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External dosimetry Dosimetry in new radiotherapeutic techniques

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Objective : To describe external dosimetric methods used in new radiotherapeutic techniques.

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Course objectives

- What are "new "radiotherapy techniques those using xray beams for :
  - « Standard » - IMRT, helical tomotherapy,
  - Linac based stereotactic radiotherapy (radiosurgery,…).

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Radiotherapy objective

- To deliver the absorbed dose prescribed in the totality of the target volume at better than ± 5% while limiting to the maximum the irradiation of surrounding healthy tissues, organs
- Delivered dose =>Prescribed dose ≤ ± 5%

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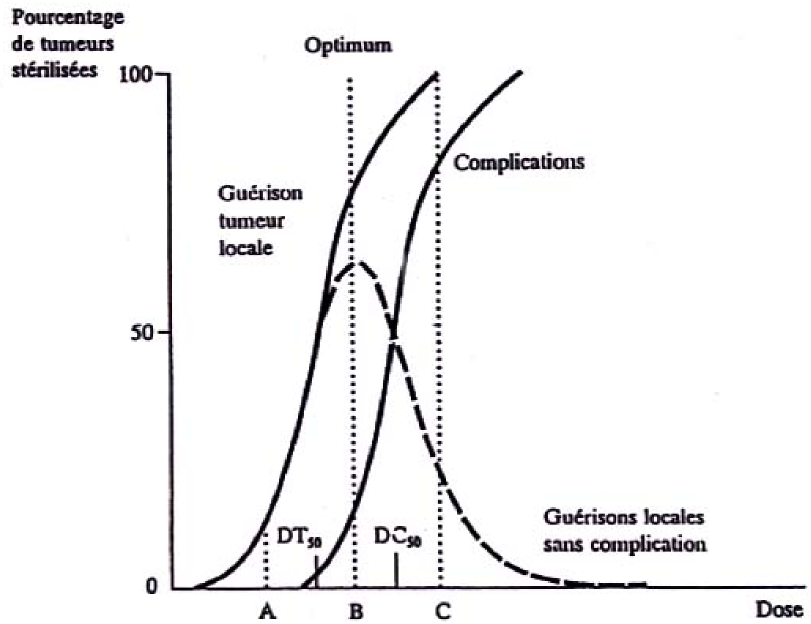
External Radiotherapy

- Medical prescription : Dose variations from 5 to 10% to the target volume can lead to a significant change in the local tumor control and in the toxicity
- Random errors
  - Human factor
- Systematic errors
  - Network, TPS, beam calibration,...



Relation dose-effet sur le taux de contrôle local et les complications
DT50 : dose permettant d'obtenir 50 % de contrôle local
DC50 : dose entraînant 50 % de complications

Objective (…)

Imply :

– A precise knowledge of the physical and dosimetric properties of the beams used for radiotherapy (in house calibration, relative dose distributions,…).

– Perticular attention to pay during the different steps :

- Treatment preparation (anatomic patient data acquisition, choice of the radiotherapy technique, medical prescription …),
- Treatment delivery (patient positionning, in vivo dosimetry, controls).

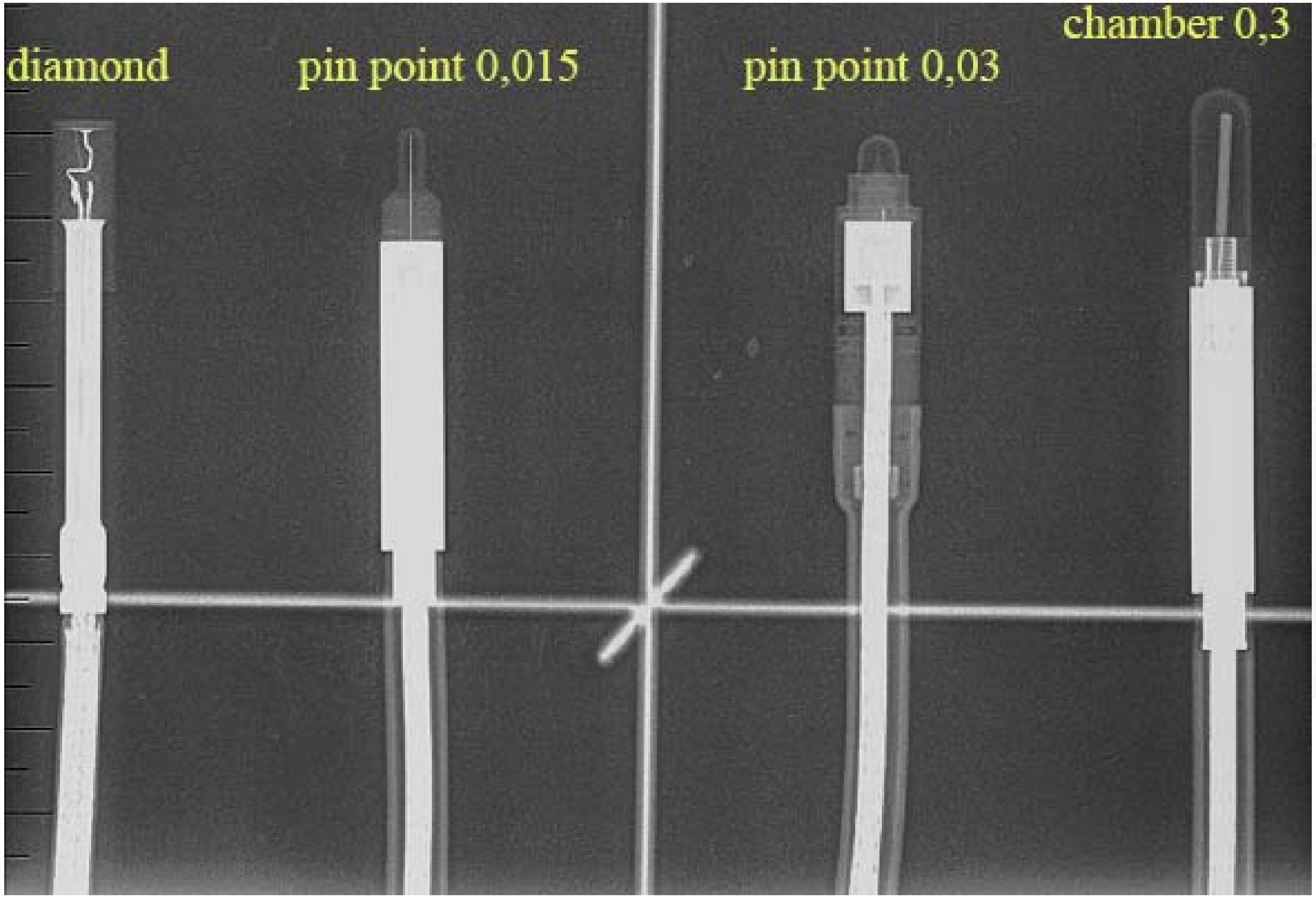
Detectors

- To know the detectors used in radiotherapy beams (limitations eg : detector size vs field size)
- To use in connection with radiotherapy technique.

Some air cavity ionisation chambers chambres used in radiotherapy beams

- Ionisation chambers
  - $0{,}1 cm^3 < V_{air} < 1 cm^3$
  - 7 mm < internal diameter < 25 mm
  - - low Z for thin wall thickness
  - - wall material air or water equivalent
  - RX or γ Co 60
  - E- HE

Capuchon d'équilibre électronique d'épaisseur adaptée au Co 60 dans l'air


diamond
pin point 0,015
pin point 0,03
chamber 0,3

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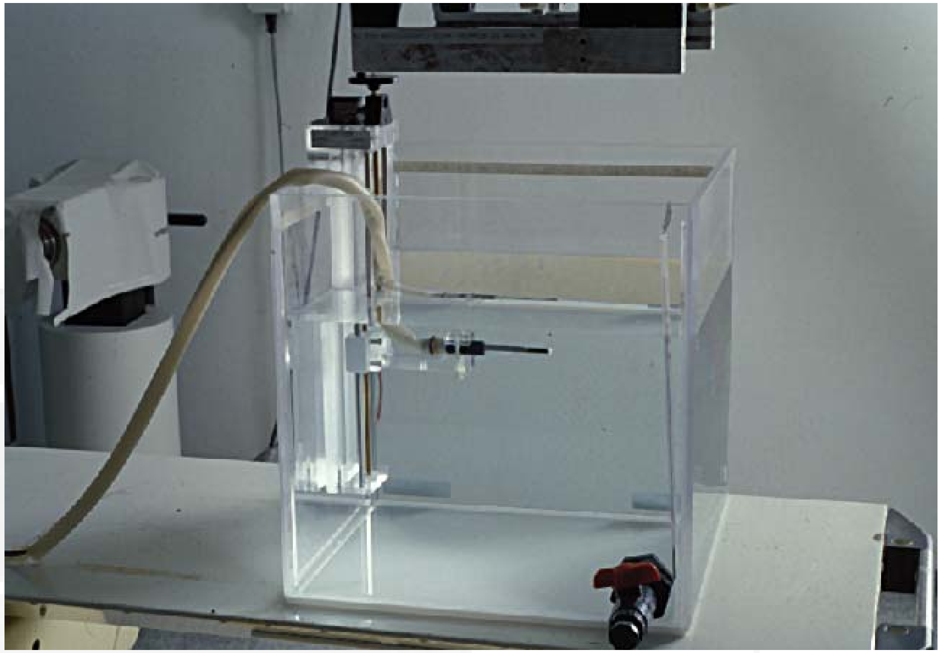
Reference detector for radiotherapy = ionisation chamber calibrated in a Second Standard Dosimetry Lab

→ application = « absolute dosimetry » and relative dosimetry



"Absolute" Dosimétry :
Reference dose rate measurement

Main advantages and characteristics of the ionisation chamber

- well known geometric and physics properties
- good response reproducibility
- low response dependance with energy, dose, dose rate
- calibration in a SSDL every 3 ans (France)

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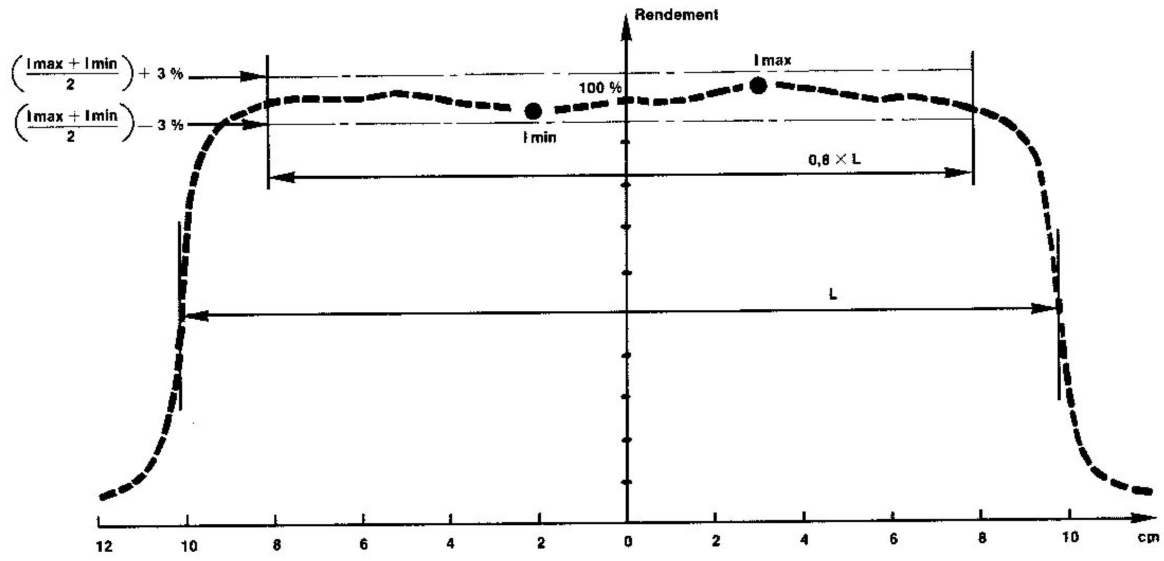
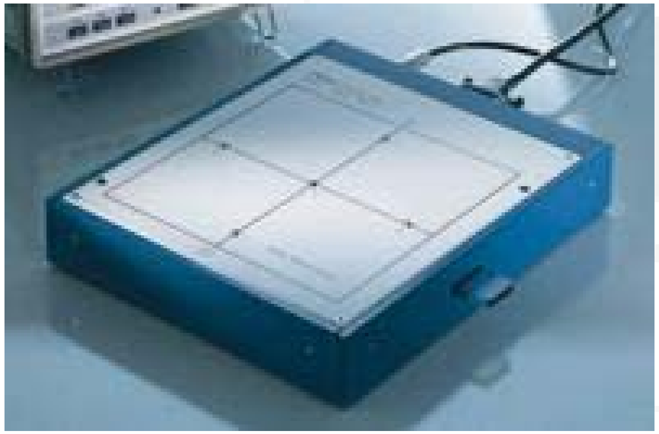


Figure 6.
Définition des critères d'homogénéité en régime photons.
L'exemple présenté sur cette figure correspond à un champ de dimensions 20 × 20 cm².

<u>Relative dosimetry :</u>
Check of symetry and homogeneity beam



1D, 2D ou 3D measurements

DIODES : PRINCIPLE

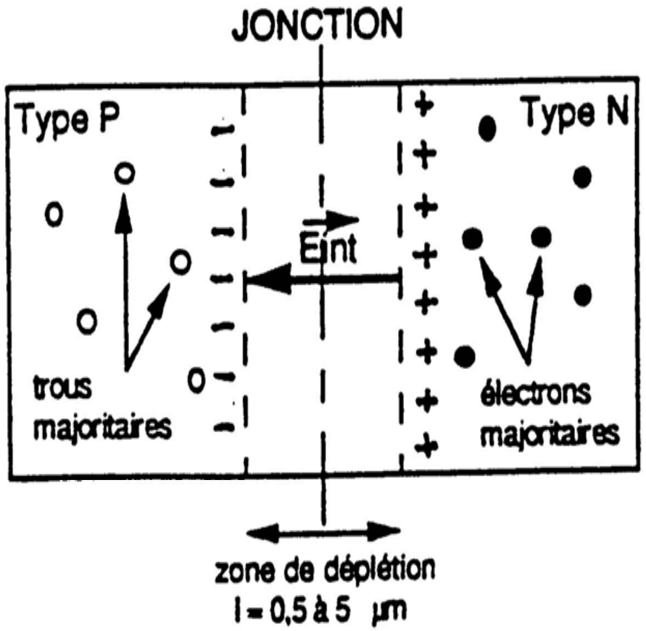
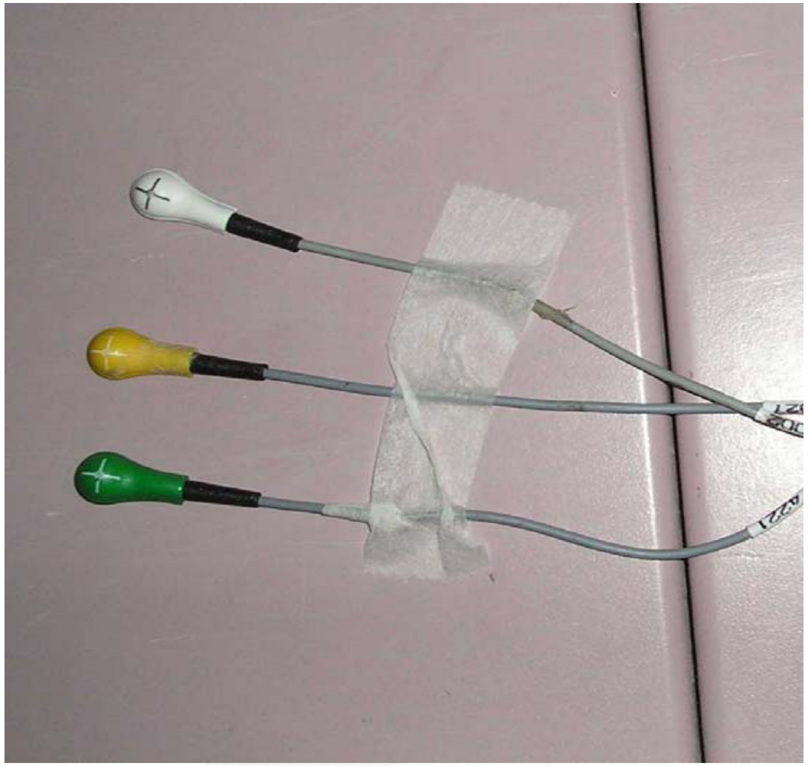


Figure 1 : JONCTION PN. Le champ électrique régnant dans la zone de déplétion repousse les porteurs majoritaires des régions N et P et accélère les porteurs minoritaires à travers la jonction.



irradiation→ electron-hole creation → current → absorbed dose

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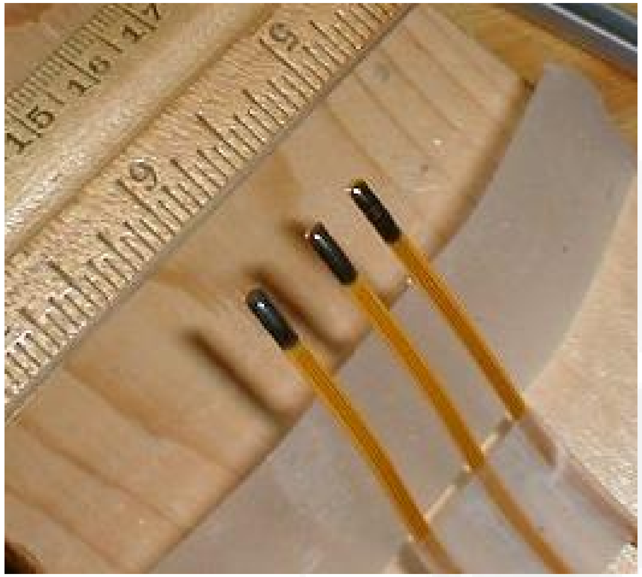
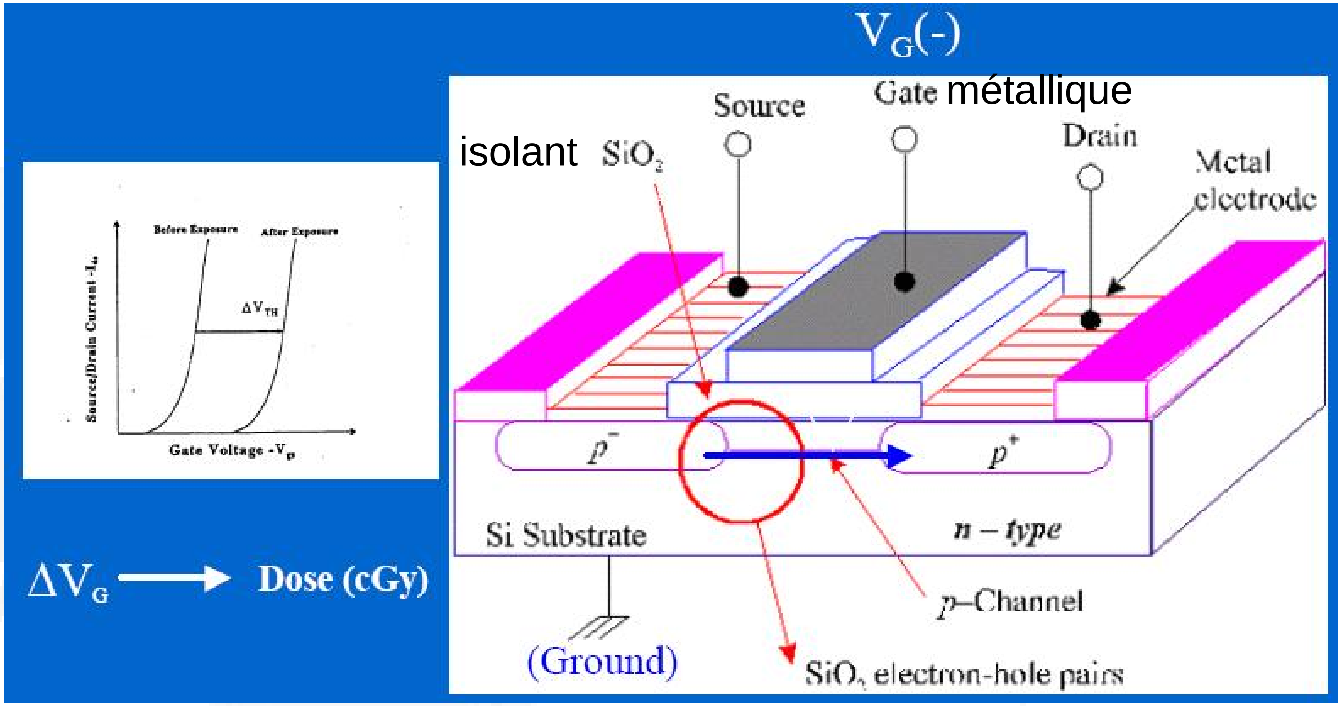
MOSFET : Metal Oxyde Semiconductor Field Effect Transistor

