

Monte Carlo calculation of absorbed doses due to imaging sessions delivered to patients during Tomotherapy Image-Guided RadioTherapy courses

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Aim of the study

In clinical practice, for Tomotherapy treatments:

- Daily MVCT in-room imaging sessions
- Additional dose
 - Not prescribed
 - Not calculated
 - Not reported

Calculation of the MVCT absorbed dose distribution

- Model the Tomotherapy MVCT with GATE
- Validate the model on anthropomorphic phantoms
- Evaluate the dose distribution for clinical cases

Helical scanner imaging

Acquisition of the anatomical volume by slice
requiring a translation of the couch and several
rotations

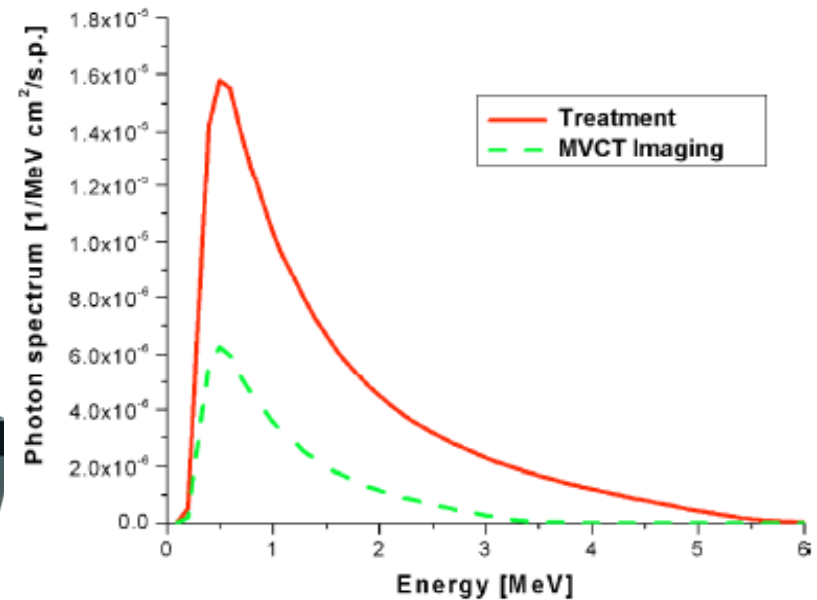
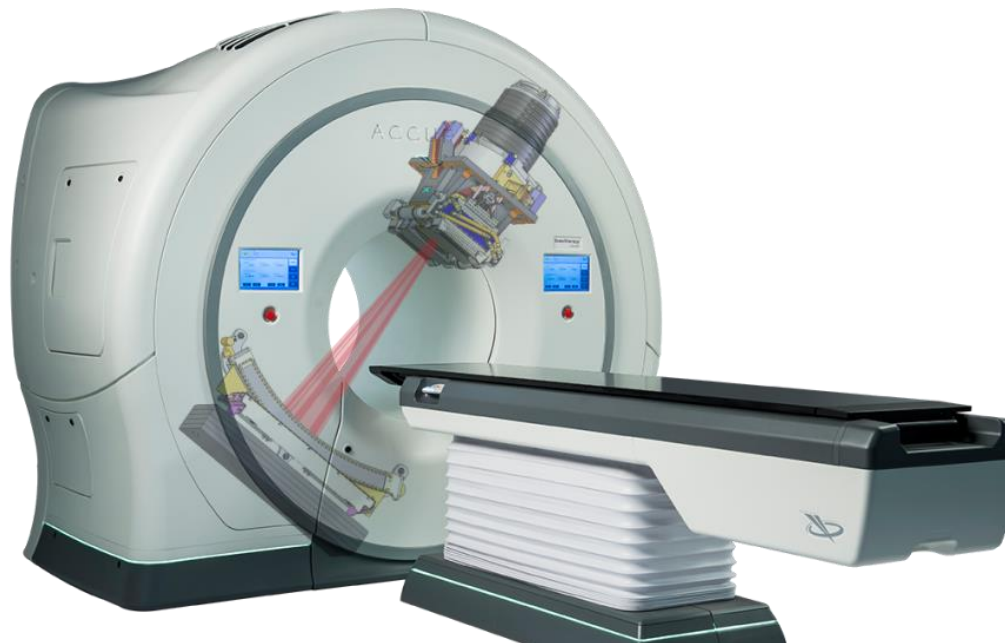
MVCT beam collimation:

Field of $0.4 \times 40 \text{ cm}^2$ (J1) at isocenter
source-isocenter distance = 85cm

Gantry rotation: 10 sec ($36^\circ/\text{sec}$)

