Medical Physics challenges in modern radiotherapy

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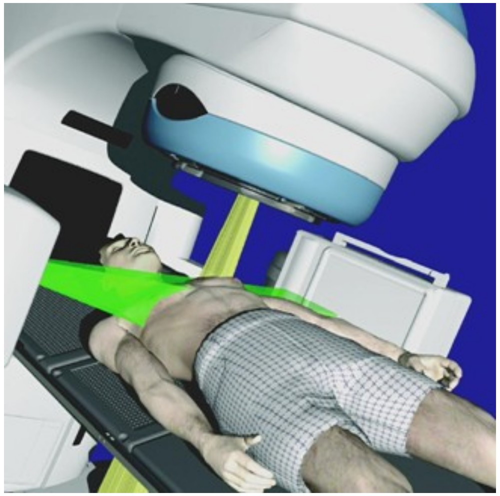
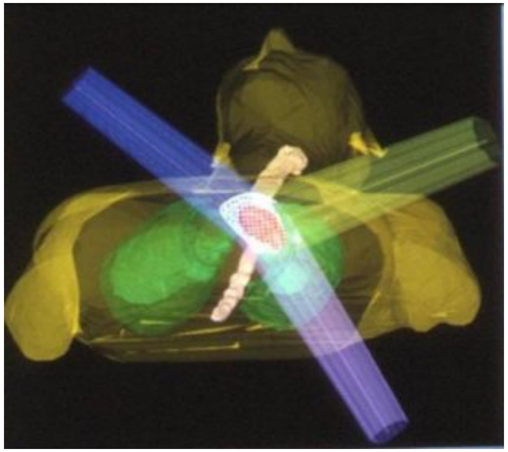
Grenoble-Alpes University Hospital

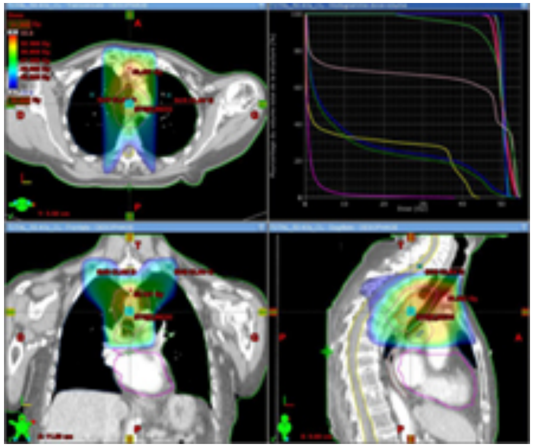
"Don't forget me in this godforsaken donut hole!"

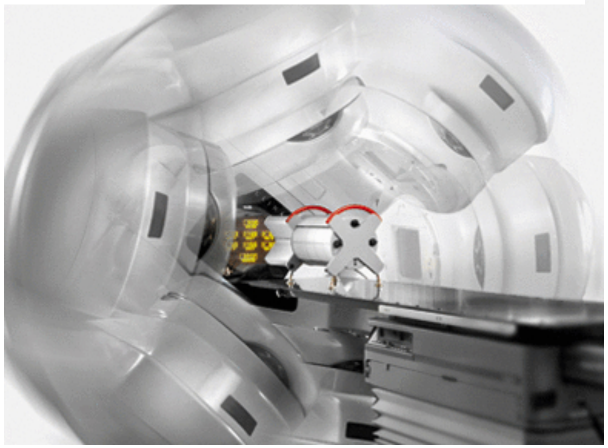
Radiotherapy in the management of cancer



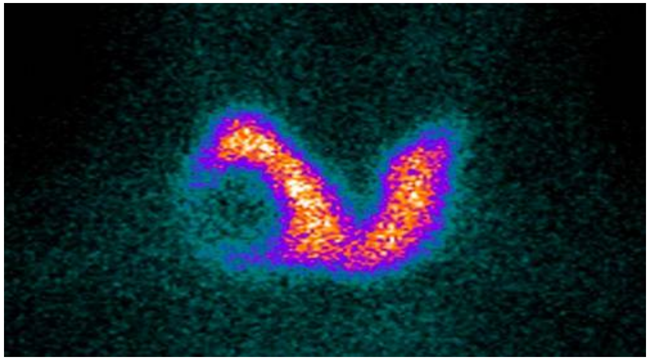
- Every second cancer is treated with radiotherapy.
- Radiotherapy: locoregional treatment of cancer
- Using ionising radiation to destroy cancer cells and blocking their ability in dividing.
- The aim : achieve a differential effect where all tumour cells are killed whilst the peripheral healthy tissues are preserved.
- The key parameter in radiotherapy: the dose dE/dm in Gy (J/kg)
- The key step is called treatment planning
- The dosimetry plays a key role and leads to complex modeling and experimental methods.



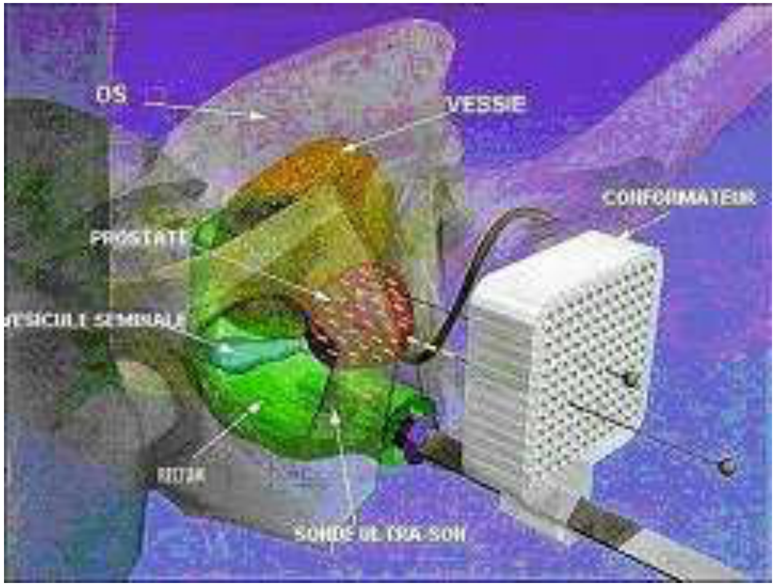




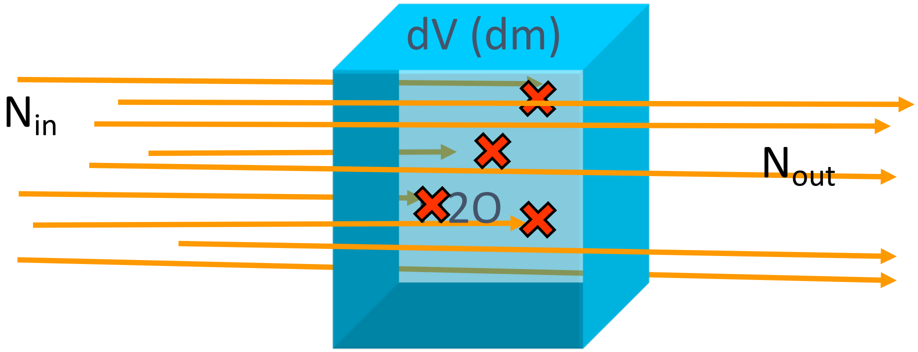
Radiotherapy

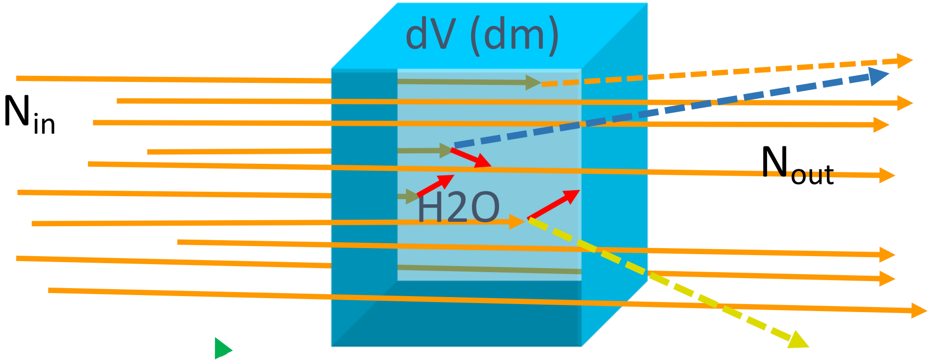


- Using ionizing radiation for treating cancer
  - Radiotherapy / Brachitherapy / Metabolic Radiotherapy



Concept of Dose (3 step process for photons)





- Attenuation

$\mu / \rho = n\ \sigma / \rho$ en cm^2/g

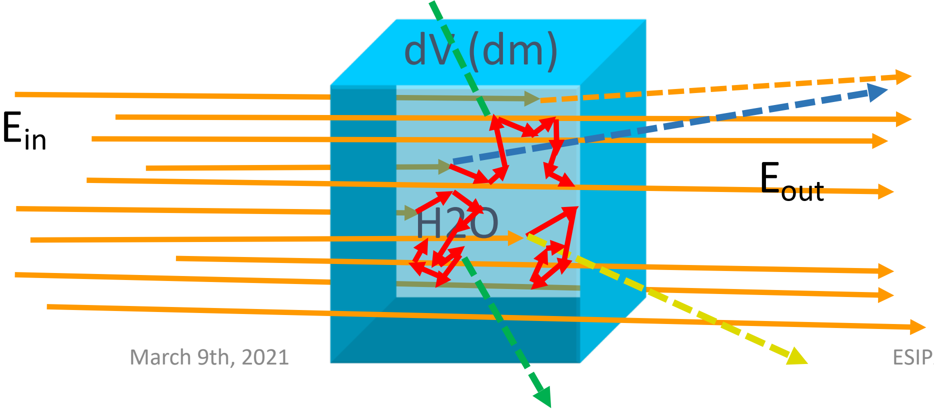
- Transfert

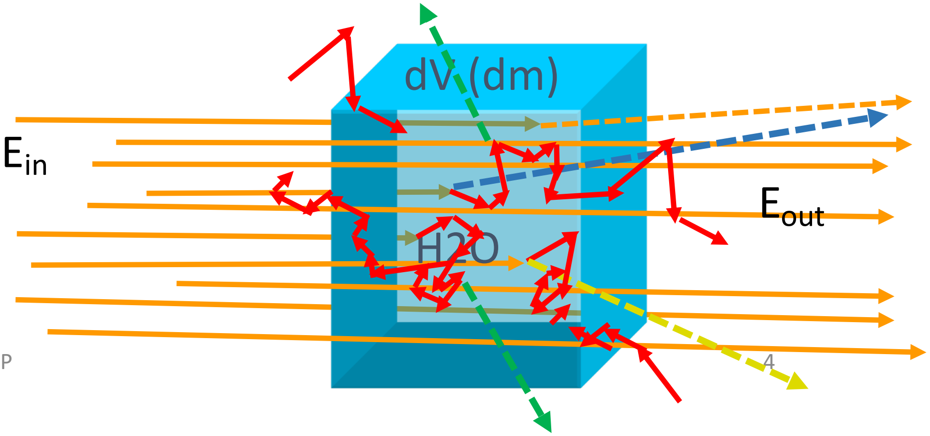
$\mu_{tr} / \rho = (E_{tr} / E) \times (\mu / \rho)$

- Absoption (Dose)

$\mu_{en} / \rho = (E_{ab} / E) \times (\mu / \rho)$

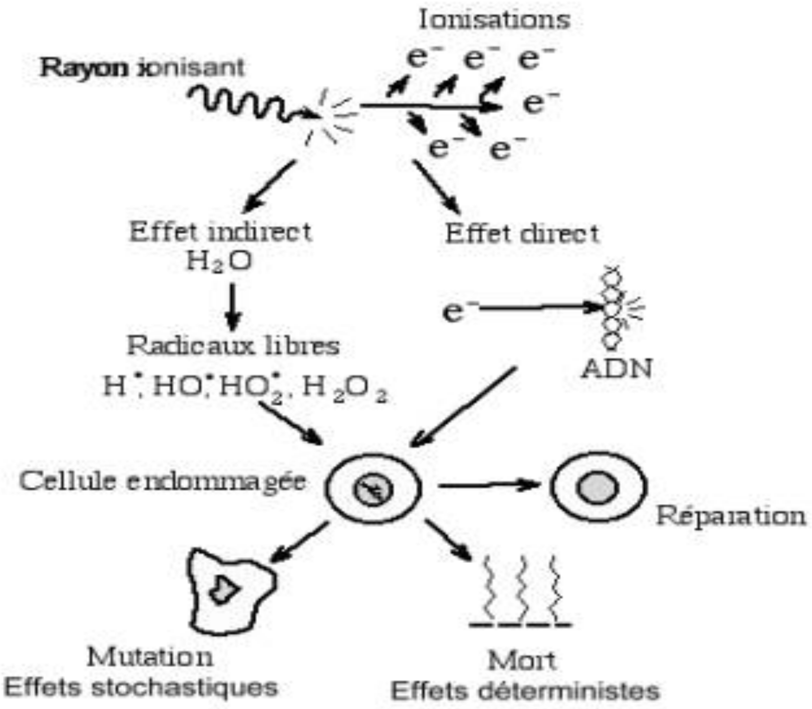
$S_{col} / \rho = dE_{col} / (\rho\ dx)$

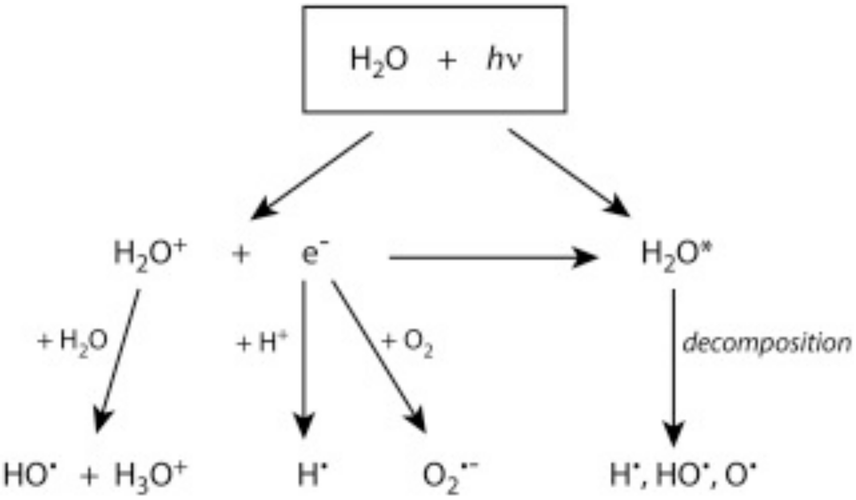




Prerequisite

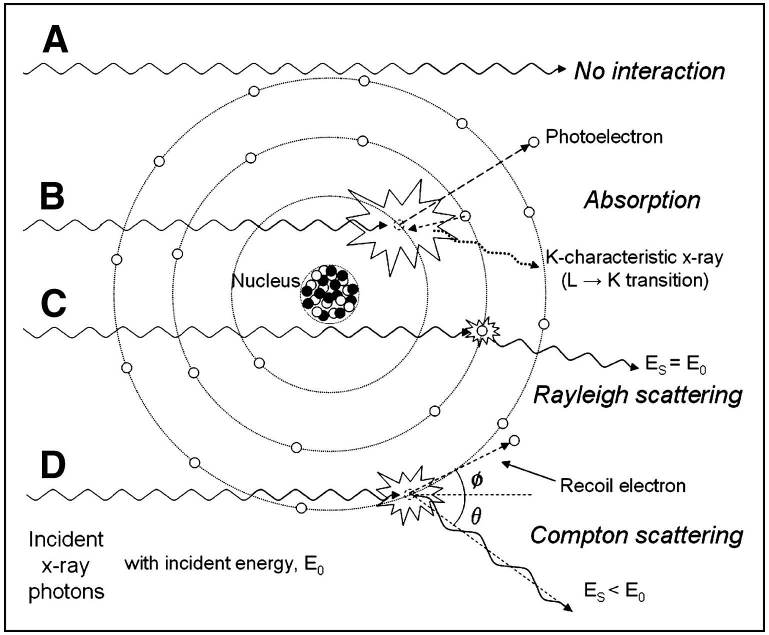
- Biological consequences

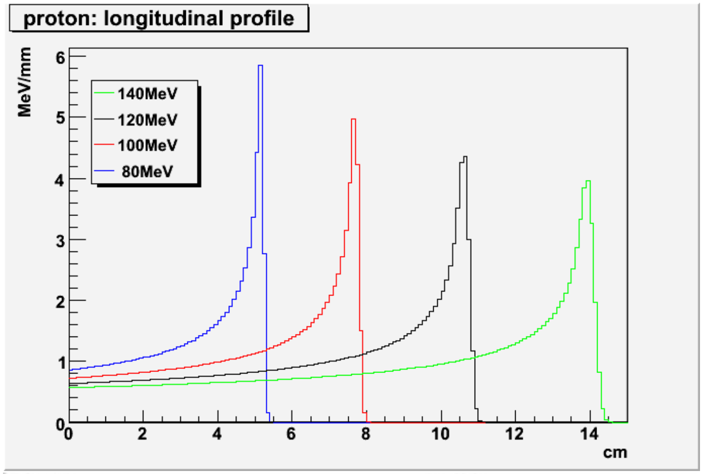


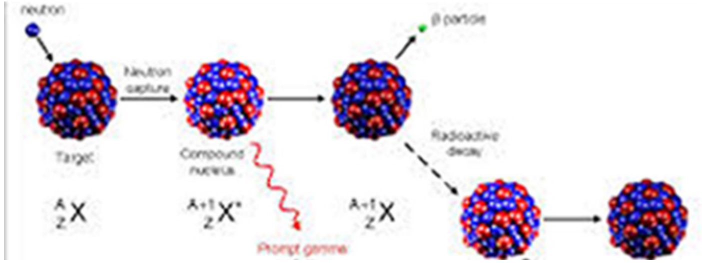


Prerequisite

- Physics of radiation, detectors and statistics

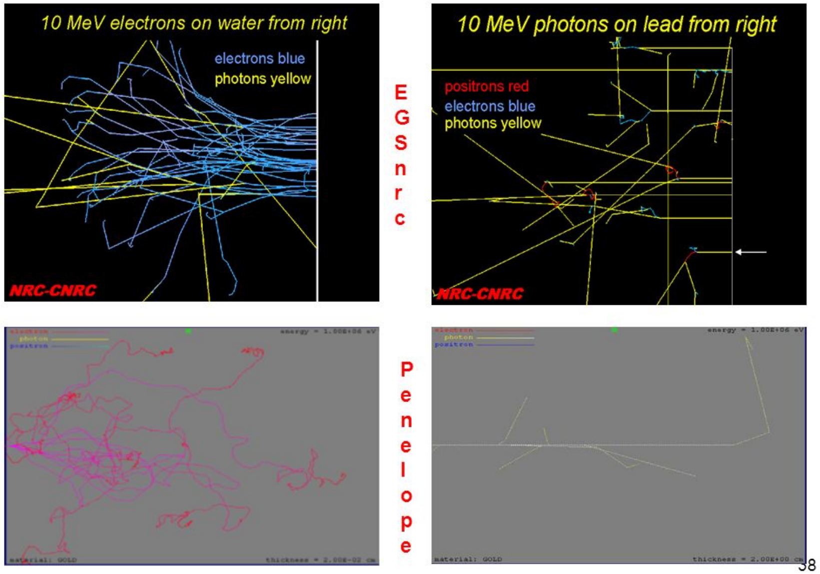


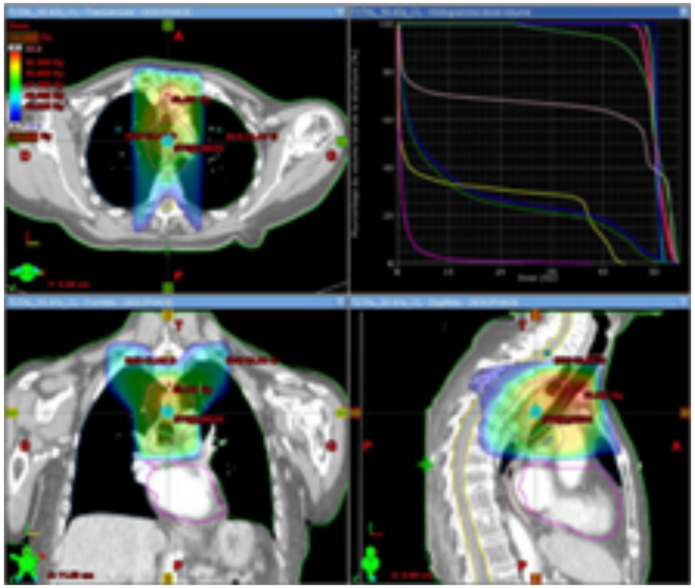




Prerequisite

- Physics of ionising radiation: modeling, simulation : Theoretical dosimetry–Monte Carlo Methods





Prerequisites

- Experimental medical Physics
- Radiotherapy dosimetry, radiobiology.