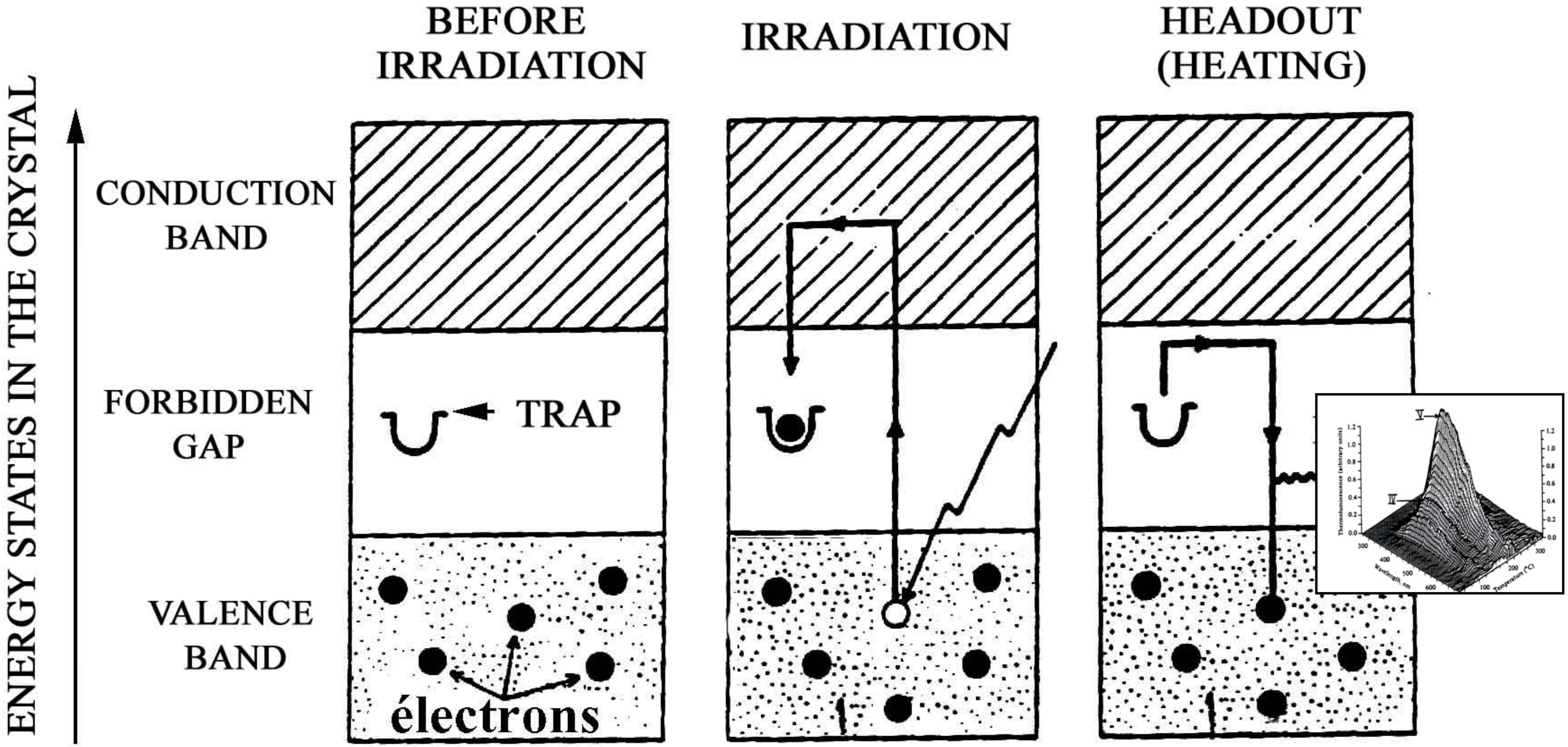
Characteristics : Si small transistor (2 p zones inserted in n zone)





Principle :
A polarization voltage is applied during irradiation
Th irradiation induces an increase of the transistor threshold voltage
The measurement of the threshold voltage is a linear function of absorbed dose

RADIOTHERMOLUMINESCENCE DOSIMETRY



Photographic film

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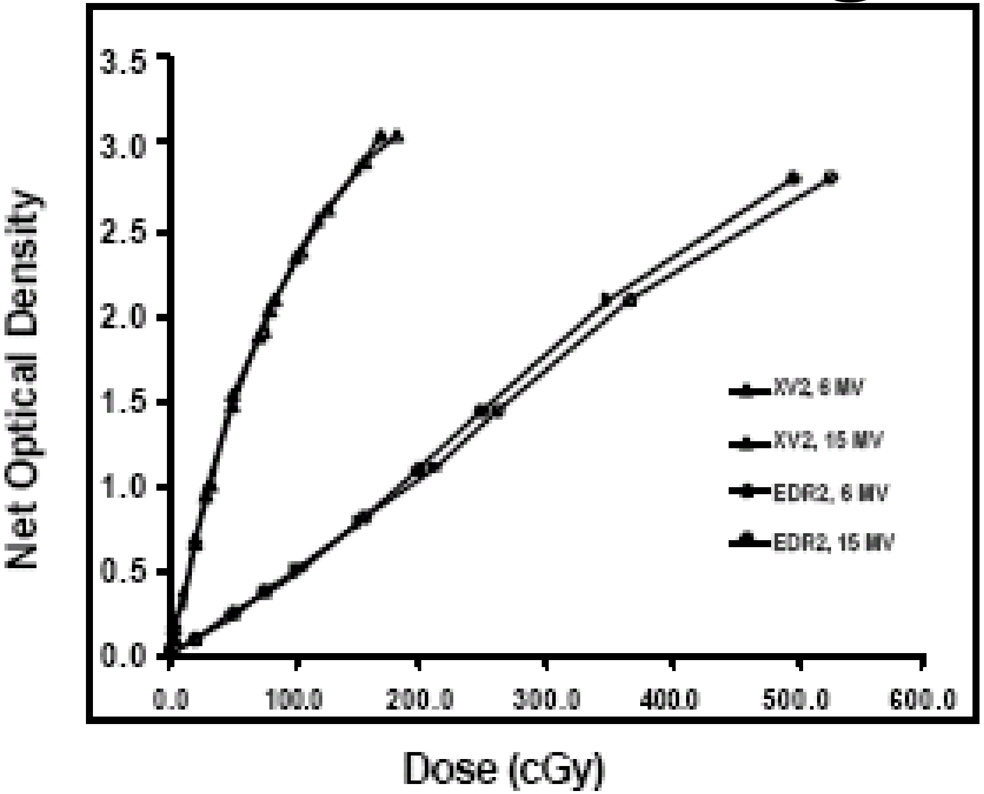

Film	Responsive Range	Approximate Saturation Exposure
PPL	0.25–5 cGy	10 cGy
XTL	1–15 cGy	30 cGy
XV-2	5–100 cGy	200 cGy
EDR2	25–400 cGy	700 cGy

Films Kodak

Dose sensitivity

Conversion curve

OD vs dose depending on film characteristics

Dose rate sensitivity

Film response is independant versus dose rate (for the dose rate range used for radiotherapy)

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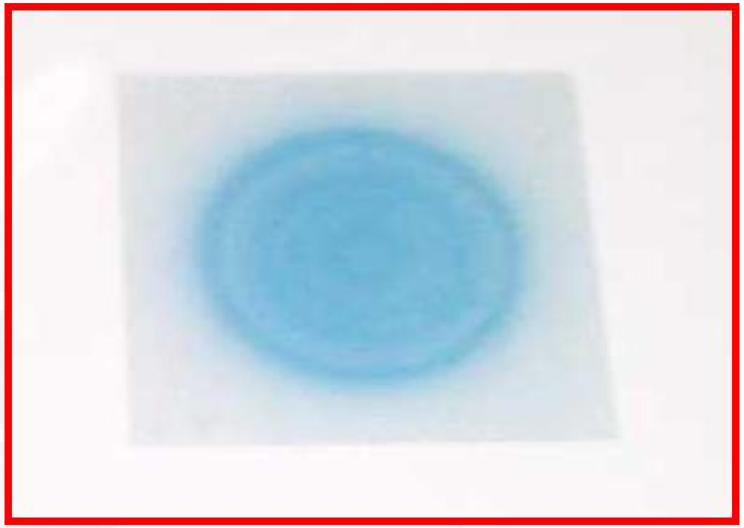
Radiochromic Film

Characteristics

New type of film for dosimetry in radiotherapy

- one of the more used : **Gafchromic film**



Gafchromic film composition

- 9,0 % H
- 60,6 % C
- 11,2 % Zn
- 19,2 % O

> composition closed to human tissue, better tissue equivalent (Z between 6 et 6.5, closer than radiographic film)

Non irradied Gafchromic film is incolore > blue coloration when irradiated

Principle

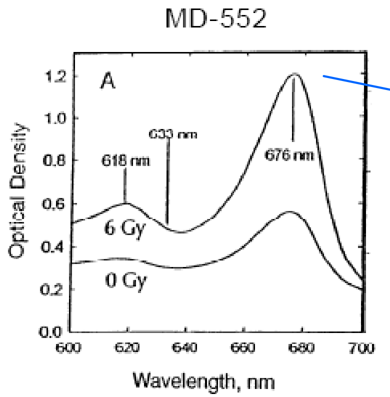
Under irradiation radiochromic film polymerises due to a special included colourant

Self-processsing :

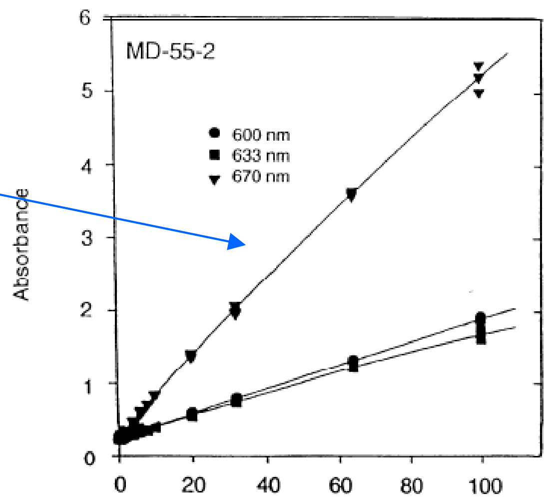
Definitive film coloration < 24 h after irradiation

The polymer on the support absorbes the light so transmission light through the film can be measured with a flat scanner (or a bed scanner)

Optical density measured for a narrow wavelength
(choice of a light source adapted to the film in order to get the best sensitivity, response)
OD vs dose linear relation can be established under calibration



The optical absorption spectrum of unirradiated GafChromic MD-55-2 (lower spectrum) and GafChromic MD-55-2 several weeks after a dose of about 6 Gy (upper spectrum). The bandpass used was 3.5 nm. Some useful wavelengths are indicated.



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IMRT

IMRT

- Today several technical solutions to deliver IMRT treatments :
  - « Standard » IMRT (static mlc beams),
  - Rotational IMRT (VMAT, IMAT),
  - Helical radiotherapy (Tomotherapy).

3D CRT

- To increase target dose with sparing of healthy tissue.
- Use of adapted equipments :
  - 3D dose calculation software (convolution-superposition algorithms),
  - Linac,
  - MLC,
  - Real-time imaging devices.

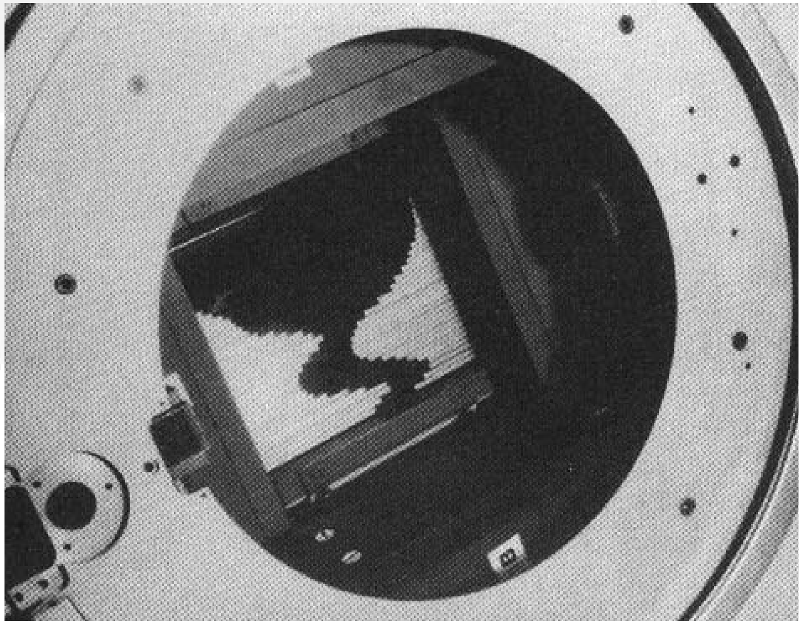
IMRT

- To increase target dose with sparing of healthy tissue by 3D CRT optimization.
- Same equipments + :
  - Inverse planning software using doses-volumes constraints (knowledge data bases).

The linac

The multi leaves collimator

(from 3 mm to 10 mm width size at isocenter)



Treatment Planning System

- A 3D software application using :
  - A calculation software supporting convolution superposition algorithms,
  - An inverse planning software planification for IMRT.

$$SV_{PTV} = \sum_{i=1}^{N} [IW^{i}_{PTV} (D^{i}_{PTV} - GD_{PTV})^2]$$

$$SV_{OAR} = \sum_{j=1}^{M} [IW^{j}_{OAR} (D^{j}_{OAR} - GD_{OAR})^2]$$

Example : Head & Neck and IMRT

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Ballistic

- 4 MV X-ray
- 5 beams with following gantry angulations :
  - 0°, 72°, 144°, 216°, 288°

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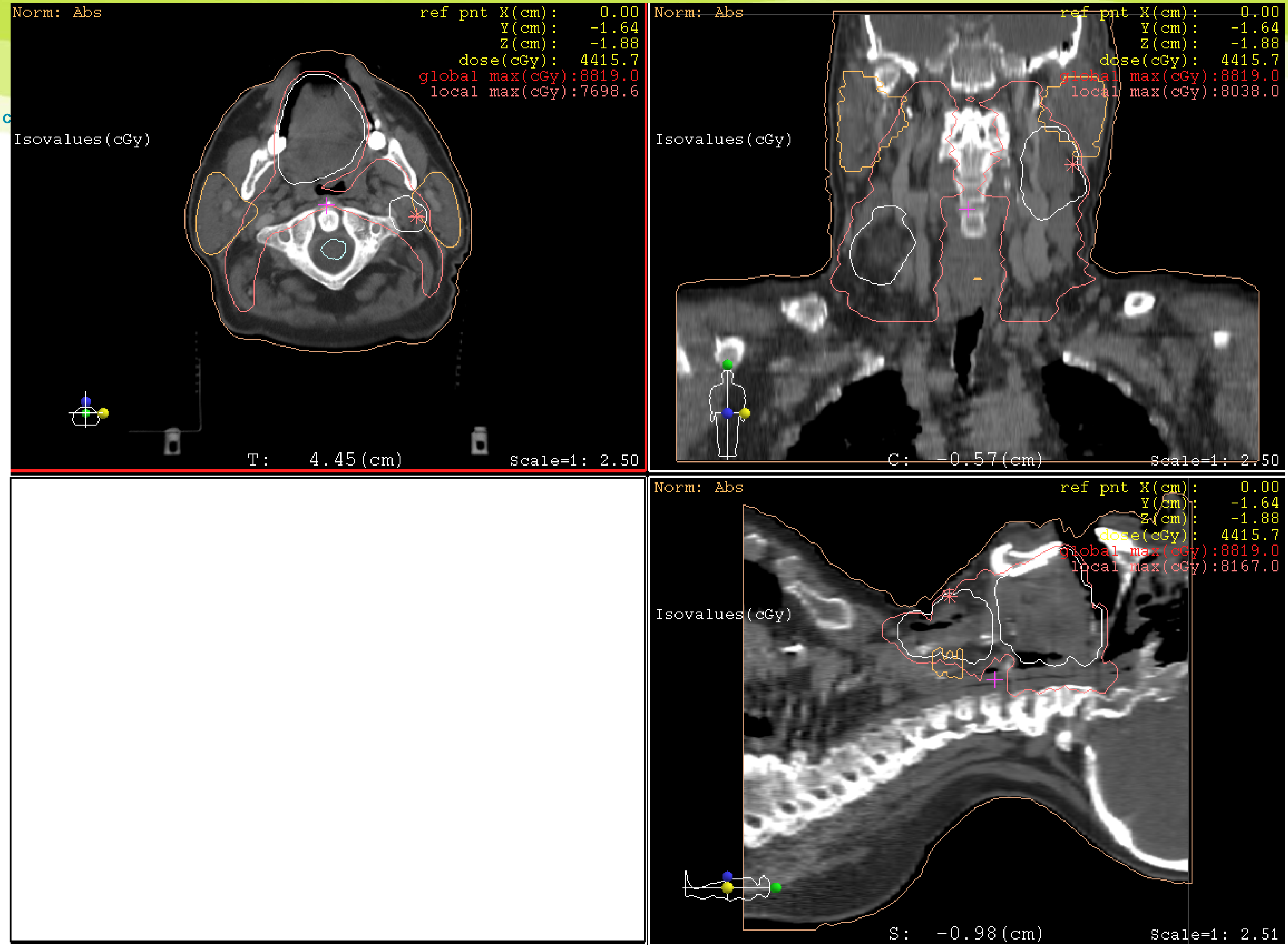
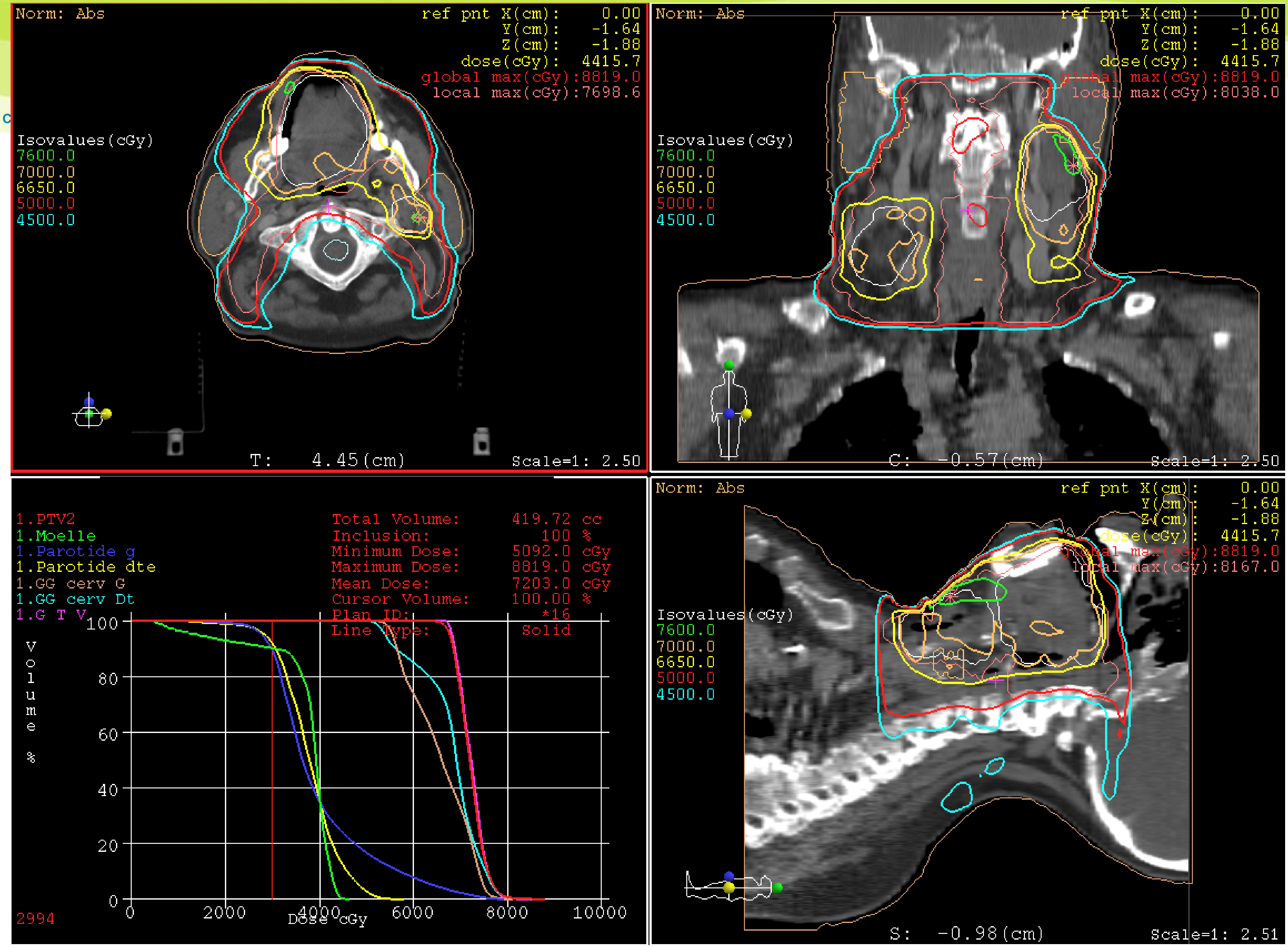
Example of doses-volumes constraints in H&N

