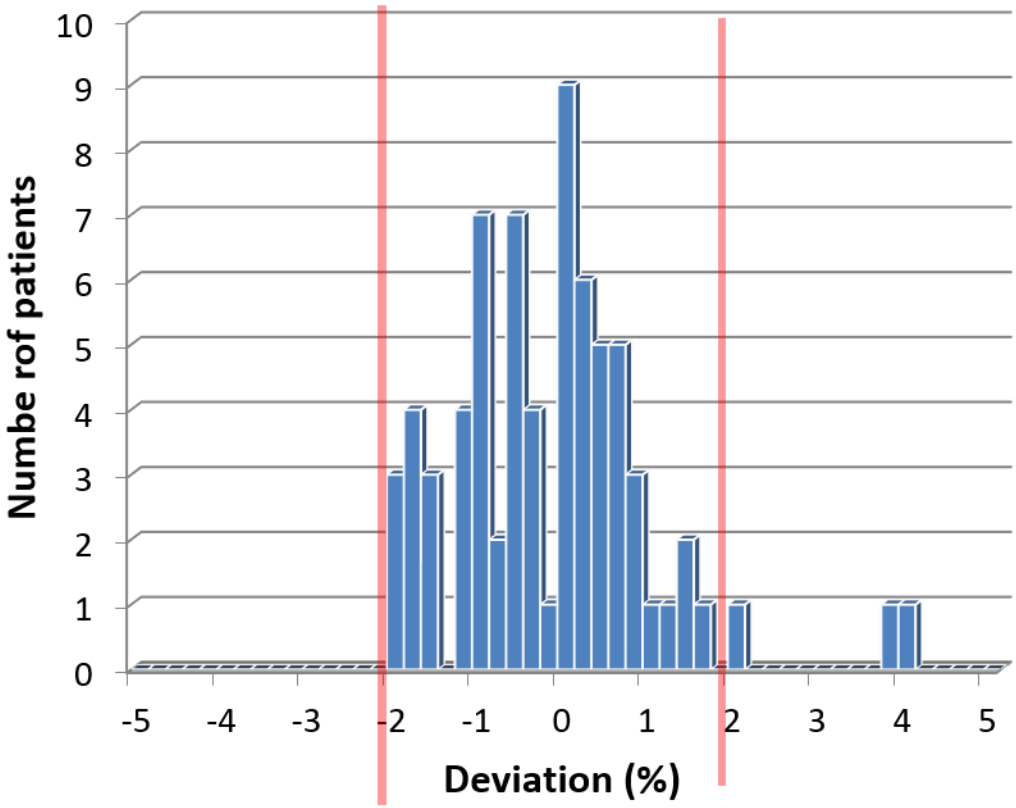
- Tomotherapy
  - Picket fence test : 7 GTVs with OARs between to force the system to close intermediate leaves



3 Results

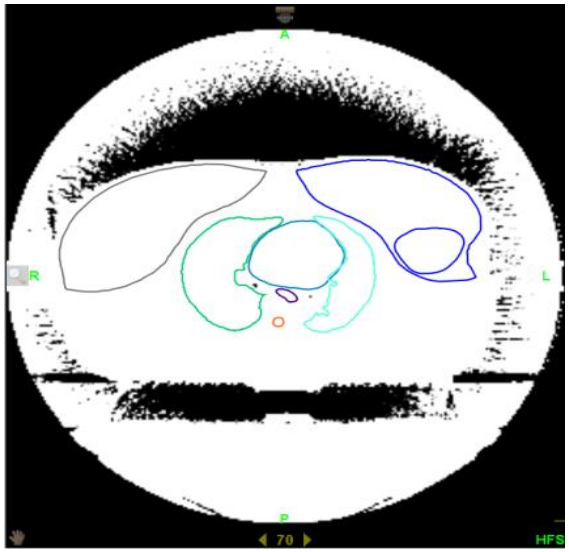
- Patients : excellent agreement for 23 patients with different indications (within 2 % for all but one case)

