

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

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P 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 should 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 modelled¹
 - 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, Vandeveld 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 spot² 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

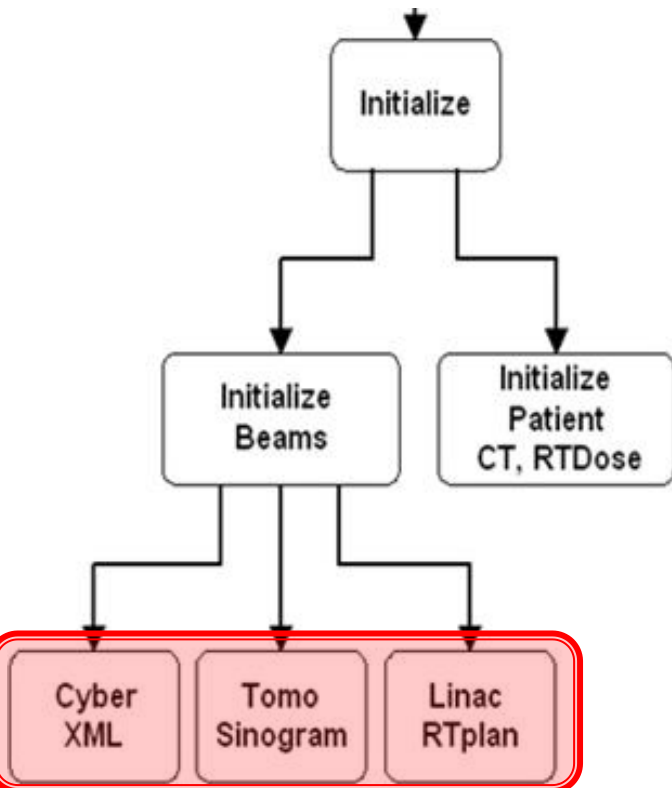
2 Moderato system

- Originally based on *MCDE* (*Monte Carlo Dose Engine*)
 - System developed in Ghent university in 2004³
 - 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