Couch translation: Normal = 8mm/rotation (0.8mm/sec)

Slice thickness: 2mm (pitch normal)



Jeraj *et al.*: Radiation characteristics of helical tomotherapy

GATE model

Source

Definition of the spectrum point by point from Jeraj et al.
Source shape defined by double gaussian

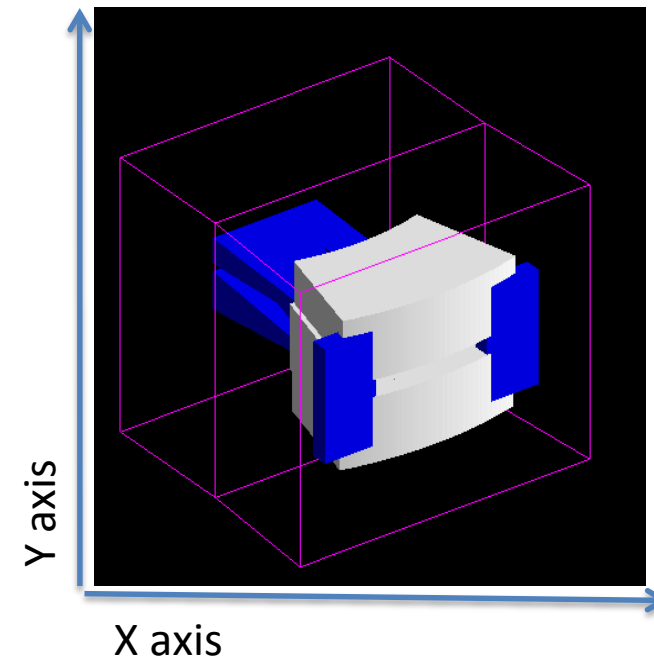
Geometry

Jaws (blue): four symmetrical volumes inclined two by two on the side
MLC (white): one volume, repeated N times with translation rotation
Output Screen (Blue): Stop unnecessary particles

Physics

Standard model suitable for the energy range (MeV)

For dose measurements in static conditions, use of a second beam $5 \times 40 \text{ cm}^2$ corresponding to fully opened jaws.



Measurements either in water or solid water

	Field	Detectors
PDD (SSD 80cm)	5x40cm ²	A1SL
	0.4x40cm ²	A1SL and EBT3
Profile (SSD 80cm SAD 85cm)	5x40cm ²	A1SL and EBT3
	0.4x40cm ²	EBT3
Reference Dose Rate (SSD 80cm SAD 85cm)	5x40cm ²	A1SL
OF (SSD 80cm SAD 85cm)	5x40cm ² 0.4x40cm ²	EBT3 and Diamond

Corresponding simulations either in water or solid water

- Two models: 0.4x40cm² and 5x40cm²
- Voxel volume: 0.25³ mm³ to 2³mm³
- Simulated particles: 10⁹ to 10¹¹
- GateLab Calculation Grid

Measurements in anthropomorphic phantom STEEV

STereotactic End-to-End Validation phantom (CIRS)

Anthropomorphic head phantom

Interchangeable inserts (63.5 x 63.5 x 63.4 mm³)

Dose measurement at isocenter with external marks

Nanodot dosimetry

2D point-to-point dosimetry in two orthogonal directions with 27 OSL



Measurements in clinical conditions (Normal mode)

-couch translation **normal** (0.8mm/s)

-slice reconstruction **2mm**

Corresponding simulation

Integration of the acquired MVCT scan in the simulation

Assignment of materials in each voxel according to MVCT grey level

Resolution of output voxels: 2x2x0.8mm³

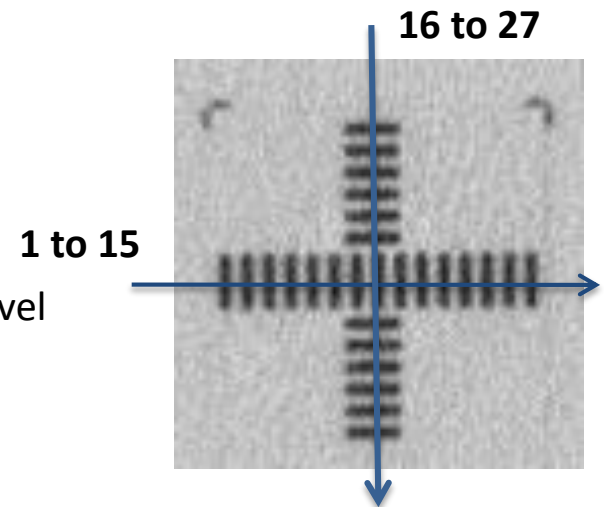
Parameters

-couch translation 0.8mm/s Beam rotation 36deg/s

-discretization of the simulation in « second »