Survival curves

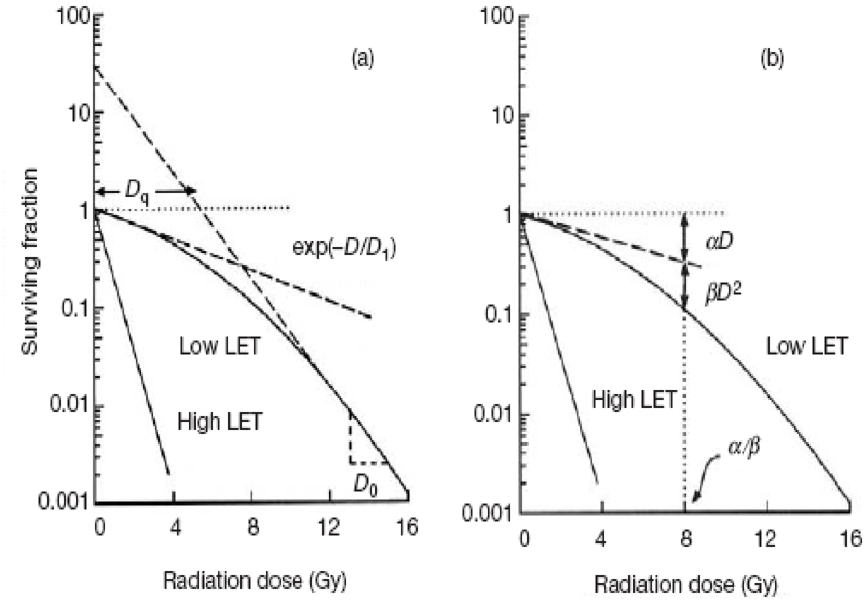
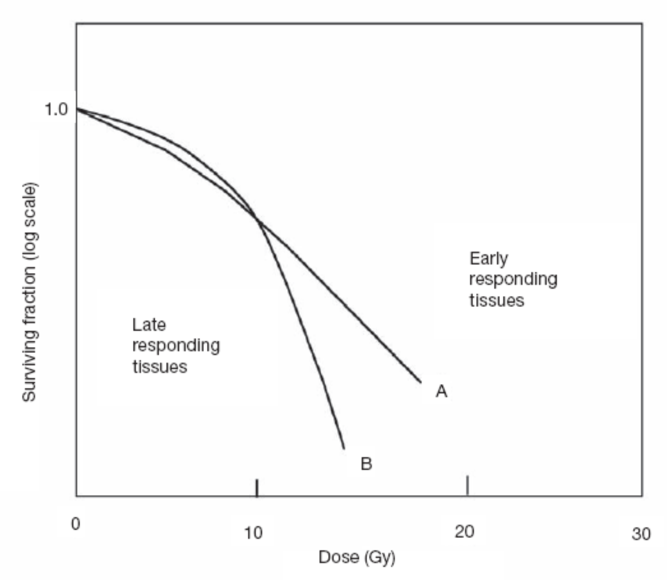


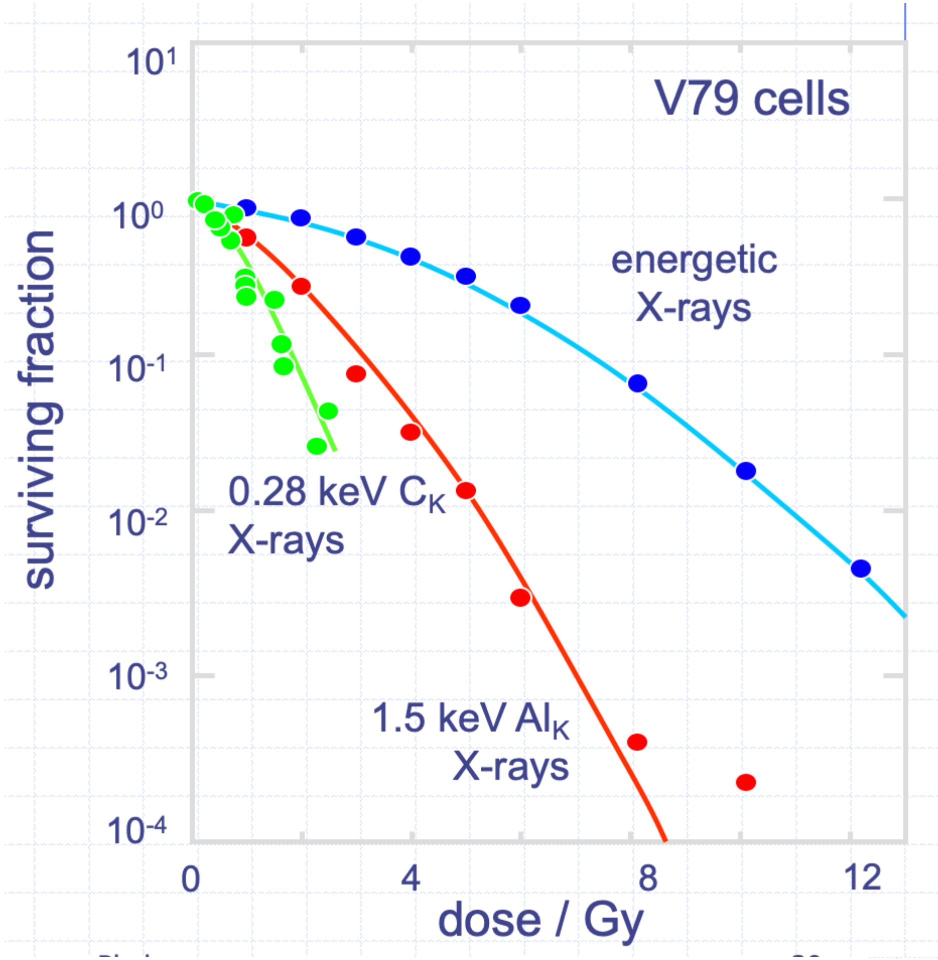
FIG. 14.1. Typical cell survival curves for high LET (densely ionizing) radiation and low LET (sparsely ionizing) radiation. (a) The earlier multitarget single hit model; (b) the current linear quadratic model.

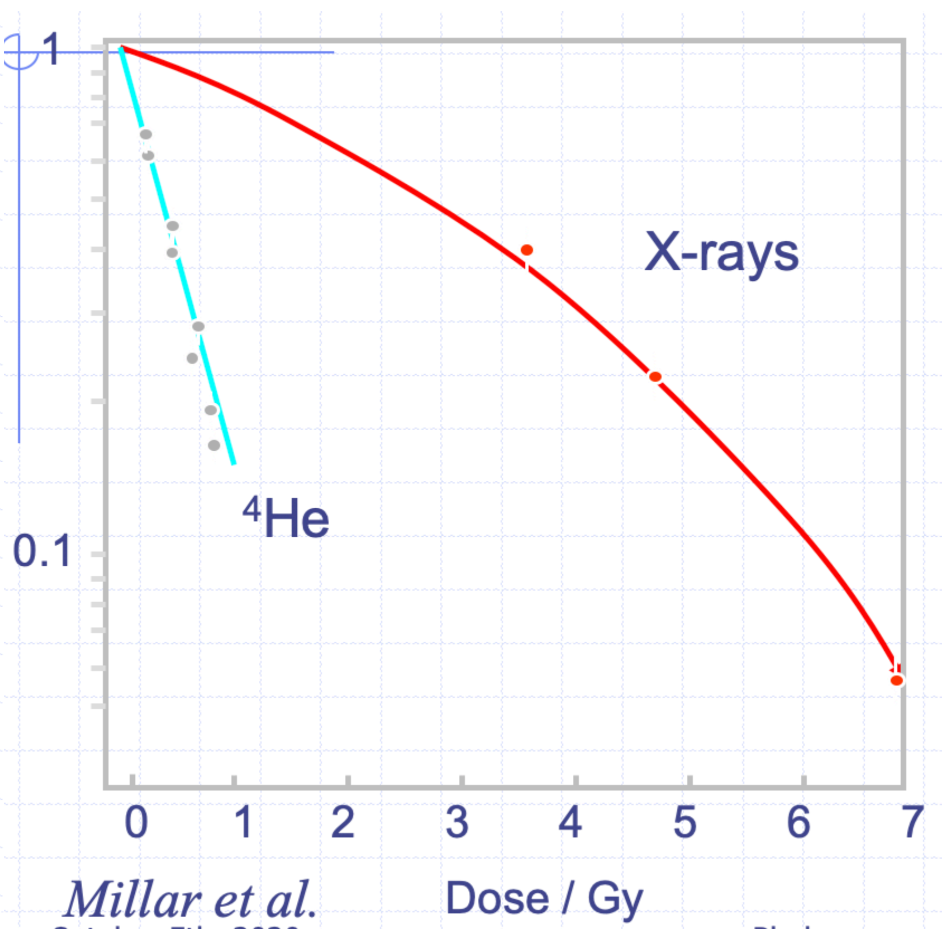
$$S(D) = e^{-\alpha D - \beta D^2}$$



α/β ratio
- 10 for tumours
- 3 for healthy tissues

RBE

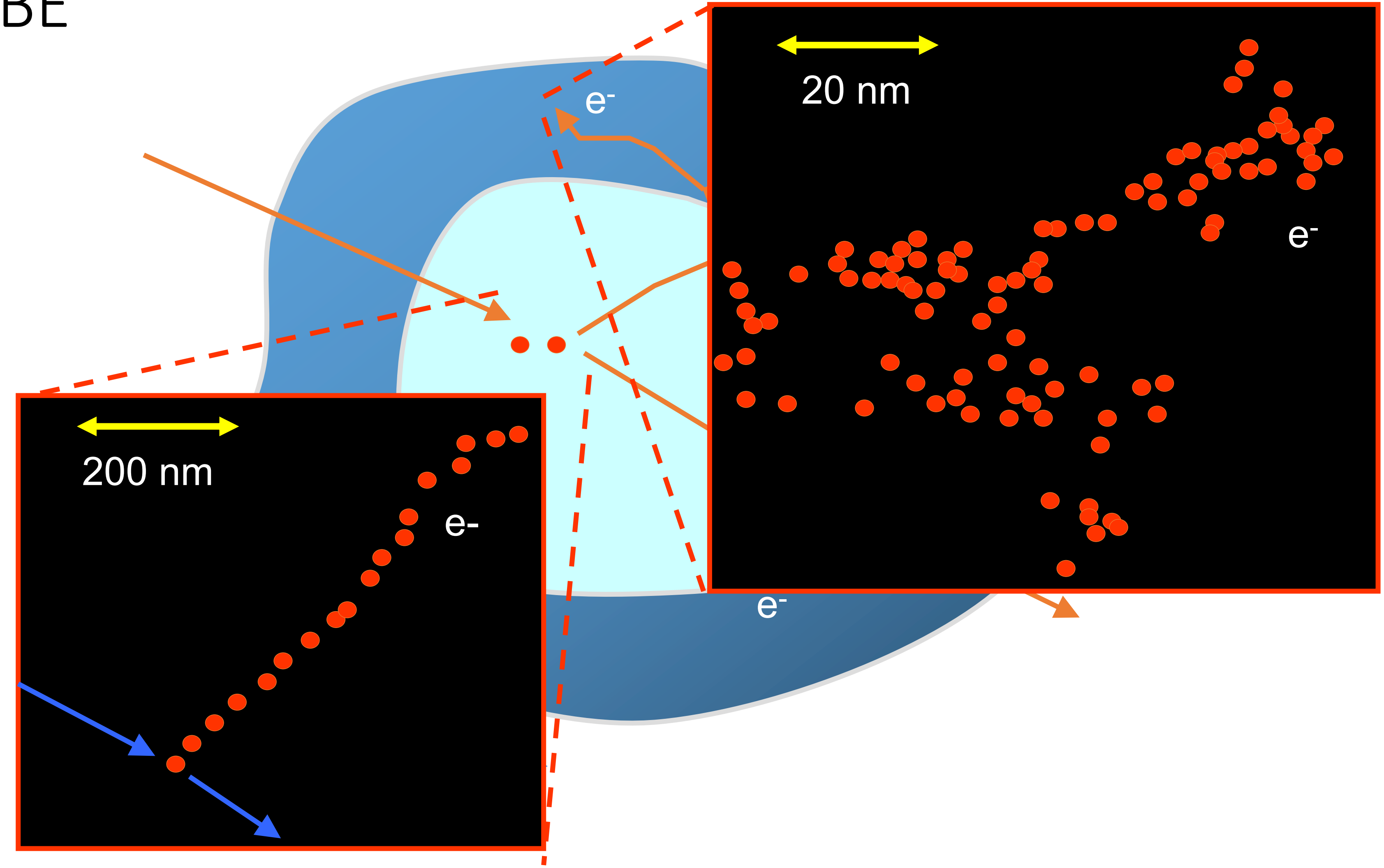




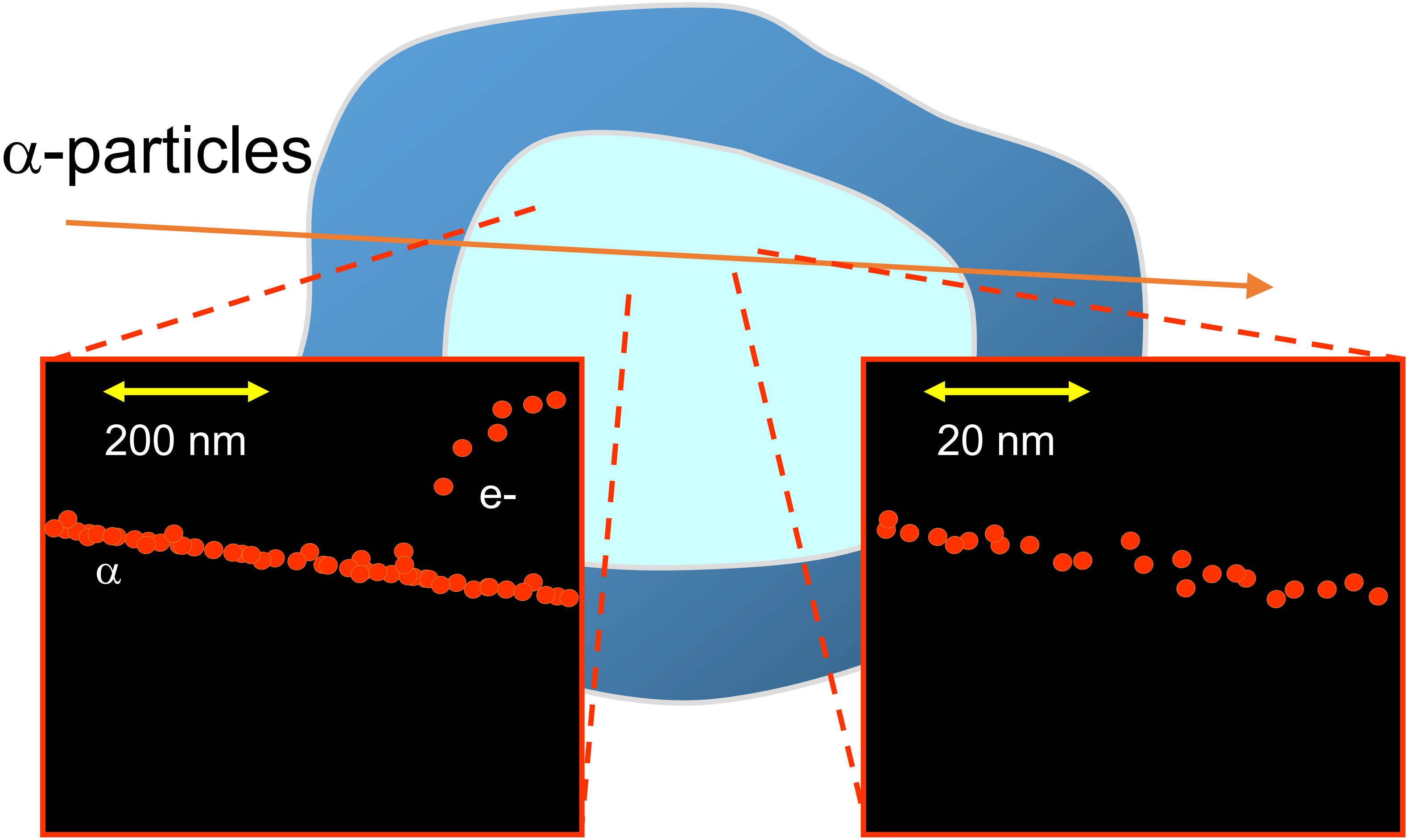
Millar et al.

RBE

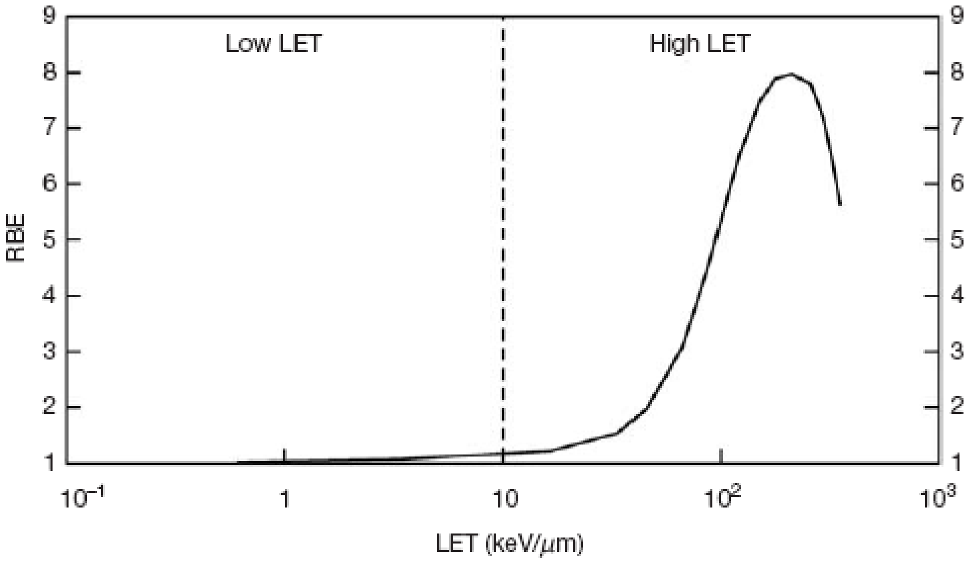
electrons, photons



RBE

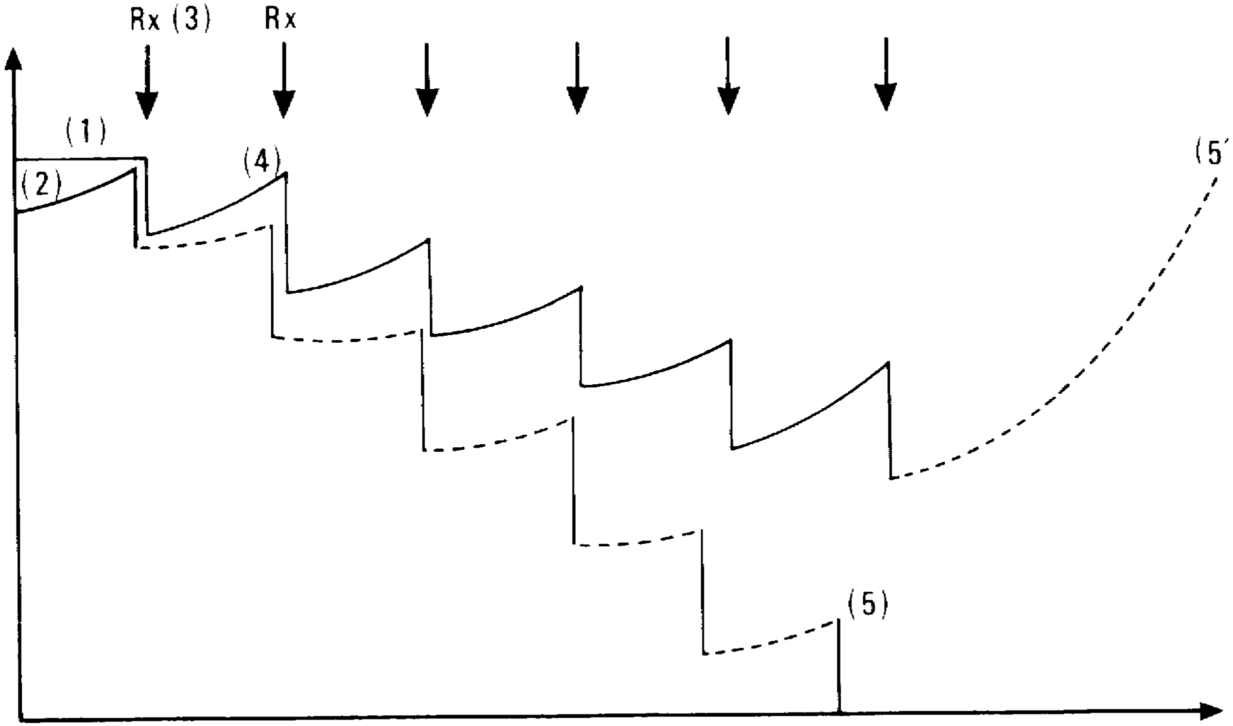


RBE



- Reference Beam (250 kVp, ^{60}Co)
- Other beam or conditions ?