- Target volumes objectives
  - 70 Gy to the therapeutic volume at least 95 % of the dose delivered to 95 % of the target volume.
  - 50 Gy to the prophylactic volumes (delineation as Amsterdam-Brusells medical consensus) at least 95 % of the dose delivered to 95 % of the target volumes.
- Organs At Risk (OAR) constraints
  - Spinal cord : 100 % vol < 46 Gy
  - Larynx : 50 % vol < 40 Gy
  - Left and Right parotids : 50 % vol < 30 Gy


Norm: Abs
ref pnt X(cm): 0.00
Y(cm): -1.64
Z(cm): -1.88
dose(cGy): 4415.7
global max(cGy):8819.0
local max(cGy):7698.6
Isovalues(cGy)
T: 4.45(cm)
Scale=1: 2.50
Norm: Abs
ref pnt X(cm): 0.00
Y(cm): -1.64
Z(cm): -1.88
dose(cGy): 4415.7
global max(cGy):8819.0
local max(cGy):8038.0
Isovalues(cGy)
C: -0.57(cm)
Scale=1: 2.50
Norm: Abs
ref pnt X(cm): 0.00
Y(cm): -1.64
Z(cm): -1.88
dose(cGy): 4415.7
global max(cGy):8819.0
local max(cGy):8167.0
Isovalues(cGy)
S: -0.98(cm)
Scale=1: 2.51


Norm: Abs
ref pnt X(cm): 0.00
Y(cm): -1.64
Z(cm): -1.88
dose(cGy): 4415.7
global max(cGy):8819.0
local max(cGy):7698.6
Isovalues(cGy)
7600.0
7000.0
6650.0
5000.0
4500.0
T: 4.45(cm)
Scale=1: 2.50
local max(cGy):8038.0
C: -0.57(cm)
Scale=1: 2.50
1.PTV2
1.Moelle
1.Parotide g
1.Parotide dte
1.GG cerv G
1.GG cerv Dt
1.G T V
Total Volume: 419.72 cc
Inclusion: 100 %
Minimum Dose: 5092.0 cGy
Maximum Dose: 8819.0 cGy
Mean Dose: 7203.0 cGy
Cursor Volume: 100.00 %
Plan ID: *16
Line Type: Solid
Volume %
0
20
40
60
80
100
0
2000
4000
6000
8000
10000
Dose cGy
2994
local max(cGy):8167.0
S: -0.98(cm)
Scale=1: 2.51

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Patient setup

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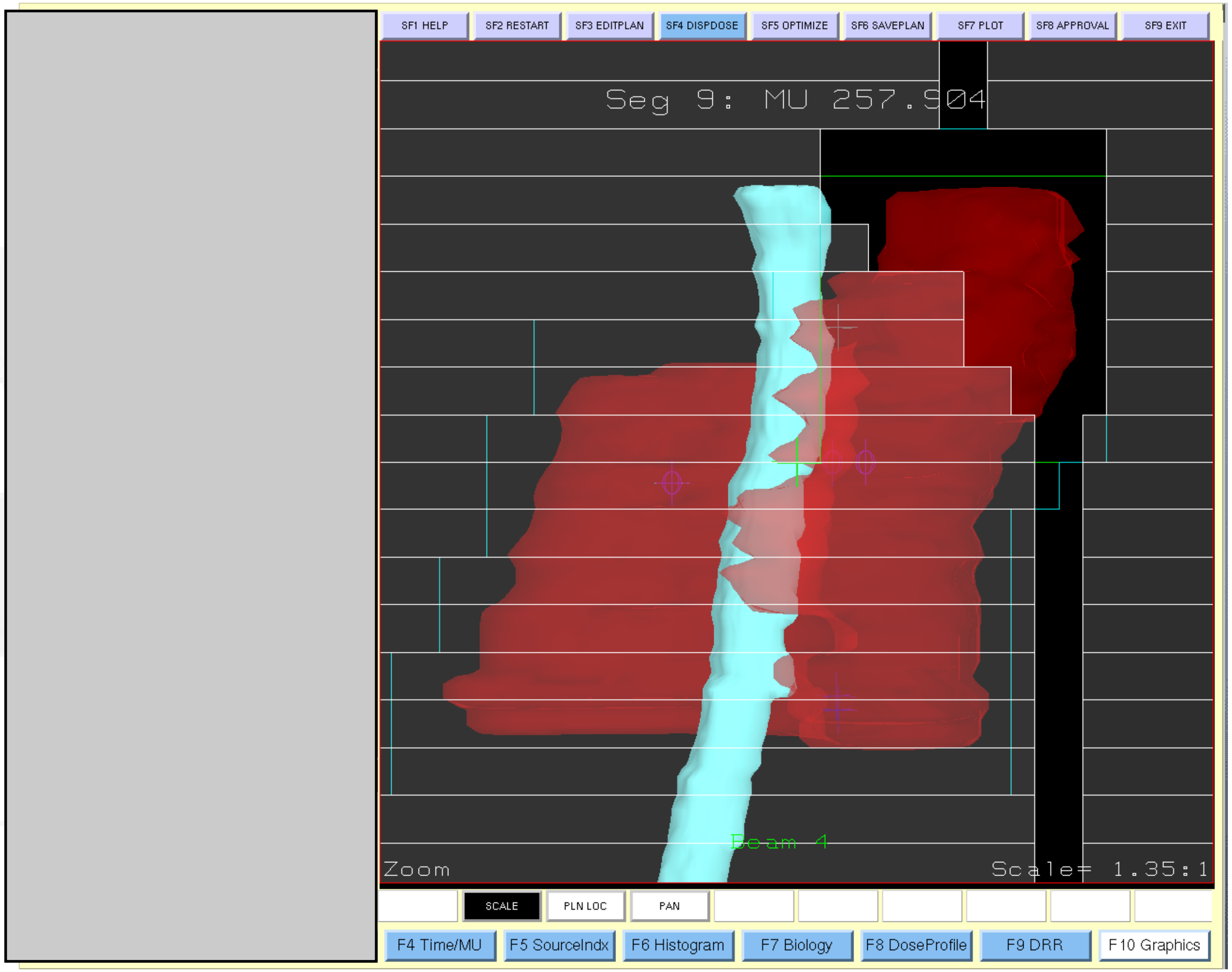
MLC Segmentation



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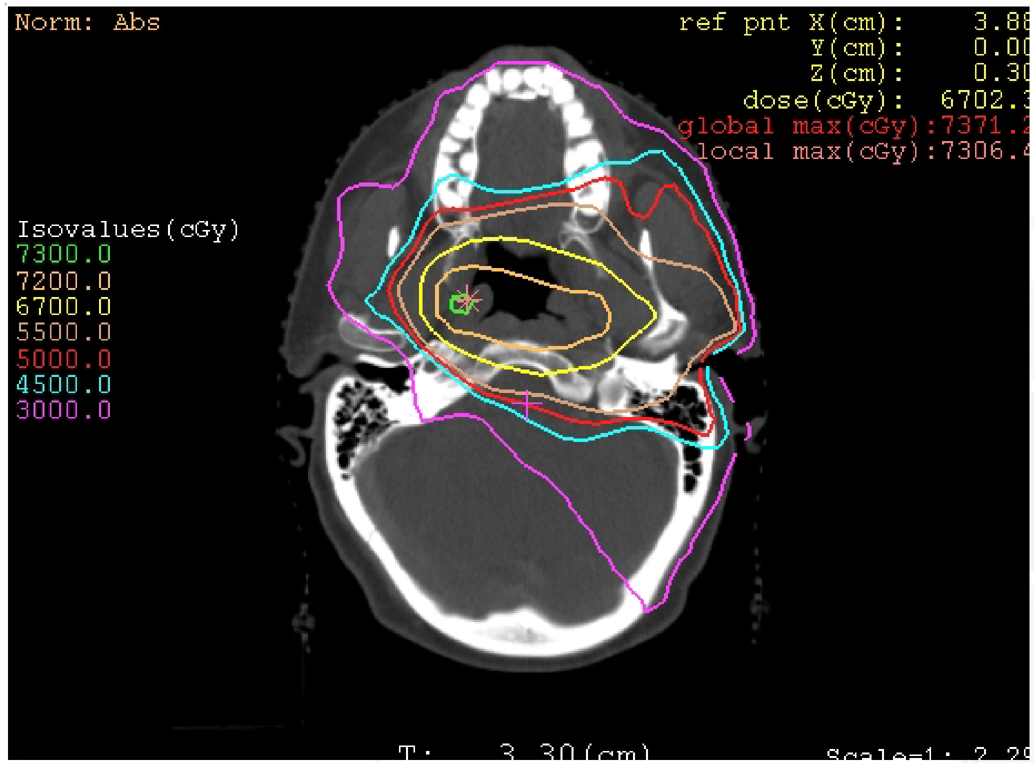
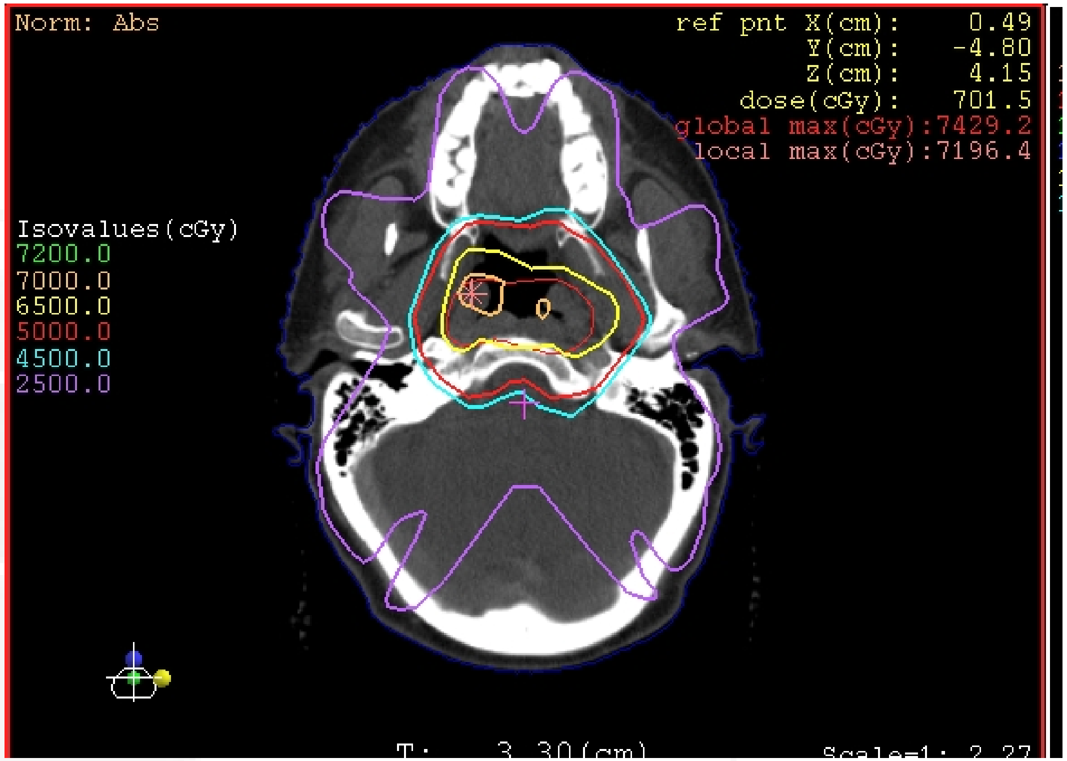
Qualitative evaluation