Duration

About 30h simulation using the GateLab



CIRS ATOM® 5-year old pediatric anthropomorphic phantom

Height 110 cm, weight 19 kg

Tissue-equivalent epoxy resins

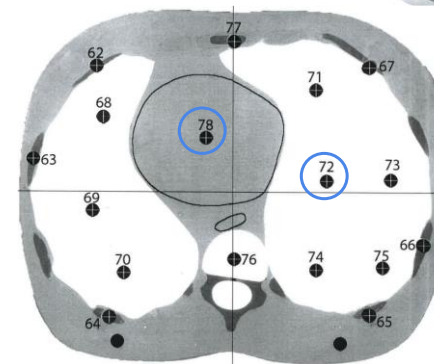
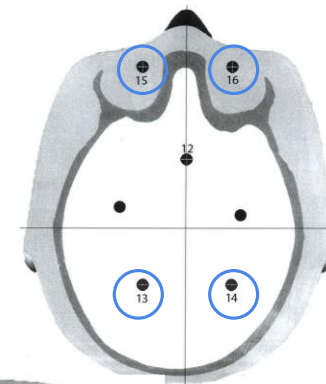
26 slabs (thickness 25 mm)

Nanodot dosimetry

180 OSL available inserts

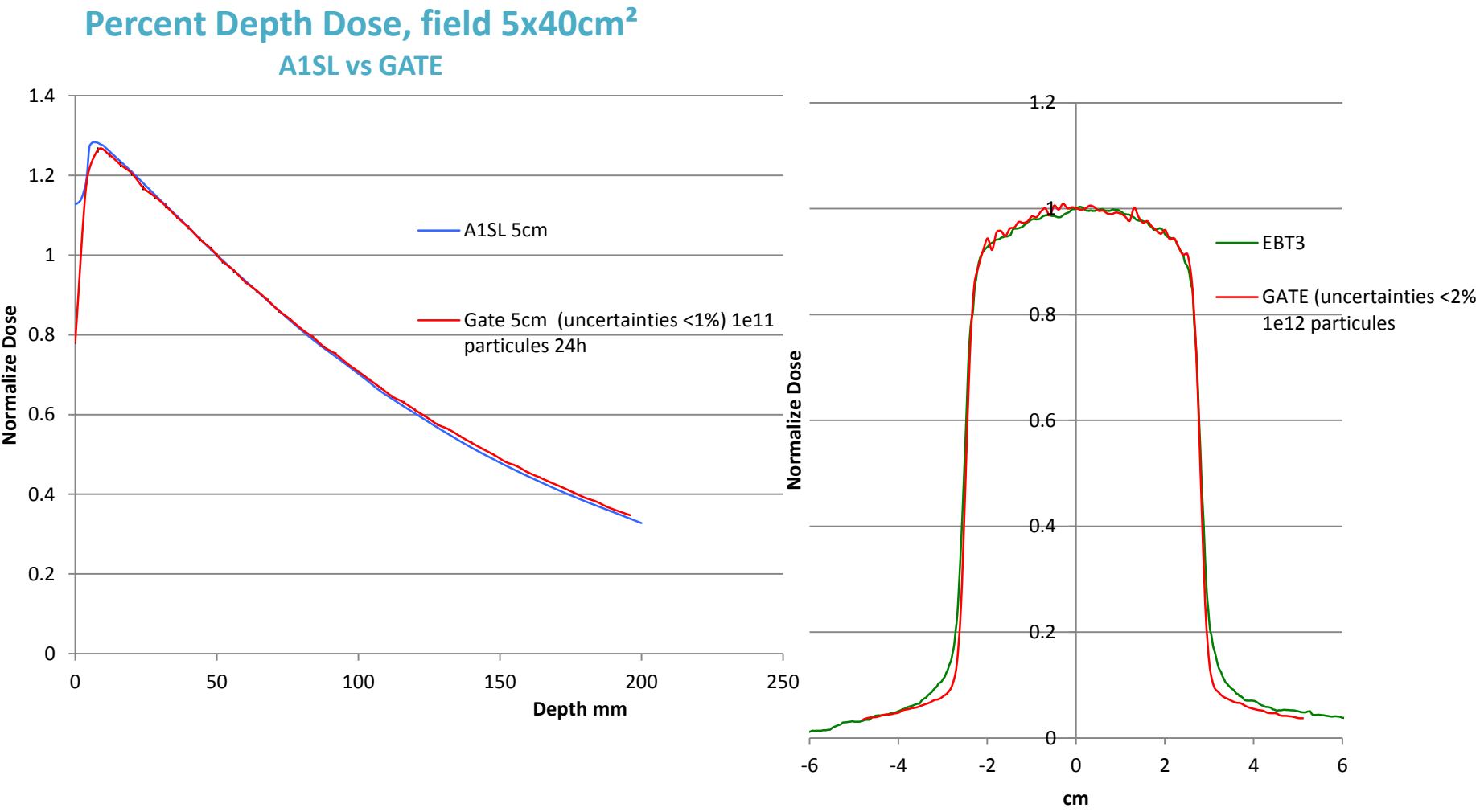
39 point measurements in different anatomical regions