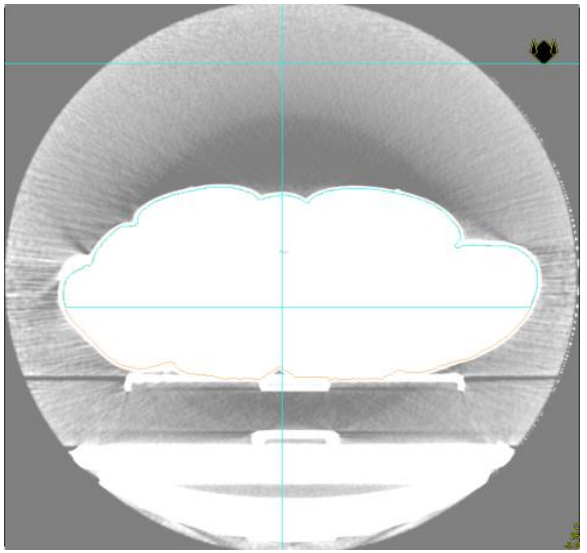




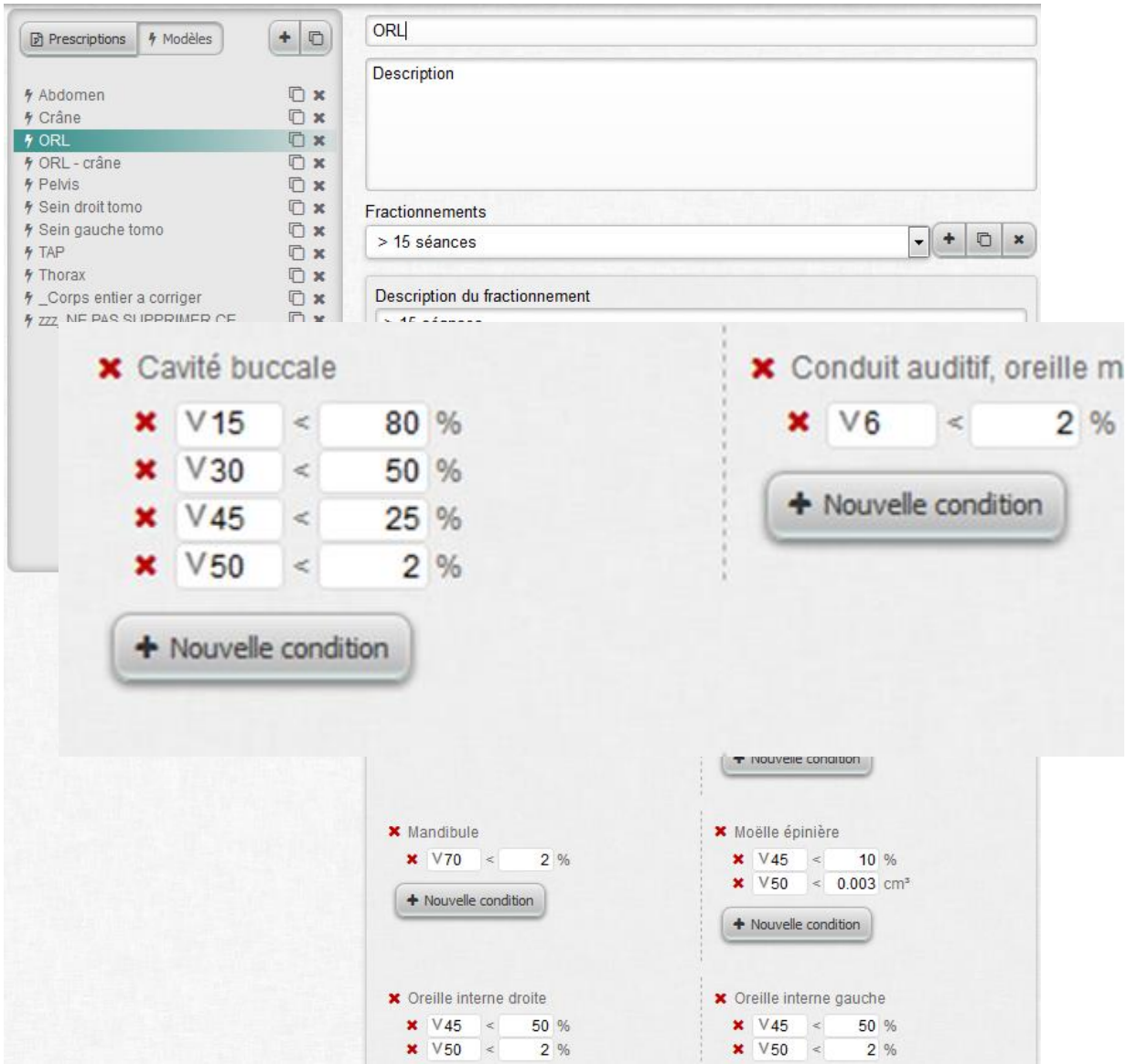
3 Results

- Large difference detected for a specific breast case
- Inspecting the scan revealed a high CT reconstruction diameter (70 cm) with an artifact surrounding the patient (air voxels with a density > 0.1 g/cm^3)