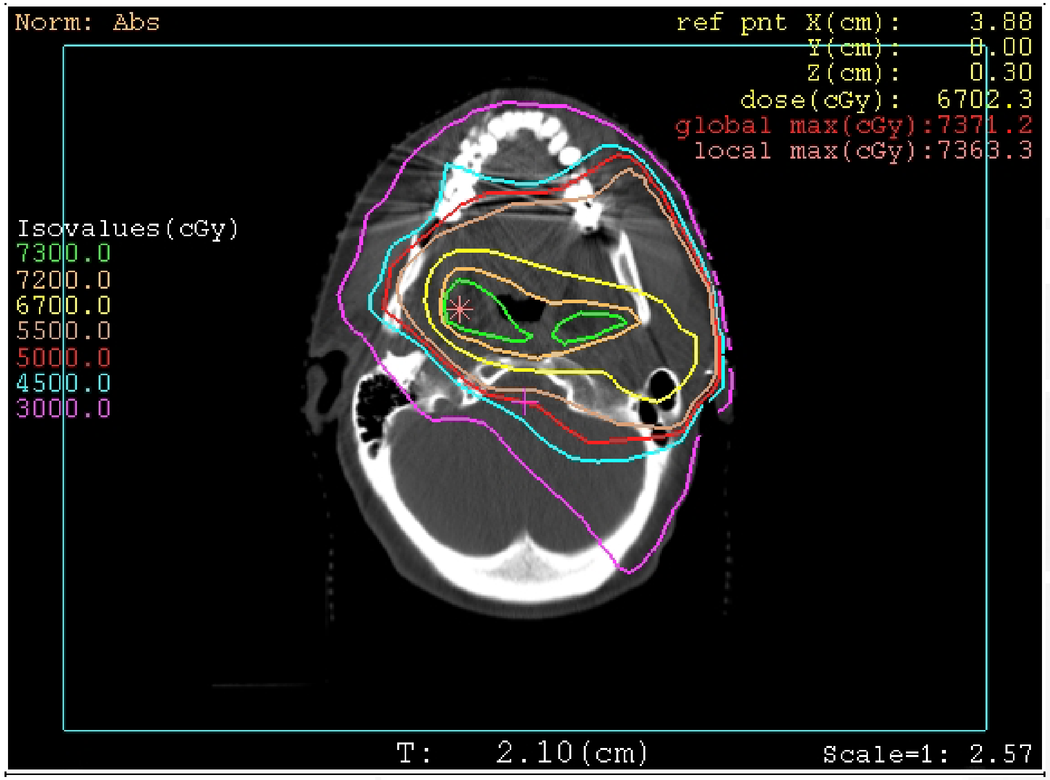


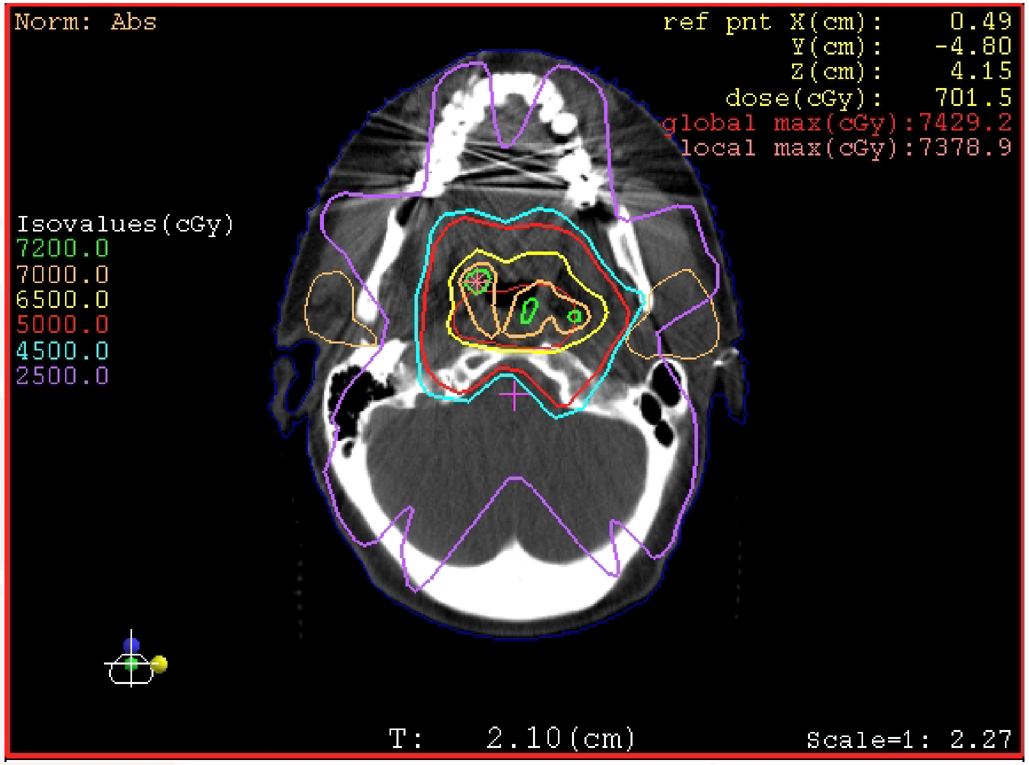


3D CRT

IMRT

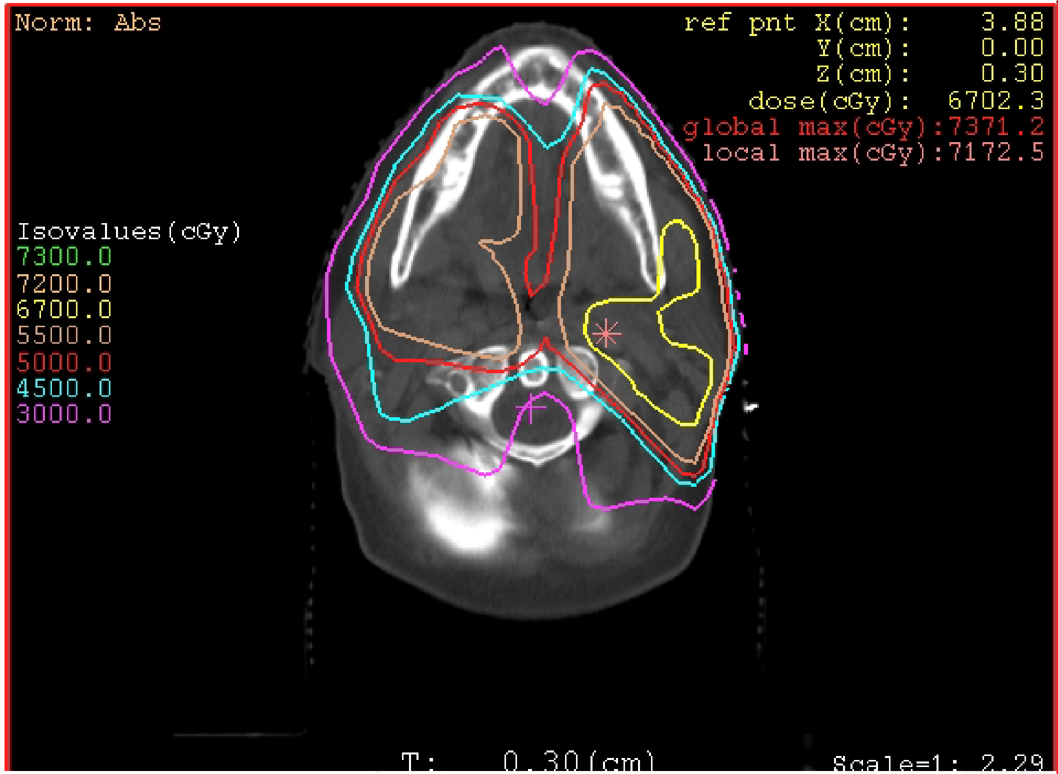
Qualitative evaluation

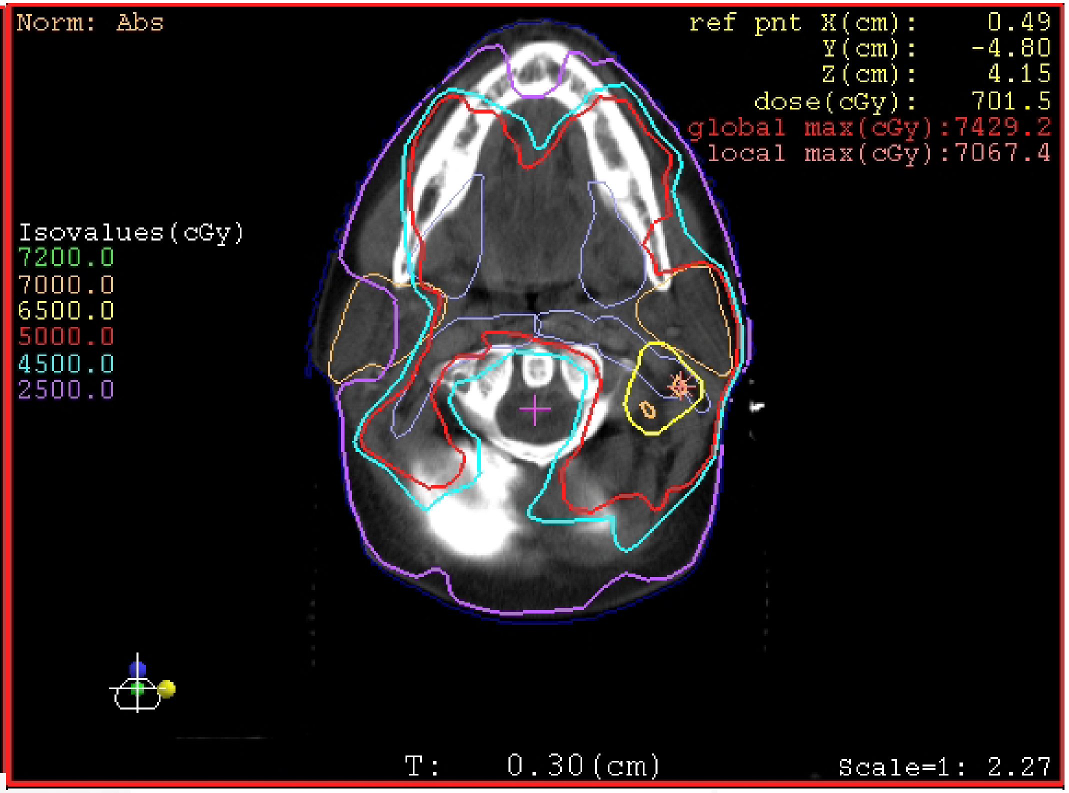




3D CRT **IMRT**

Qualitative evaluation





3D CRT

IMRT

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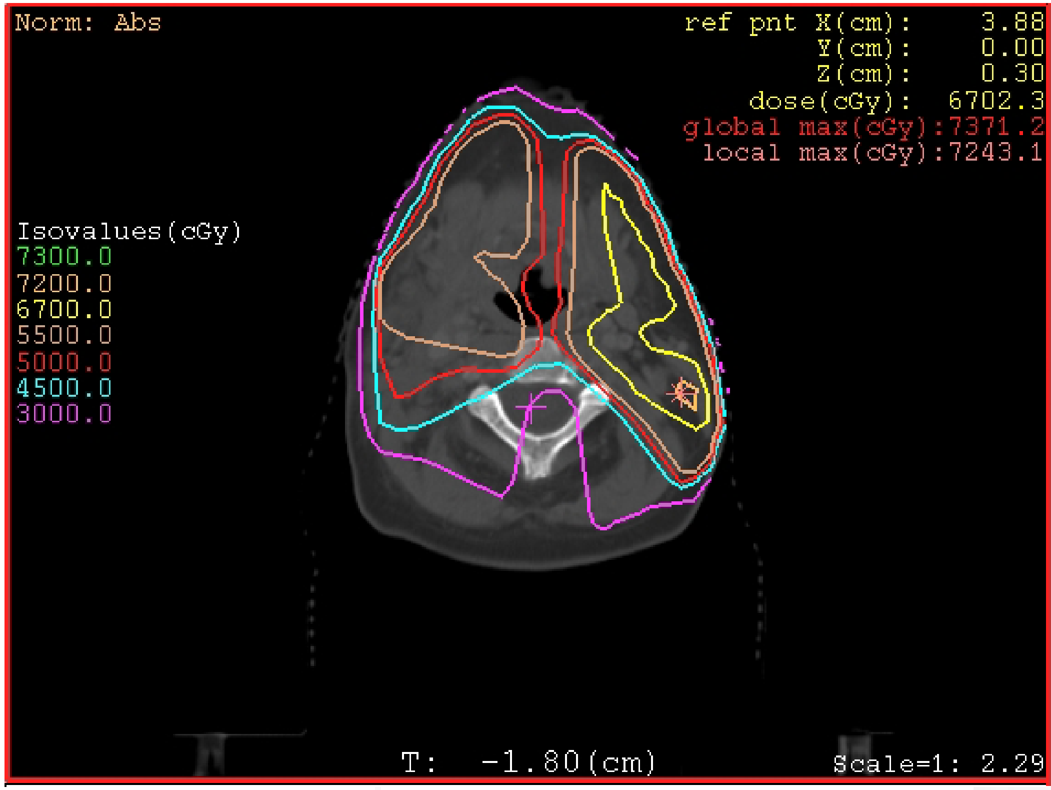
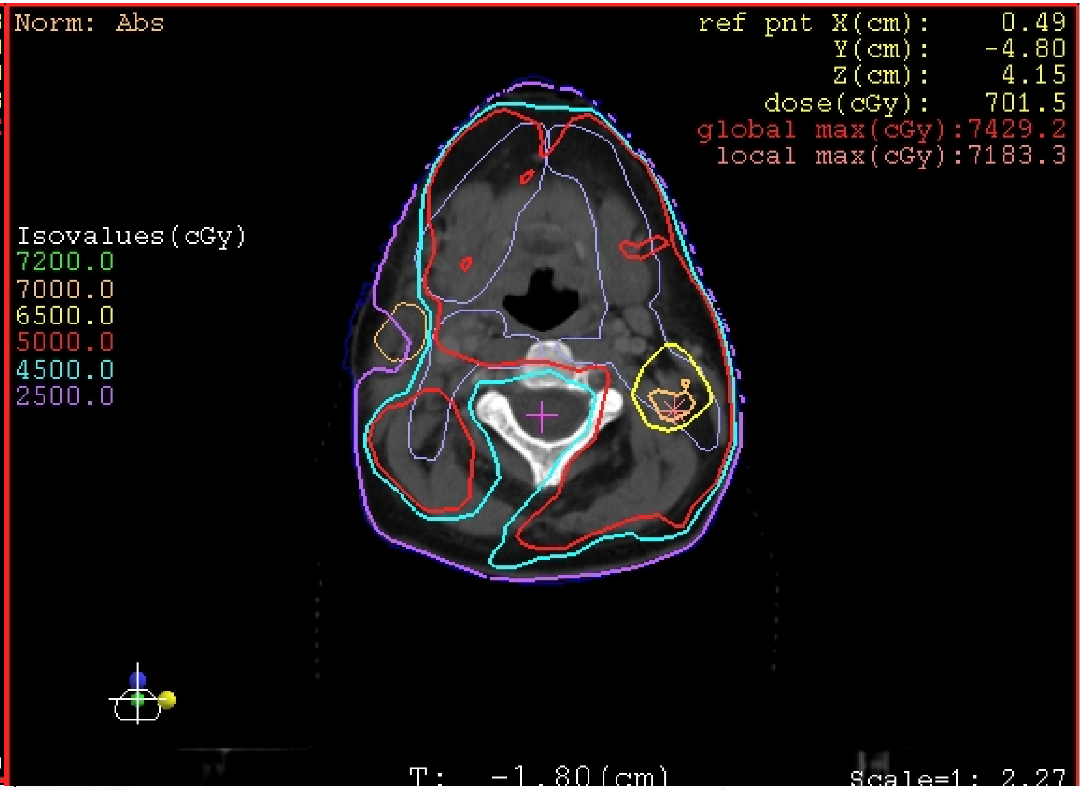
Qualitative evaluation

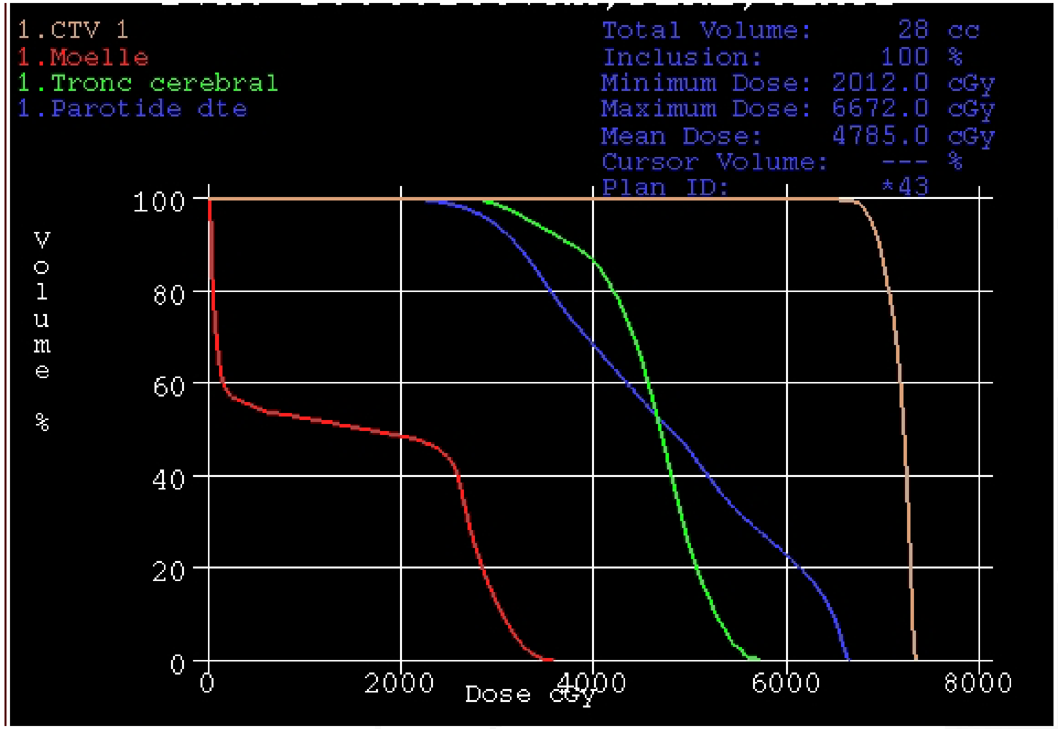


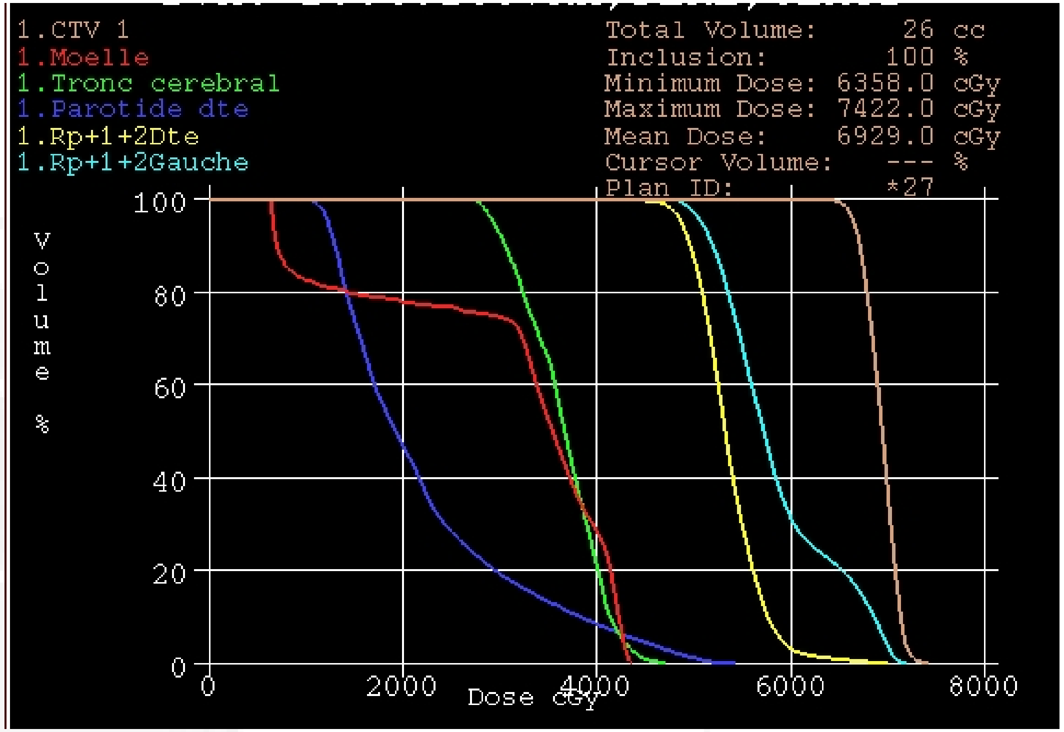
3D CRT



IMRT

Quantitative evaluation





3D CRT **IMRT**

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IMRT Pre treatment verification

Objectives

- To validate the calculation by a measurement
- To "treat" one fraction of a phantom (anthropomorphic shape , plastic slabs) with the fluences defined and validated by the physician and the physicist for the patient treatment.
- In the phantom we can introduce different detectors :
  - Ionization chambers,
  - Radiographic, radiochromic films,
  - 2D arrays detectors

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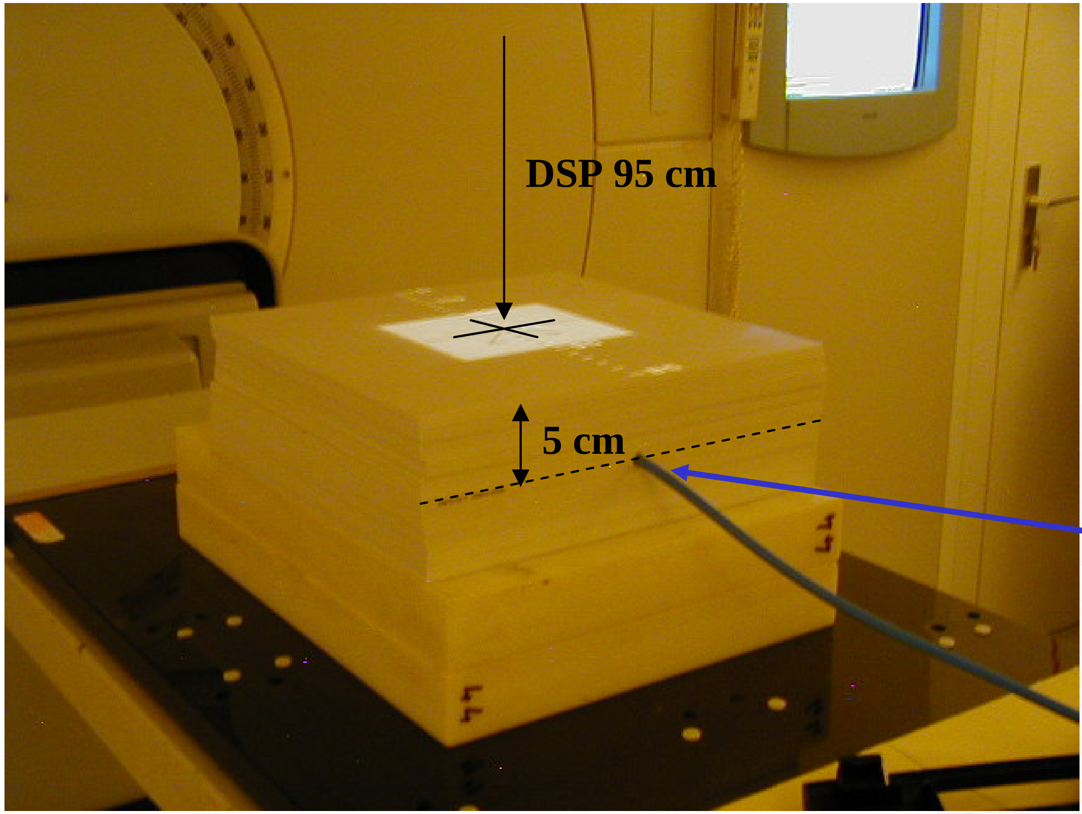
Equipment pre-treatment verification