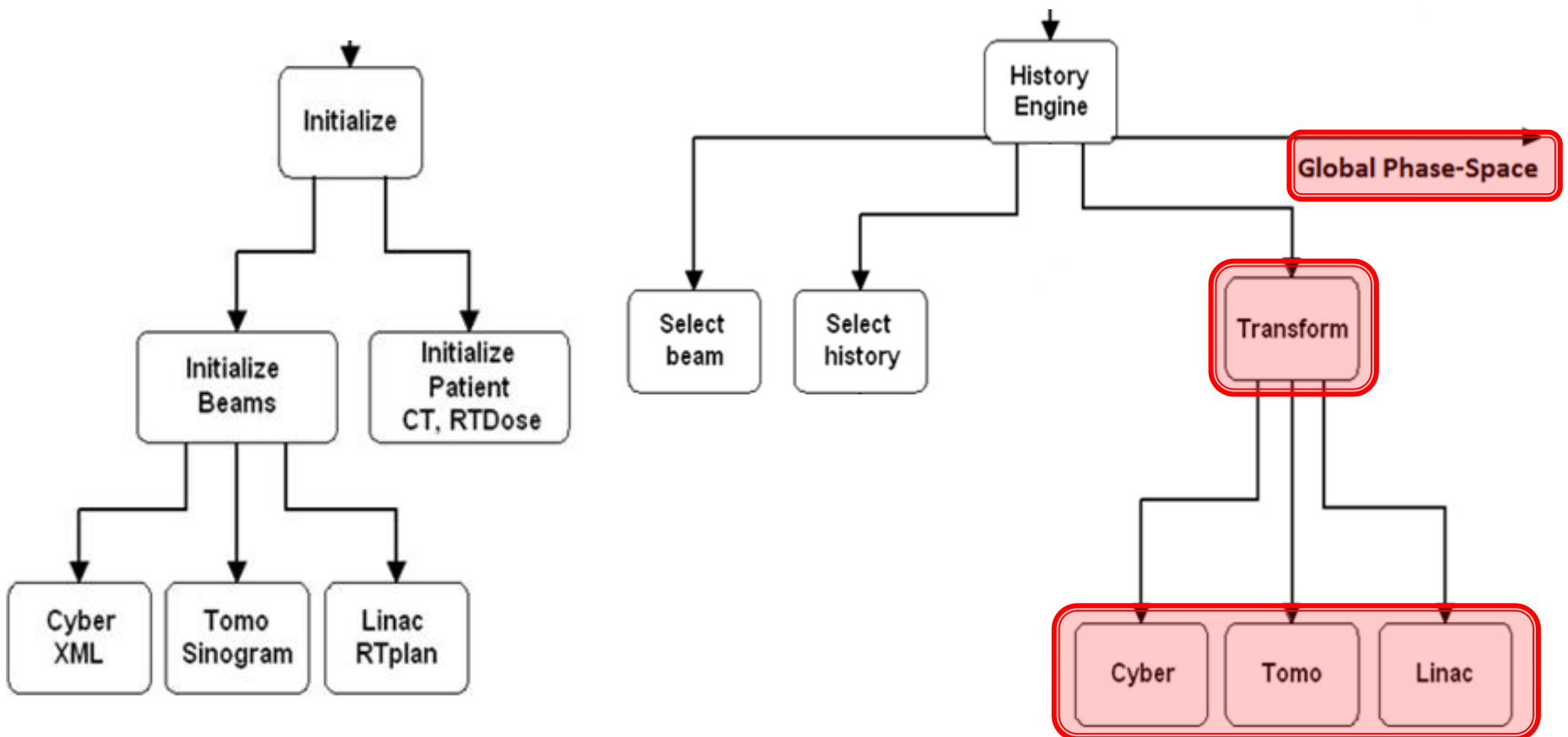
2 Moderato system : process

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



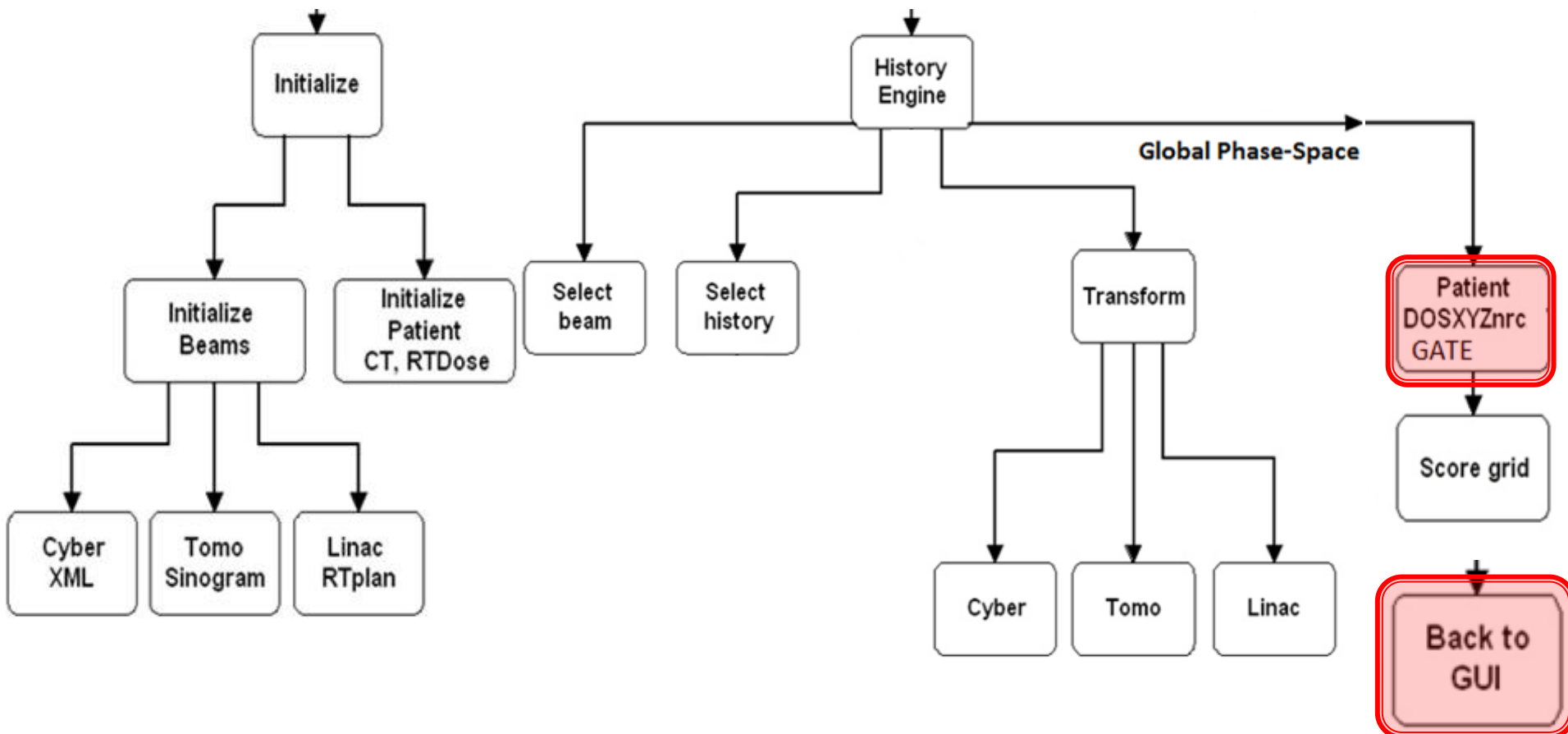
2 Moderato system : process

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



2 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

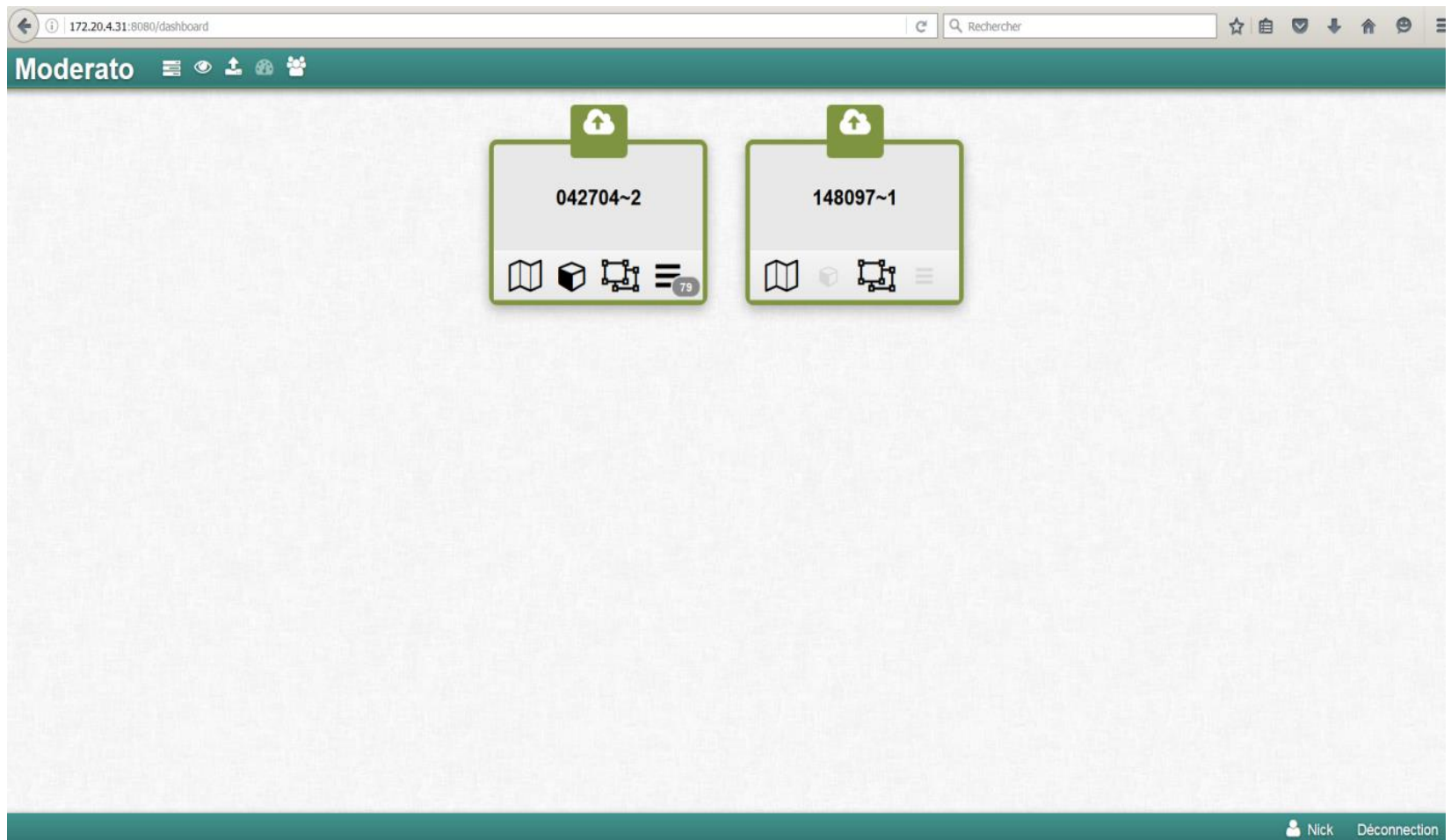
The screenshot displays the Moderato web interface. The top navigation bar is green with the 'Moderato' logo and several icons. The main content area is divided into two panels. The left panel, titled 'En cours' (In progress), shows a list of files with a total size of 298.07 Mo. The right panel, titled 'Téléchargé' (Downloaded), shows a list of files with a total size of 57.14 Mo. The 'Téléchargé' panel also displays a warning message for file 20140919a (4 coupes), indicating missing files for TPS (RTDOSE), RTPLAN, and RTSTRUCT.

En cours		298.07 Mo
1.2.840.113619.2.278.3.163578213.265.1411123975.355.445_fixed.dcm		516 Ko
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coll7_FXE_MCMP_M_rtdose.dcm		57.14 Mo
coll7_FXE_plan.xml		5.88 Mo
coll7_FXE_RTH_rtdose.dcm		5.61 Mo
RTSS.dcm		1.21 Mo
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1.2.840.113619.2.278.3.163578213.265.1411123975.355.22_fixed.dcm		516 Ko

Téléchargé		57.14 Mo
20140919a (4 coupes) ✖		
⚠ Fichier de doses TPS (RTDOSE) manquant		
⚠ Fichier de traitement (RTPLAN) manquant		
⚠ Fichier de structures (RTSTRUCT) manquant		

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)