- Removing this artifact restored the agreement between both algorithms

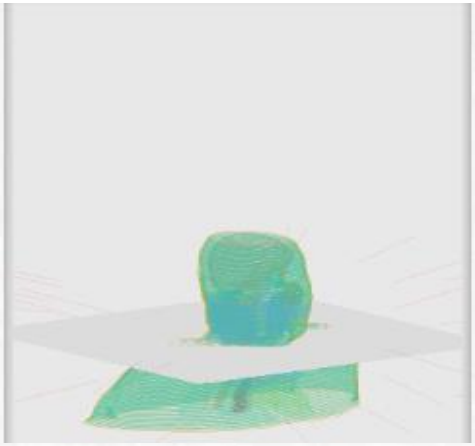


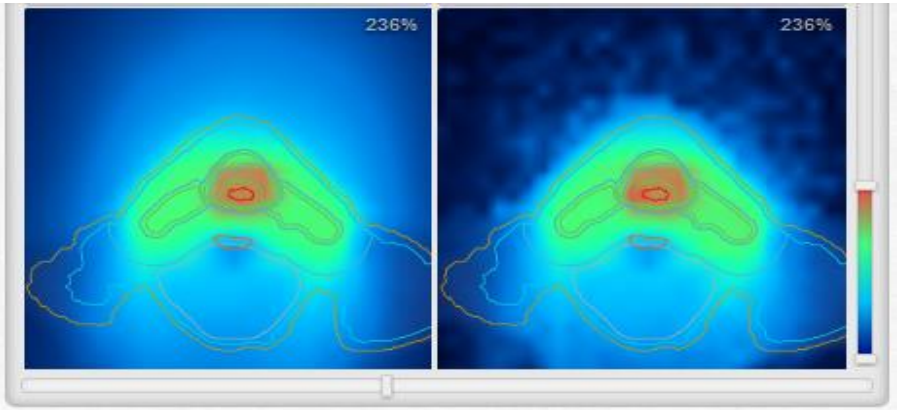


3 Standardized prescription



3 Plan validation





	tps	task1787
Cavité buccale		
V15 < 80%	18.3 Gy	18.2 Gy
V30 < 50%	23.8 Gy	23.8 Gy
V45 < 25%	29.3 Gy	29.3 Gy
V50 < 2%	42.0 Gy	43.0 Gy