Parallelepipedic Phantom (RW3)



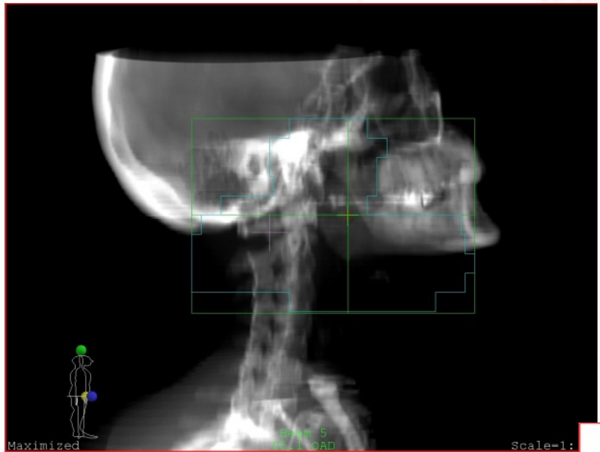
Each treatment beam in a simple, reproducible geometry

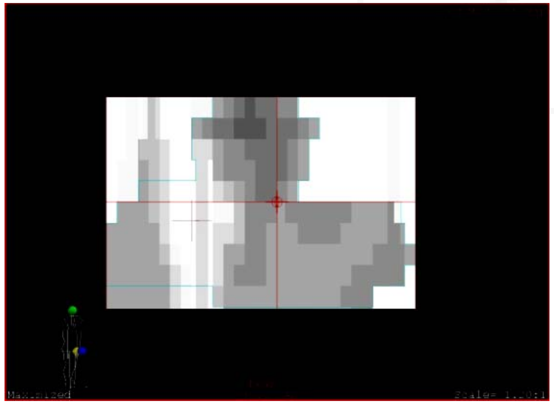
An ionisation chamber can be inserted and/or a radiographic film between 2 slabs of tissue equivalent material

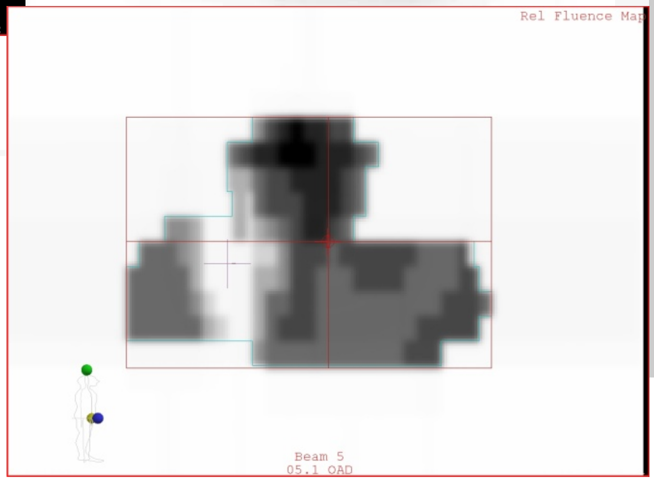
➢ **Beam per beam Verification**

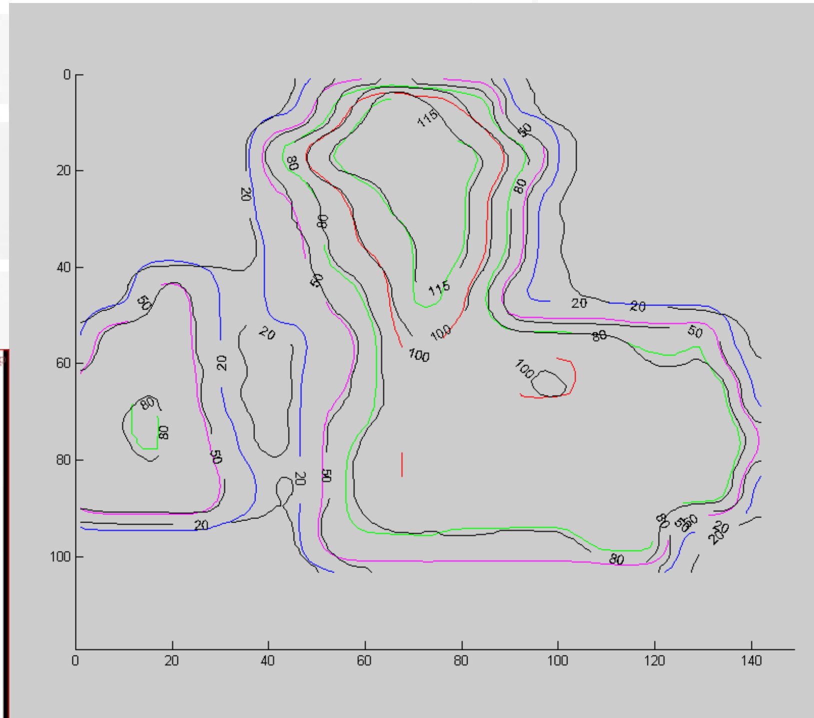
H&N rao IMRT Field

A dosimetric film (photographic or radiochromic) is calibrated (OD vs dose) and directly compared to the calculated TPS dose distribution.









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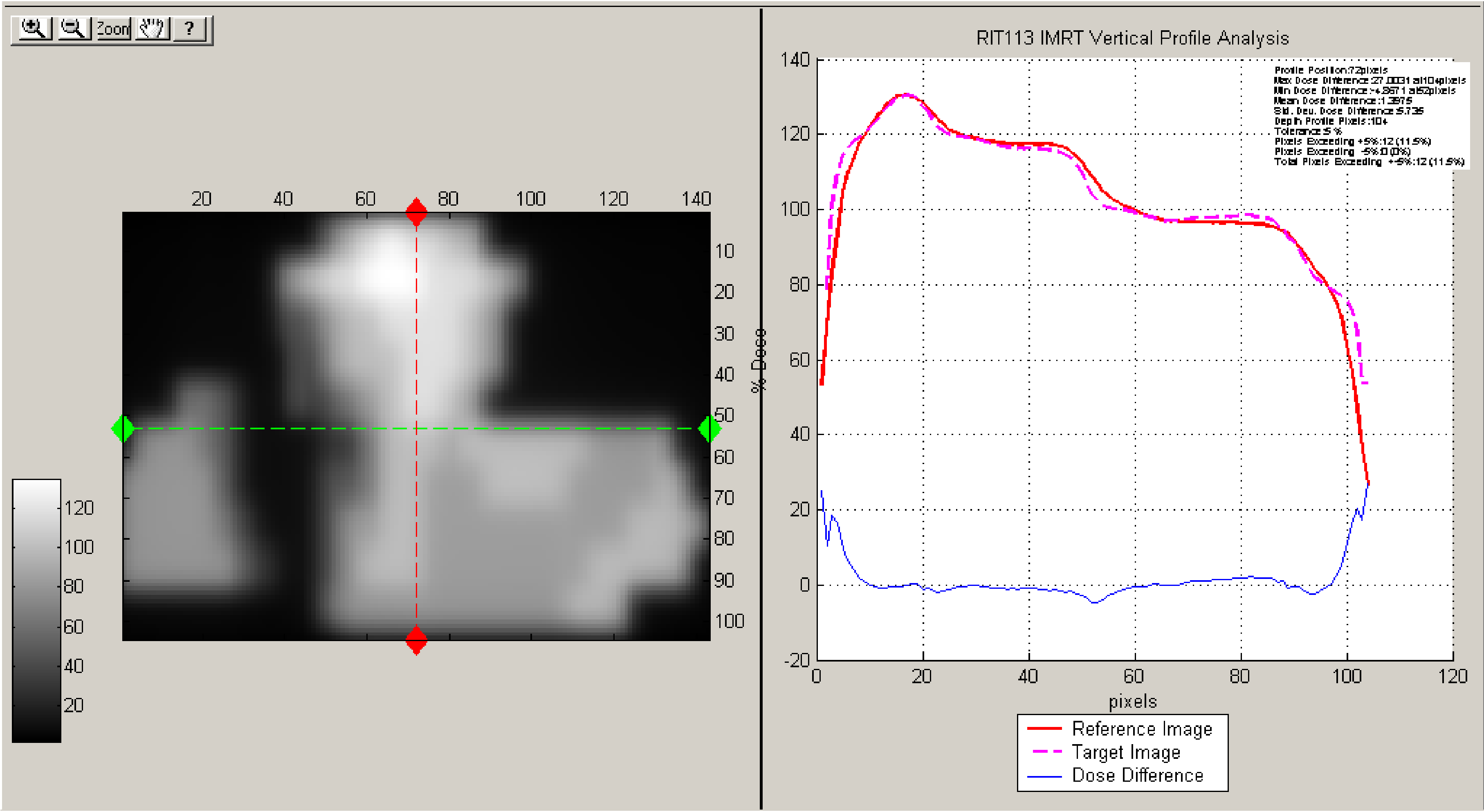
H&N rao IMRT Field



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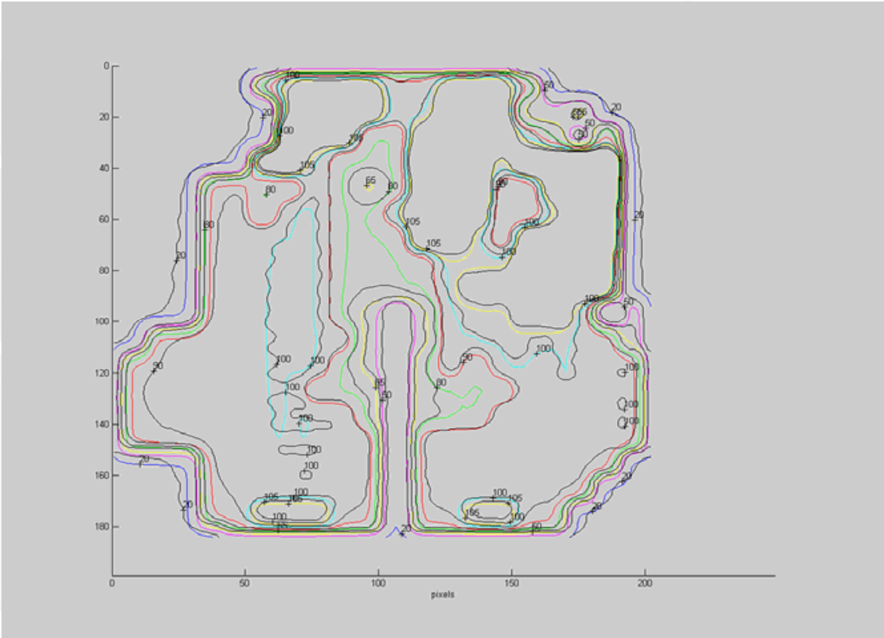
H&N ant IMRT Field



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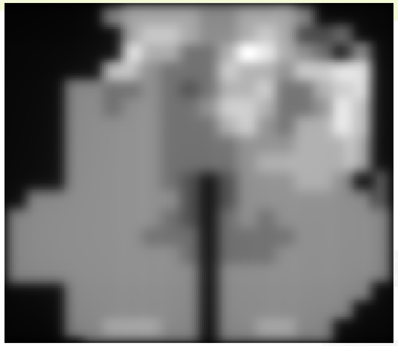
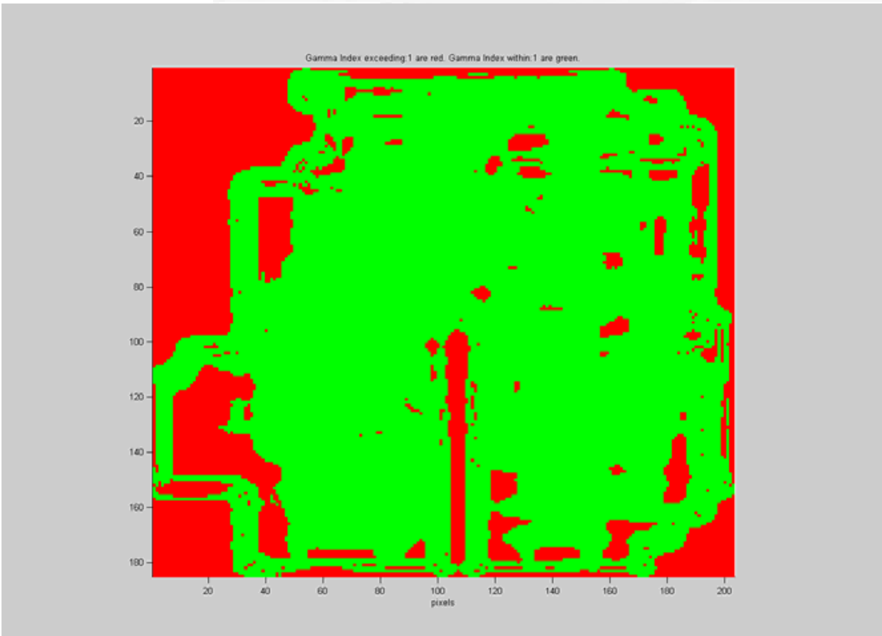
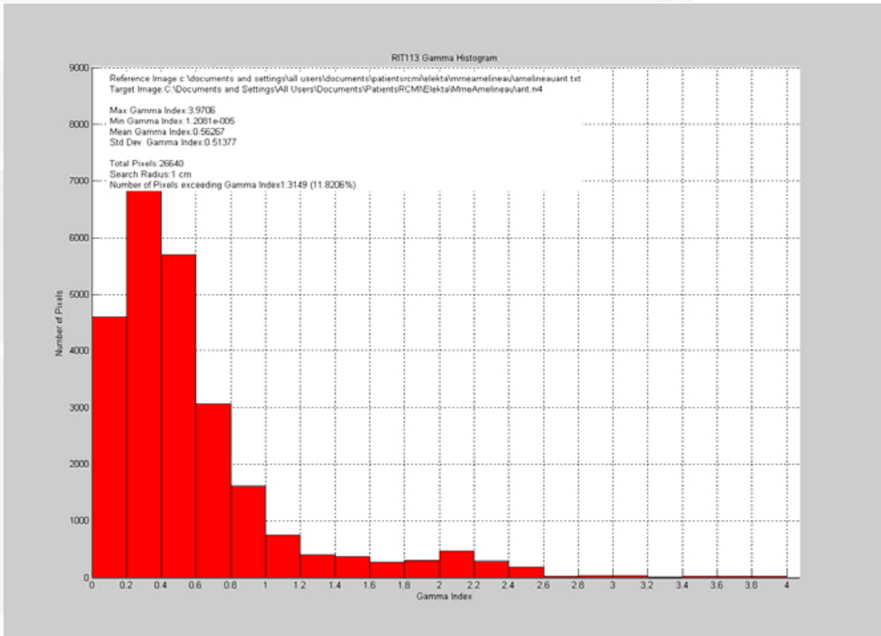
H&N ant IMRT Field



$$\min\left\{\sqrt{\frac{\Delta D^2}{\Delta D_{\max}^2}+\frac{(\Delta x^2+\Delta y^2)}{\Delta d^2}}\right\}\equiv\gamma$$





Comparison of two dose matrices (calculated, measured).Here the criterions are dose difference (3 %) and distance to agreement (3 mm). Values exceding 1 fail the criteria.

Patient specific QA - Equipment

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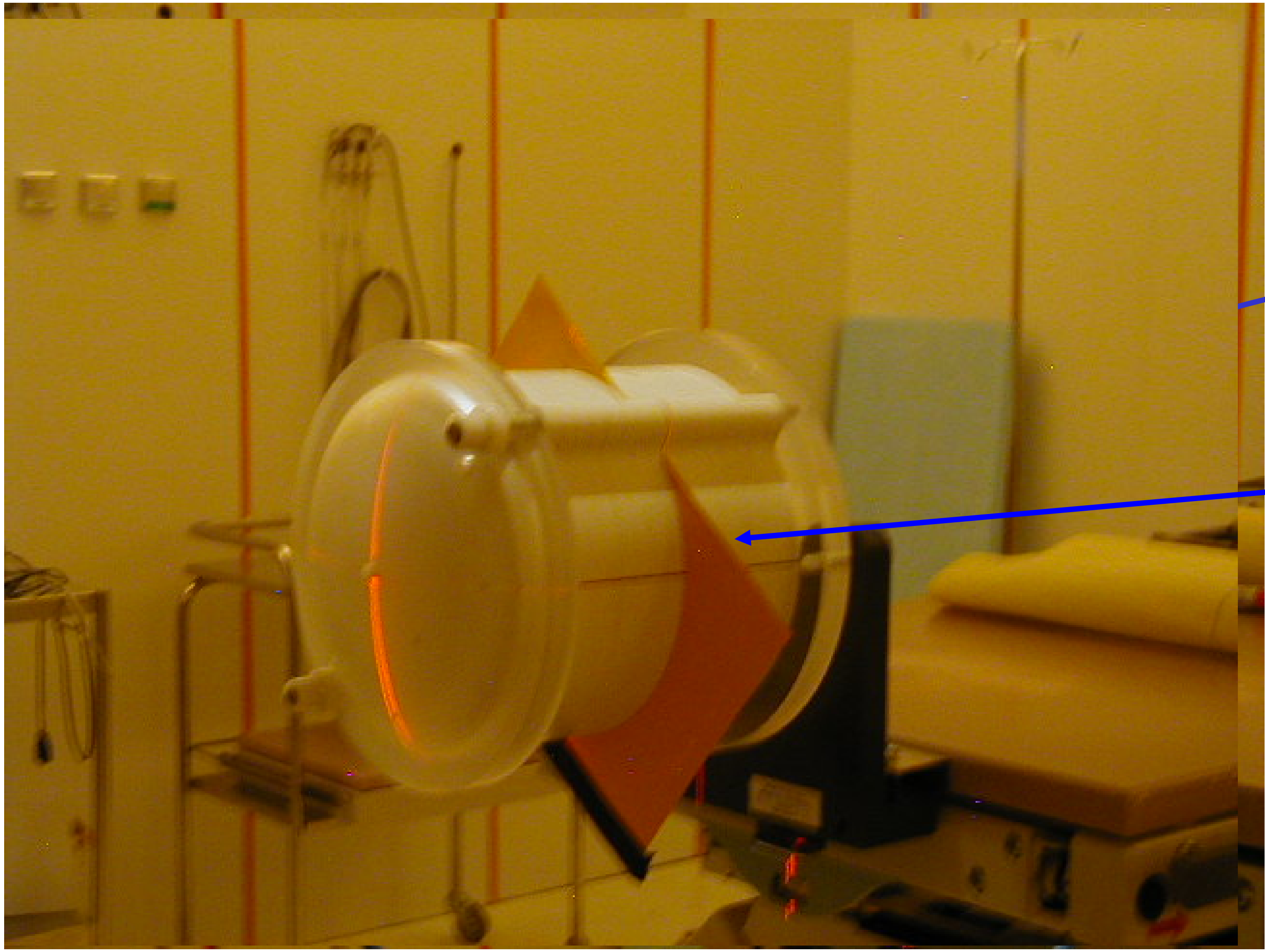
H&N phantom from PTW (RW3 water equivalent material)