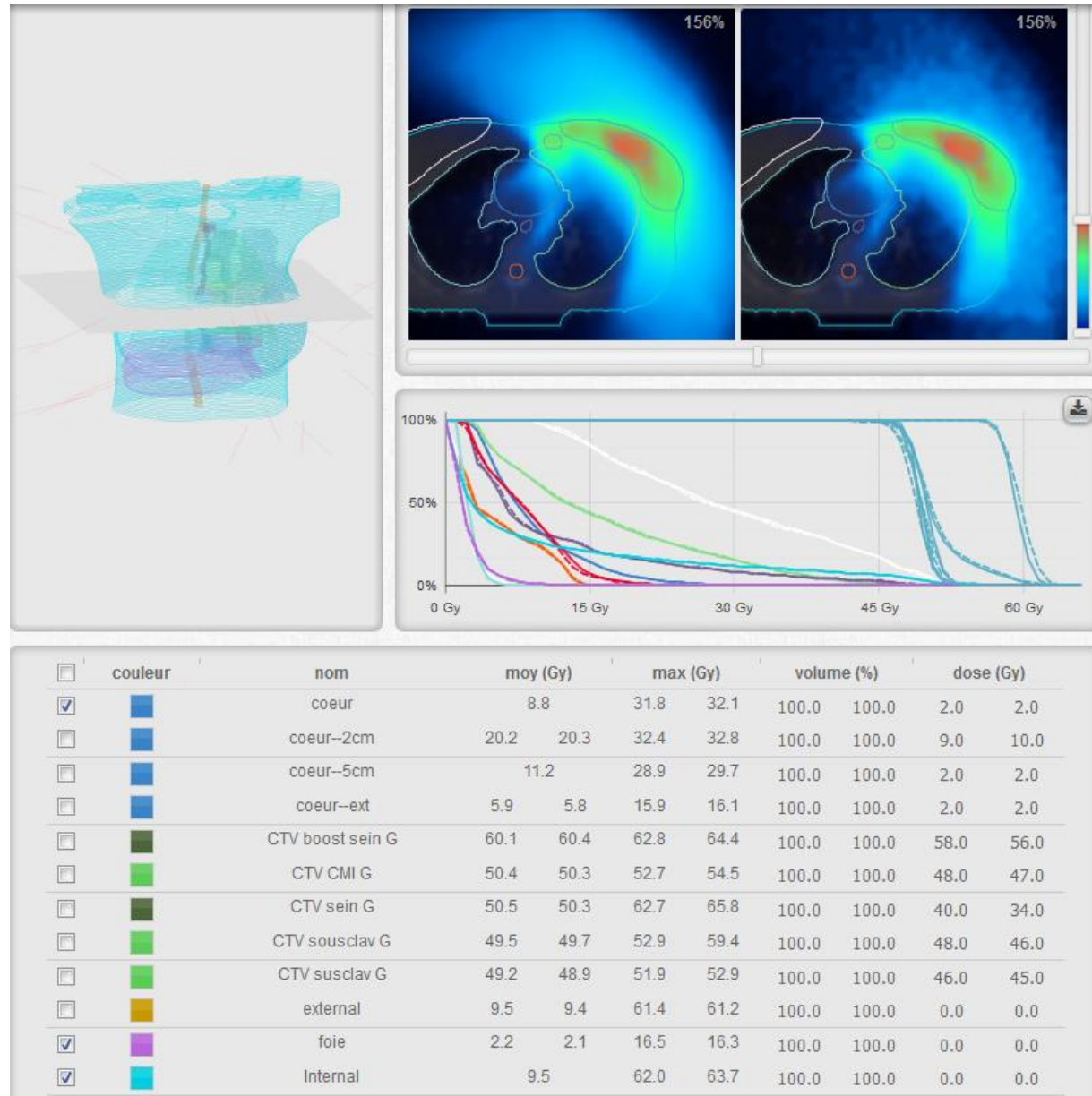
2 Interface and practical use

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

Image / Prescription		Dosimétrie		Validation		Prêt p
En cours	Valid. contours / prescription	En attente d'une dosimétrie	Dosimétrie en cours	En attente de validation	Validé	
Traitements BLANCO BCD HENNEBELLE AC BEHAGUE BCD GIOT DP En attente BOULOGNE BCD	Traitements P 186018 BERTOT AC P 281754 ZYCIAC TLE R P 281443 TONG FLT R P 281903 DECAE TLE P 280594 FOLCKEN AC P 281979 DAUDI BCD R P 282254 GADENNE AC	Traitements P 167851 DHILLIT FLT P 281992 SANFILIPPO BCD P 282182 BOUCHEZ BCD	Traitements P 279232 PELLEGRIN BCD P 280624 HERAULT DP	Traitements P 280093 PARDOEN DP P 282124 VERDIERE AC P 280841 FOURMESTR DP P 281217 TOTH FLT P 281564 LEFEVRE BCD P 281450 GORIS FLT R P 275244 BUCAMP JF	Traitements P 281653 MARTIN BCD P 280557 COUSIN DP P 281762 DRAN FLT R P 276577 DIOP AC P 276577 DIOP AC P 281702 HUGOT DP P 280474 BARJE FLT R	
5 Traitements	7 Traitements	3 Traitements	2 Traitements	7 Traitements	7 Traitements	
En attente VITELLO BCD	Traitements 266819 ZEBBOUDJI AC 90624 GOETGHELU DP 277329 BINNEMA DP 281077 LEDUCE DP 282346 RENARD TLE 270559 HEDDOUCHE TLE P 233601 LEFEVRE DP 282415 BOUMAZA TLE	Traitements P 277421 SCHAELOTZ SIS P 144870 NEALE XM 281151 CAPENDU DP 281838 HEQUET SIS 282056 LIGNIE XM 255863 MARTINACH DP	Traitements P 280723 MONTAGNE TLE P 218666 BERCKMANS BCD 281993 JOVENIN BCD 279865 RAVISSE TLE 209045 MELIN XM 231372 HOULIEZ DP 280267 DRAPIER DP	Traitements ! 219588 Delzenne FLT P 276491 KASPROWIA BCD P 281810 ANTON BCD 278454 DELCROIX TLE 278283 LOBSTEIN TLE 282177 RICHARD BCD 282243 TURCK BCD 282239 COLPAERT BCD 281619 LEFEVRE TLE	Traitements P 279695 MAHIEU DP P 275535 LACQUEMEN TLE P 281209 MARRANNES TLE P 144604 LEFRANC TLE	
1 Traitement	8 Traitements	6 Traitements	7 Traitements	13 Traitements	4 Traitements	
Traitements FLAMENT XM En attente FAUST BCD LAURENT XM OLIVIER XM	En attente 271441 QUINTIN TLE 281689 LEULIETTE XM 241166 HOUILLIEZ DP	Traitements 281871 FILLATRE BCD R 275447 BAILLEUL XM 281599 LALANNE XM 281904 BOURREAU TLE 281783 DARDENNE XM 282121 ROUSSEAU BCD 281511 LUKASIK XM 281345 FINET XM	Urgence ! 281807 DEHAUT XM Traitements 268426 hauville XM 281709 HU TLE	Traitements 263522 DUQUENNE BCD 281636 BRUGE TLE 281617 VAN HAMME XM	Traitements P 261082 WINOCQ TLE P 281212 LEBLANC XM En attente 280982 BRUNEL XM	