	tps	task1787
Thyroïde		
V50 < 50%	52.2 Gy	52.3 Gy

	tps	task1787
Articulation temporo-mandibulaire gauche		
V55 < 2%	2.5 Gy	2.2 Gy

	tps	task1787
Encéphale irradiation partielle		
V60 < 10cm³	3.4 Gy	2.9 Gy

Moëlle épinière		
V45 < 10%	19.5 Gy	19.7 Gy
V50 < 0.003cm³	27.1 Gy	27.9 Gy

Oesophage		
V45 < 40%	2.5 Gy	2.3 Gy
V55 < 30%	3.4 Gy	3.0 Gy

Oreille interne droite		
V45 < 50%	1.9 Gy	1.5 Gy
V50 < 2%	2.1 Gy	1.9 Gy

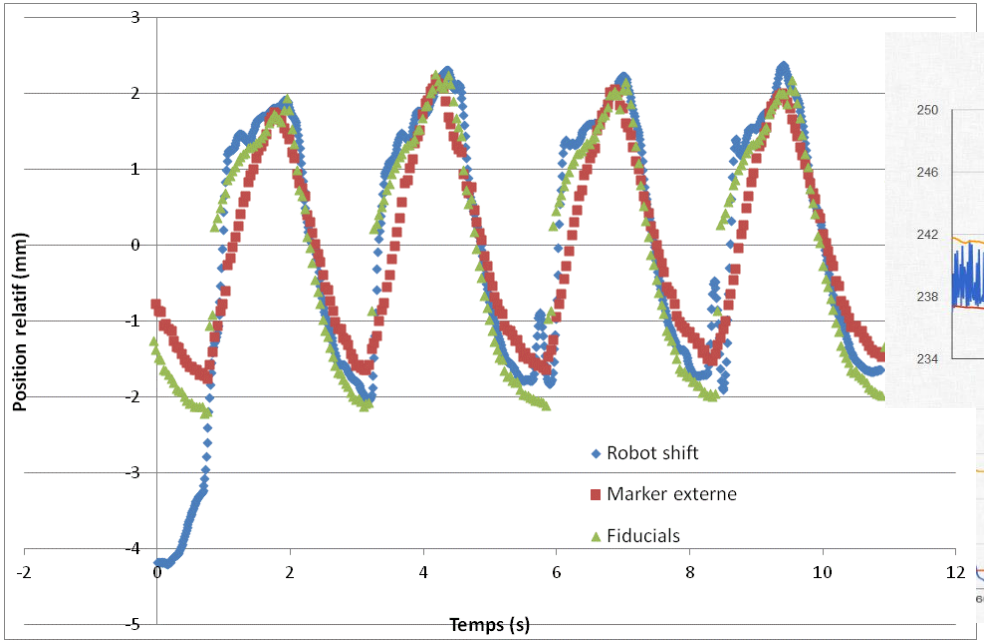
[4] Wagner A, Crop F, Mirabel X, Tailly C, Reynaert N. Use of an in-house Monte Carlo platform to assess the clinical impact of algorithm-related dose differences on DVH constraints. Phys Med. 2017 (in press)