(Head, Thorax, Abdomen, Pelvis)



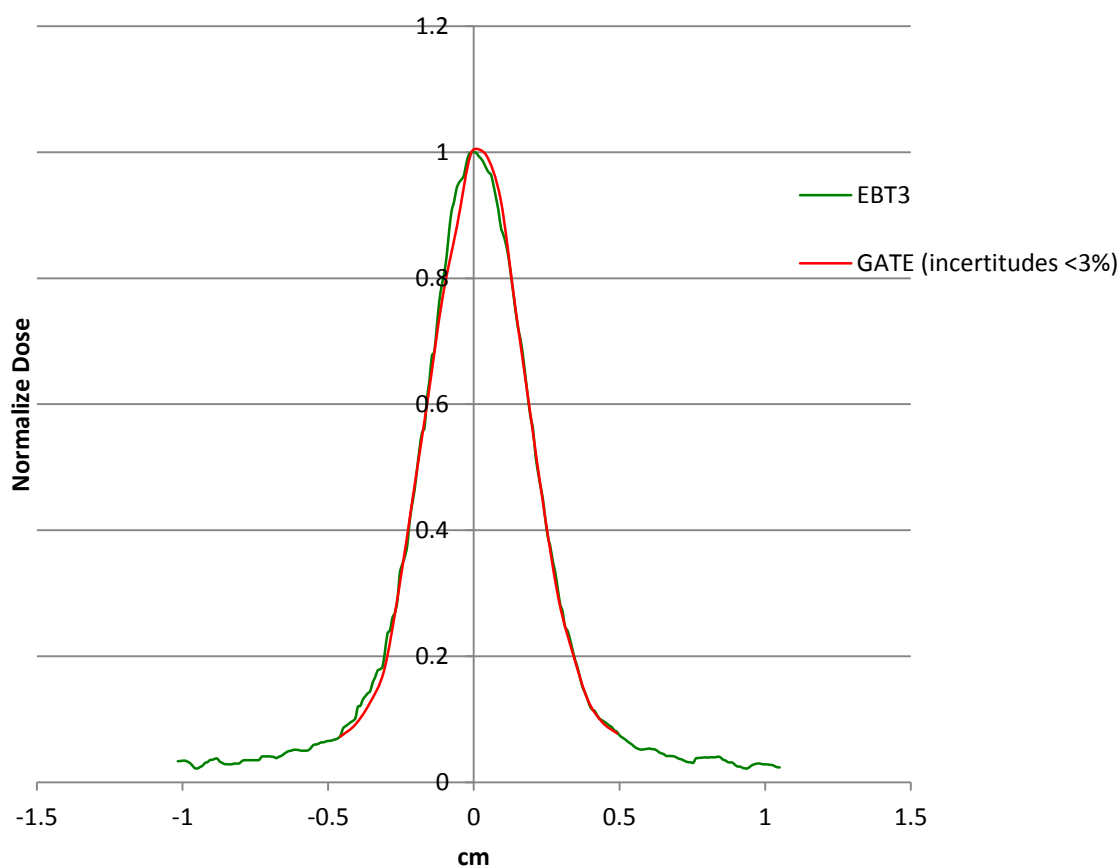
Corresponding simulation





For a static beam, good agreement between measurements and simulations
(deviation < 2% in high dose regions)