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

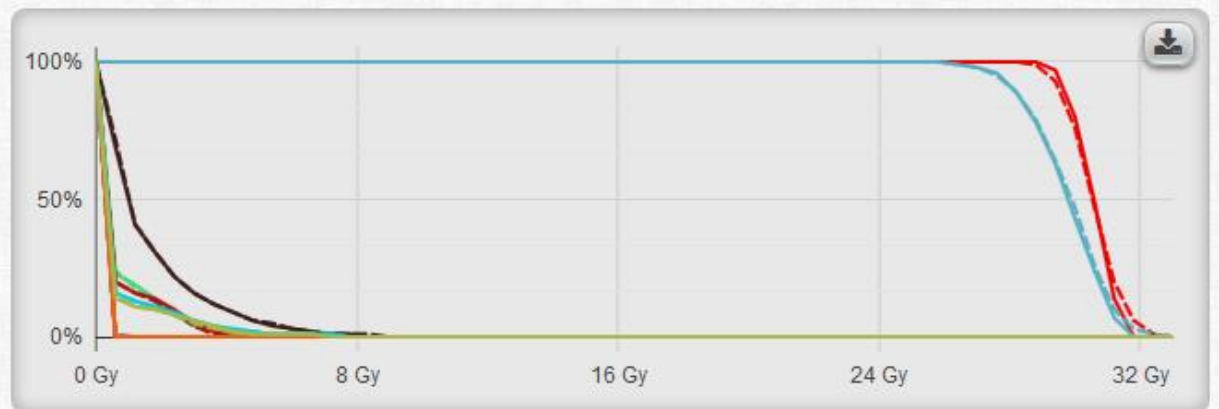
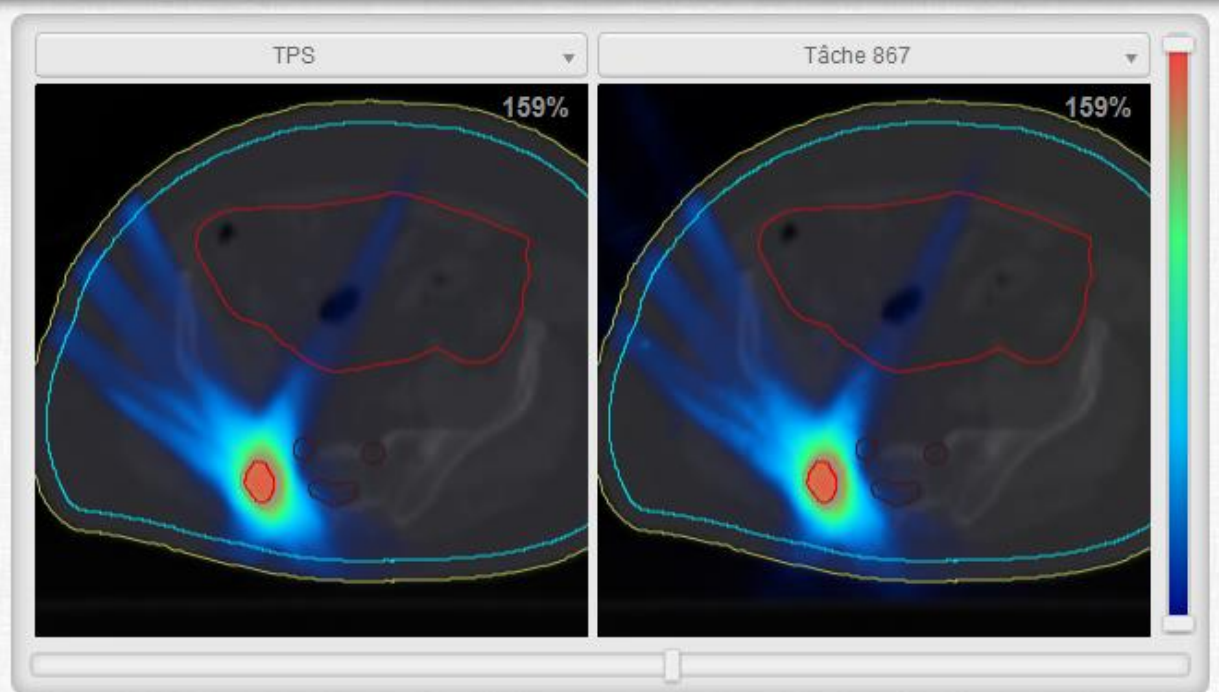
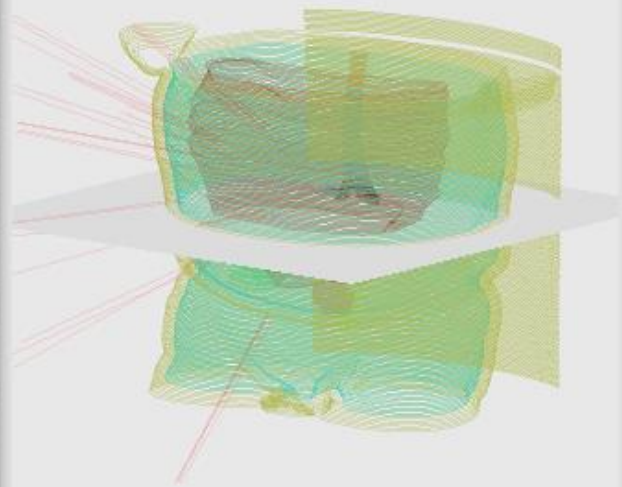


3 Clinical Applications

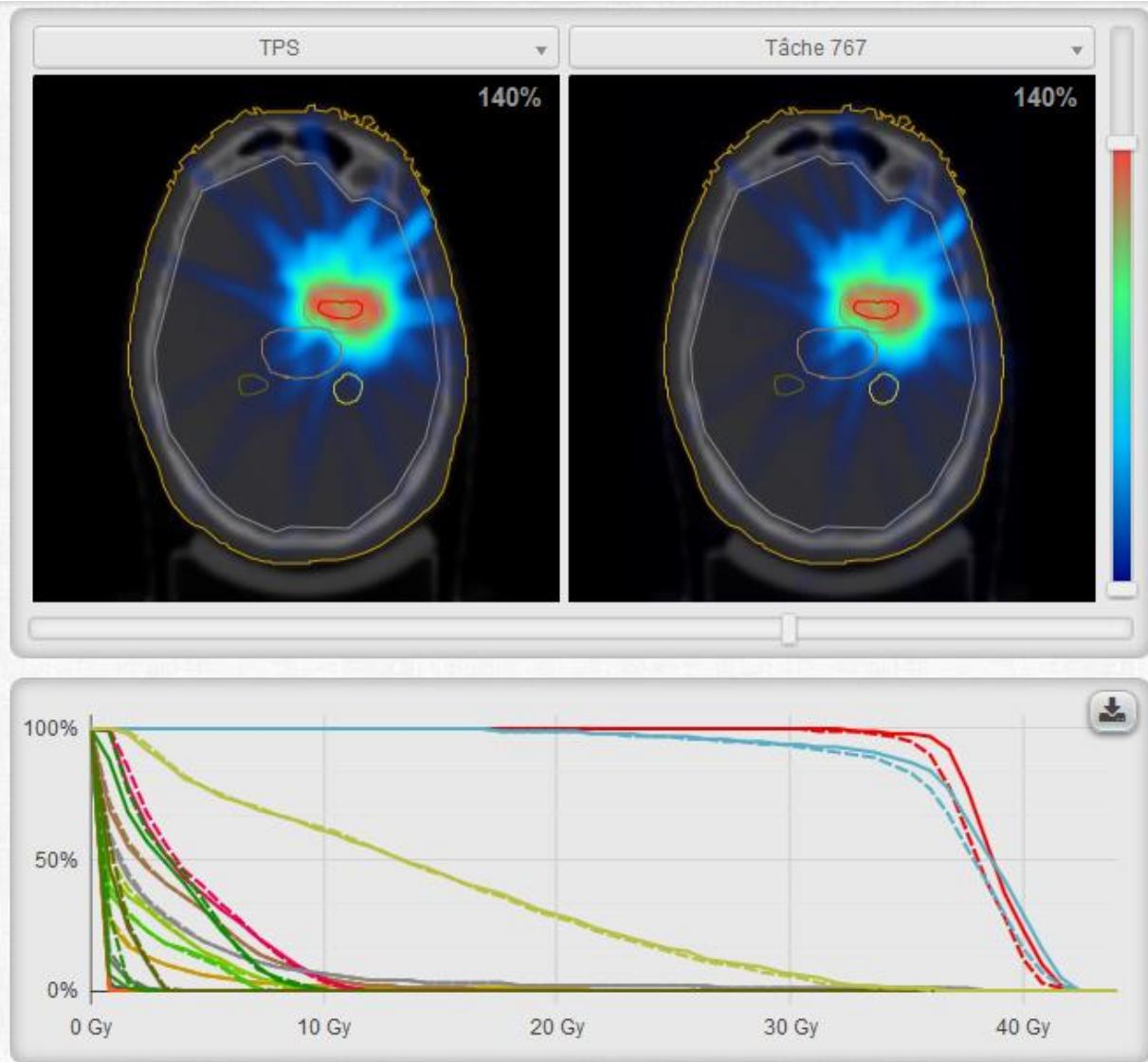
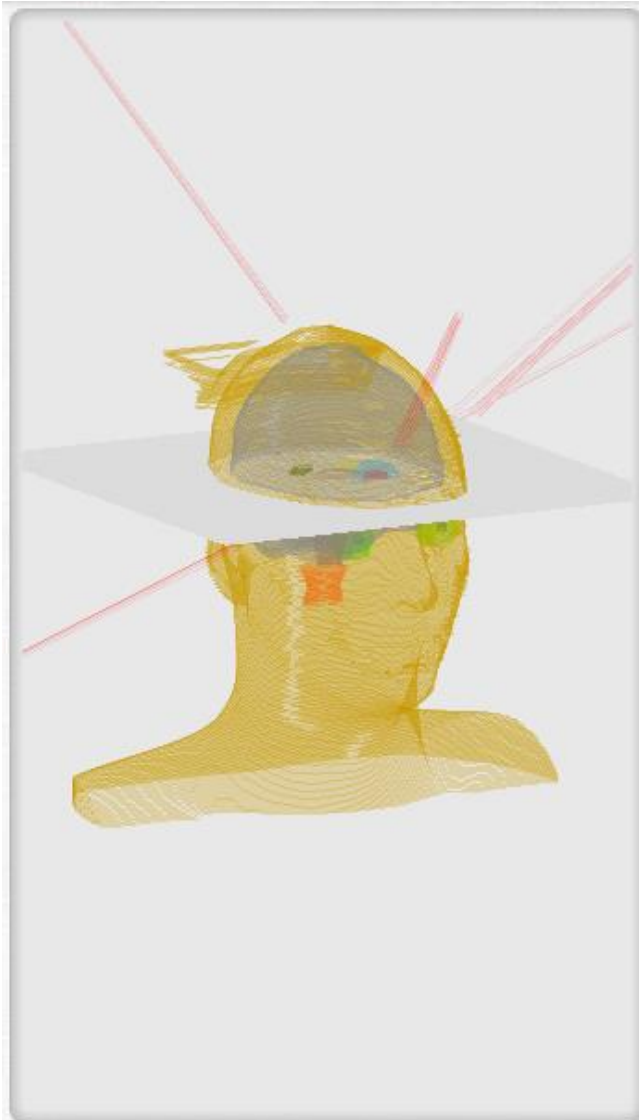
3 Results