Introduction: Fractionation



Introduction: Therapeutic Ratio

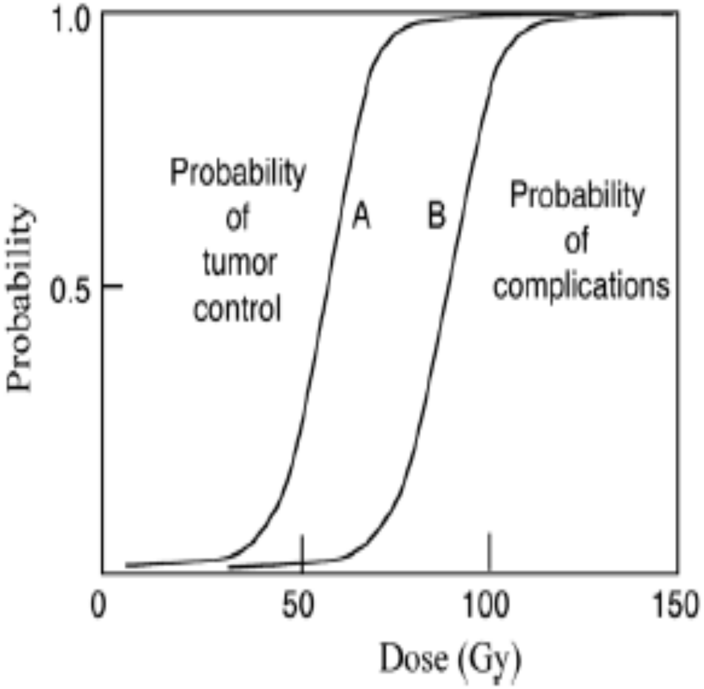
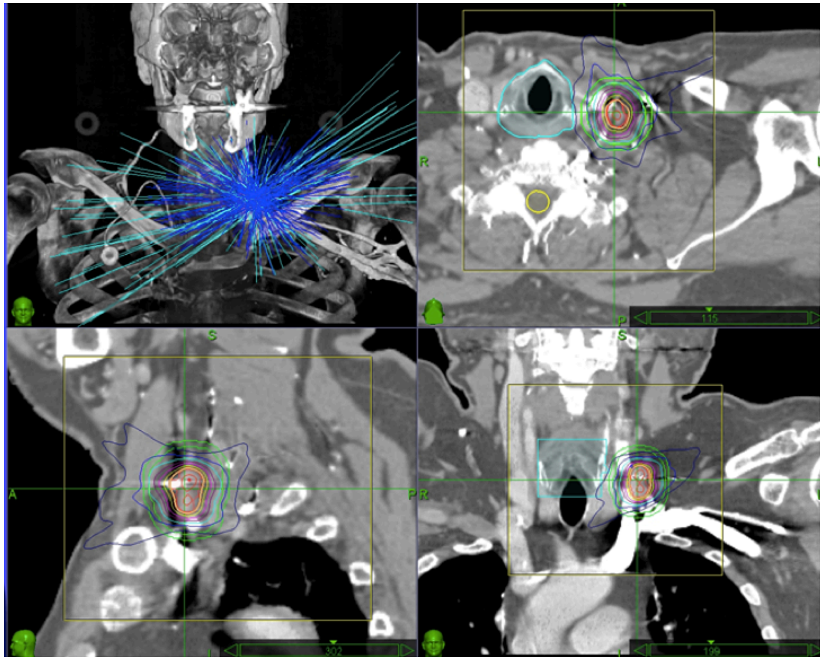
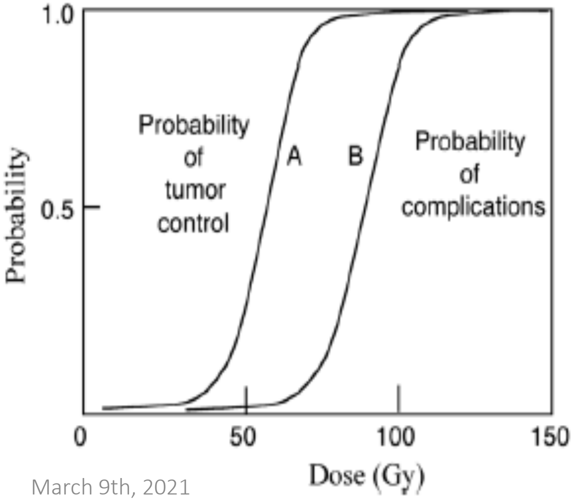


FIG. 14.4. The principle of therapeutic ratio. Curve (A) represents the tumour control probability, curve (B) the probability of complications. The total dose is delivered in 2 Gy fractions.

Dose volume effect in radiotherapy



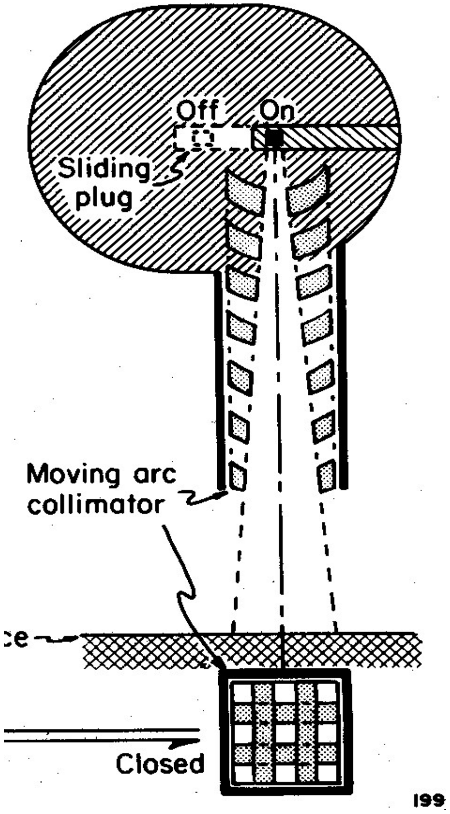


- Optimizing the balistic allows to increase the differential effect up to a certain point.
- The dose is conformed to the target volume

Treatment types: Photons

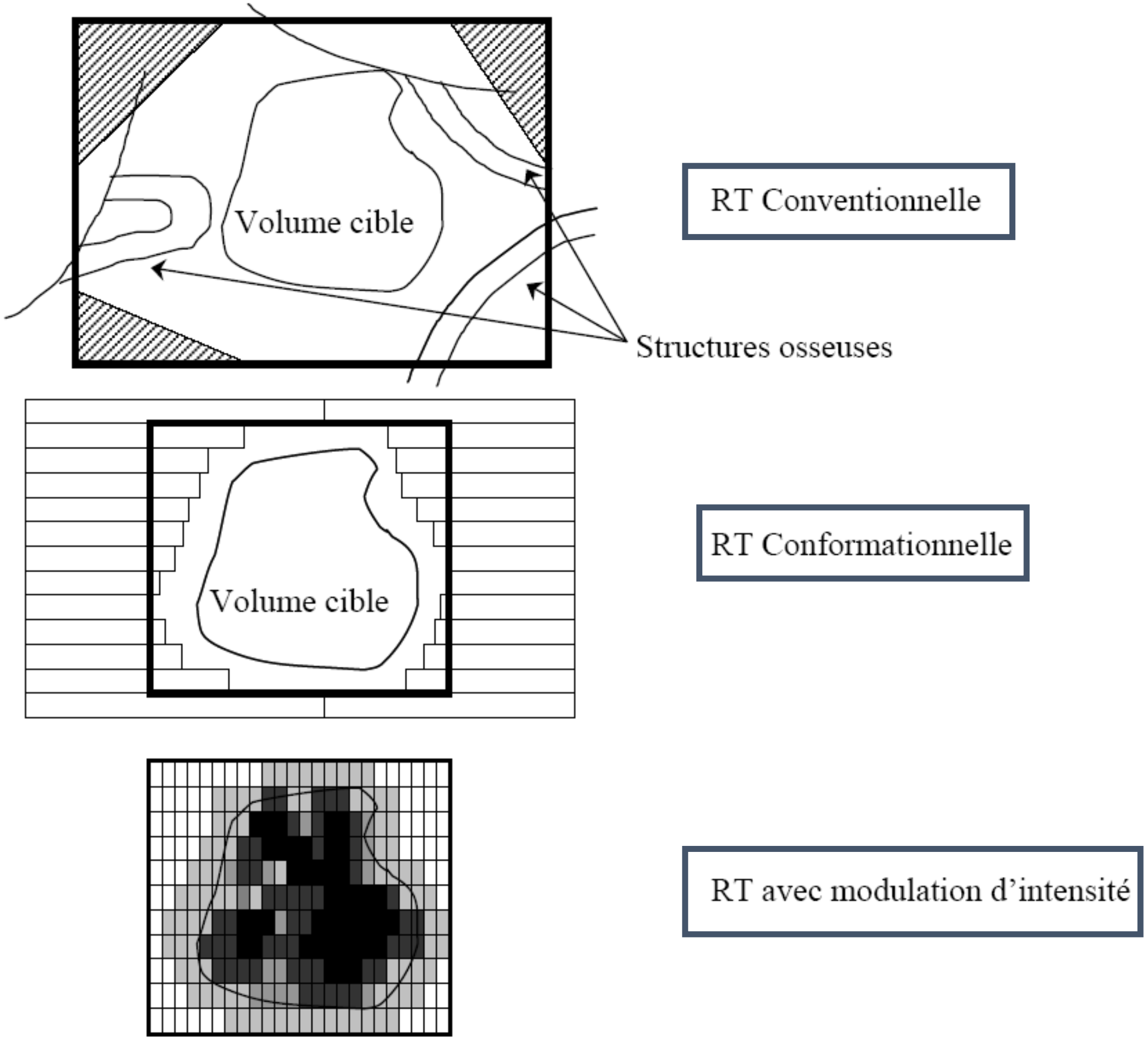
50-250 kVp

Fig.6

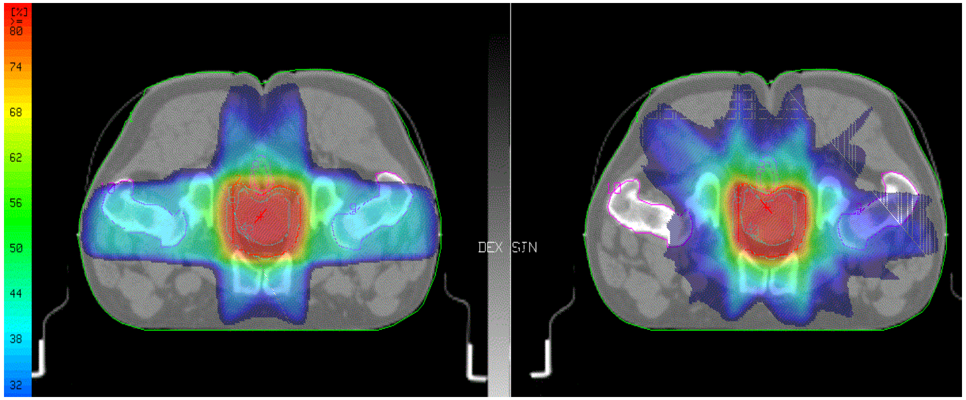


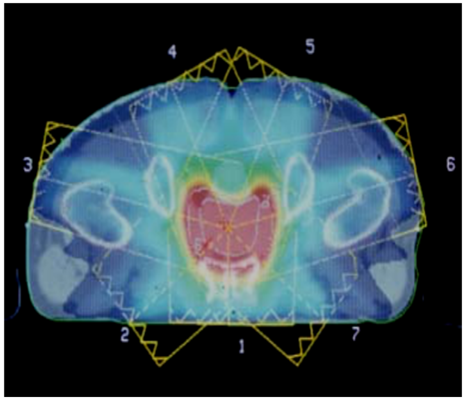
^{60}Co (1.25 MeV)

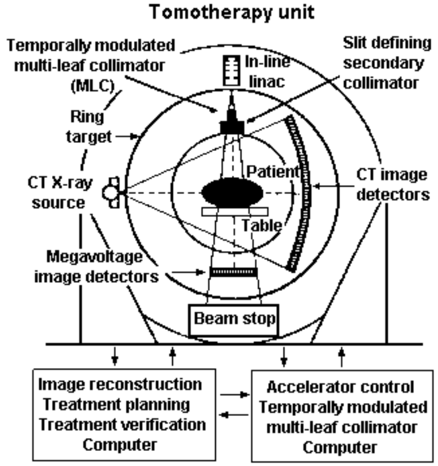
Treatment types: photons

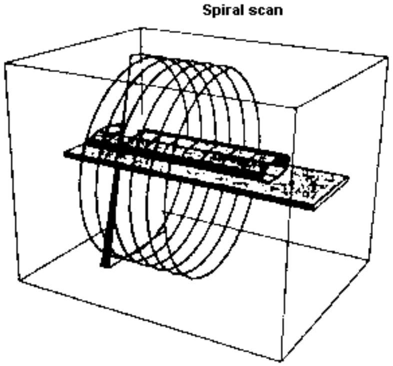


Treatment types : intensity modulated radiotherapy

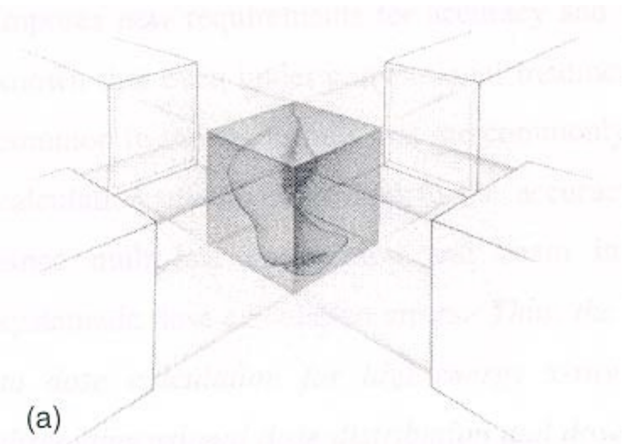


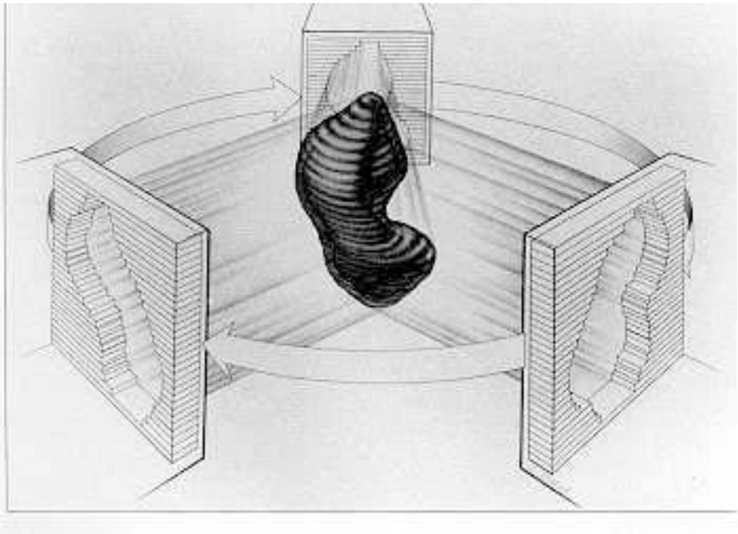






Conformation



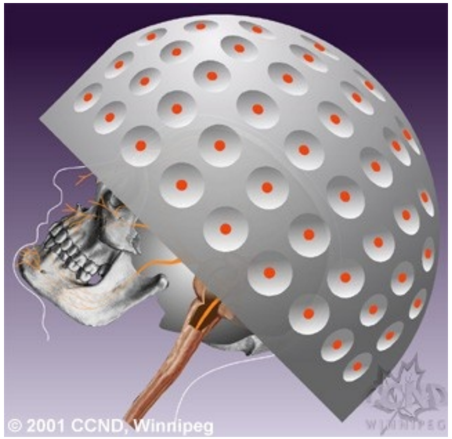


1950's

2000's

Stereotactic Radiotherapy / Radiosurgery

The GTC is positioned on a patient for treatment.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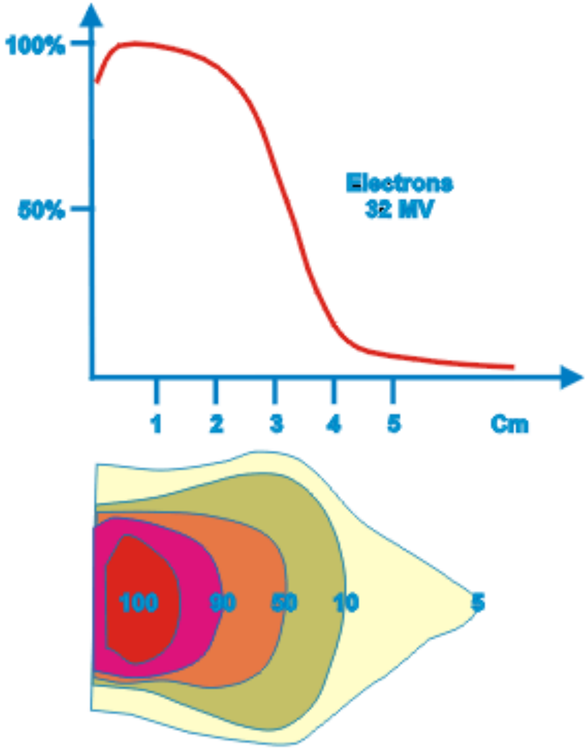
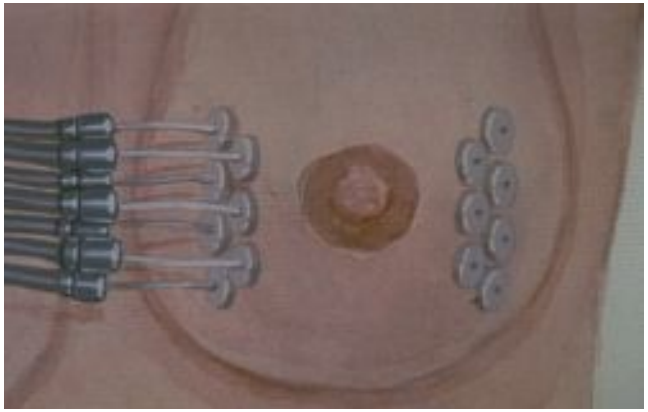
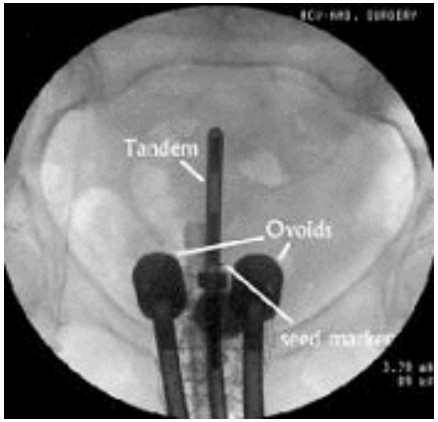
Electrons beams