Longitudinal beam profile 0.4x40cm²
EBT3 vs GATE virtual water



Dose	10-20%	20-80%	80-100%
Dev max (EBT3 vs Gate)	3,1%	1,5%	2,1%

Reference dose rate field 5x40cm²

Water-60 seconds

SSD 80cm

SAD 85cm

$D_{A1SL} = 37.2 \text{ cGy/min}$

OF results

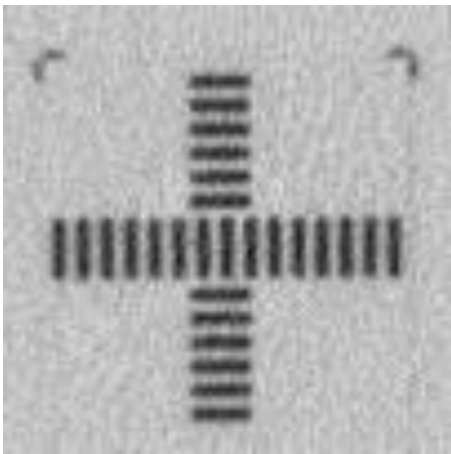
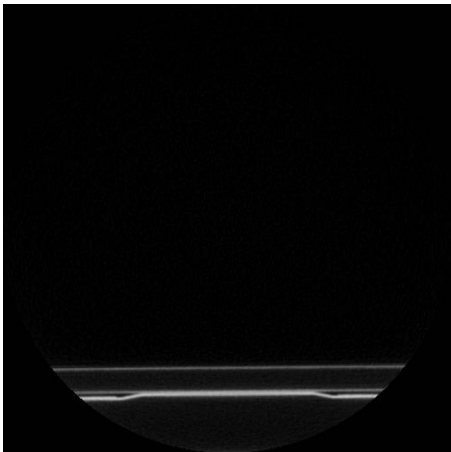
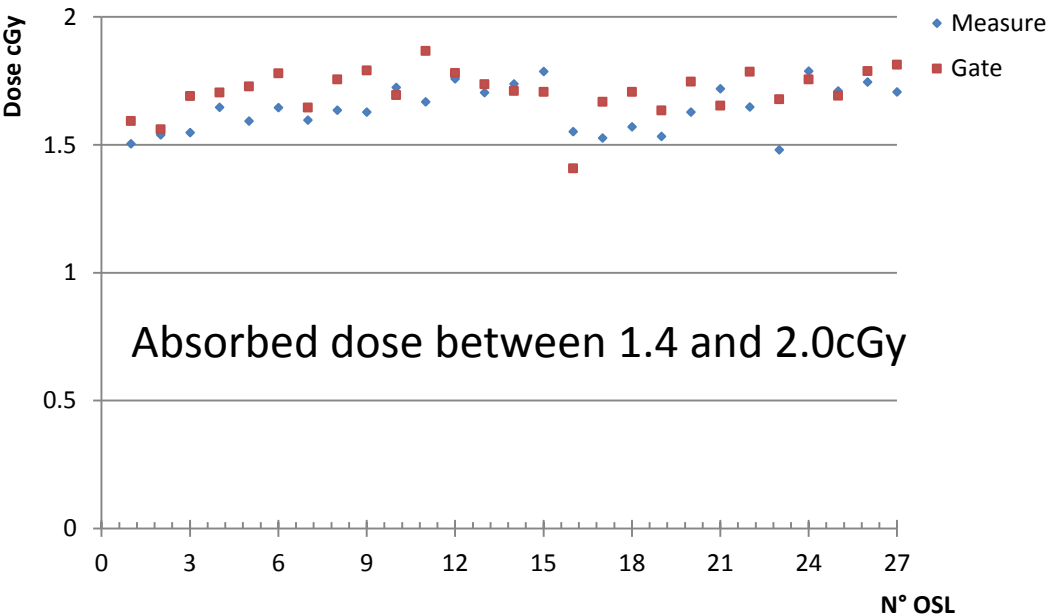
	OF
EBT3	0,49
Diamond	0,50
Gate	0,50

Reference dose rate field 0.4x40cm²

$D_{A1SL} \times \text{OF} = 18.6 \text{ cGy/min}$

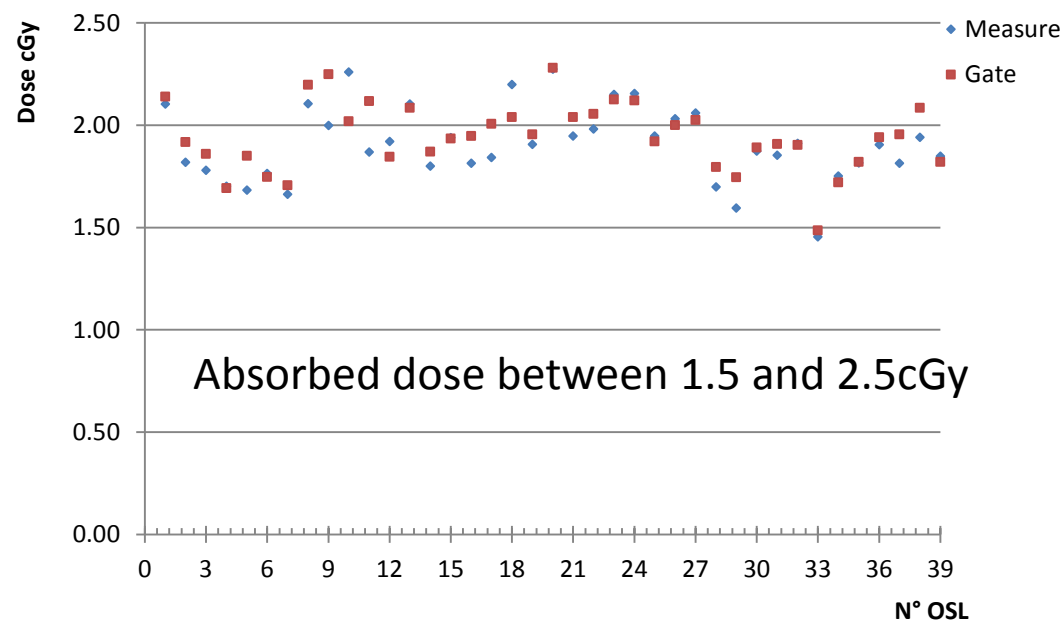
Satisfactory results in water for relative measurements (PDD, OAR)
Calculation of the dose rate in our reference settings