insertion of a small volume detection ionisation chamber

insertion of a radiographic film between 2 slabs

➢ **Global verification using the patient treatment ballistic validated**

Contrôle qualité Plan de traitement – Analyse qualitative

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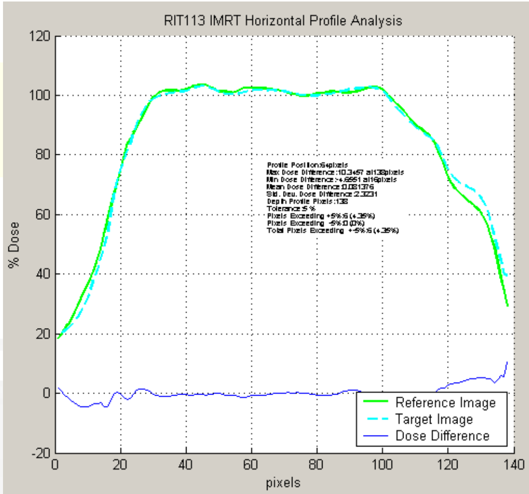
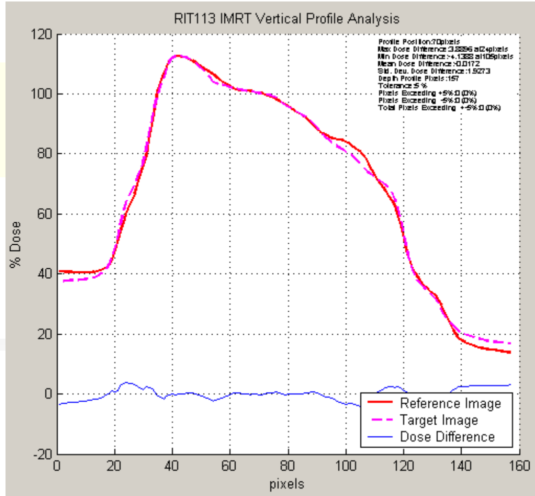
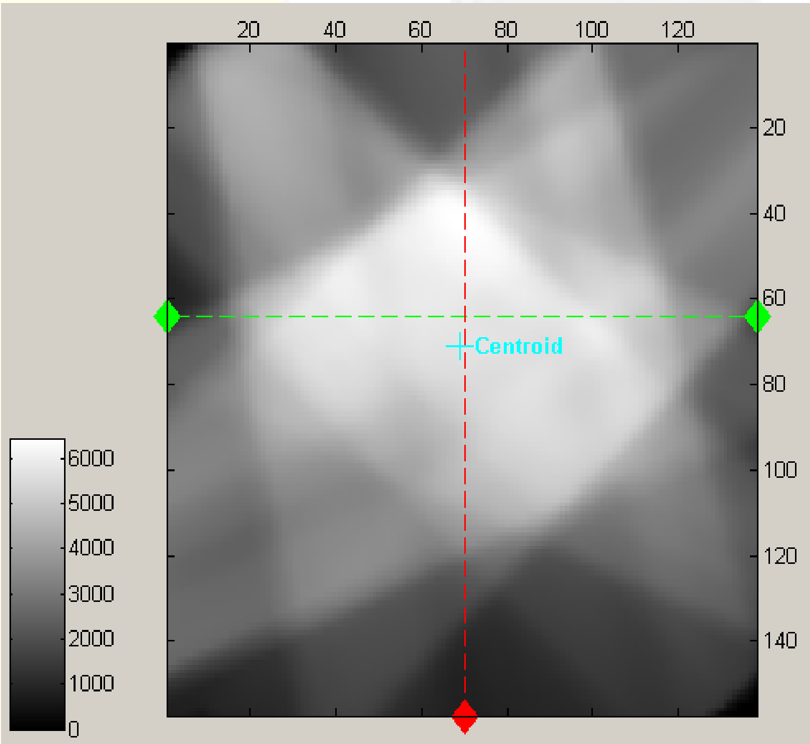
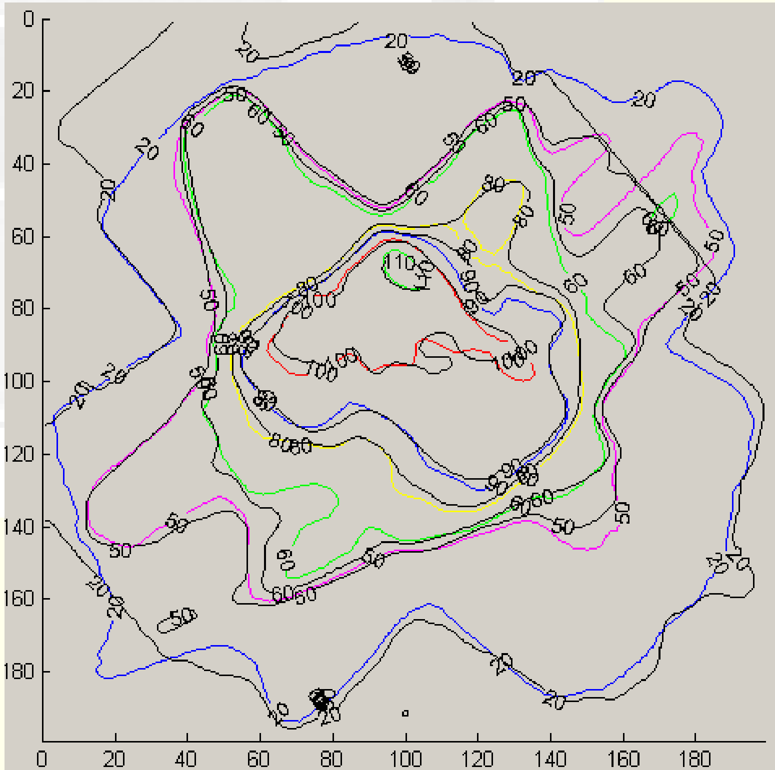
Dose profiles comparison









Calculated and measured isodoses

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External audits or comparisons between delivered and calculated doses

Reference	*Region*	*Site*	*No*	*Average*	*SD (%)*
Gillis *et al.*, 2005 ESTRO-QUASIMODO	Europe	Pelvis PTV OAR	10	 1.014 0.997	 1.6 3.6
Tomsej *et al.*, 2005 GORTEC	France and Belgium	Head-and-neck	16	0.992	3.9
Ibbott *et al.*, 2006 RPC-RTOG	US	Head-and-neck Primary PTV Secondary PTV	 450 223	 0.99 0.99	 8 7
Tomsej *et al.*, 2007 ESTRO-OECI TomoTherapy	Europe	Fictitious volume (after internal QA)	7	0.966 0.978	2.4 1.5

Results from studies of the accuracy of dose determinations of IMRT treatments.
(GUIDELINES FOR THE VERIFICATION OF IMRT- ESTRO Booklet 9)

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Linac based Stereotactic Radiosurgery Stereotactic Radiotherapy

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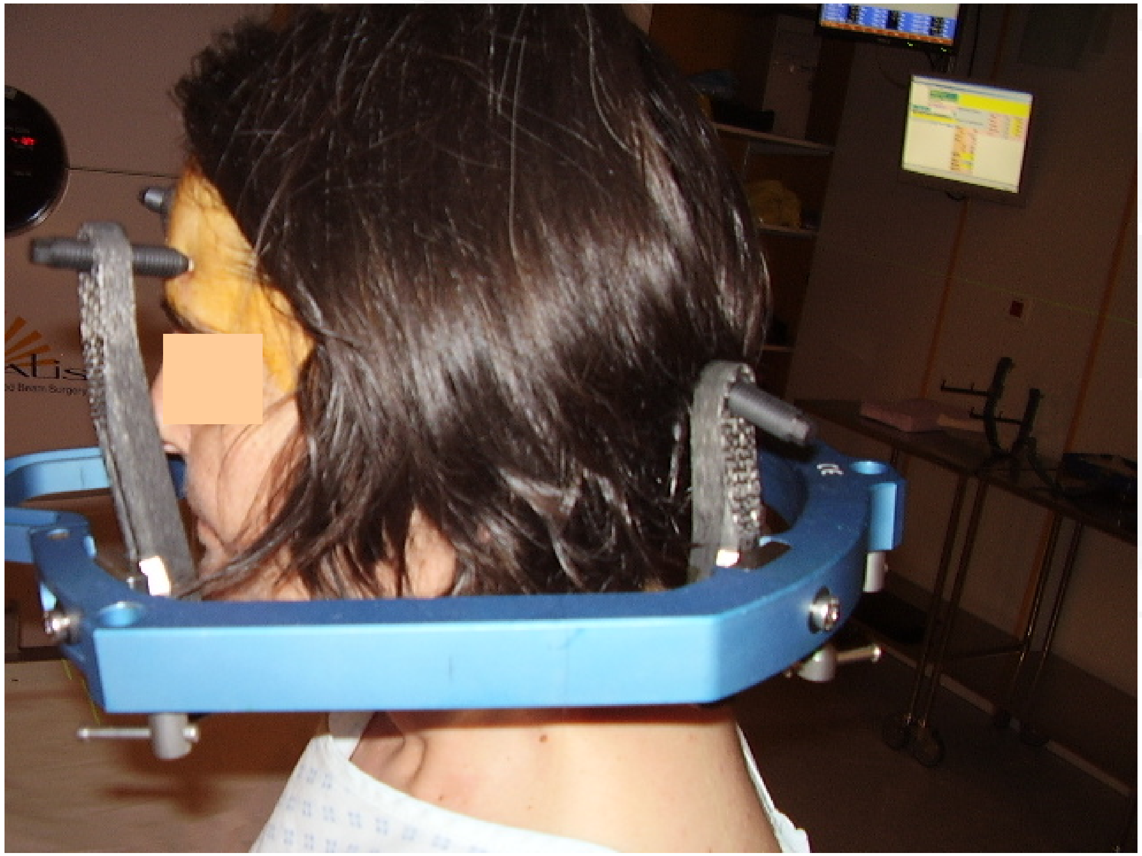
–Nante

Stereotactic RadioSurgery - SRS

- **BrainLab frame**



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Stereotactic RadioTherapy - SRT

intracranial fractionné

Bivalb mask BrainLab with mouth support

Dedicated Linac - NOVALIS

Novalis Technical Data

Integrated M3 micro-mlc 10x10 cm²

- 26 pairs of tungsten leaves 60mm thickness
- 14 pairs 3mm width at isocenter (42x42mm²)
- 6 pairs 4.5mm width at isocenter
- 6 pairs 5.5mm width at isocenter
- Leaves Transmission < 4%
- Leaves speed : 1.5 cm/s

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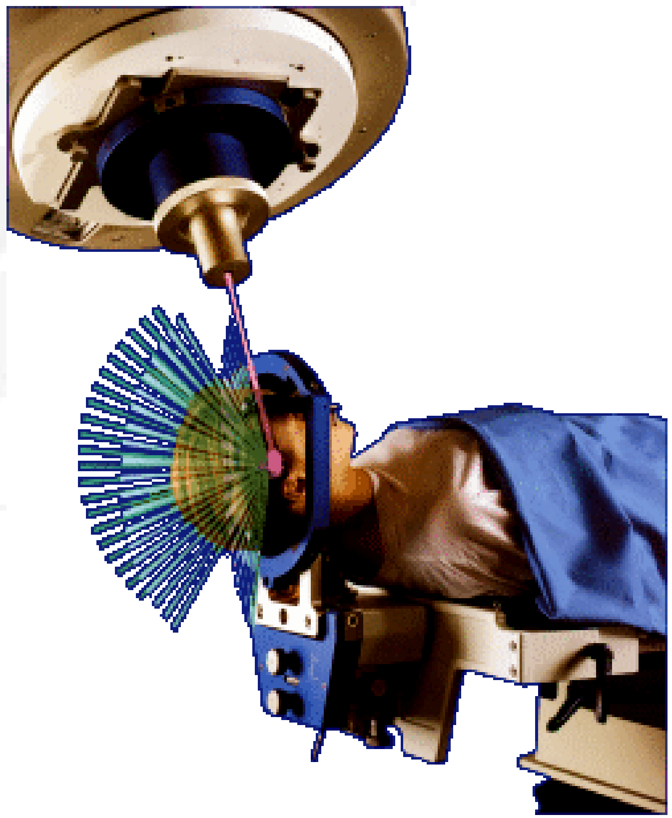
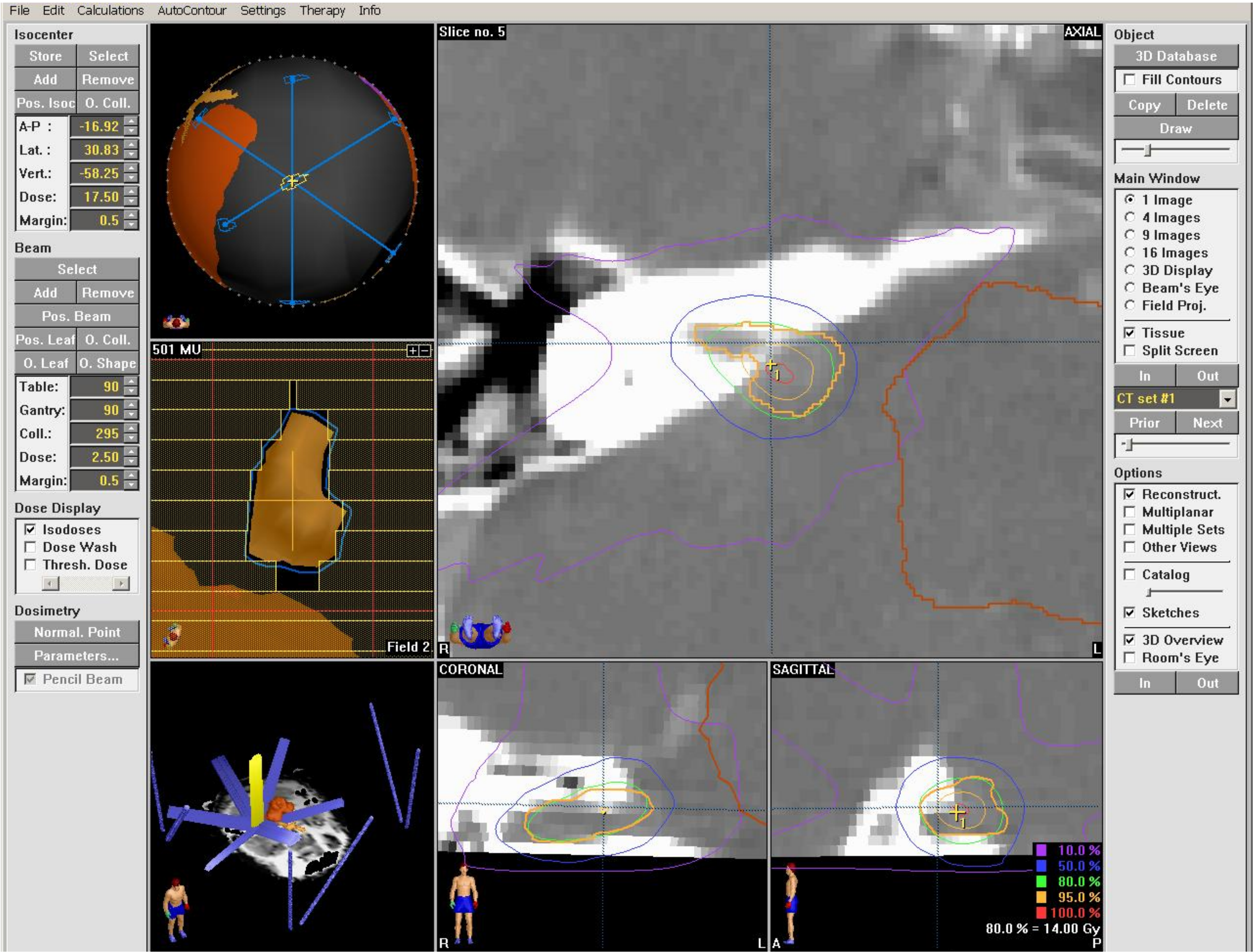
Radiosurgical circular cones