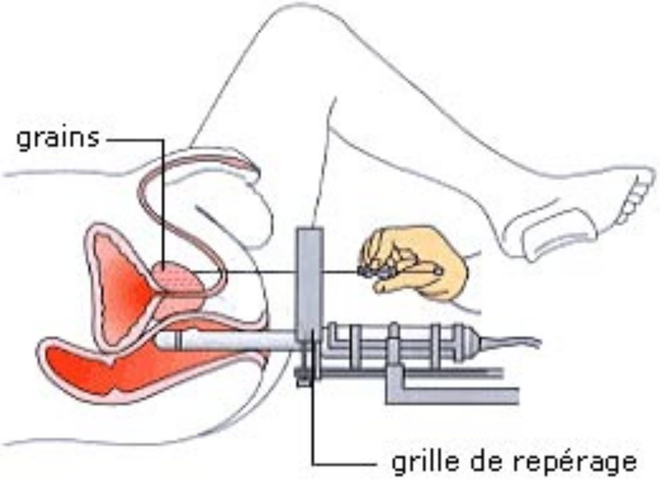
5 MeV - 35 MeV



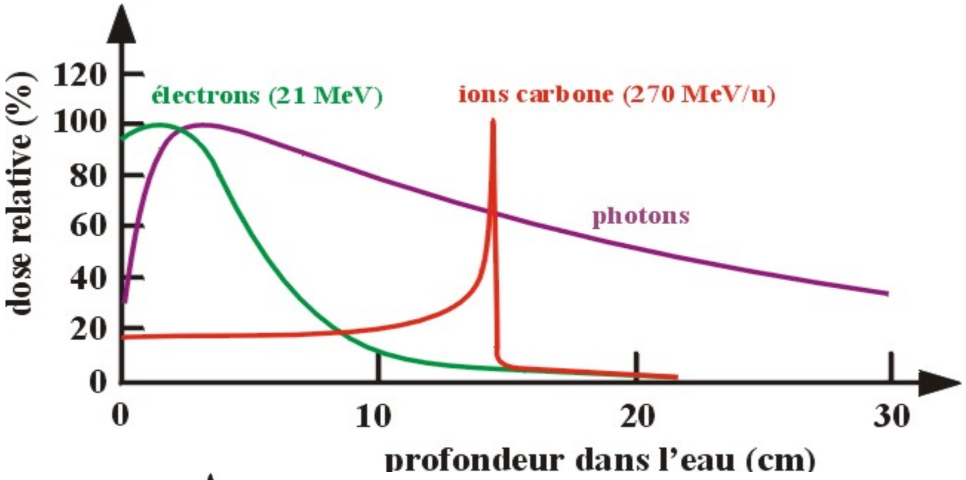
Brachytherapy

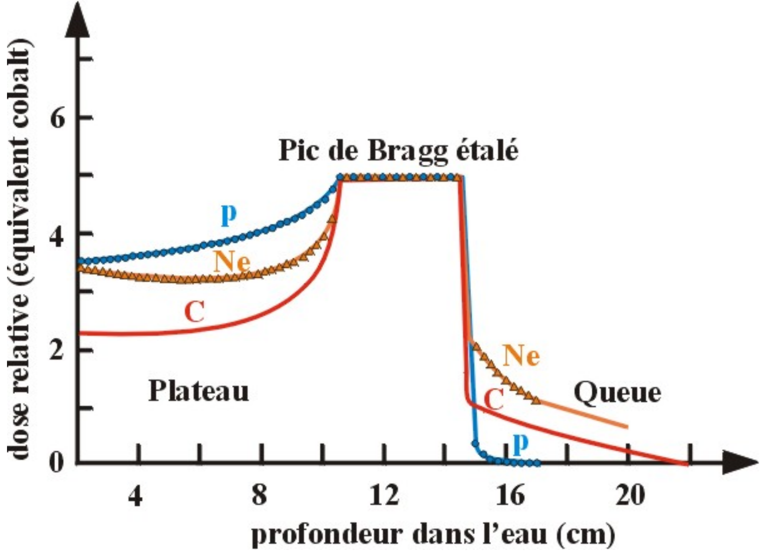




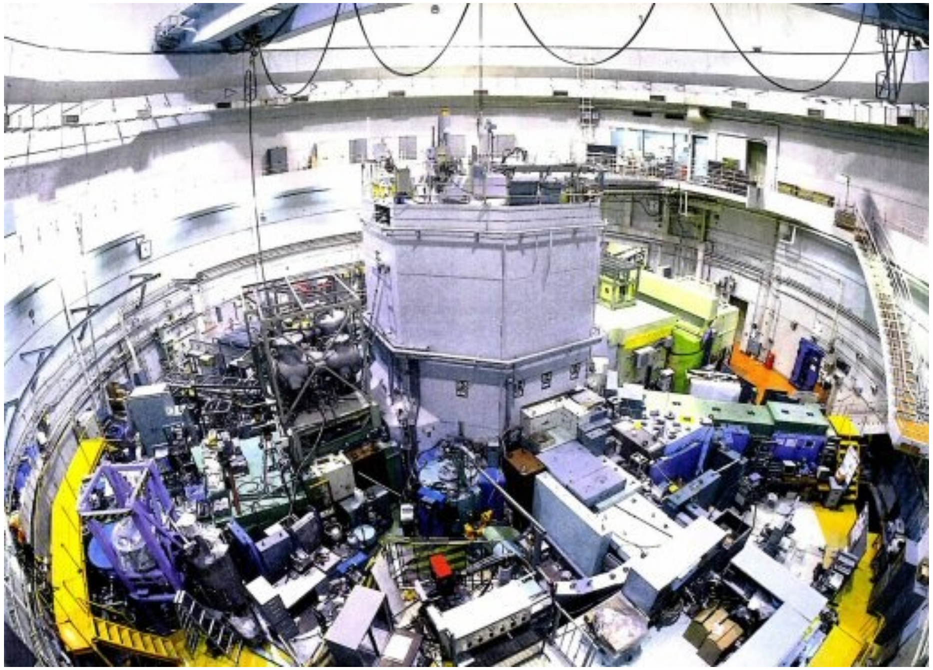


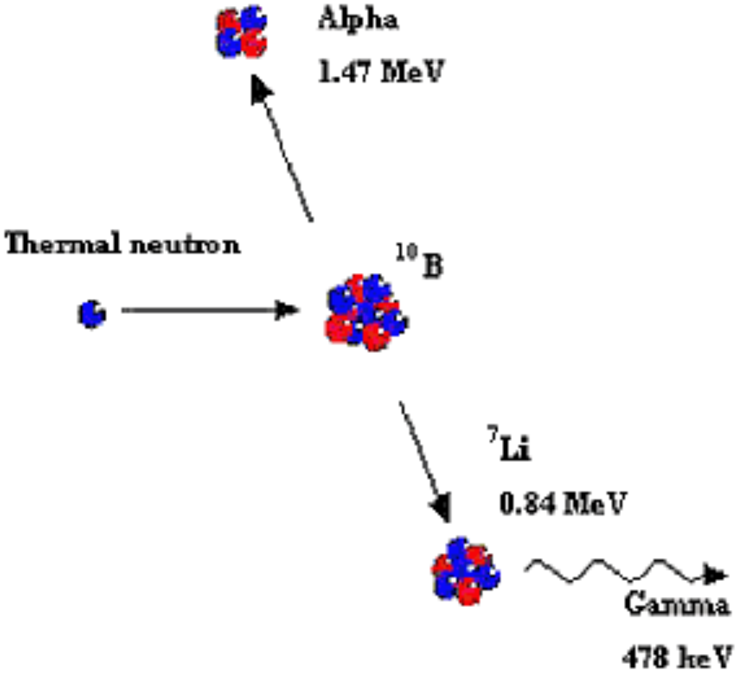
Treatment types: protons /ions





Treatment types: neutrons





Treatment planning

- IAEA TRS 430
- Irradiation technique.
    - Biology and localisation.
    - Patient data
    - Adverse effects
    - Availibility, expertise and costs
- **Treatment planing**
- Treatment delivery and report
- Quality assurance

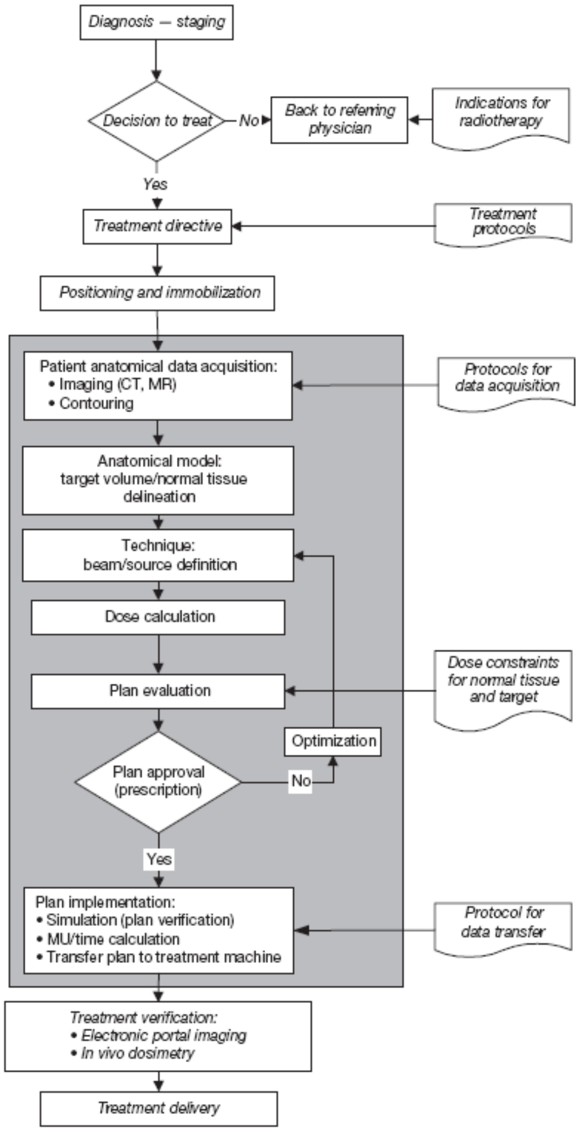
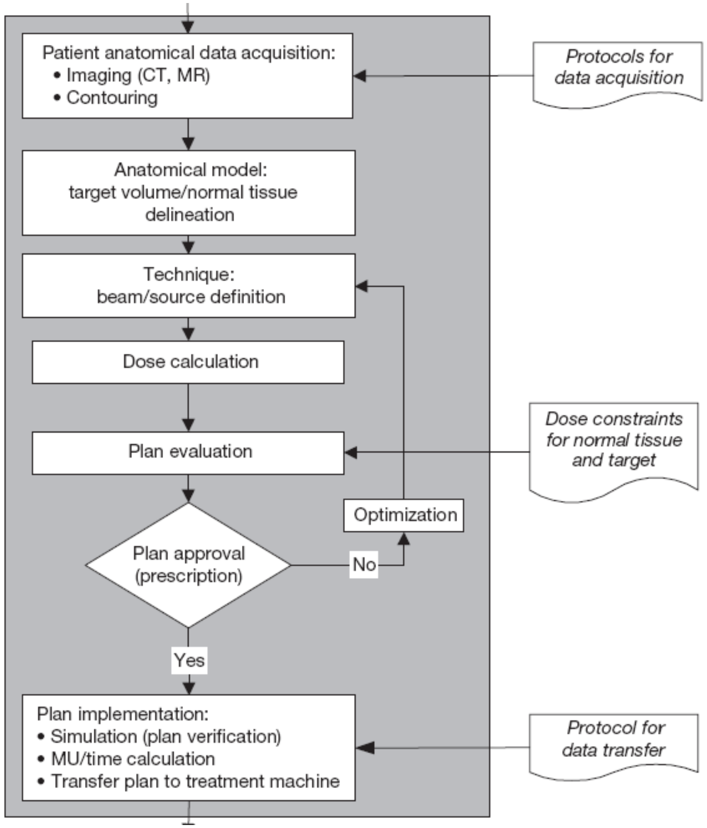


FIG. 1. Steps in the radiation therapy planning process. Note: Process parts in italics are not included in this report.

Treatment planning

- IAEA TRS 430



Patient anatomical data acquisition:
- Imaging (CT, MR)
- Contouring

Anatomical model: target volume/normal tissue delineation

Technique: beam/source definition

Dose calculation

Plan evaluation

Plan approval (prescription)

No

Optimization

Yes

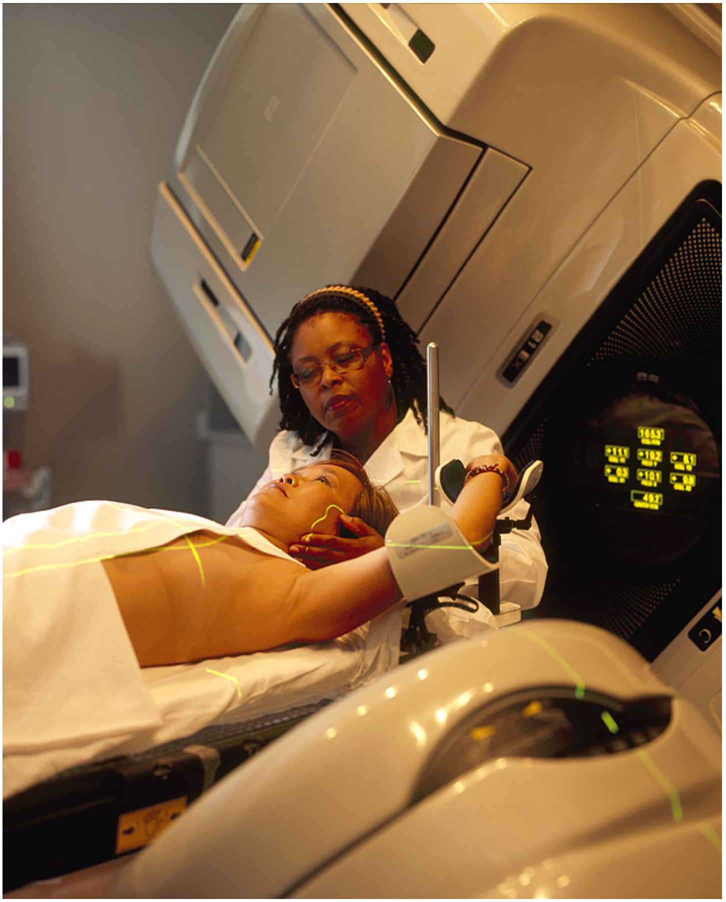
Plan implementation:
- Simulation (plan verification)
- MU/time calculation
- Transfer plan to treatment machine

Protocols for data acquisition

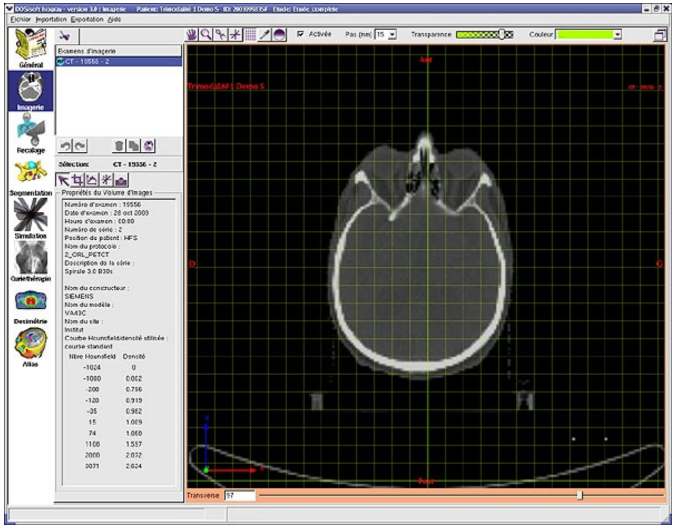
Dose constraints for normal tissue and target

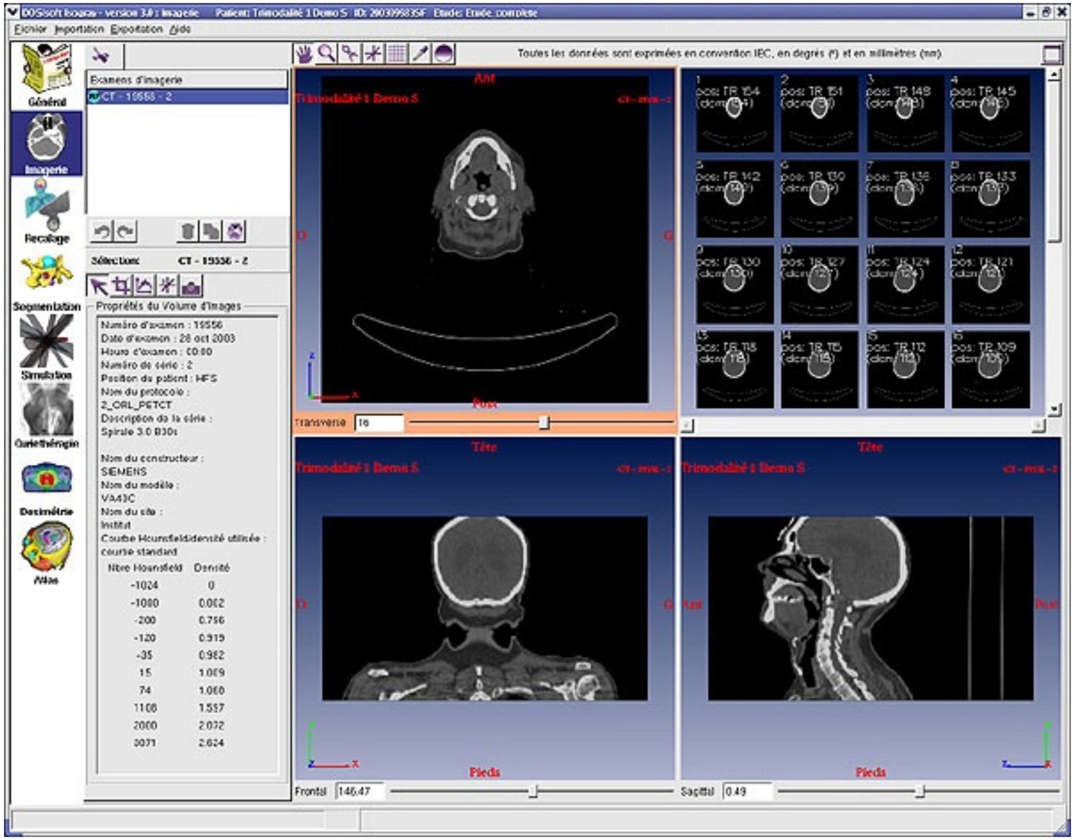
Protocol for data transfer

Positioning and immobilization



Anatomical data





Toutes les données sont exprimées en convention IEC, en degrés (°) et en millimètres (mm)

Sélection: CT - 19556 - 2

Propriétés du Volume d'Images

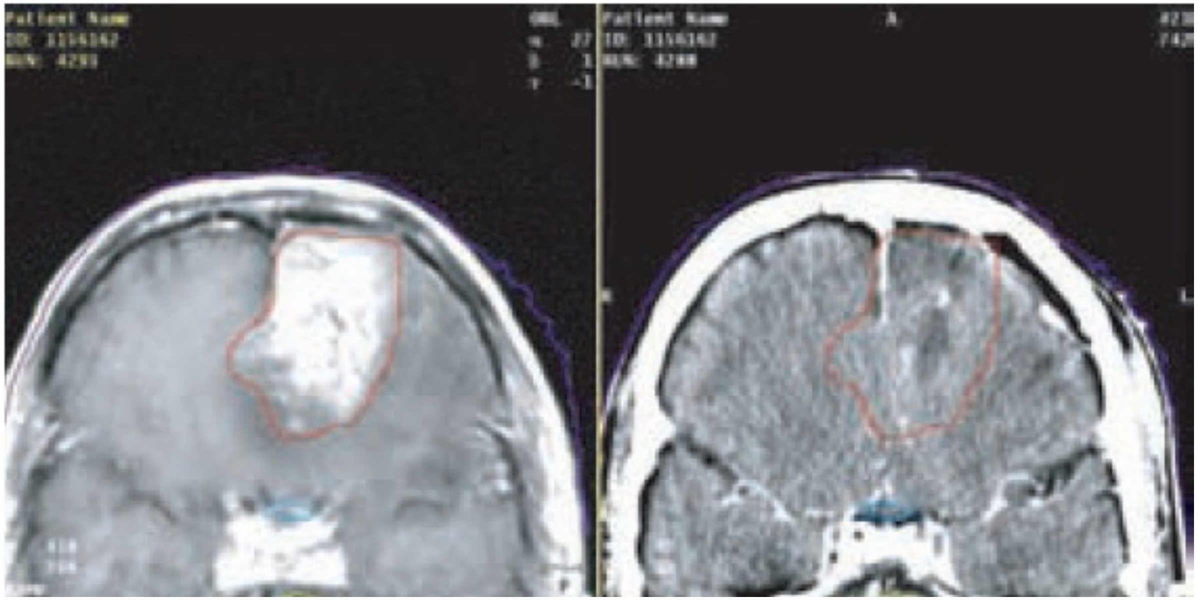
Numéro d'examen : 19556
Date d'examen : 28 oct 2003
Heure d'examen : 00:00
Numéro de série : 2
Position du patient : HFS
Nom du protocole :
2_ORL_PETCT
Description de la série :
Spirale 3.0 B30s

Nom du constructeur :
SIEMENS
Nom du modèle :
VA43C
Nom du site :
Institut
Courbe Hounsfield/densité utilisée :
courbe standard

Nbre Hounsfield	Densité
-1024	0
-1000	0.002
-200	0.756
-120	0.919
-35	0.982
15	1.009
74	1.060
1108	1.557
2000	2.072
3071	2.624