- 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

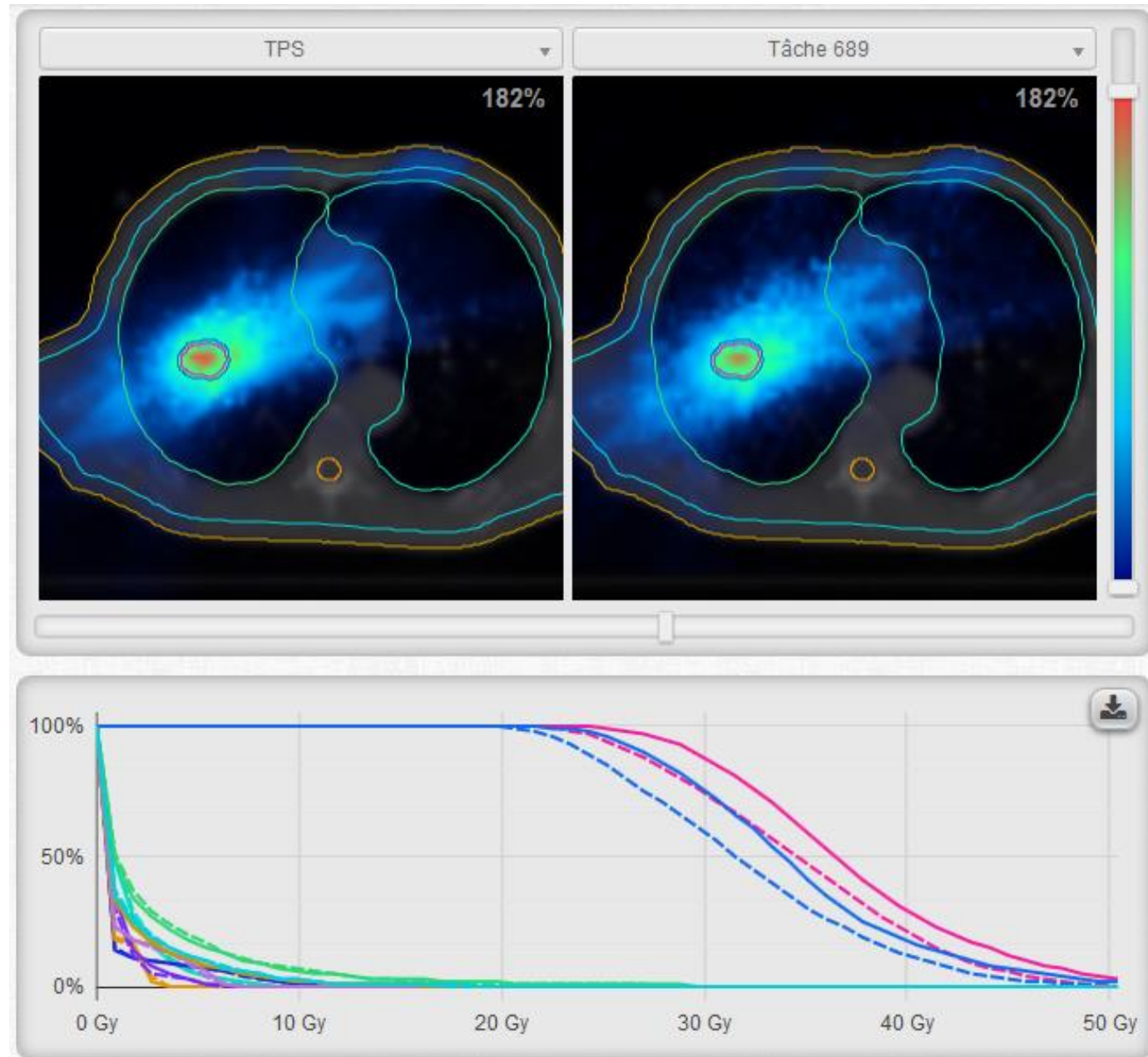


3 Results



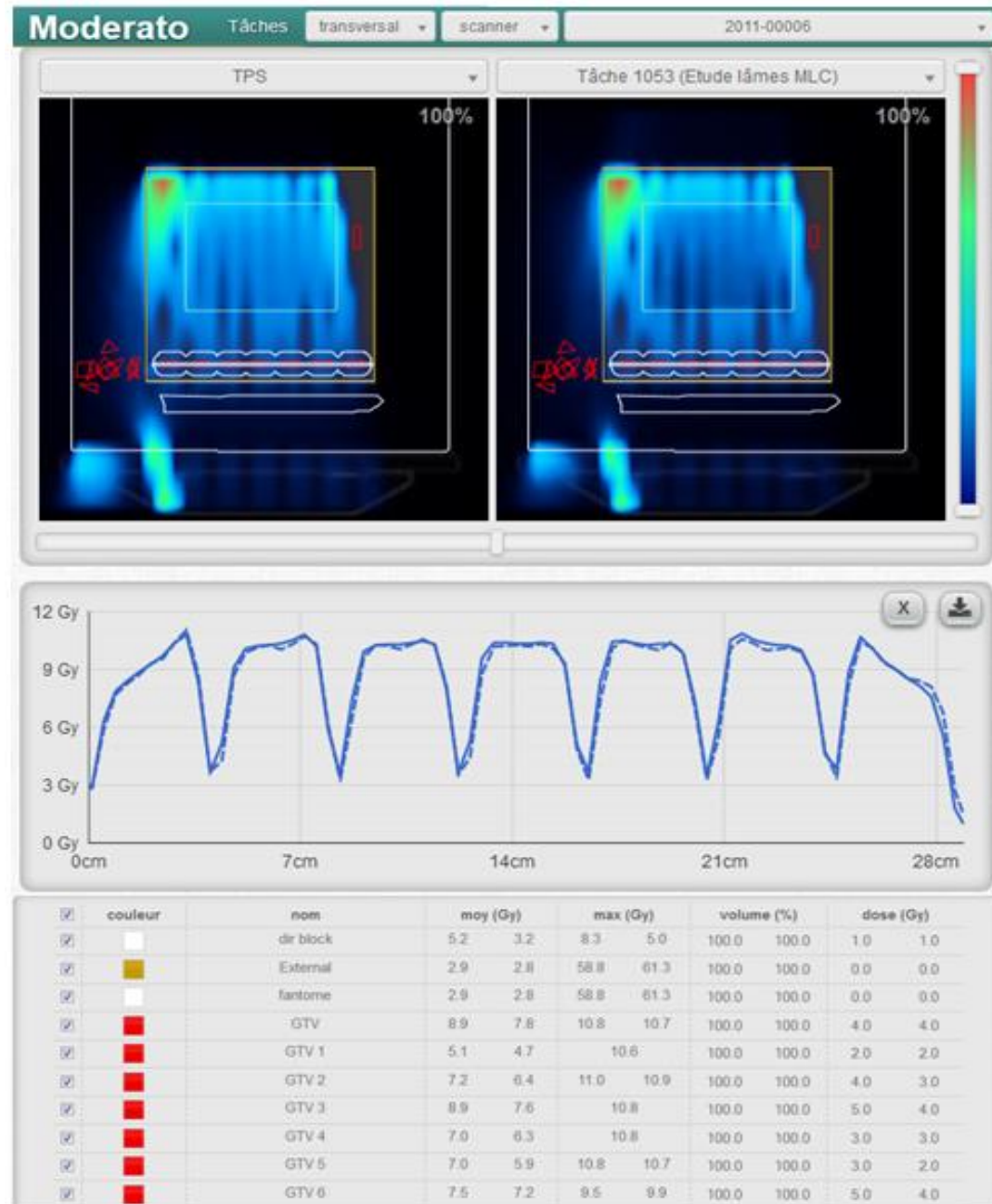
3 Results

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