Radiosurgical circular cones ranging from Ø 4 mm to 15 mm

Patient frame (or mask) support with 5 degrees of freedom



Acoustic neuroma : 1 single fraction 14 Gy @ 80 %



Radiosurgery Trigeminal Neuralgia : 1 single fraction 80 Gy

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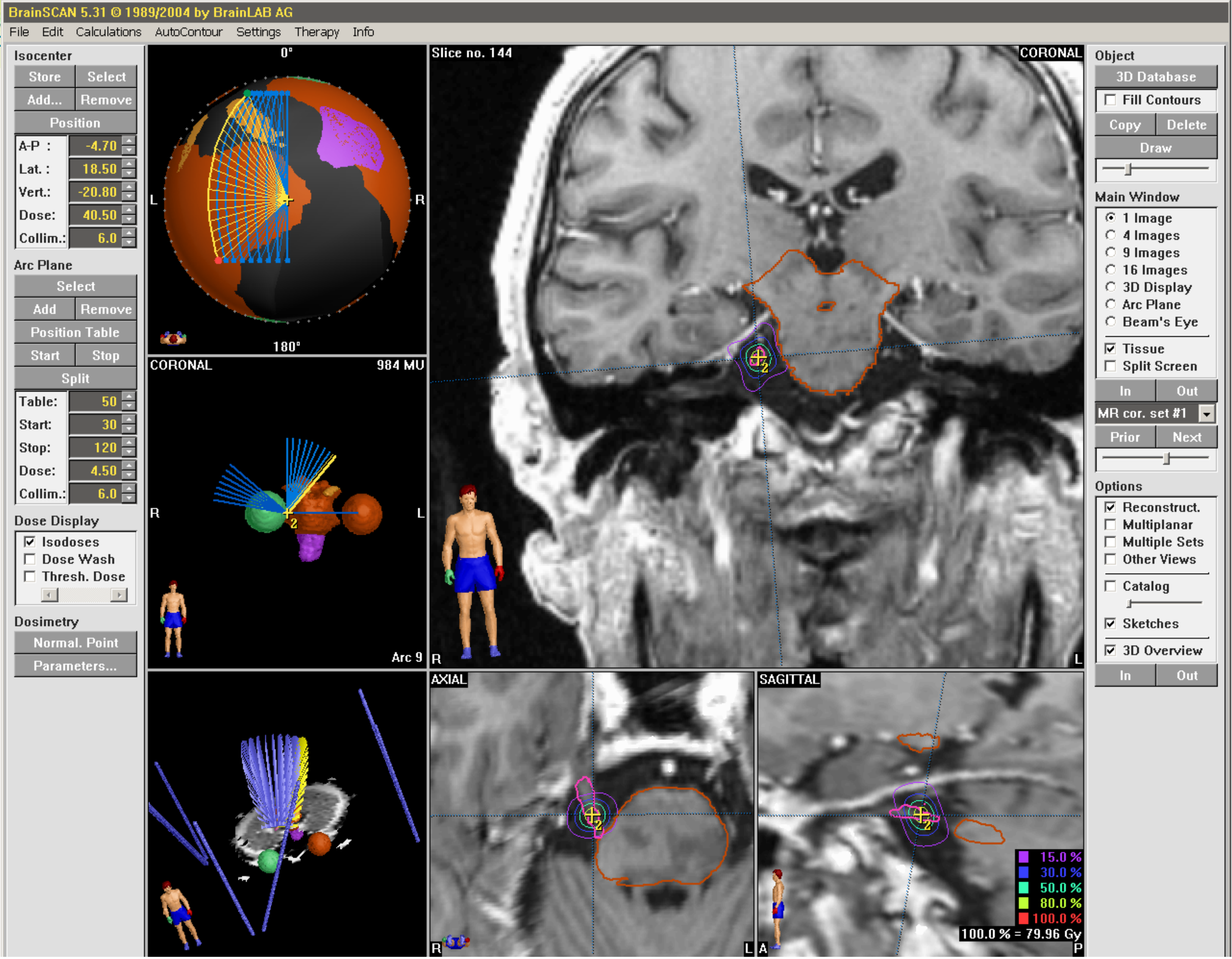
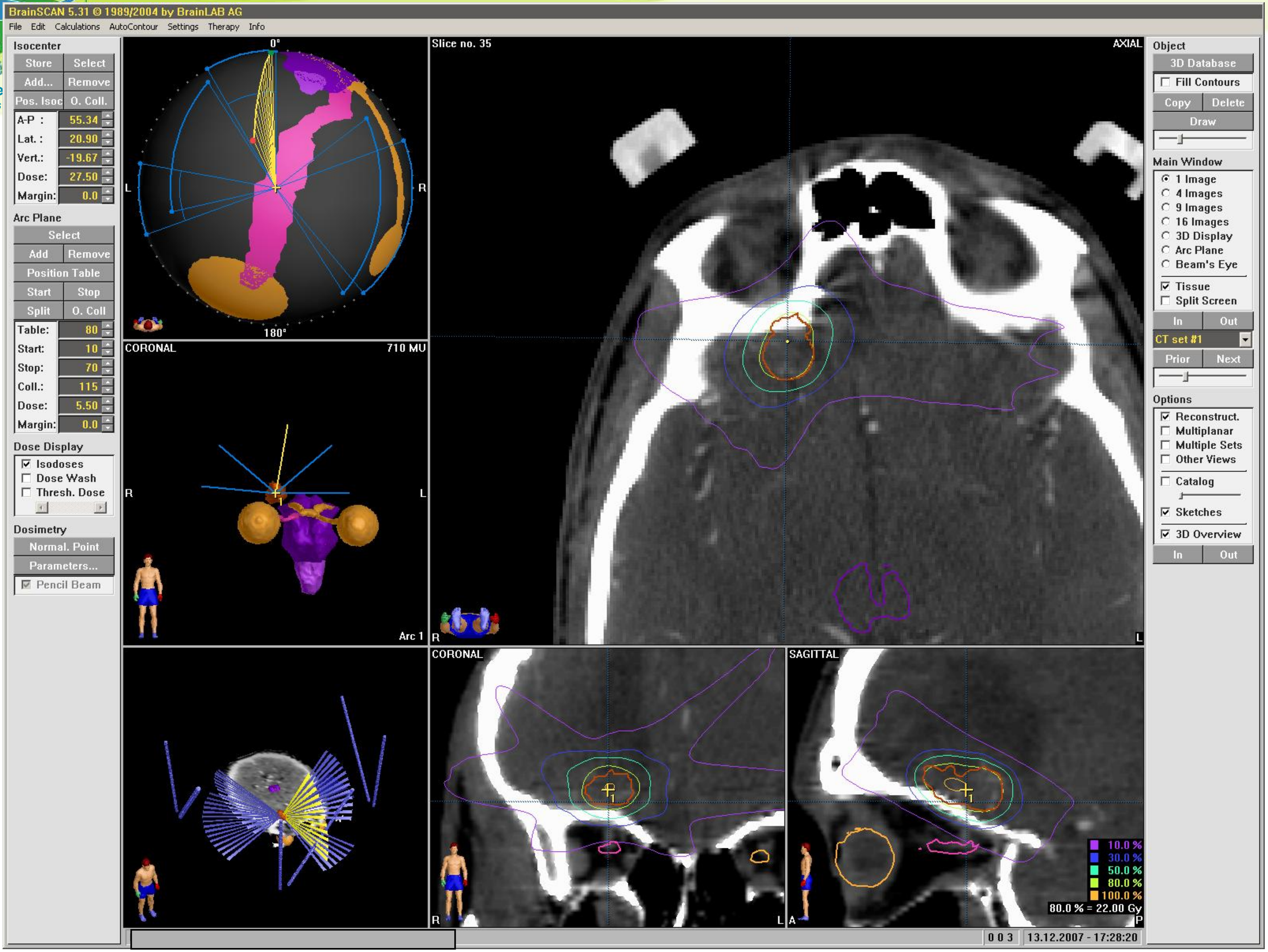
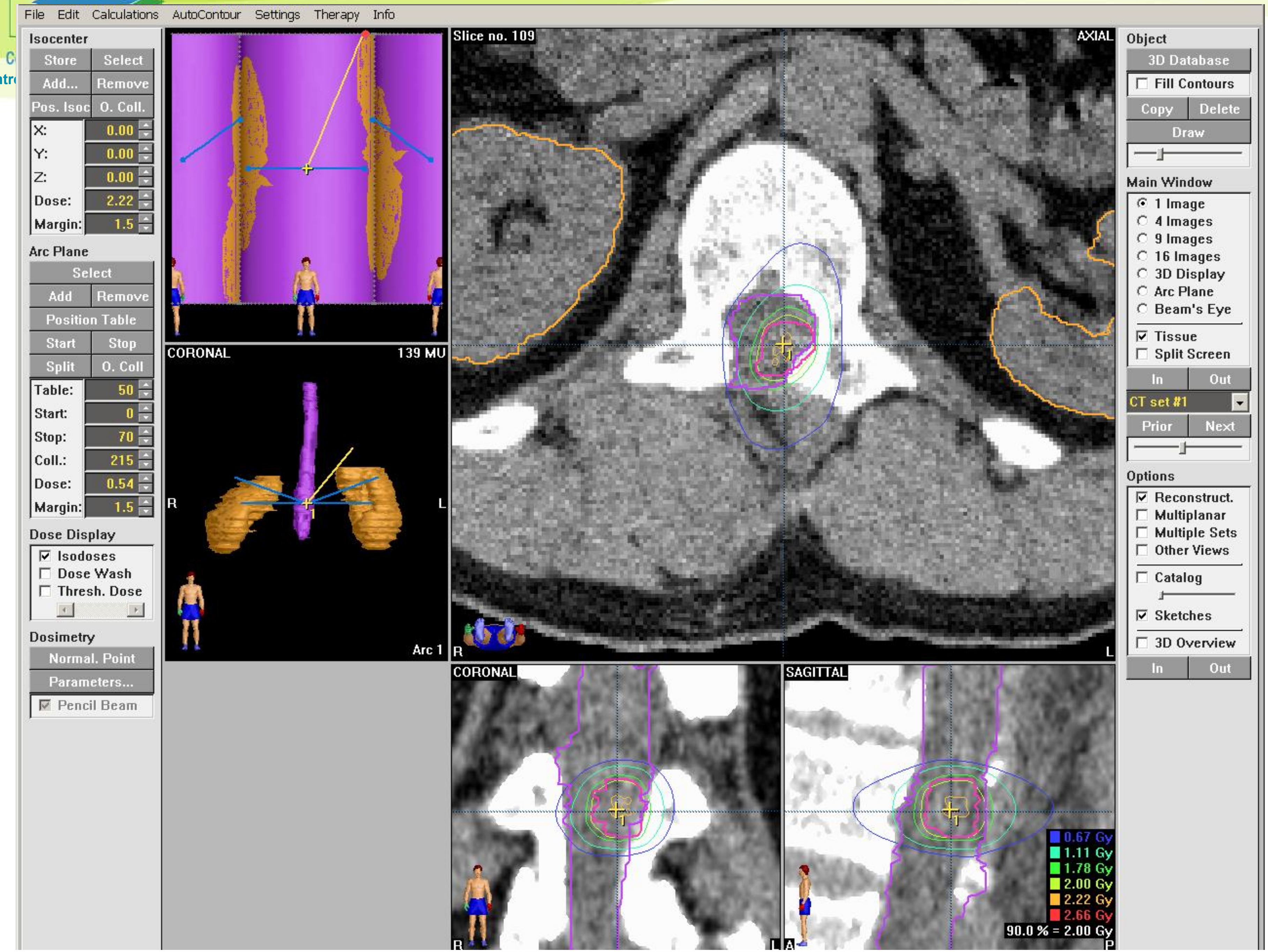


Cerebral ArterioVenous Malformations



AVM 22 Gy @ 80% - 1 fraction – 6 DCA


File Edit Calculations AutoContour Settings Therapy Info
Isocenter
Store Select
Add... Remove
Pos. Isoc O. Coll.
X: 0.00
Y: 0.00
Z: 0.00
Dose: 2.22
Margin: 1.5
Arc Plane
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Position Table
Start Stop
Split O. Coll
Table: 50
Start: 0
Stop: 70
Coll.: 215
Dose: 0.54
Margin: 1.5
Dose Display
Isodoses
Dose Wash
Thresh. Dose
Dosimetry
Normal. Point
Parameters...
Pencil Beam
CORONAL
139 MU
R
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Arc 1
Slice no. 109
AXIAL
R
L
CORONAL
SAGITTAL
R
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A
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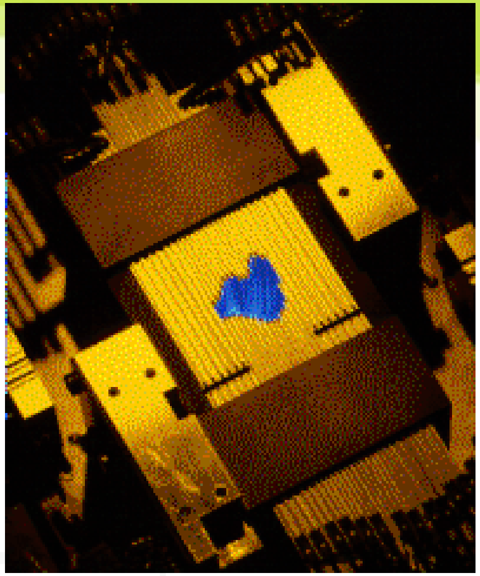
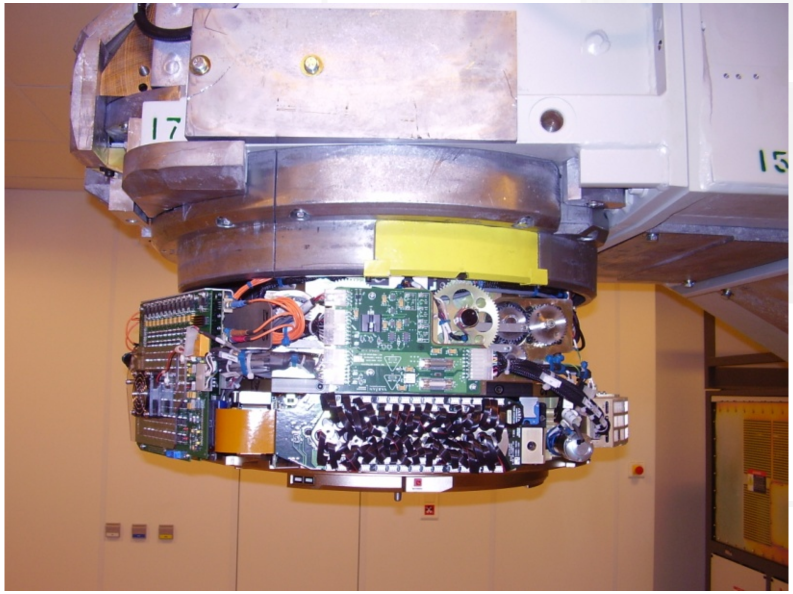
0.67 Gy
1.11 Gy
1.78 Gy
2.00 Gy
2.22 Gy
2.66 Gy
90.0 % = 2.00 Gy
Object
3D Database
Fill Contours
Copy Delete
Draw
Main Window
1 Image
4 Images
9 Images
16 Images
3D Display
Arc Plane
Beam's Eye
Tissue
Split Screen
In Out
CT set #1
Prior Next
Options
Reconstruct.
Multiplanar
Multiple Sets
Other Views
Catalog
Sketches
3D Overview
In Out

Dedicated Linac - NOVALIS



Caractéristiques techniques : Novalis

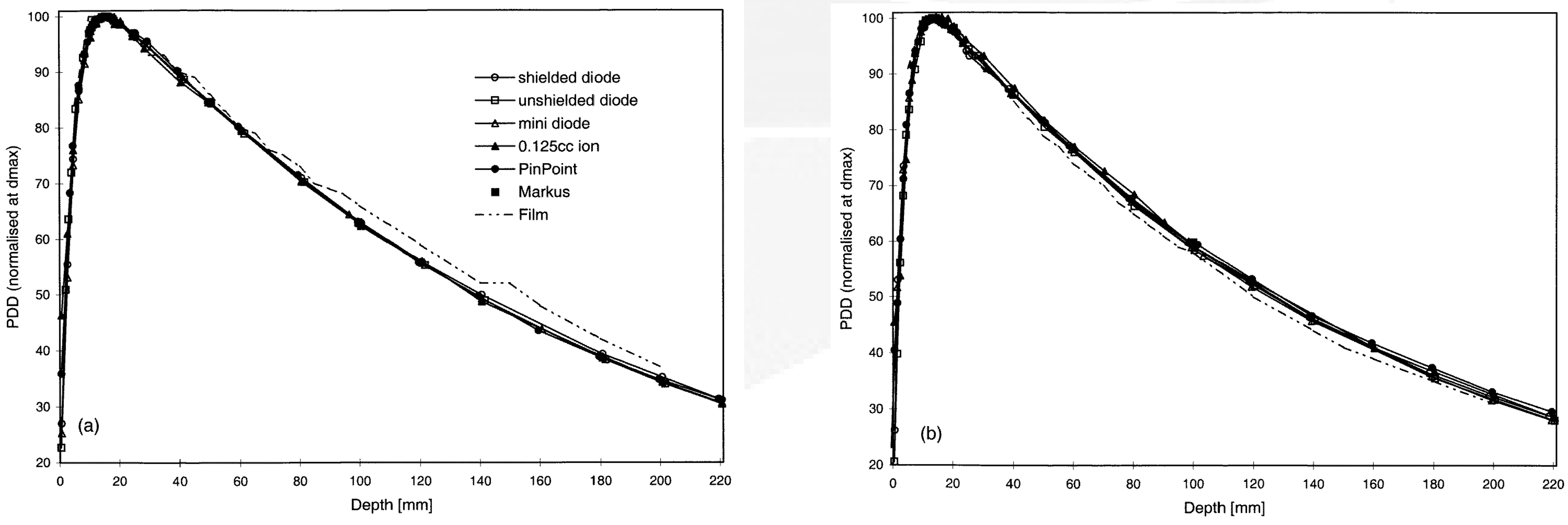
Integrated BrainLab M3 micro-mlc 10x10 cm²



Dosimetry measurements

- **Percentage Depth Dose (PDD)**
  C McKerracher and D I Thwaites - Phys. Med. Biol. **44** (1999) 2143–2160

  – **Ø 40 mm** **Ø 12.5 mm**

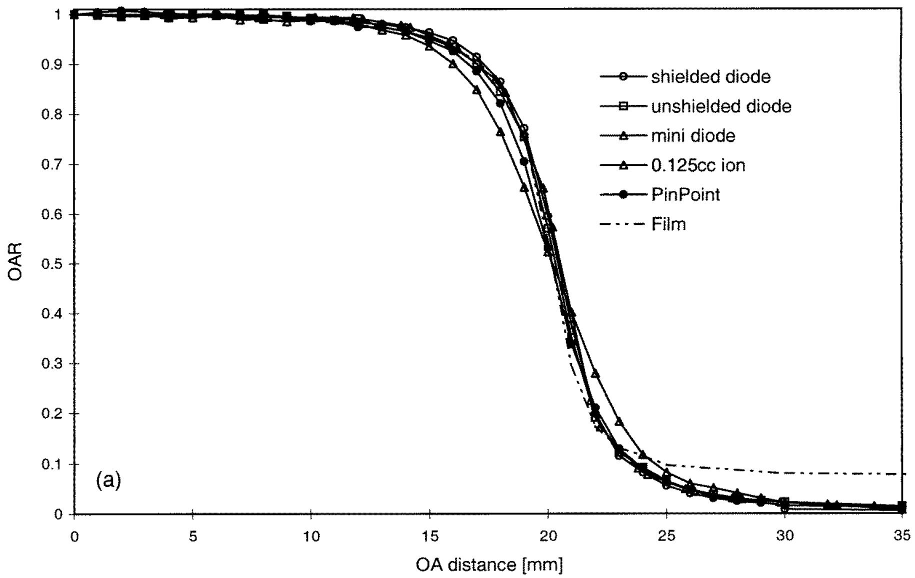


Dosimetry measurements

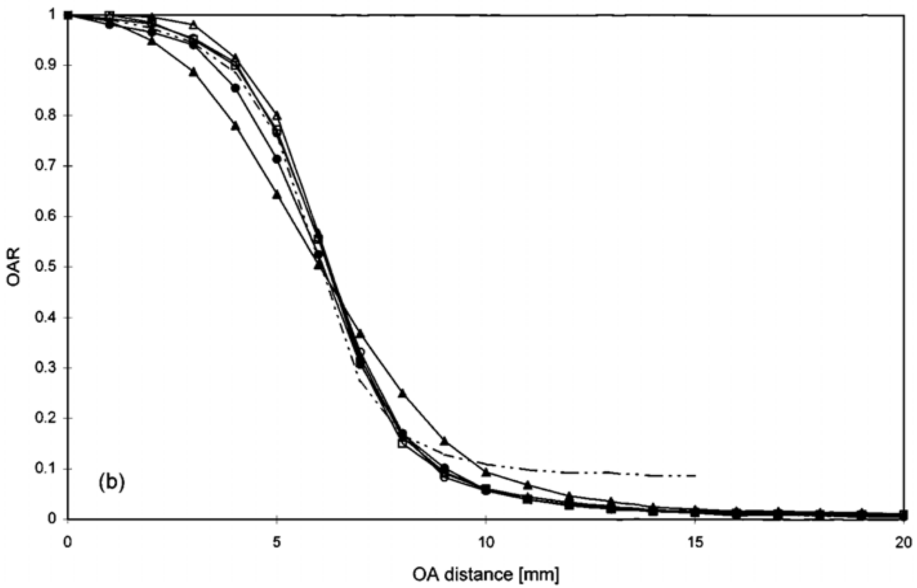
- **Off Axis Ratio - OAR**

  C McKerracher and D I Thwaites - Phys. Med. Biol. **44** (1999) 2143–2160

Ø 40 mm



Ø 12.5 mm

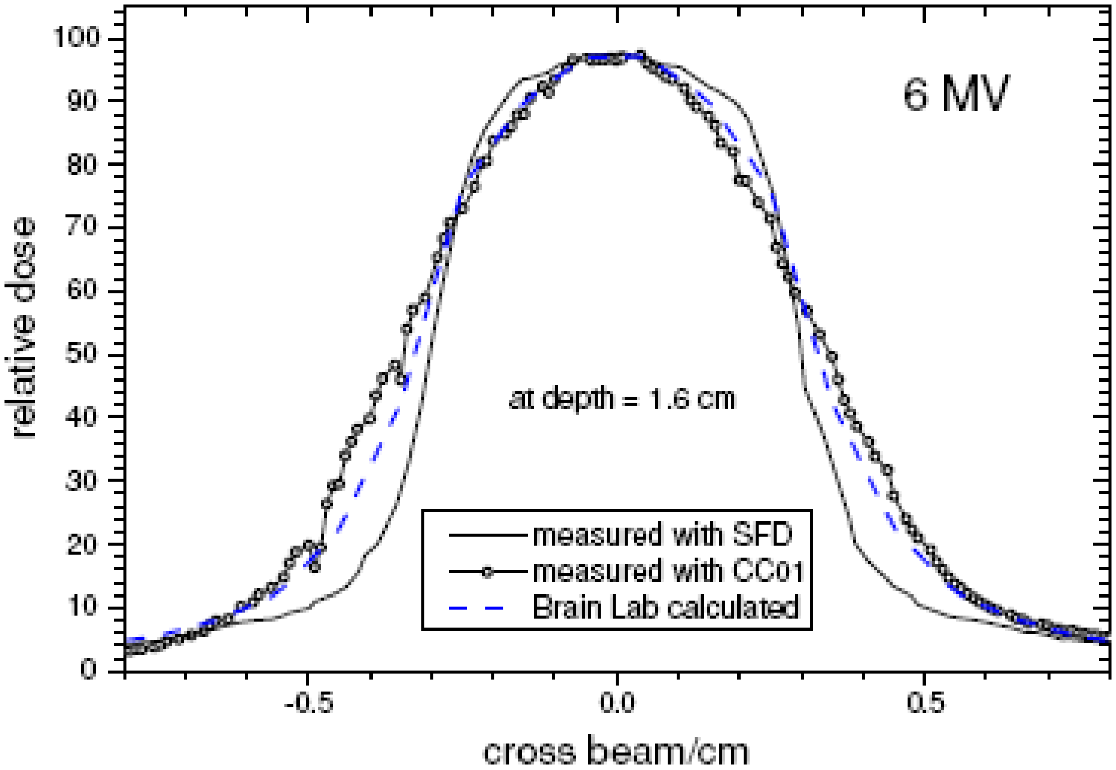


Dosimetry measurements

- **Off Axis Ratio - OAR**

  George X Ding - Phys. Med. Biol. 51 (2006) 2549–2566

  - **6MV**
  - **Various detectors**
  - **Field size 6x6 mm²**



Dosimetry measurements

- Off Axis Ratio - OAR

  – Detector choice – spatial resolution

    - Diode - diamond for very narrow beams
    - Pin Point ionisation chamber for other field sizes
    - Alternative : photographic or radiochromic film