Dimensions
Dosimetry data
Protocoles (KV, mAs, dim.)
DICOM Format

Multimodal imaging

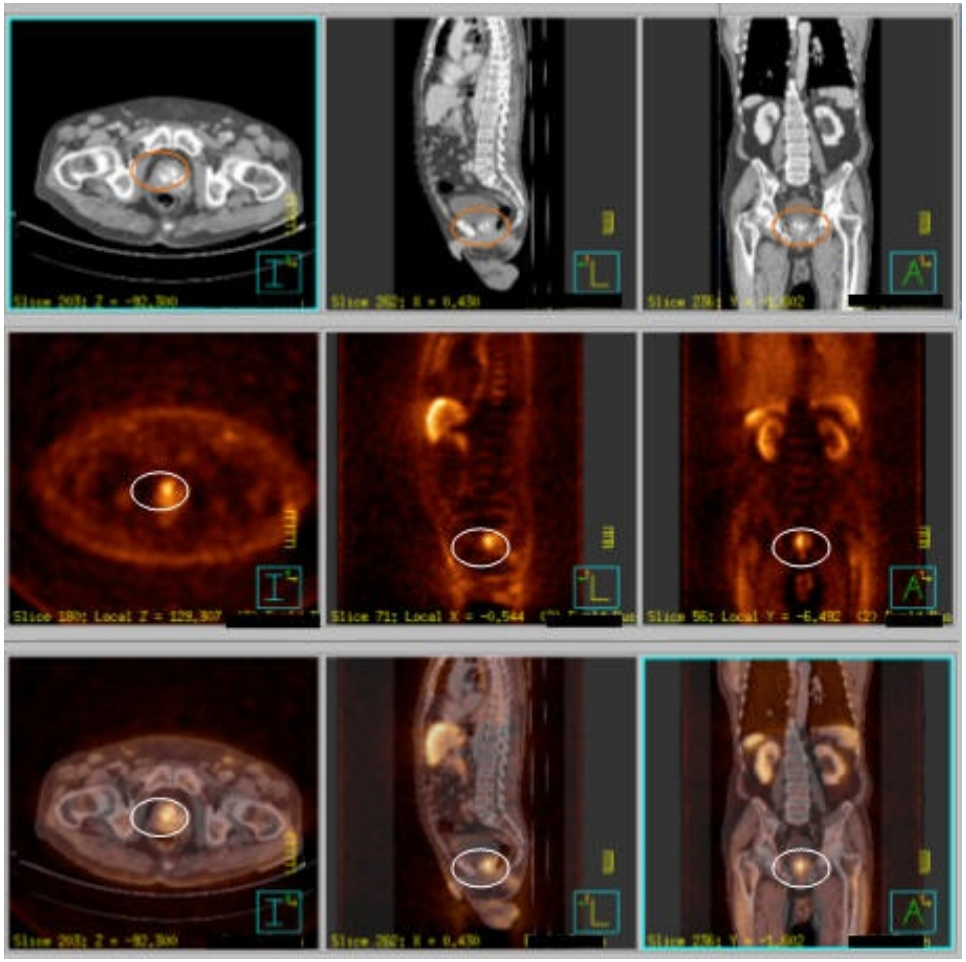


Deformations- Artefacts

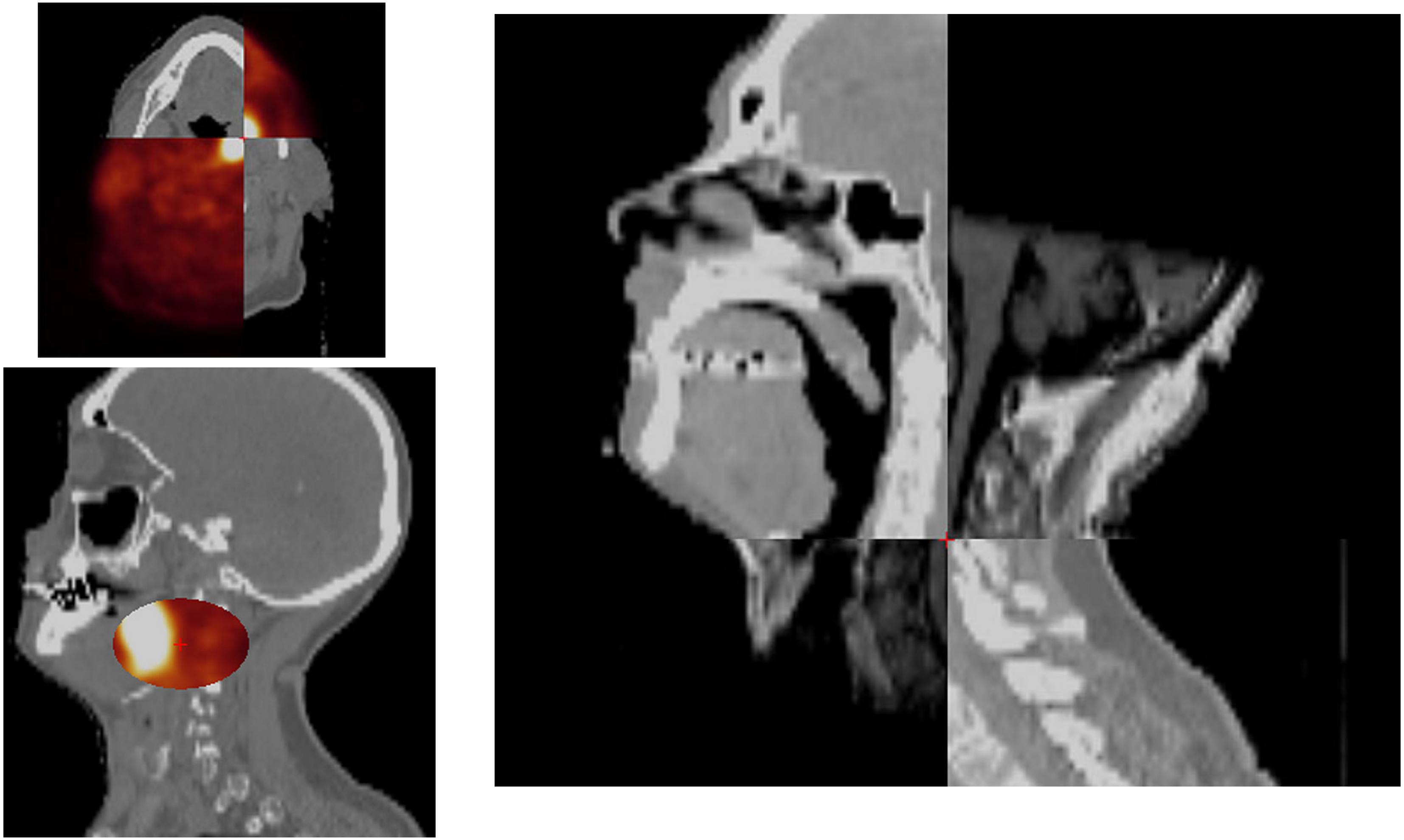
Multimodal imaging : PET

Image Registration?

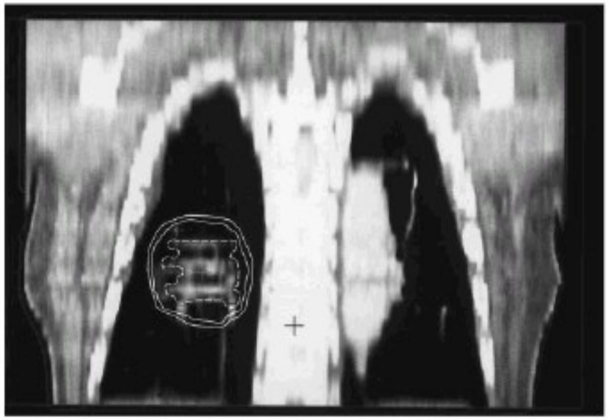
- Rigid
- Non Rigid



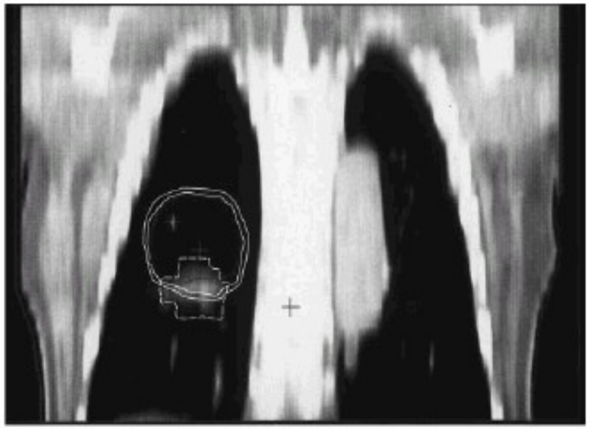
Multimodal imaging : registration

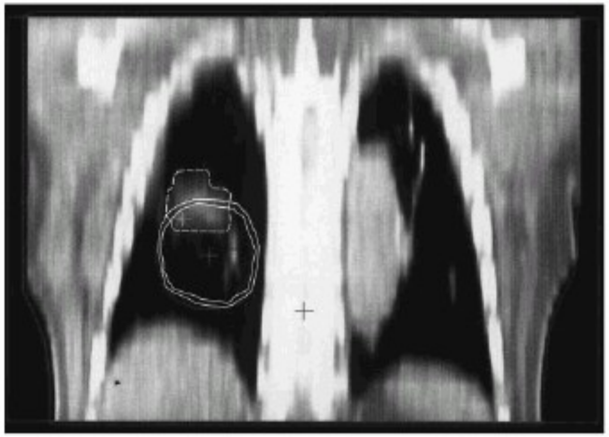


4D-CT

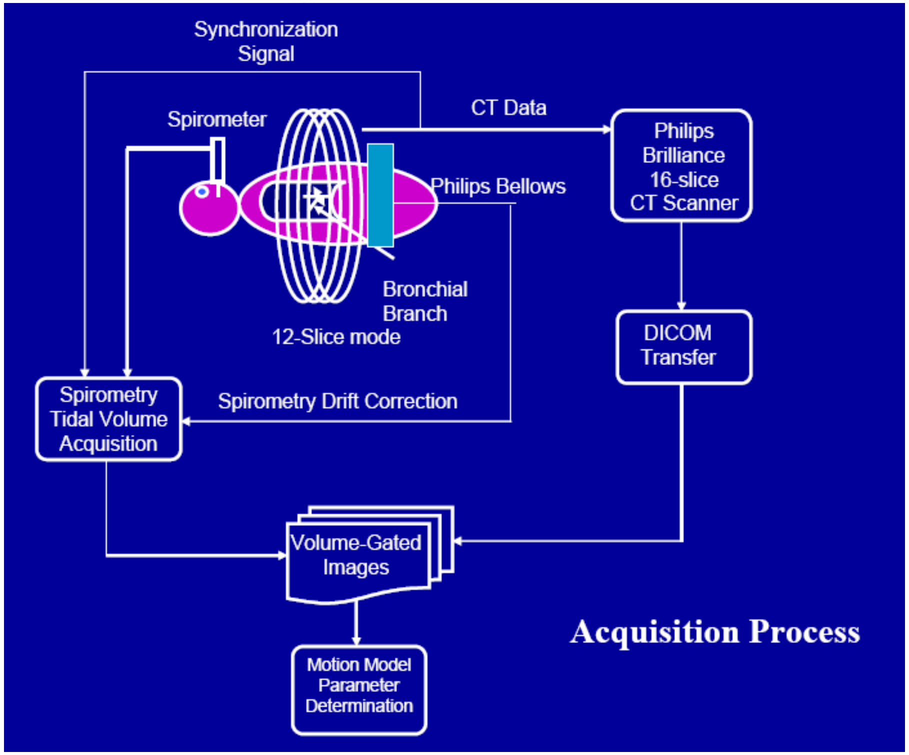


(a)

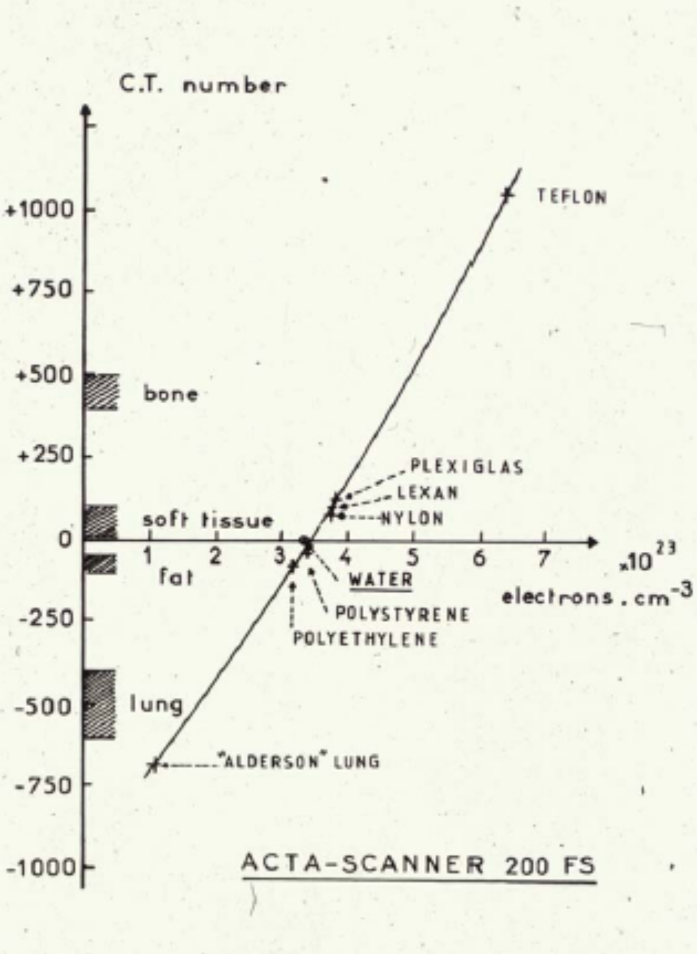




(c)


Synchronization Signal
Spirometer
CT Data
Philips Brilliance 16-slice CT Scanner
Philips Bellows
Bronchial Branch
12-Slice mode
DICOM Transfer
Spirometry Tidal Volume Acquisition
Spirometry Drift Correction
Volume-Gated Images
Motion Model Parameter Determination
Acquisition Process

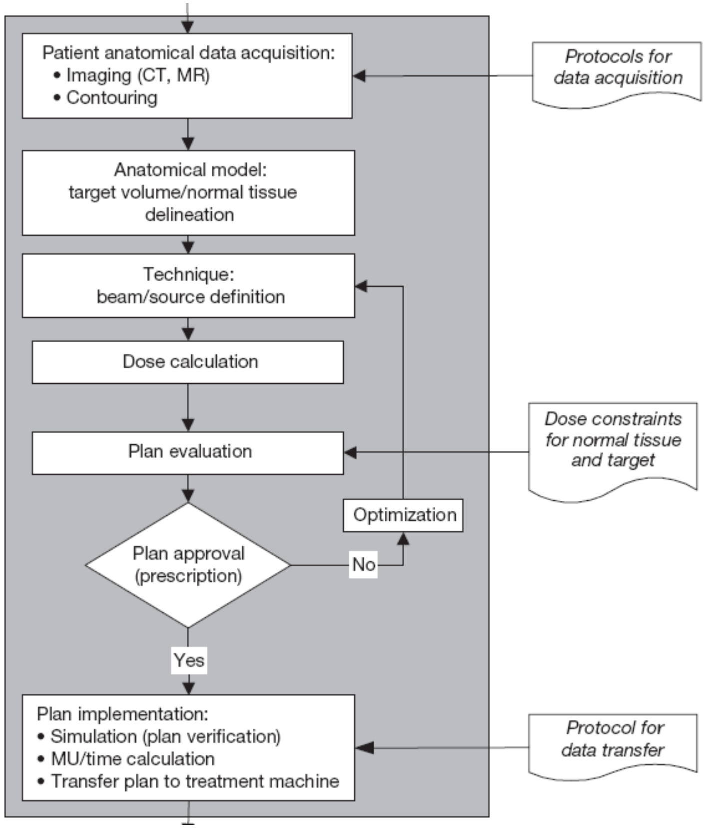
CT scanner calibration



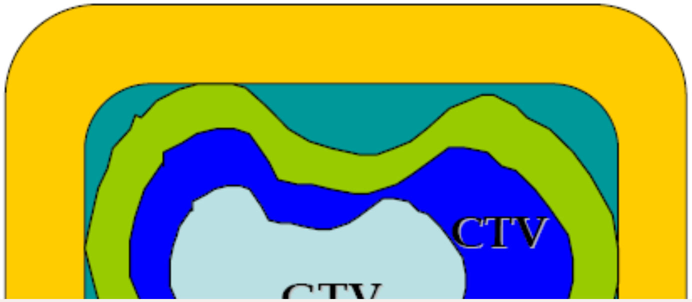
$$\boxed{I_H = \frac{\mu - \mu_{eau}}{\mu_{eau}} \times 1000}$$

Treatment Planing

- IAEA TRS 430



Contouring (volume definition)




Journal of the ICRU

ICRU REPORT 83

Prescribing, Recording, and Reporting Photon-Beam Intensity-Modulated Radiation Therapy (IMRT)

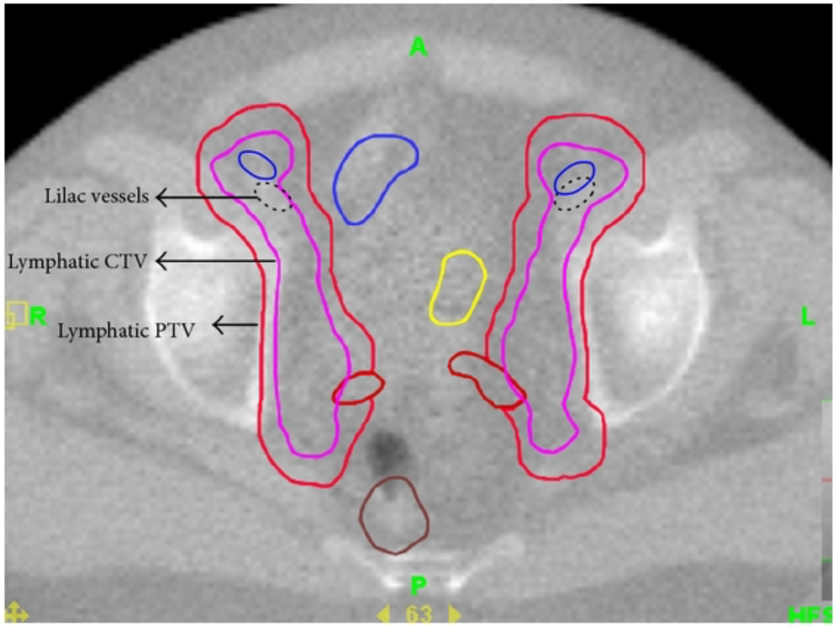
Ir
V

A reasonable way of thinking would be: "Choose the margins so that the target is in the treated field at least 95% of the time."

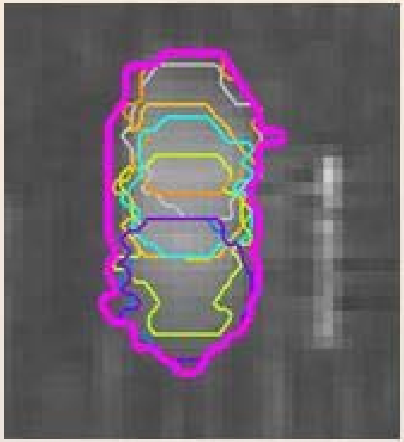
- Growth Tumor Volume (GTV)
- Clinical Target Volume (CTV)
- Planing target volume (PTV)

→ • Internal target Volume (ITV)
↘ • Set-Up Margins

Clinical Practice



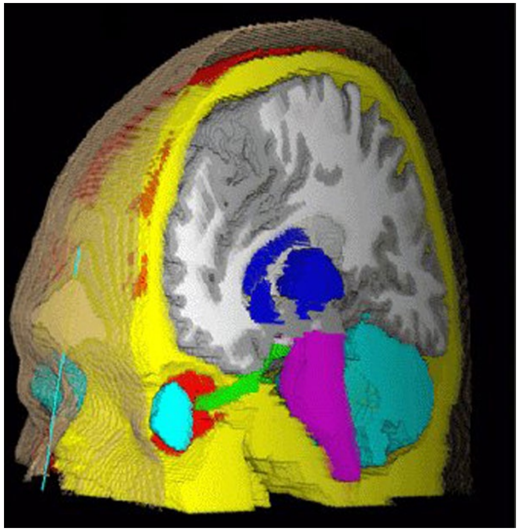
PTV

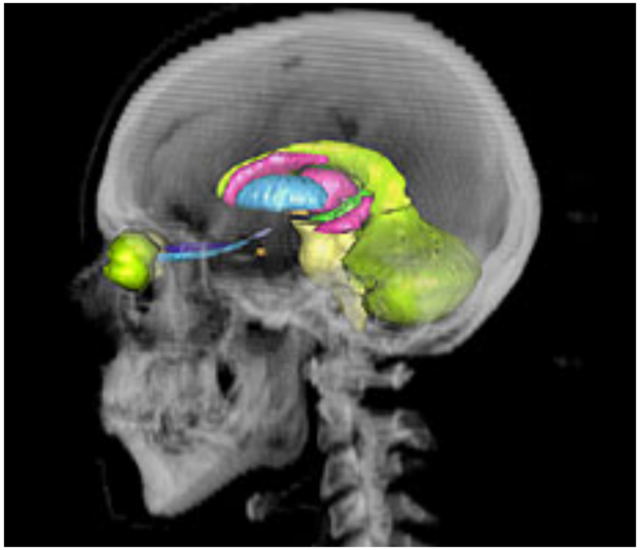


ITV- 4DCT

Volumes

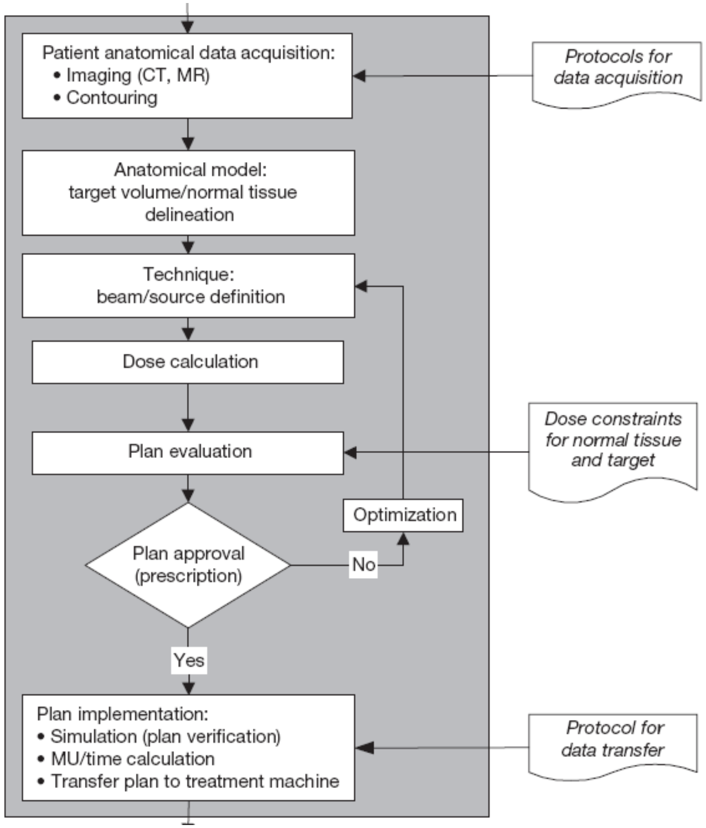
- Organ at risks (OAR): tolerance doses
- treatment plan depends on the dose to OARs