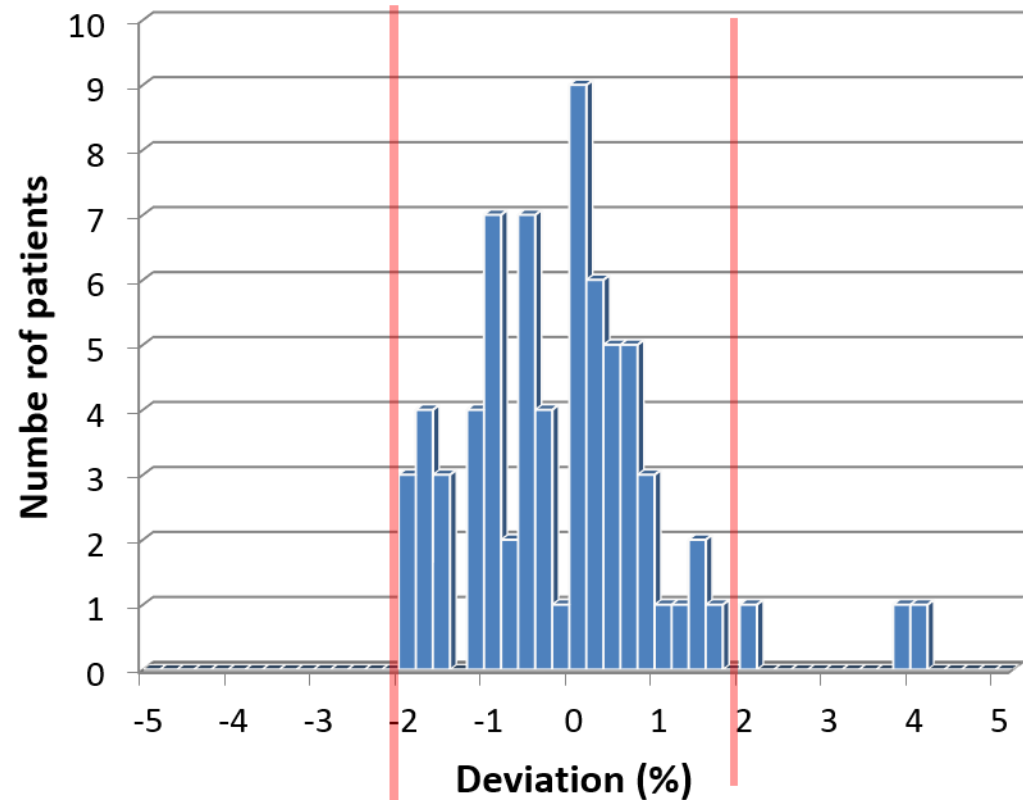
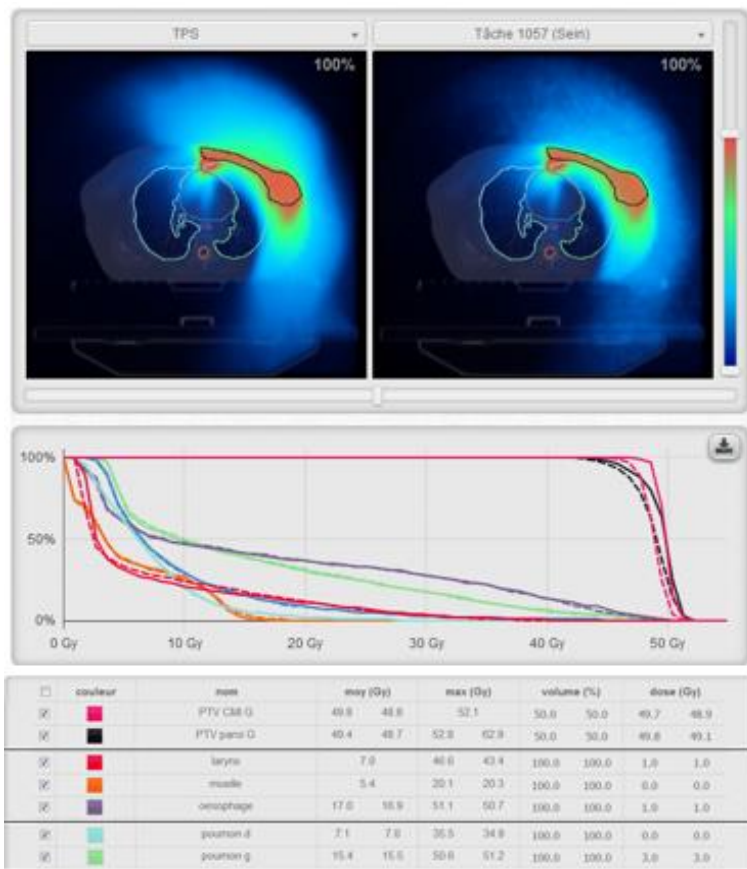
3 Results

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



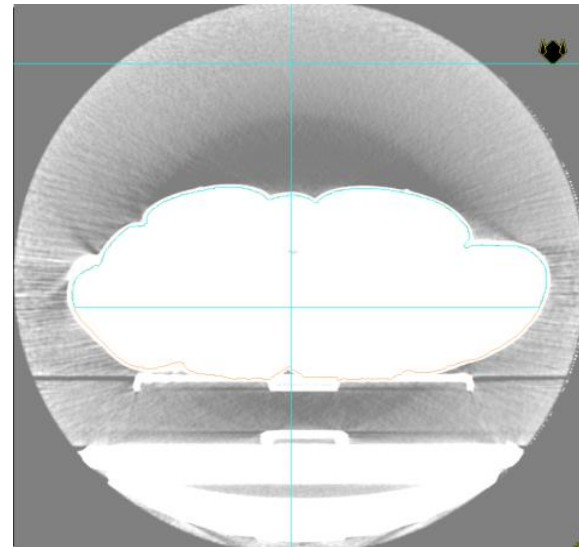
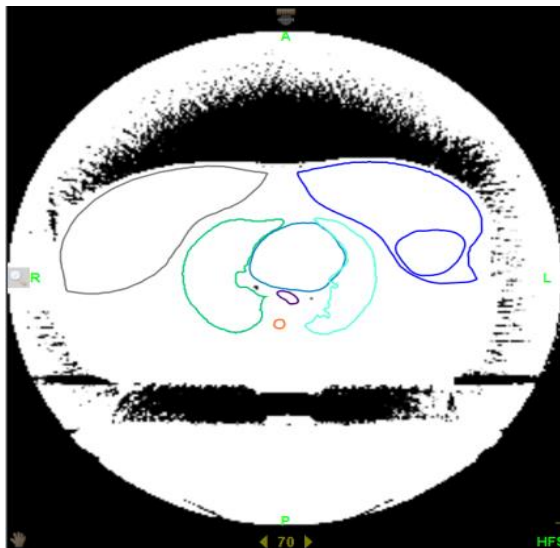
3 Results