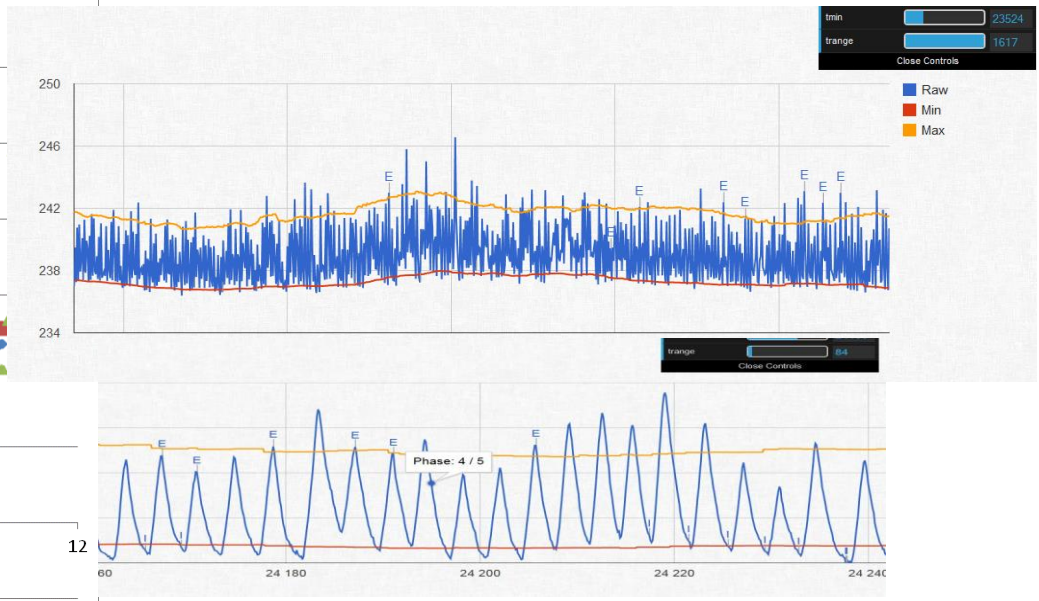
3 Delivered dose reconstruction

- Cyberknife
  - *Synchrony* treatments : construction of a correlation model between external markers and internal fiducials to treat moving targets (lung, liver)

3 Delivered dose reconstruction

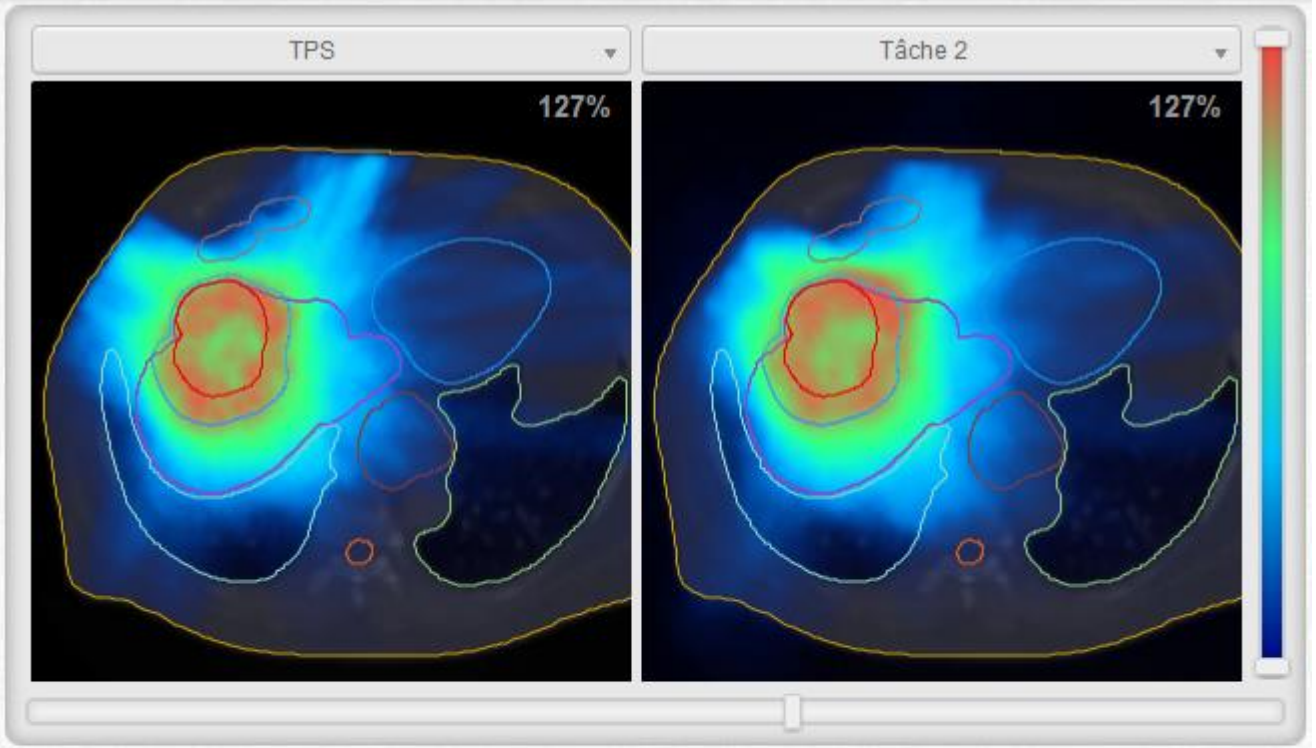
- The log files containing the actual positions of the robot and of the internal and external markers can be used in conjunction with the planning 4D-CT images to reconstruct the dose actually delivered during treatment