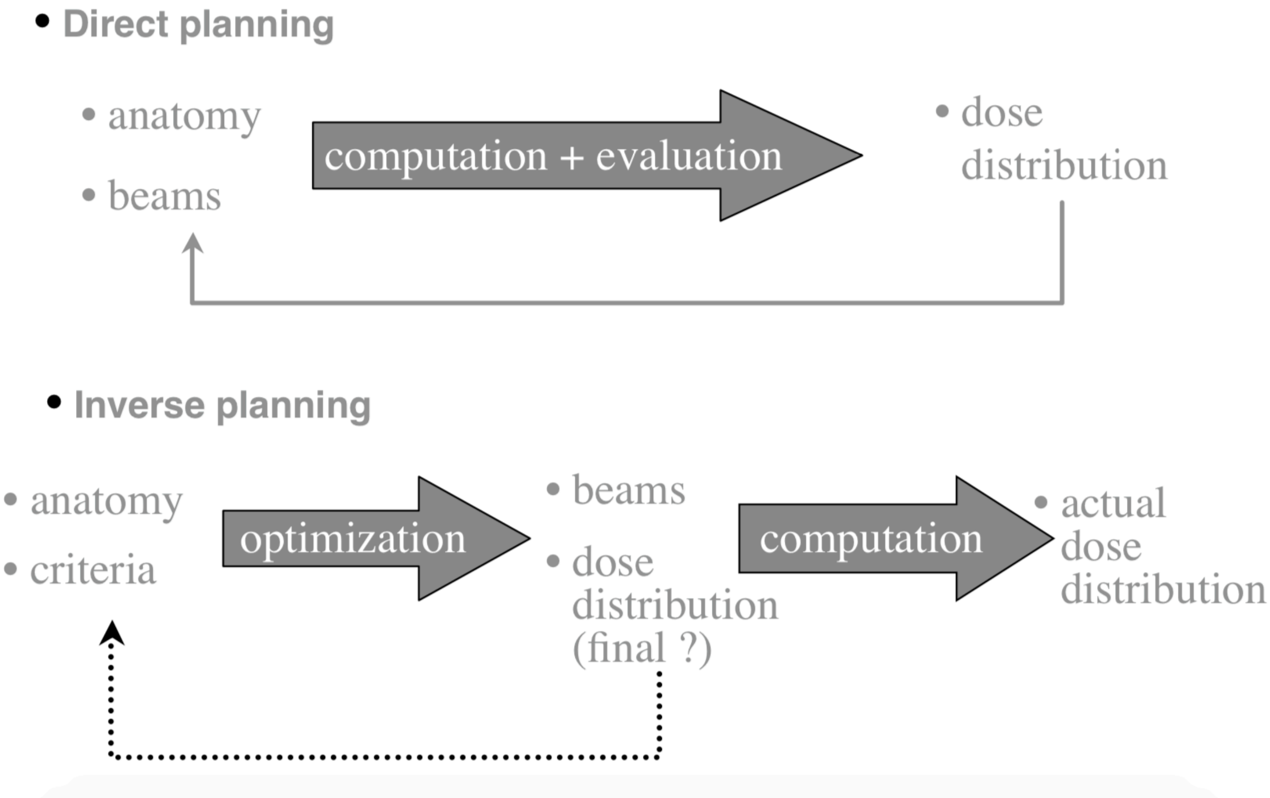


Treatment Planning

- IAEA TRS 430



Direct Planning – Invert Planning



- **Direct planning**
  - anatomy
  - beams

computation + evaluation

- dose distribution

- **Inverse planning**
  - anatomy
  - criteria

optimization

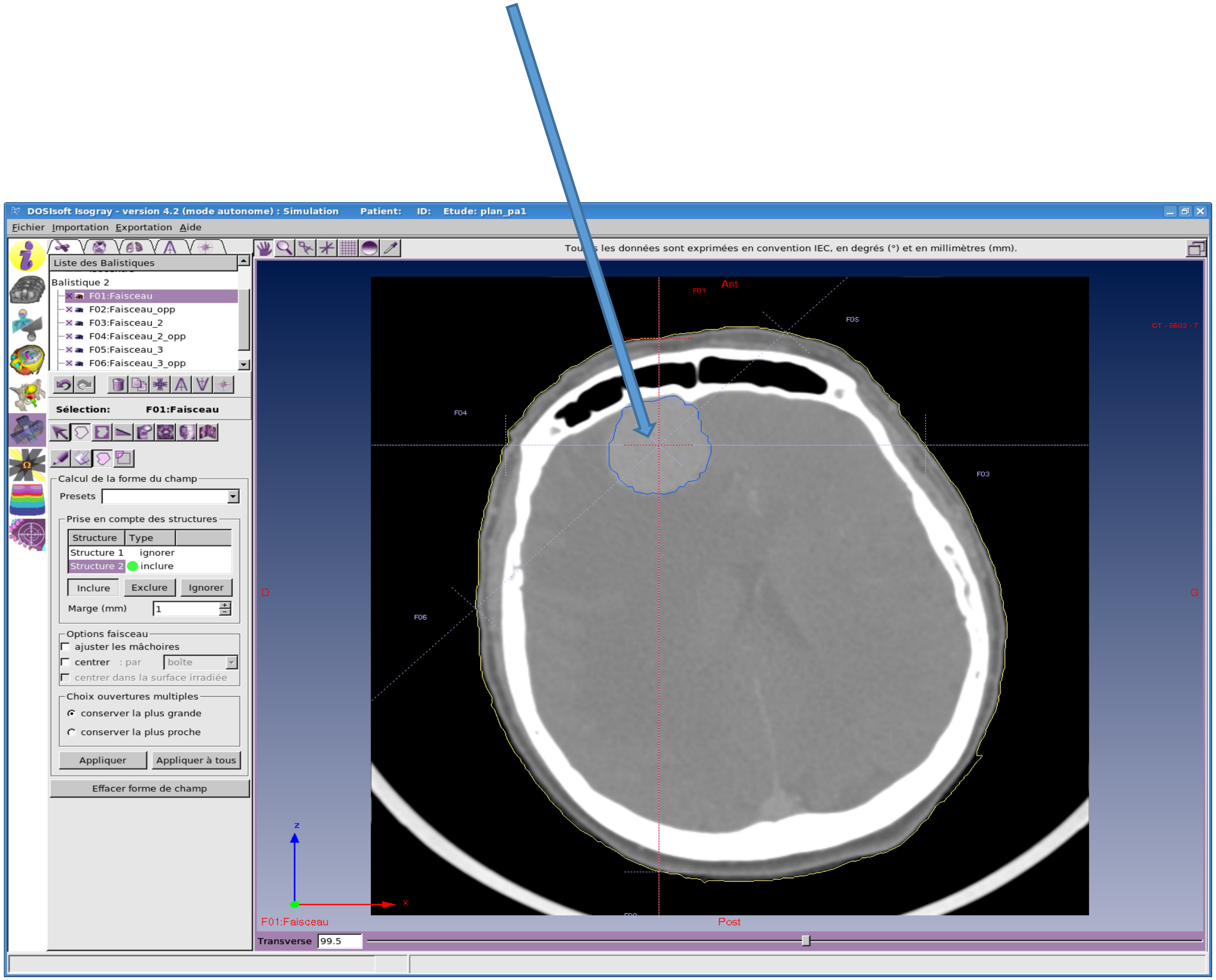
- beams
- dose distribution (final ?)

computation

- actual dose distribution

Isocenter

Center of target volume


DOSIsoft Isogray - version 4.2 (mode autonome) : Simulation   Patient: ID: Etude: plan_pa1

Tou s les données sont exprimées en convention IEC, en degrés (°) et en millimètres (mm).

Liste des Balistiques

Balistique 2
- F01:Faisceau
- F02:Faisceau_opp
- F03:Faisceau_2
- F04:Faisceau_2_opp
- F05:Faisceau_3
- F06:Faisceau_3_opp

Sélection: **F01:Faisceau**

Calcul de la forme du champ

Presets

Prise en compte des structures

Structure	Type
Structure 1	ignorer
Structure 2	● inclure

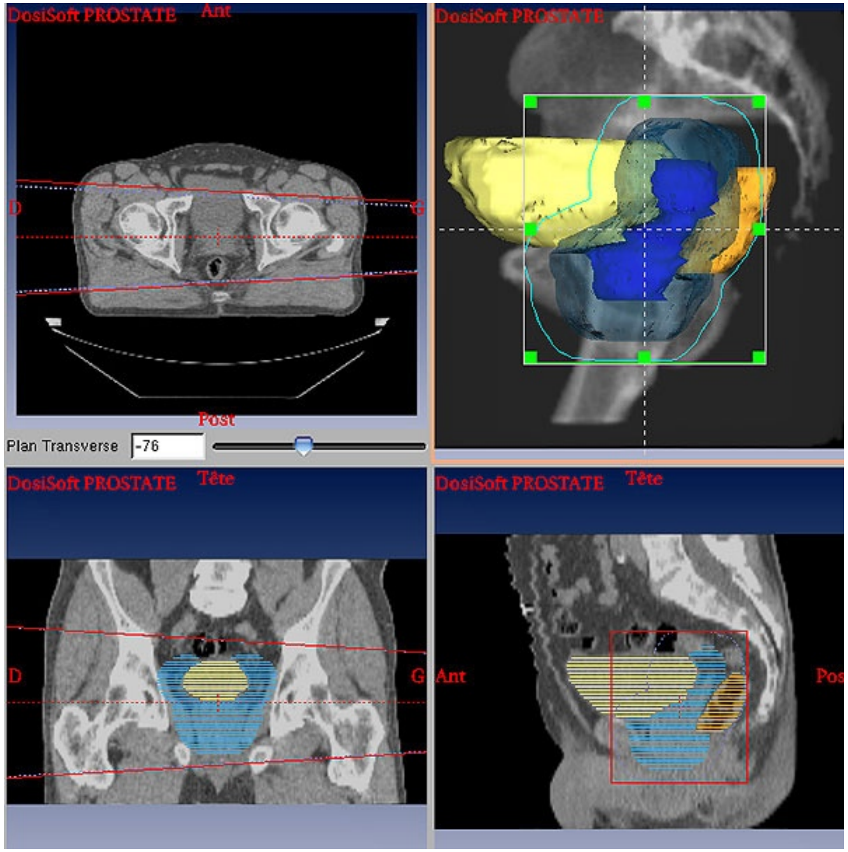
Marge (mm) 1

Options faisceau
- ☐ ajuster les mâchoires
- ☐ centrer : par boîte
- ☐ centrer dans la surface irradiée

Choix ouvertures multiples
- ● conserver la plus grande
- ○ conserver la plus proche

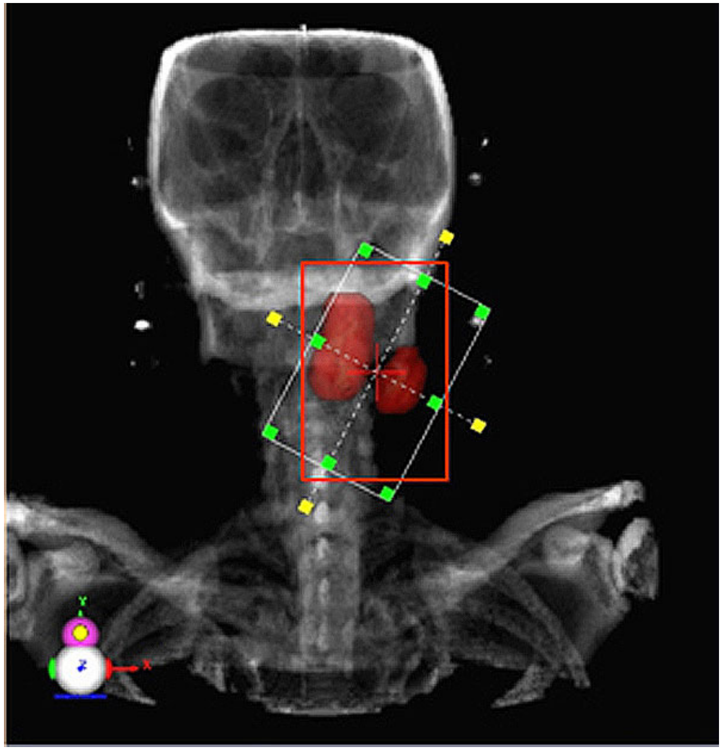
Transverse 99.5

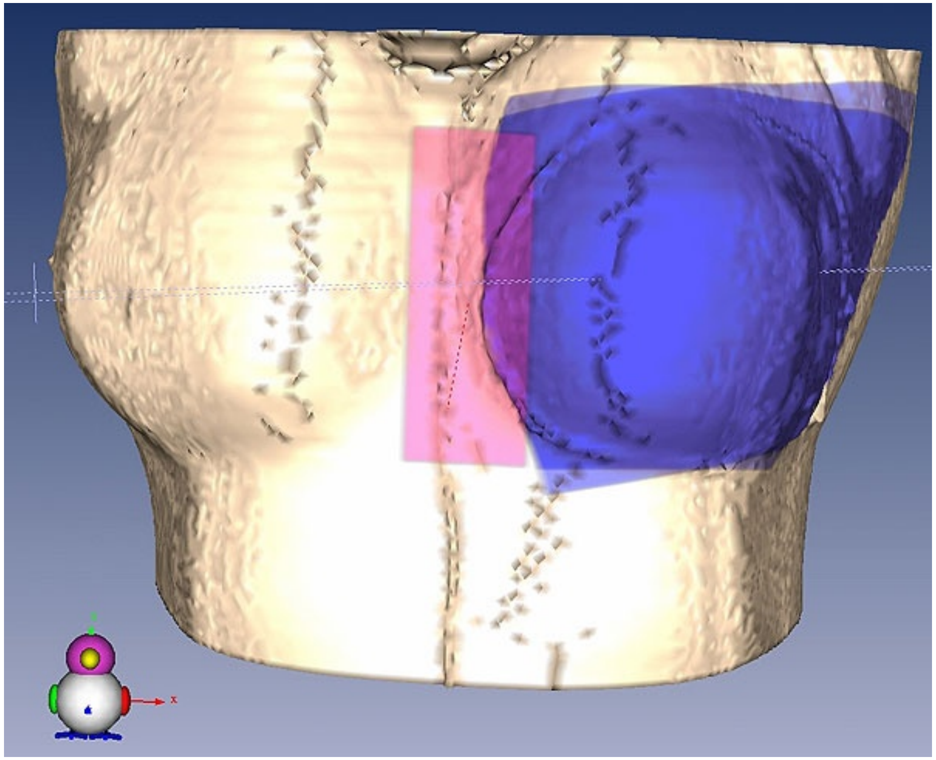
Beam positioning



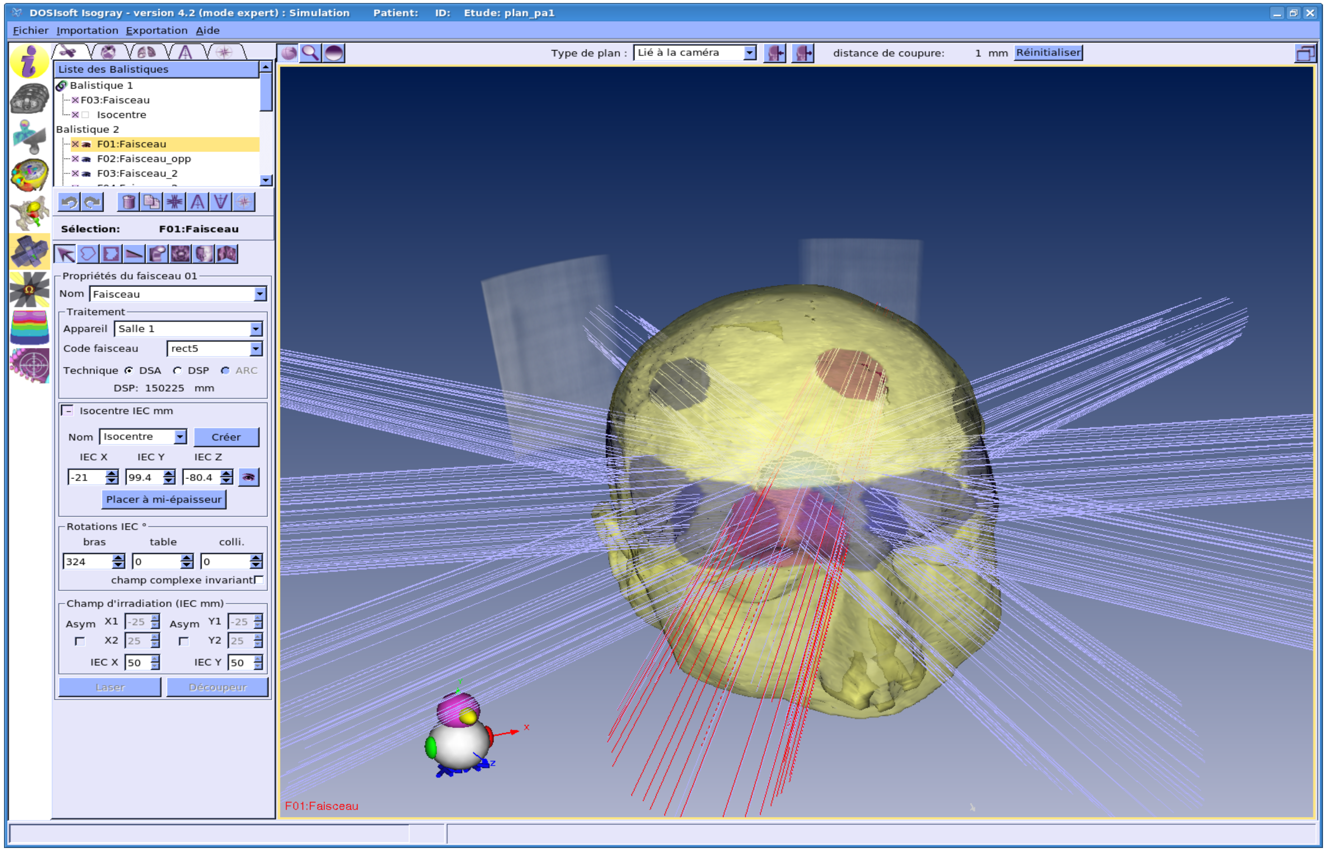
Plan Transverse -76

Beam positioning





Beam positioning



DOSIsoft Isogray - version 4.2 (mode expert) : Simulation Patient: ID: Etude: plan_pa1

Liste des Balistiques
- Balistique 1
  - F03:Faisceau
  - Isocentre
- Balistique 2
  - F01:Faisceau
  - F02:Faisceau_opp
  - F03:Faisceau_2

Sélection: **F01:Faisceau**

Propriétés du faisceau 01

Nom: Faisceau

Traitement

Appareil: Salle 1

Code faisceau: rect5

Technique: ● DSA ○ DSP ○ ARC

DSP: 150225 mm

Isocentre IEC mm

Nom: Isocentre

IEC X	IEC Y	IEC Z
-21	99.4	-80.4

Rotations IEC °

bras	table	colli.
324	0	0

champ complexe invariant ☐

Champ d'irradiation (IEC mm)