Two directions, 27 OSL

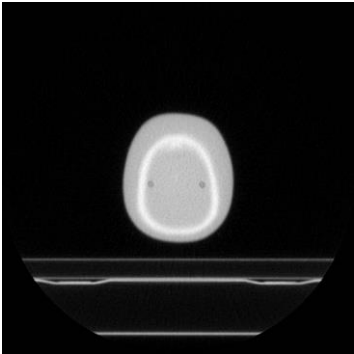


Deviation Measurement / Simulation	Measurement Point
0–5%	15
5-10%	9
>10%	3
max	11.8%
mean	3.7%

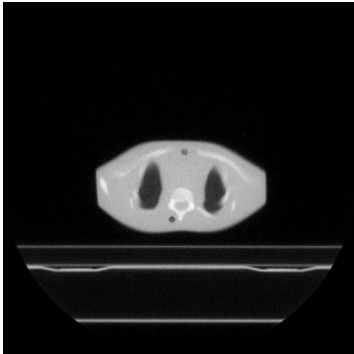
4 areas and 39 OSL



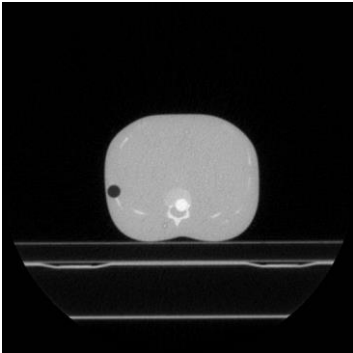
Head: OSL 1-13



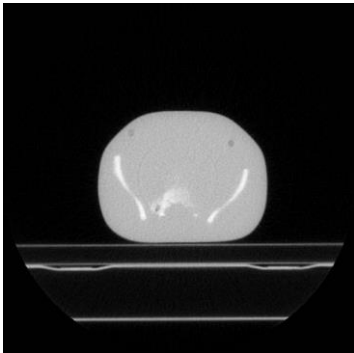
Thorax: OSL 14-26



Abdomen: OSL 27-32



Pelvis: OSL 33-39



Deviation Measure / Simulation	Measurement Point
0-5%	27
5-10%	9
>10%	3
max	11.9%
mean	4.0%

Results on anthropomorphic phantoms

Uncertainties:

OSL Measurement uncertainties 5% (according to Landauer)

GATE Statistical uncertainties voxel dose 3.5% (mean)

Additional uncertainties due to partial volume effect and angular sampling

Acceptable uncertainties for imaging dose calculation

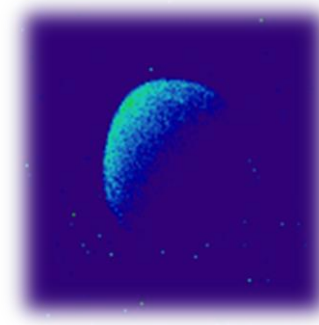
Absorbed dose measurements:

Satisfactory agreement between measurements and simulations in anthropomorphic phantoms.
No correlation between measurement/simulation deviation and material area (bone, water, air...)