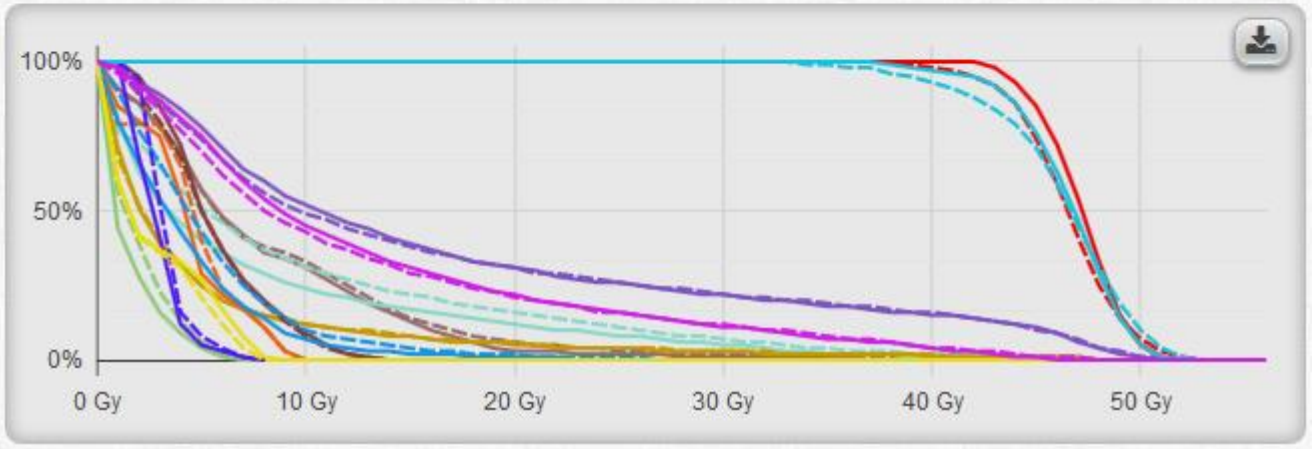


3 Delivered dose reconstruction

- Liver case : comparison of planned and delivered dose

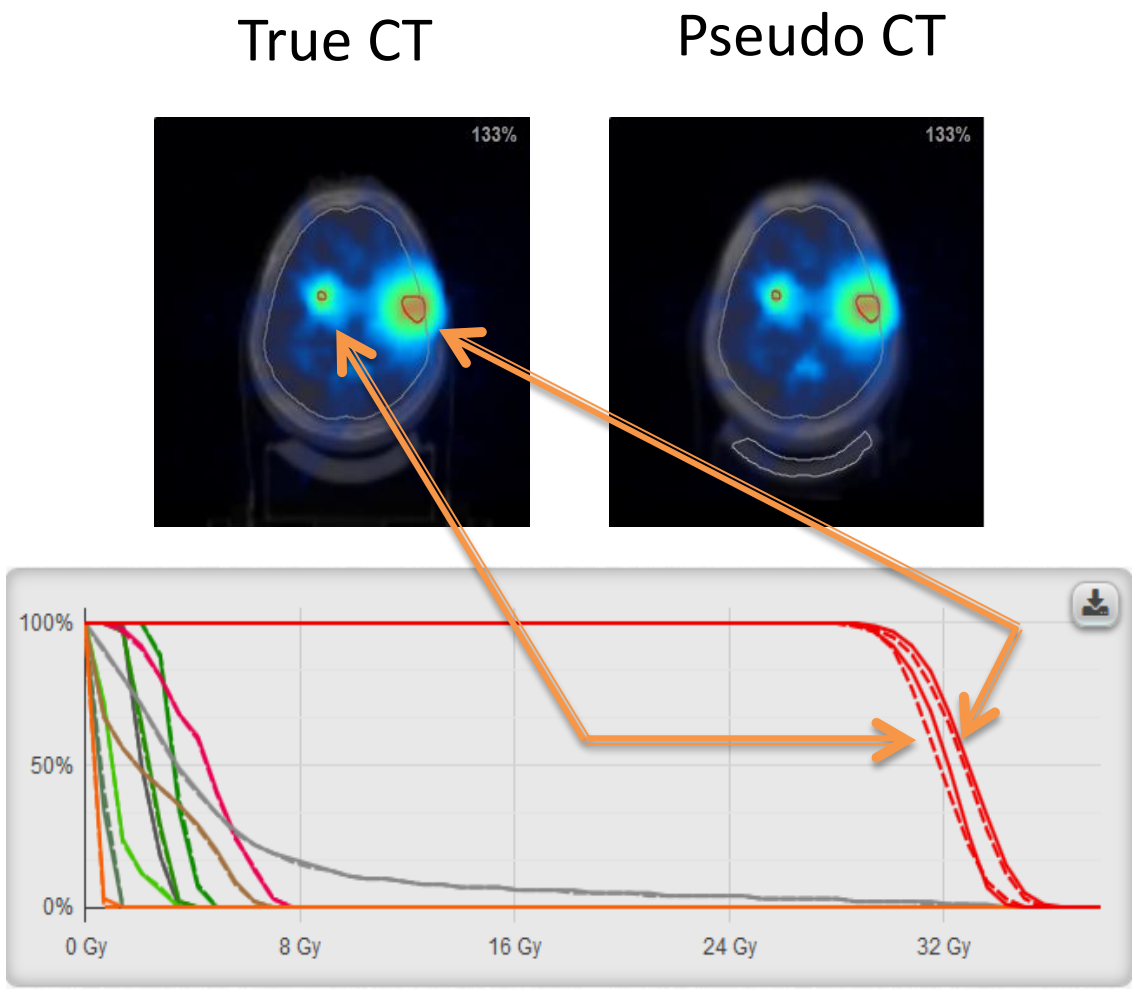


- The use of a treatment belt for all liver treatments limits the motion



3 Dose calculation on MRI

- MRI allows more accurate target volume delineation
- Moderato is used to compare dose distributions calculated using MRI and CT



4 Conclusions

4 Conclusions

- Moderato system
  - independent platform offering accurate dose verification for advanced delivery techniques
  - Fast and user-friendly (web page access, automation of the process)

    → allows for a use in the clinical routine
  - It has a cool name
  - Despite the small number of patients tested so far, detection of an IVDT problem for a large CT recon diameter

4 Conclusions

- Evolution
  - Introduce the linacs used in both centers
  - Further automation of the process
    - Introduce PTV and OAR constraints for more cases
    - Allows Moderato to « validate » the plan quality or highlight constraint violations in the GUI
  - Focus on *actually delivered dose* using treatment session information (daily images, log files, reconstructed sinograms, cone beam CT, 4D MRI ?)

    → Replacing planned by delivered dose can be linked to clinical outcome and toxicity data!

UNICANCER

Centre Oscar Lambret
Centre Régional de Lutte contre le Cancer

INSTITUT JULES BORDET

Thank you !