Asym ☐ X1 -25 X2 25

Asym ☐ Y1 -25 Y2 25

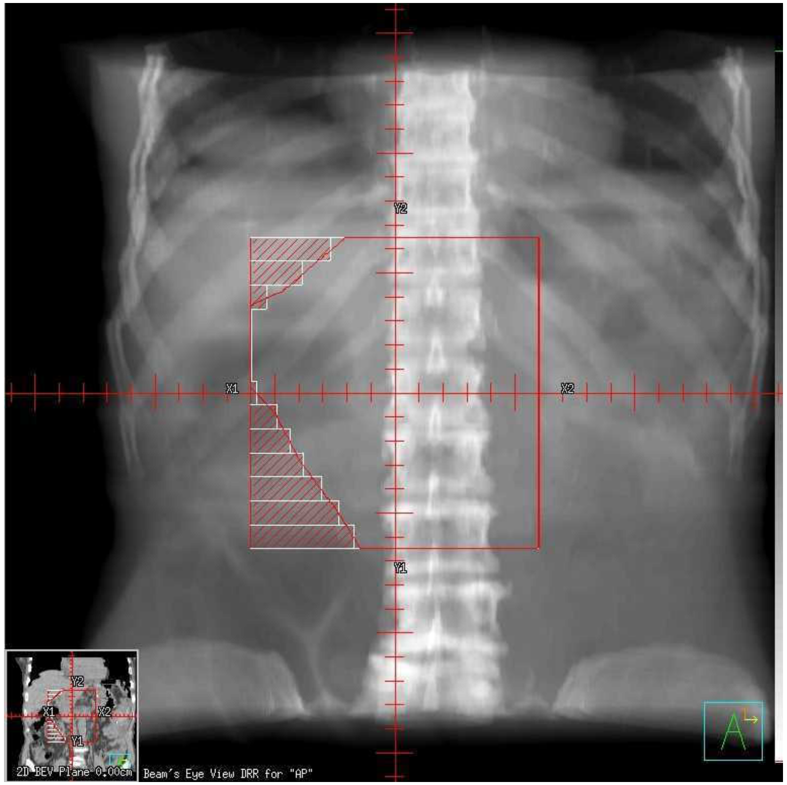
IEC X 50 IEC Y 50

Type de plan : Lié à la caméra

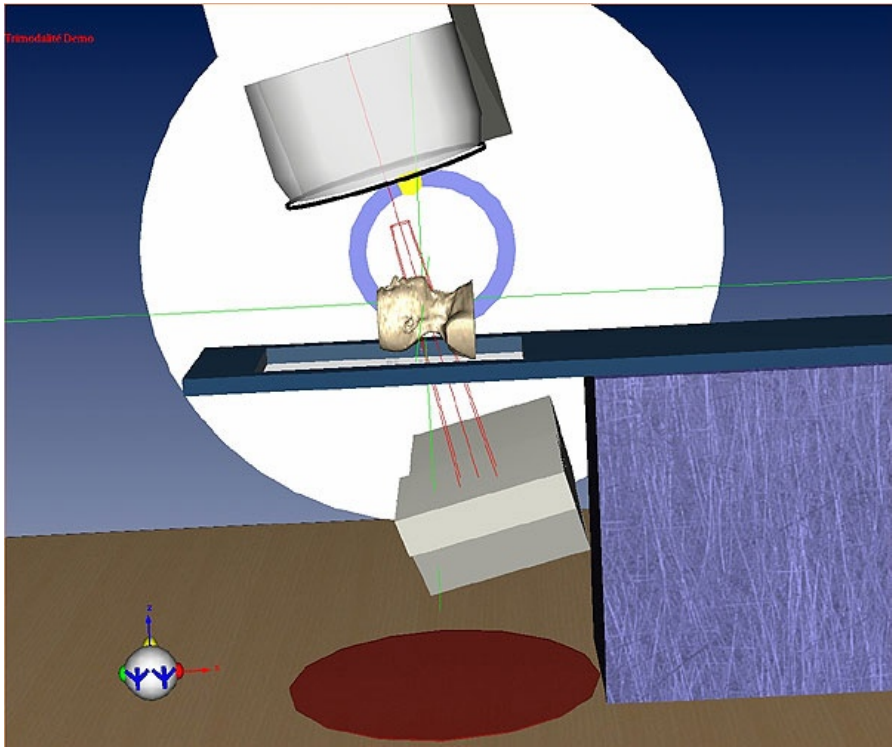
distance de coupure: 1 mm

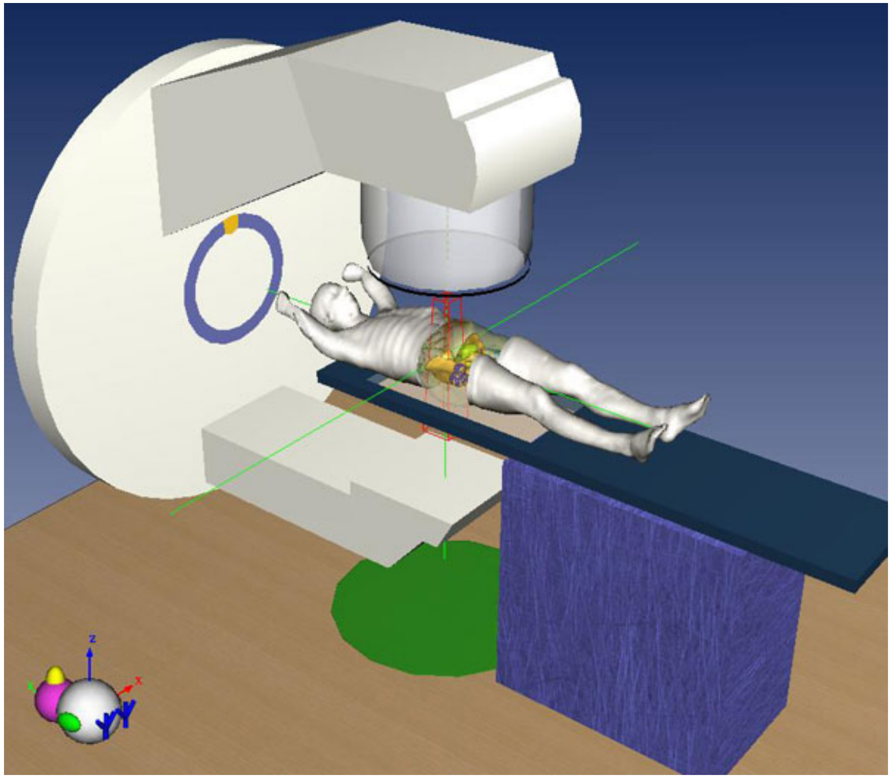
Image guidance

- Specific imaging
  - Beam ’s eye view
  - Room ’s eye view
  - DRR: Digitally Reconstructed Radiographs



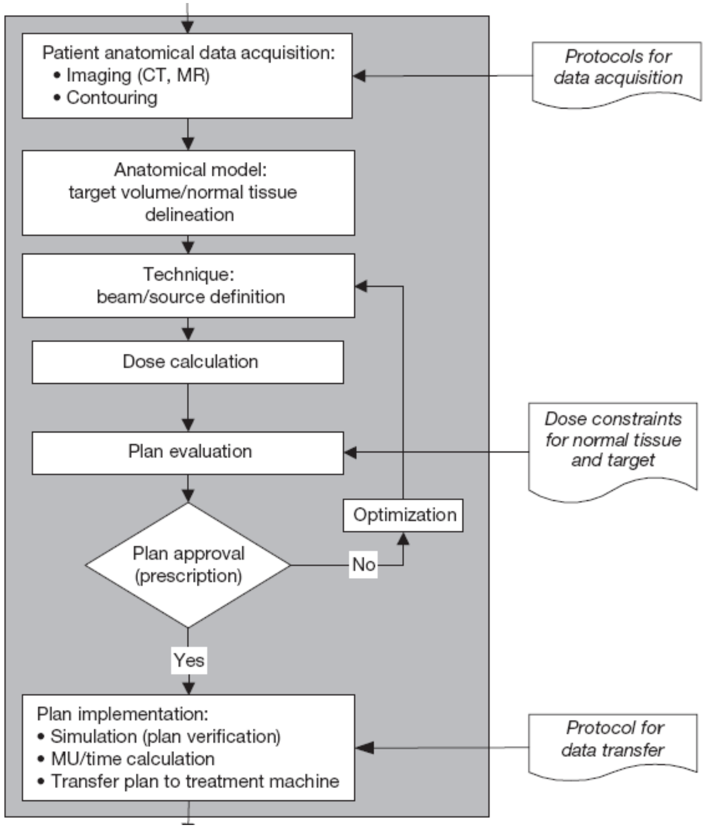
Simulated imaging





Treatment Planing

- IAEA TRS 430



Dose calculation: prerequisite

- Describing properly the interactions of radiation with matter; especially for beam generation.
- True 3D calculation
- Dose calculation with hetereogeneities
- Fast calculation

Dose constraints: AAPM TG53

- On the beam Axis (5 mm spatial resolution)
  - < 0.5 % for dmax < d < 20cm
  - < 1 % for d > 20 cm
  - < 5% for d < dmax
- Outside the beam axis
  - < 2%, low dose gradient areas, d < 30 cm
  - < 5%, low dose gradient areas, d > 30cm
  - Distance to agreement of 2 mm in high dose gradient area

Dose constraints

- Isodose 95 % covers the whole PTV.
- Avoid hot spots (uniform dose on the PTV), -5% → + 7% , (110% max)
- More than 99% of the prescribed dose should be given to more than 93% of the PTV
- Dose Volume Histograms

Dose volume histograms

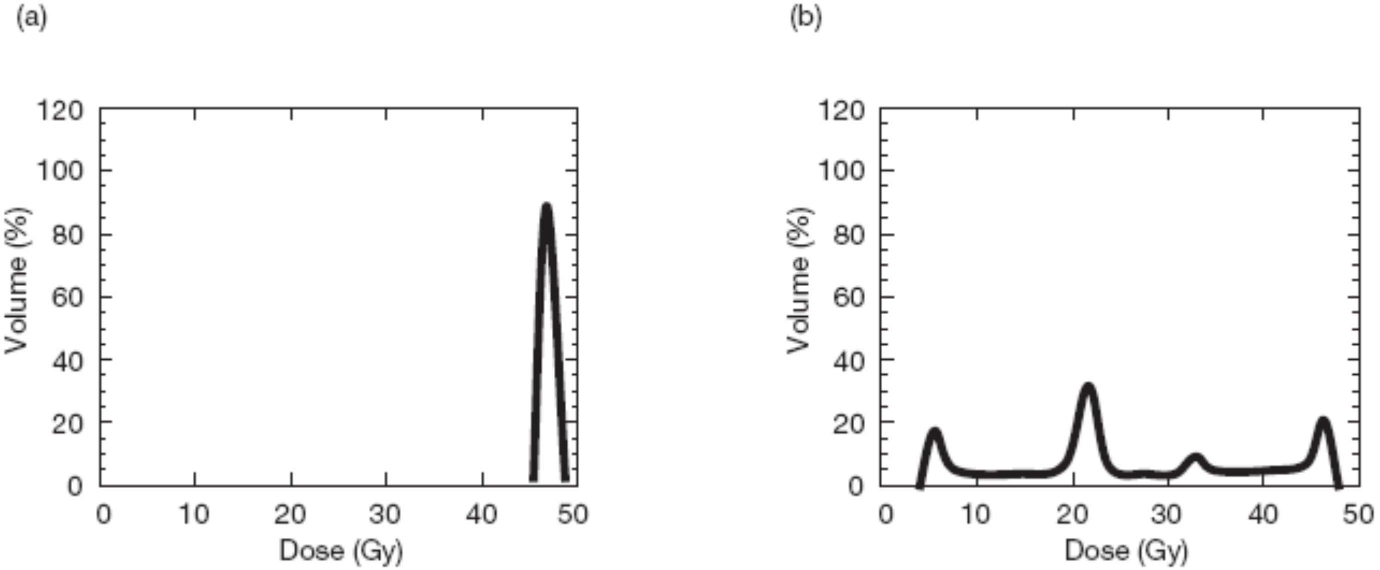


FIG. 7.26. Differential DVHs for a four field prostate treatment plan for (a) the target volume and (b) the rectum. The ideal target differential DVHs would be infinitely narrow peaks at the target dose for the PTV and at 0 Gy for the critical structure.

Photons dose calculation algorithm: AAPM TG85 categories

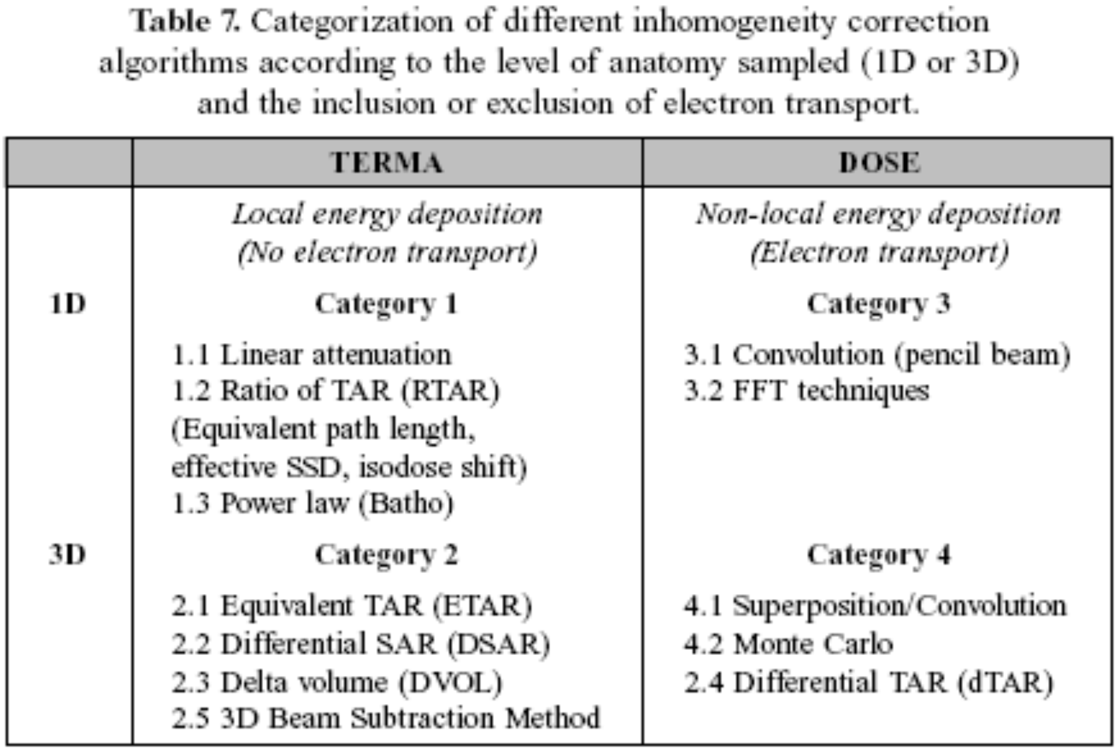


Table 7. Categorization of different inhomogeneity correction algorithms according to the level of anatomy sampled (1D or 3D) and the inclusion or exclusion of electron transport.

	TERMA	**DOSE**
	Local energy deposition *(No electron transport)*	*Non-local energy deposition* *(Electron transport)*
1D	**Category 1** 1.1 Linear attenuation 1.2 Ratio of TAR (RTAR) (Equivalent path length, effective SSD, isodose shift) 1.3 Power law (Batho)	**Category 3** 3.1 Convolution (pencil beam) 3.2 FFT techniques
3D	**Category 2** 2.1 Equivalent TAR (ETAR) 2.2 Differential SAR (DSAR) 2.3 Delta volume (DVOL) 2.5 3D Beam Subtraction Method	**Category 4** 4.1 Superposition/Convolution 4.2 Monte Carlo 2.4 Differential TAR (dTAR)

Dose calculation

$$\Phi \otimes K = \mathrm{D}$$

(a) Photon Beam

(b) Electron Beam

(c) Brachytherapy

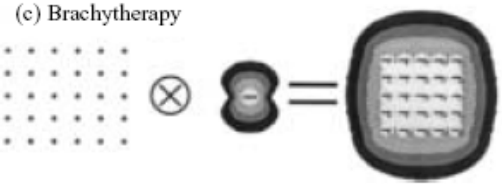
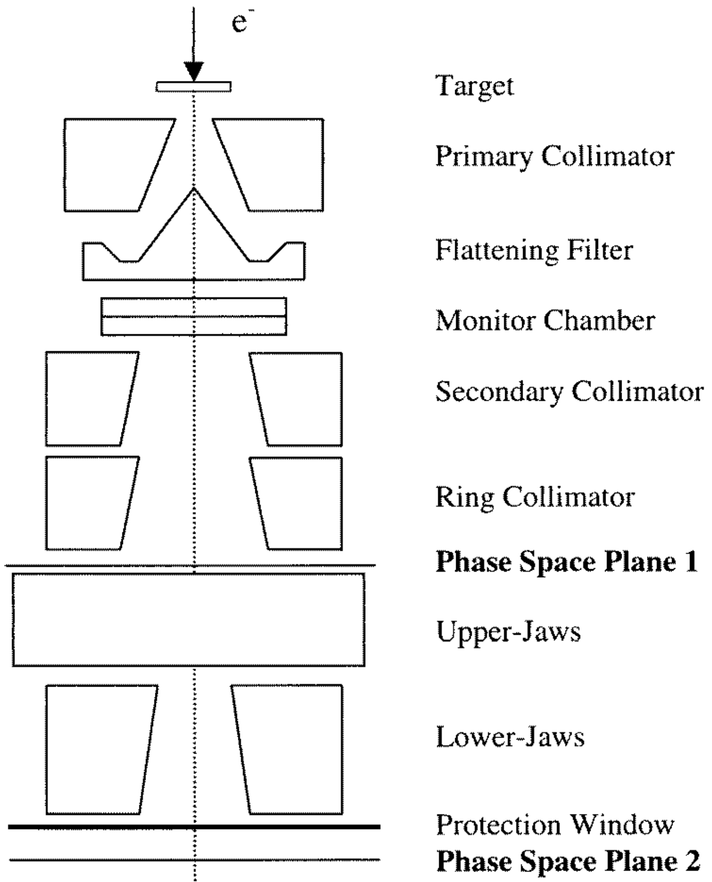
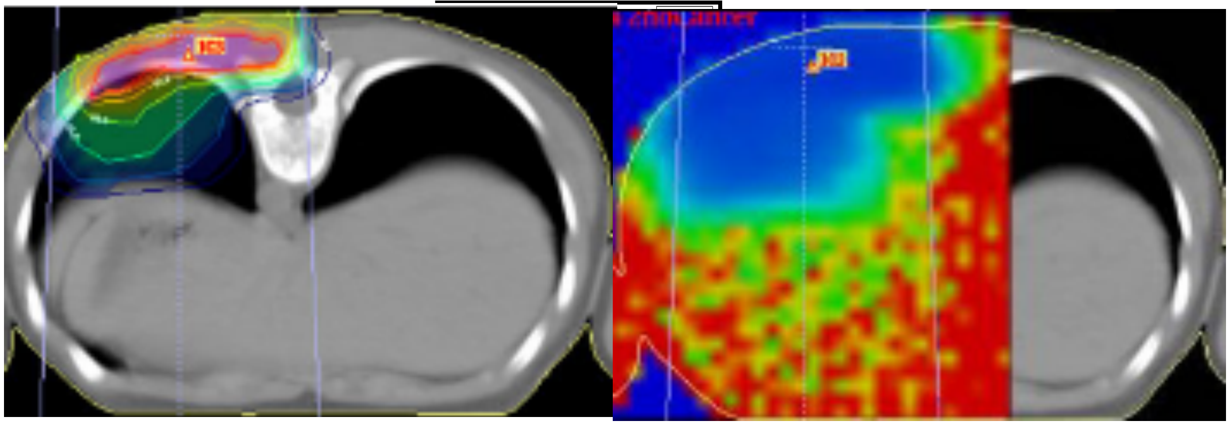
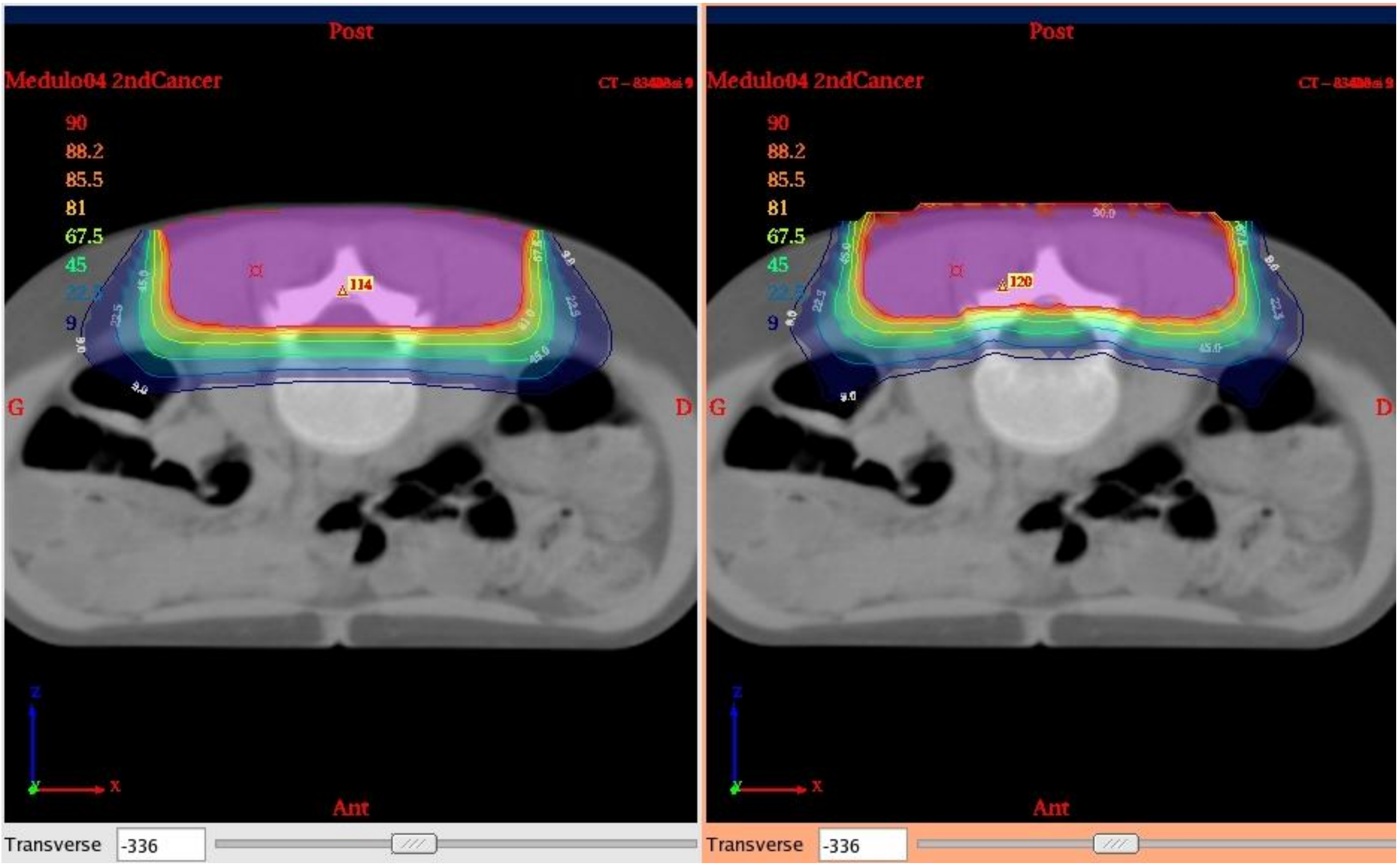


Figure 8.7
Universality of the superposition principle. (a) photon beams, (b) electron beams, and (c) brachytherapy sources. Each uses a fluence distribution (Φ) and a kernel (K) specific to the clinical application.