- 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 $> 0.1 \text{ g/cm}^3$)
- Removing this artifact restored the agreement between both algorithms



3 Standardized prescription

The screenshot displays a medical prescription software interface. On the left, a sidebar lists anatomical regions: Abdomen, Crâne, ORL (highlighted), ORL - crâne, Pelvis, Sein droit tomo, Sein gauche tomo, TAP, Thorax, _Corps entier a corriger, and ZZZ. The main area shows a search bar with 'ORL', a description field, and a 'Fractionnements' dropdown set to '> 15 séances'. Below this, a 'Description du fractionnement' field is visible. Overlaid on the main area are four panels, each with a red 'X' icon and a title, containing standardized values for different conditions. Each panel has a '+ Nouvelle condition' button.

× Cavité buccale

× V15	<	80 %
× V30	<	50 %
× V45	<	25 %
× V50	<	2 %

+ Nouvelle condition

× Conduit auditif, oreille m

× V6	<	2 %
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+ Nouvelle condition

× Mandibule

× V70	<	2 %
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+ Nouvelle condition

× Moëlle épinière

× V45	<	10 %
× V50	<	0.003 cm³

+ Nouvelle condition

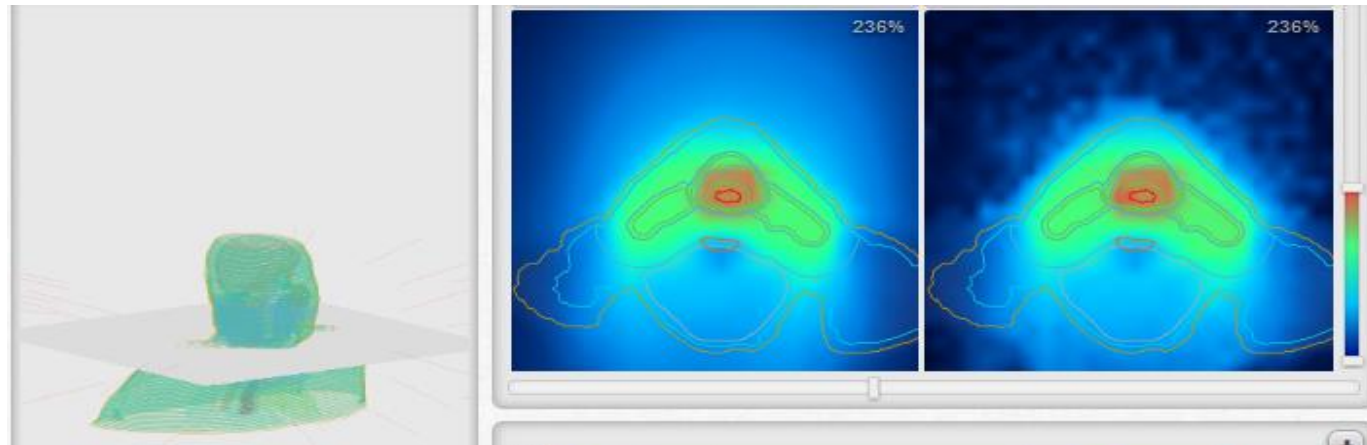
× Oreille interne droite

× V45	<	50 %
× V50	<	2 %

× Oreille interne gauche

× V45	<	50 %
× V50	<	2 %

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

	tps	task1787
Thyroïde		
V50 < 50%	52.2 Gy	52.3 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

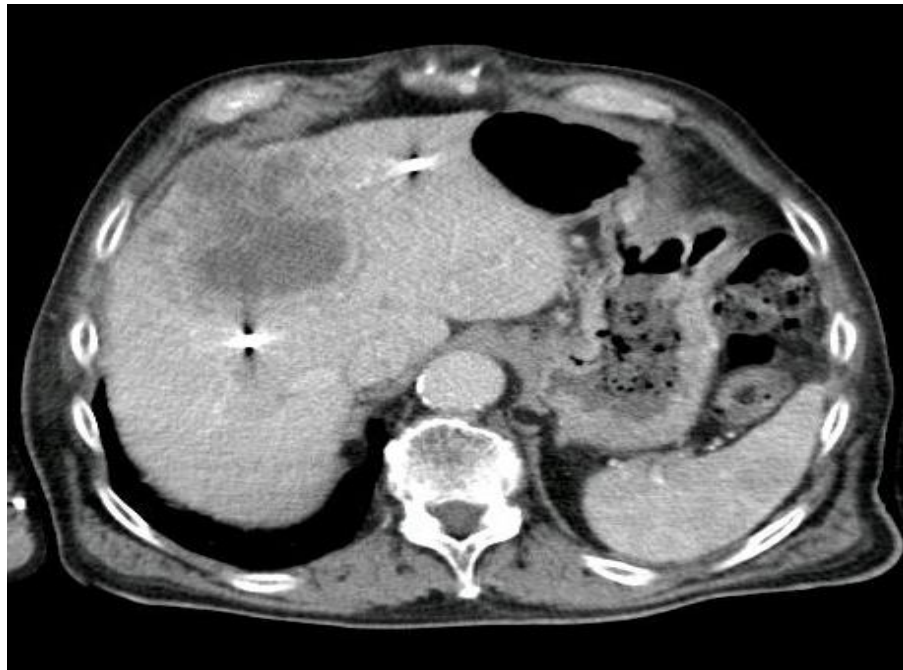
Oesophage		
V45 < 40%	2.5 Gy	2.3 Gy
V55 < 30%	3.4 Gy	3.0 Gy

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)