Similar results for STEEV and Grant phantoms

max deviation: 12% and mean deviation: 4%

Dmin=1.4cGy Dmax=2.5cGy



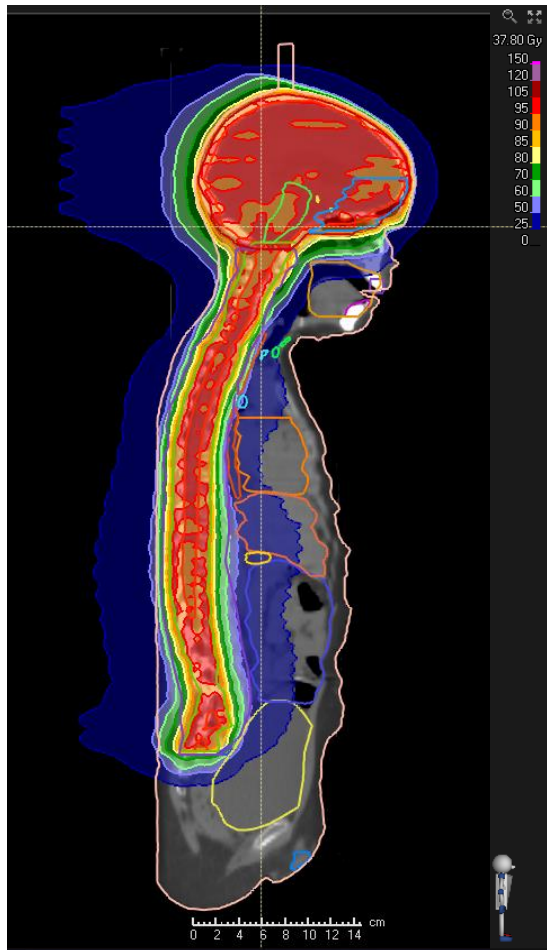
Validation of the model in anthropomorphic phantoms