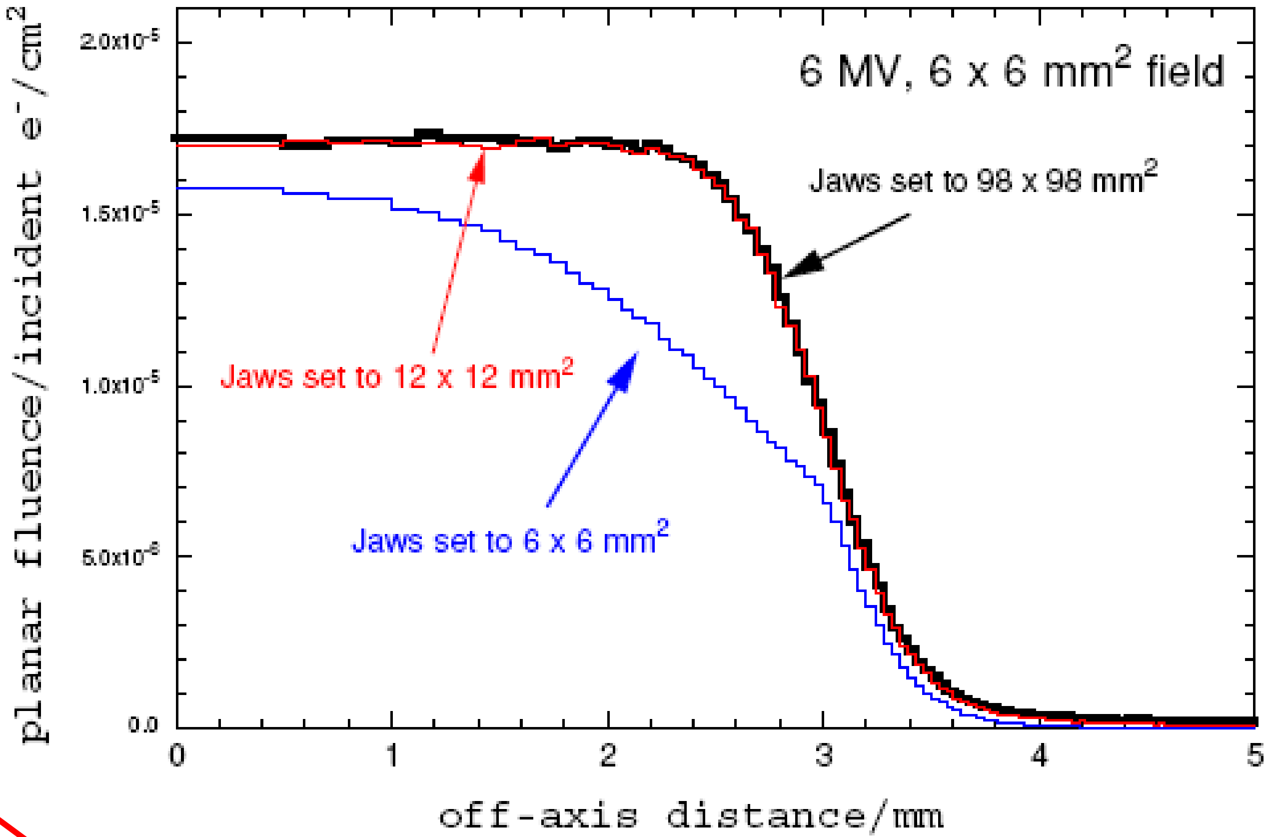
  – Jaws settings (Primary collimation) influence miniMLC and circular cones

    - Jaws settings values too small (vs mlc or cone size) can lead to a large degradation of the small field size OAR

Dosimetry measurements

- **Off Axis Ratio - OAR**
  George X Ding - Phys. Med. Biol. 51 (2006) 2549–2566

  - **6MV**
  - **Field size 6x6 mm²**



leaves

Jaws settings

Dosimetry measurements

- **Output Factor (Scatter Factor)**
  - **As for PDD and OAR this measurement becomes more difficult to perform as field size decreases**
  - **The delivered dose to the patient is directly proportionnal to the OF measured value.**
  - **Drawbacks :**
    - **Size detector vs field size**
    - **Lateral Electronic Equilibrium Problem**
  - **Detectors**
    - **Ionization chamber Pin Point type 0.015 cm³**
    - **Diamond detector**
    - **Diode**
    - **Radiographic or radiochromic film**

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Dosimetry measurements

- **Output Factor**

George X Ding - Phys. Med. Biol. 51 (2006) 2549–2566

- – **For a miniMLC BrainLab m3**

Table 1. Scatter factors as a function of field size shaped by both micro multi-leaf collimators and the X- and Y-jaws at a depth of 5 cm and SSD = 100 cm for a 6 MV beam measured using a CC01 ionization chamber.

6 MV scatter factors	Square field size set by X- and Y- Jaws (mm)									
	6	12	18	24	30	36	42	60	80	98
6	0.603	0.658	0.661	0.663	0.664	0.665	0.666	0.667	0.671	0.671
12		0.769	0.783	0.787	0.792	0.795	0.798	0.801	0.803	0.805
18			0.818	0.828	0.834	0.840	0.846	0.854	0.859	0.860
24				0.845	0.855	0.860	0.867	0.881	0.889	0.893
30					0.865	0.873	0.880	0.895	0.907	0.913
36						0.882	0.890	0.907	0.920	0.927
42							0.897	0.916	0.931	0.939
60								0.937	0.954	0.964
80									0.973	0.986
100										1.000

Dosimetry measurements

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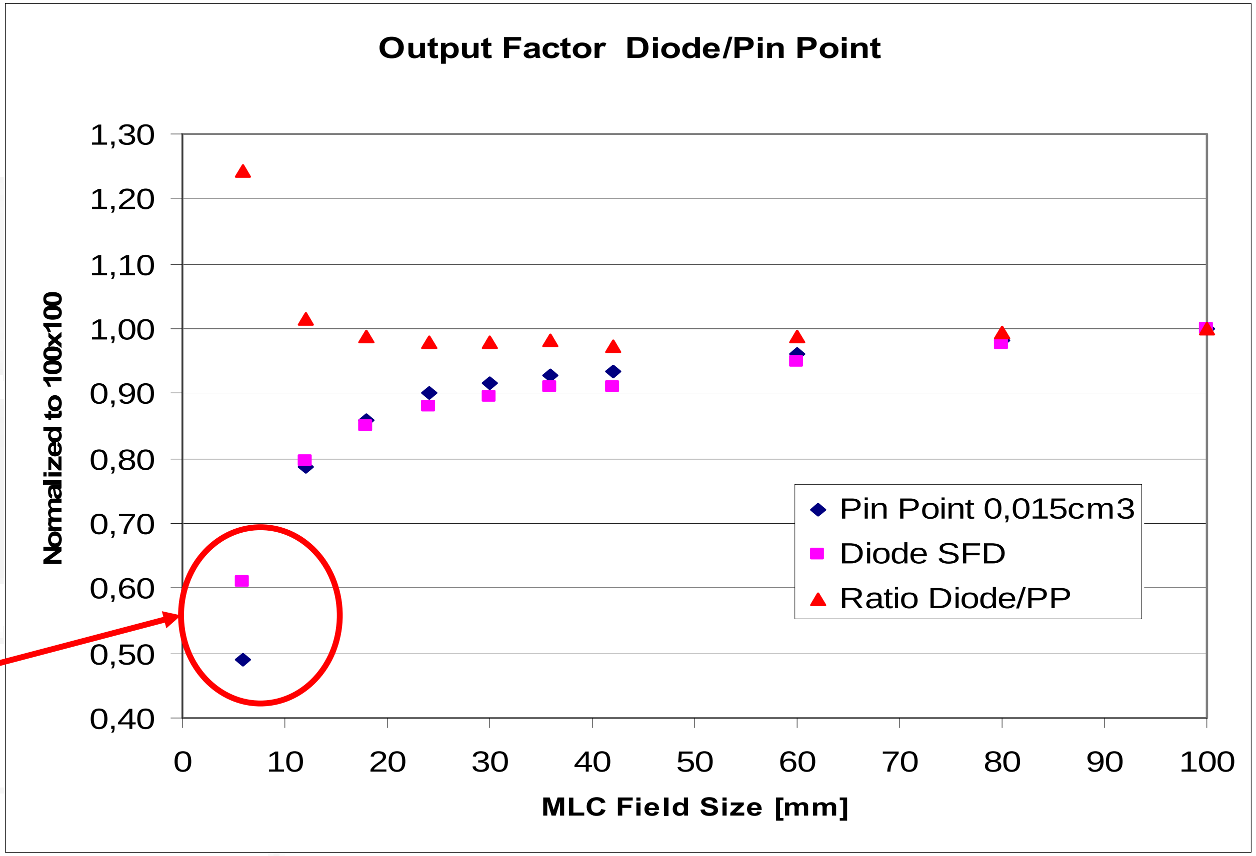
- **Output Factor (Scatter Factor)**
  MiniMLC : SFD Diode vs PinPoint 0.015cm³

- **Novalis 6MV Xray beam**

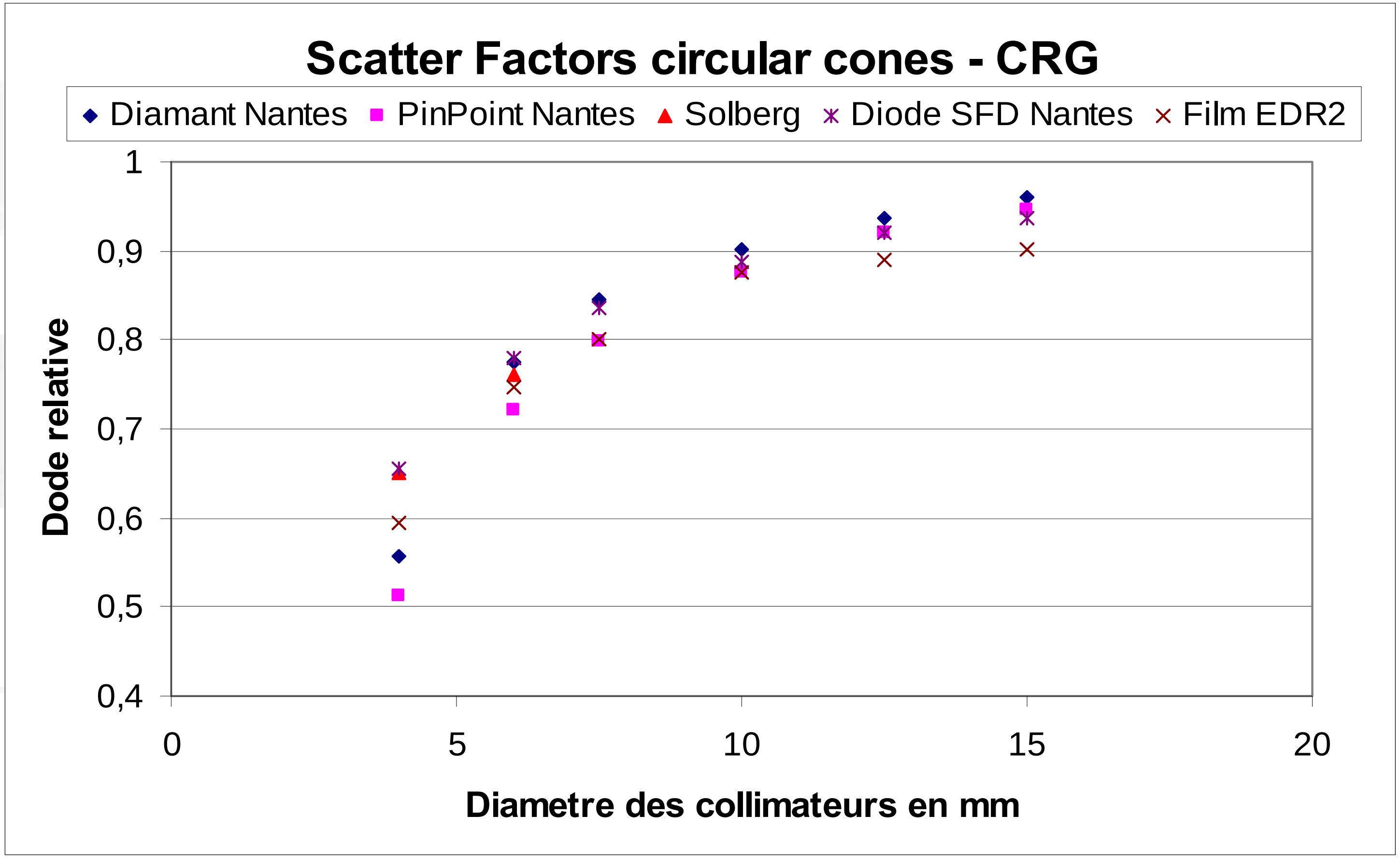


Dose difference = 25 %

- **Most important differences below 12x12mm², for clinical situations this difference is reduced by field size shaped X-jaws and Y-jaws settings 2mm more than leaves settings**
- **An under response is reported for diode (2%) between 18x18 et 60x60 mm²**

Dosimetry measurements

- **Output Factor (Scatter Factor)**
  Circular cones : measurement comparisons between differents detectors
- **Novalis 6MV Xray beam**



- **Dimensions**
  4 to 15 mm
- **Jaws settings 50x50mm²**
- **Important differences below 10mm**

- There is no international dosimetry code of practice (IAEA 2010 ?) for the narrow beams in radiotherapy (IMRT, radiosurgery,…)

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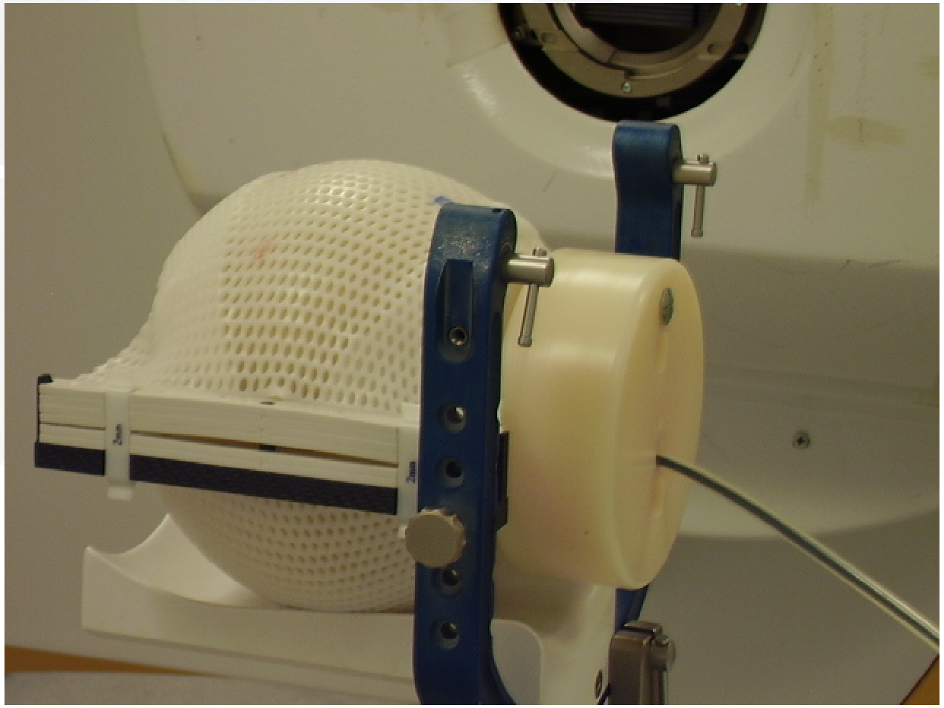
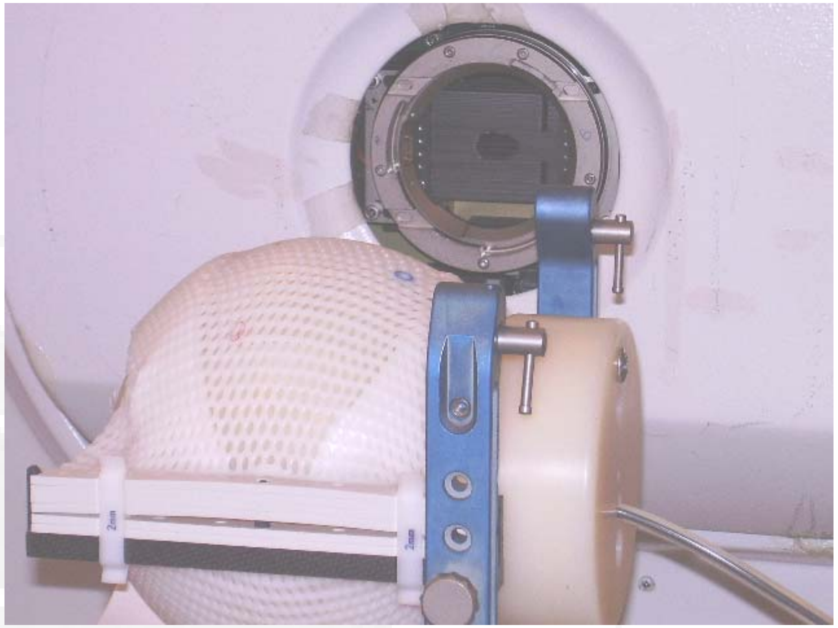
End to End checks



End to End checks



Jaws settings

X mm	16	22	28	37
Y mm	17	22	28	38
Mes/Cal	**0,918**	**0,979**	**0,995**	**0,984**

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Conclusion

- Mesures dans les minifaisceaux sont délicates
- Instruments de mesures spécifiques
  adaptés aux mesures à réaliser – investissements
- Moyens humains et temps machine
- Minutie
- Contraintes techniques liées aux mesures
- Connaître les limites : matériel, détecteurs

Conclusion

- Adequate staff, and sufficient training for all the members of the team involved in new techniques.
- Guidance, recommendation on quality assurance for new techniques (using new concepts based on risk analysis).
- Dosimetric audits for comparison and validation.

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Gracias

Thank you