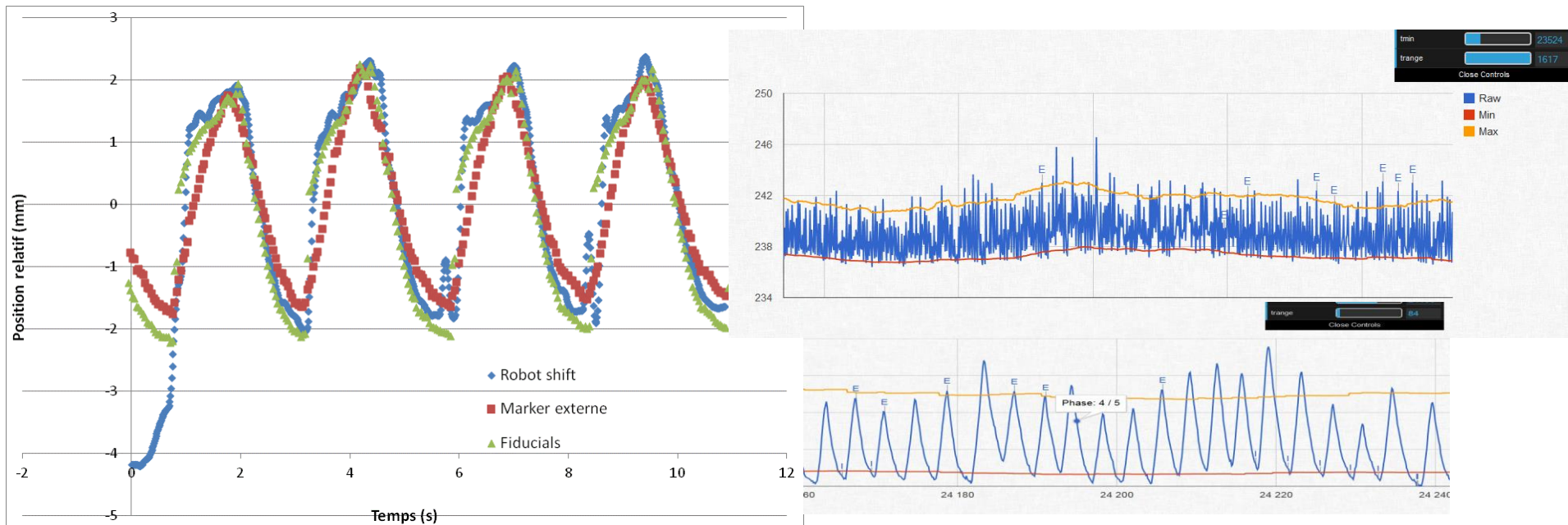
3 Delivered dose reconstruction

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



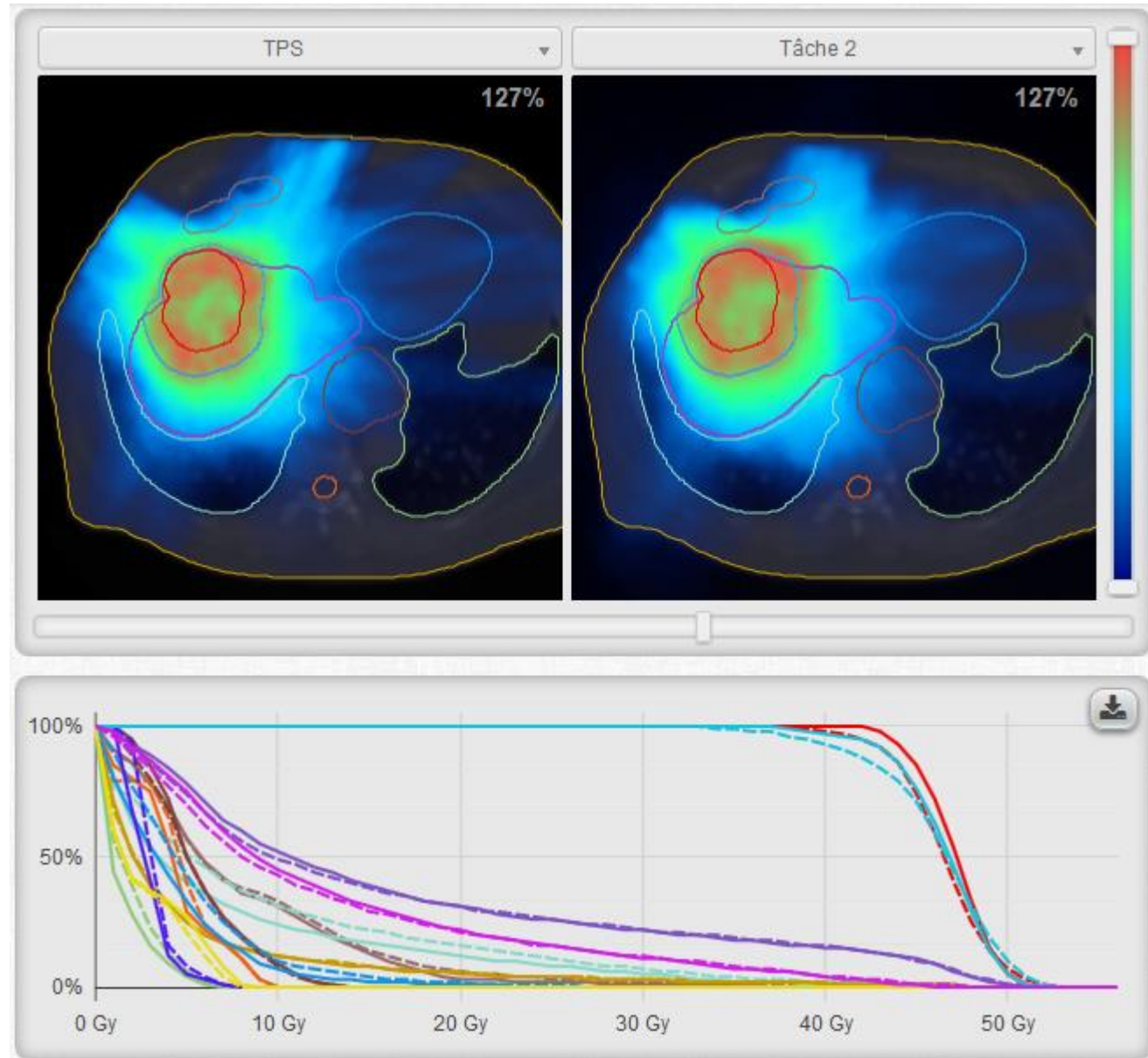
3 Delivered dose reconstruction

- 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

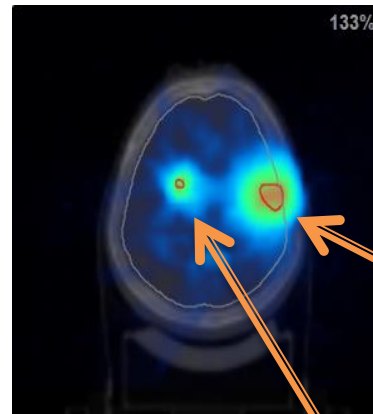
- Liver case : comparison of planned and delivered dose
- The use of a treatment belt for all liver treatments limits the motion



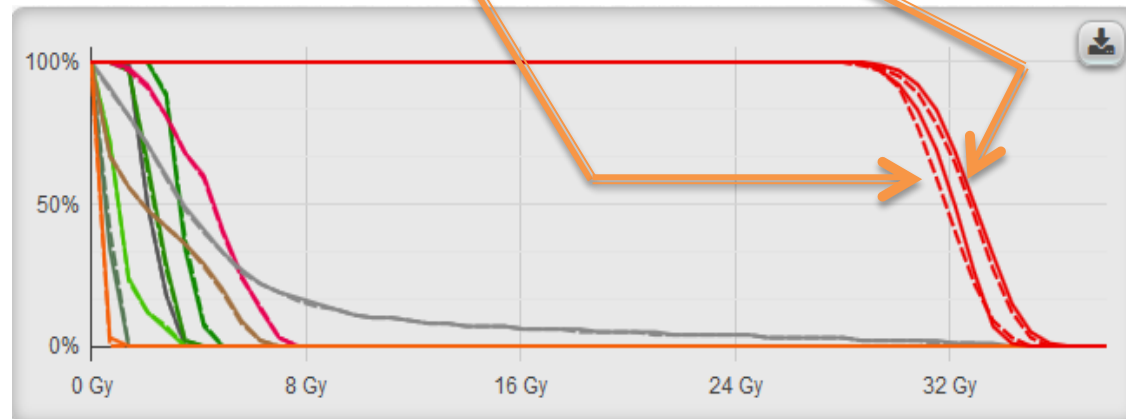
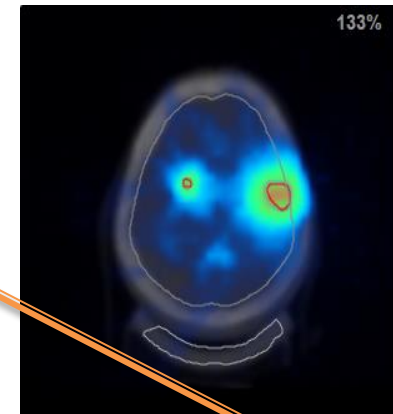
3 Dose calculation on MRI

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

True CT



Pseudo 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!



Thank you !