Example on a clinical case: Medulloblastoma

Treatment: 36 Gy in 20 fractions

Imaging: 1 Daily MVCT, but 2 sites

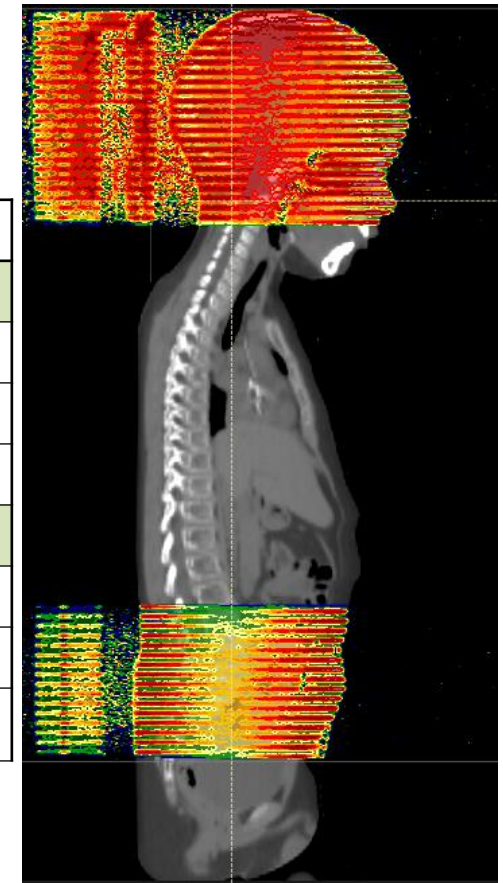
Planned Dose Distribution



**Mean absorbed dose
(cGy)**

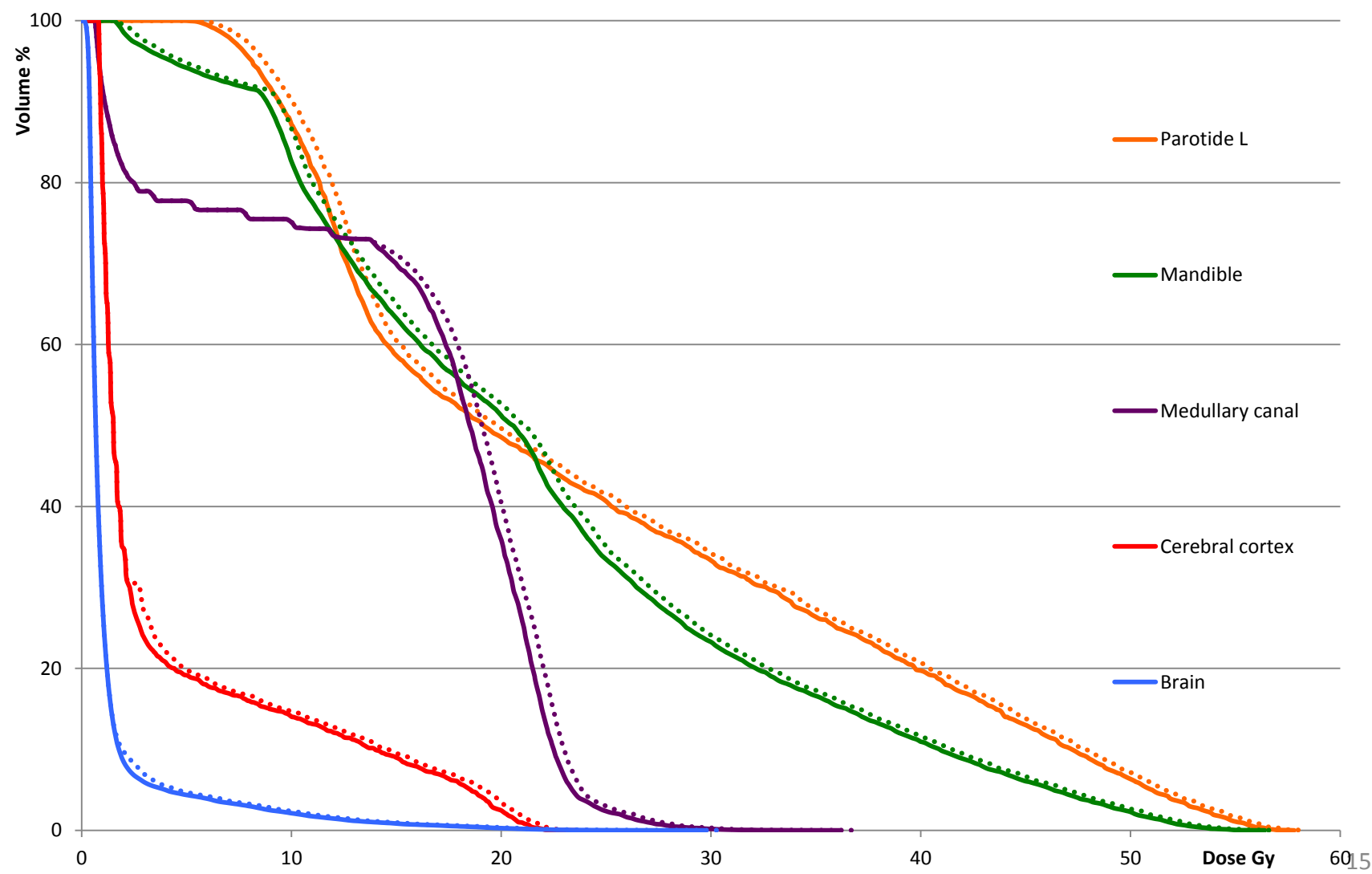
ROI	Treatment	Imaging	Increase
Bladder	680	34	+5.0%
Chiasm	3660	38	+1,0%
Brain	3610	40	+1.1%
Eye	2420	42	+1.7%
Lens	1190	42	+3.5%
Optic nerve	3610	38	+1.1%
Optic tract	3620	40	+1.1%
Parotid Gland	1340	42	+3.1%

MVCT Dose Distribution



Example on a clinical case: Head and Neck cancer 70Gy/35 fx

Dose Volume Histogram
Treatment: solid lines
Treatment+Imaging: dotted lines



Example on a clinical case: Head and Neck cancer 70Gy/35 fx

Treatment (TT) 35 fractions + 35 MVCT
Dose increase between (TT) and (TT+MVCT)

		D98 (Gy)	Average (Gy)	D2 (Gy)
Cochlea R	TT	1.94	2.34	2.81
	TT+MVCT	2.48	2.85	3.30
	Increase	27.8%	21.8%	17.4%
Maxillary articulation	TT	2.07	3.83	7.40
	TT+MVCT	2.62	4.40	8.03
	Increase	26.6%	14.9%	8.5%
Brain	TT	0.26	1.27	10.33
	TT+MVCT	0.27	1.32	10.94
	Increase	3.8%	3.9%	5.9%
Parotid gland L	TT	6.99	24.24	53.91
	TT+MVCT	7.62	24.88	54.58
	Increase	9.0%	2.6%	1.2%
CTV70Gy	TT	68.74	70.25	72.08
	TT+MVCT	69.37	70.90	72.73
	Increase	0.9%	0.9%	0.9%

Creation of a Monte Carlo model of the TomoTherapy imaging system

Validation by comparing measurements and simulations

Simple and Complex geometries

Predict the dose distribution due to imaging sessions in patients

Add absorbed dose due to imaging sessions in reporting

This work is part of the AID-IGRT Project led by Delphine Lazaro (CEA, France):

Additional doses related to in-room imaging systems in IGRT

Systems: Tomotherapy, OBI, XVI, CyberKnife, ExacTrac



Le Carrousel des Mondes Marins et le Grand Eléphant © Jean-Dominique Billaud

<http://www.lesmachines-nantes.fr>

Thank you for your attention