Dose Calculation

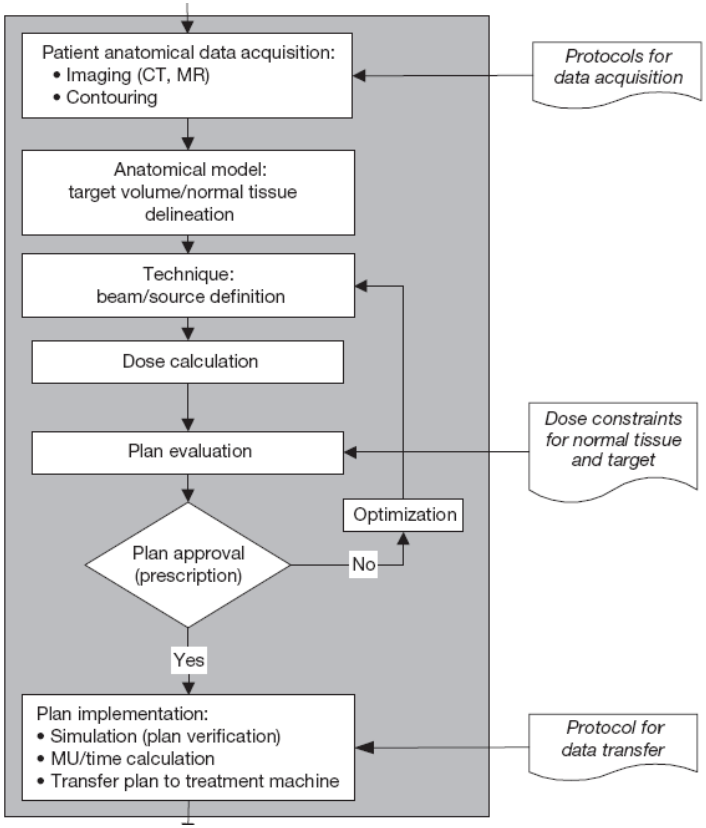


Transverse -336

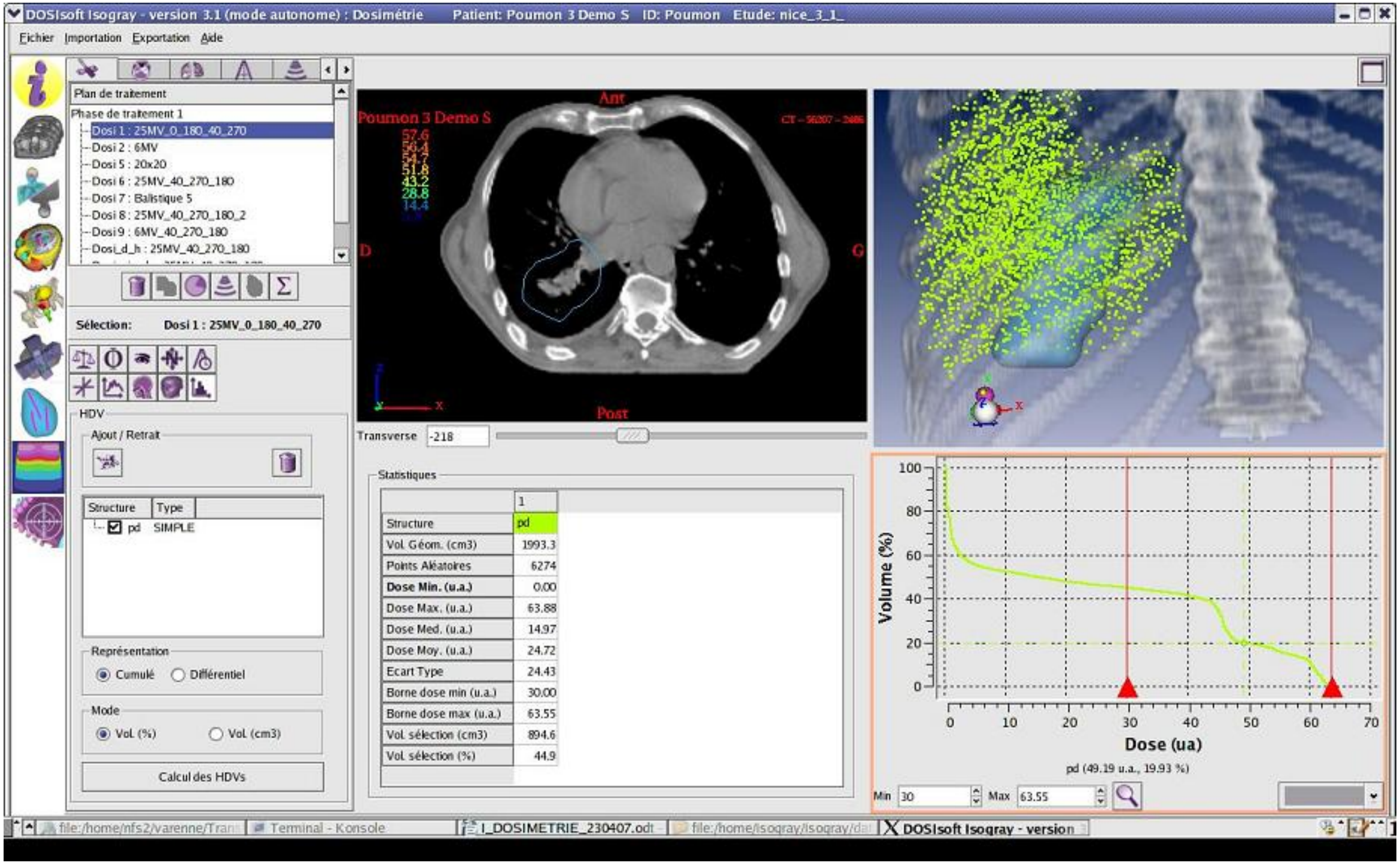
Transverse -336

Treatment Planing

- IAEA TRS 430



Constraints



Plan de traitement

Phase de traitement 1
- Dosi 1 : 25MV_0_180_40_270
- Dosi 2 : 6MV
- Dosi 5 : 20x20
- Dosi 6 : 25MV_40_270_180
- Dosi 7 : Balistique 5
- Dosi 8 : 25MV_40_270_180_2
- Dosi 9 : 6MV_40_270_180
- Dosi_d_h : 25MV_40_270_180

Sélection: Dosi 1 : 25MV_0_180_40_270

HDV

Ajout / Retrait

Structure	Type
☑ pd	SIMPLE

Représentation: ● Cumulé ○ Différentiel

Mode: ● Vol. (%) ○ Vol. (cm3)

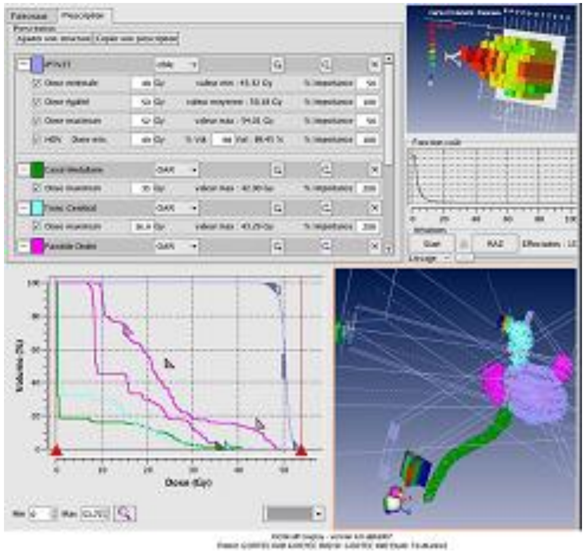
Transverse -218

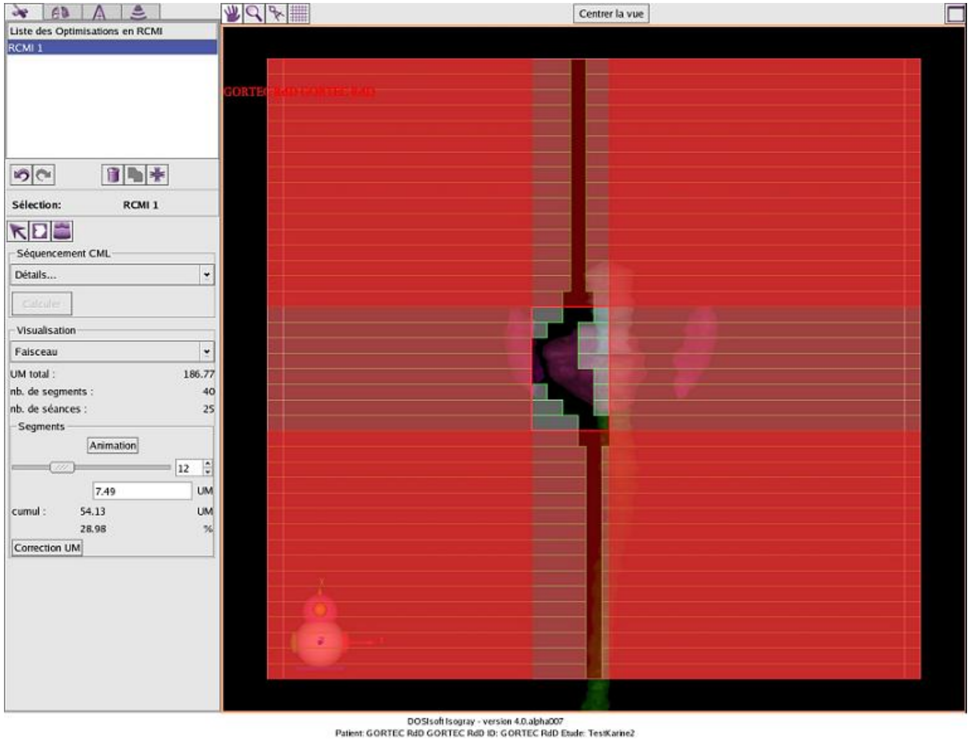
Statistiques

	1
Structure	pd
Vol. Géom. (cm3)	1993.3
Points Aléatoires	6274
Dose Min. (u.a.)	0.00
Dose Max. (u.a.)	63.88
Dose Med. (u.a.)	14.97
Dose Moy. (u.a.)	24.72
Ecart Type	24.43
Borne dose min (u.a.)	30.00
Borne dose max (u.a.)	63.55
Vol. sélection (cm3)	894.6
Vol. sélection (%)	44.9

Min 30 Max 63.55

MLC Sequencing





Liste des Optimisations en RCMI
RCMI 1

Sélection: RCMI 1

Séquencement CML
Détails...

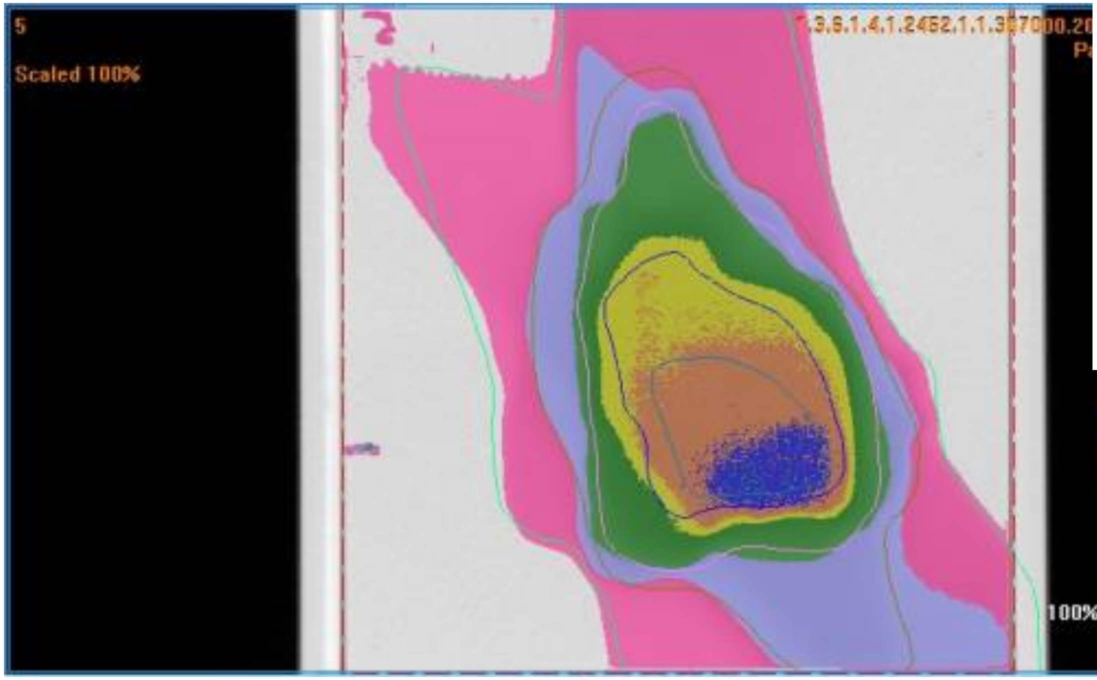
Visualisation
Faisceau

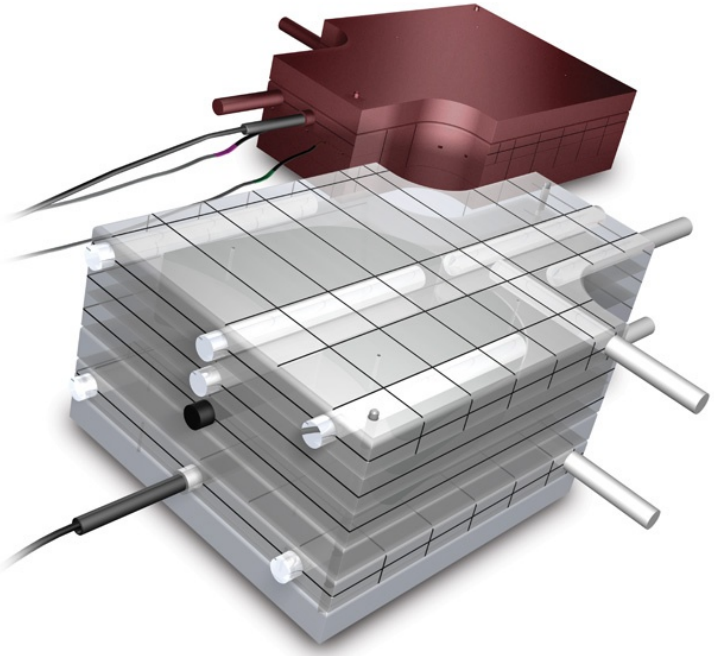
UM total : 186.77
nb. de segments : 40
nb. de séances : 25

Segments
12
7.49 UM
cumul : 54.13 UM
28.98 %

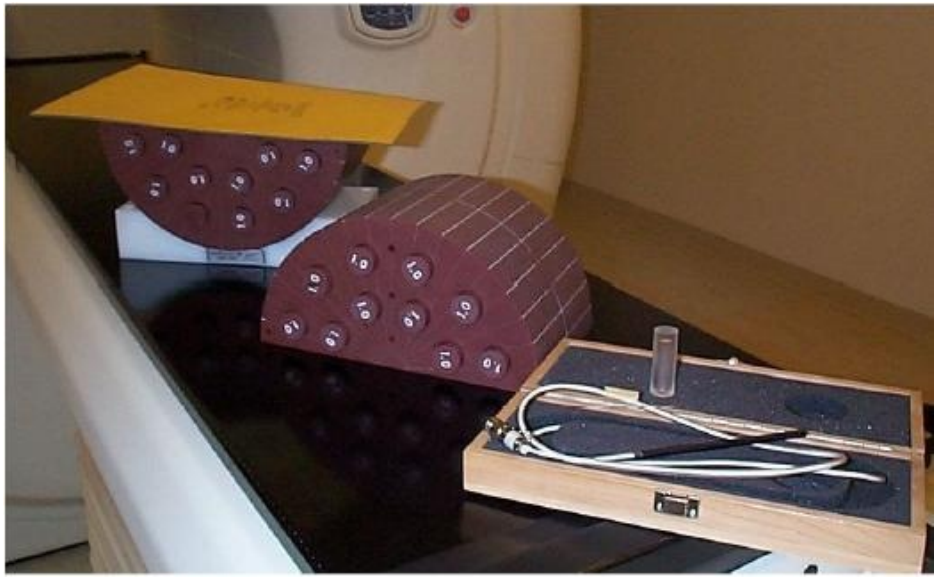
DOSIsoft Isogray - version 4.0.alpha007
Patient: GORTEC RdD GORTEC RdD ID: GORTEC RdD Etude: TestKarine2

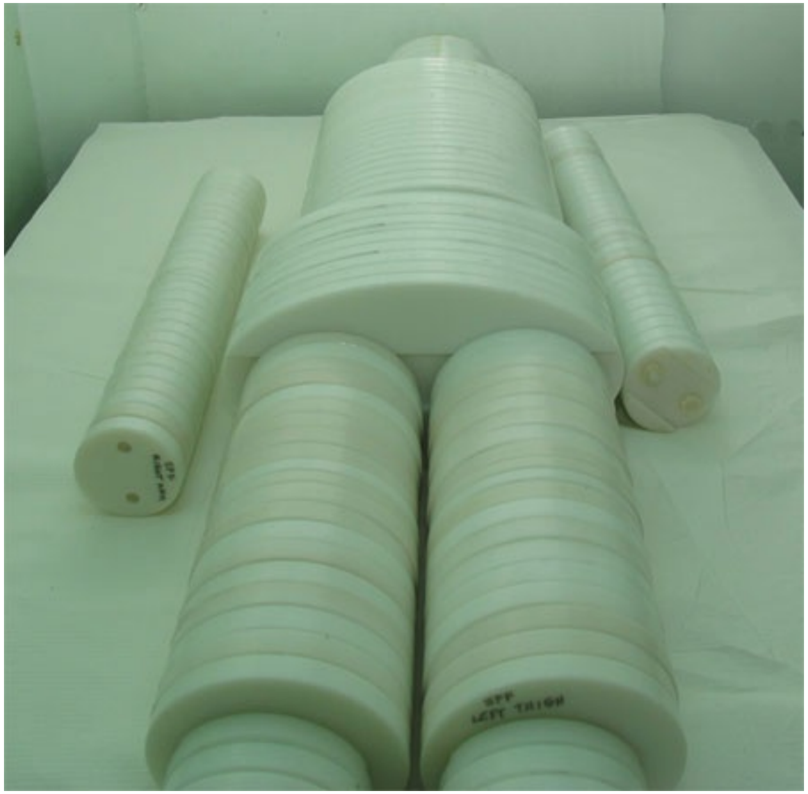
Dose verification

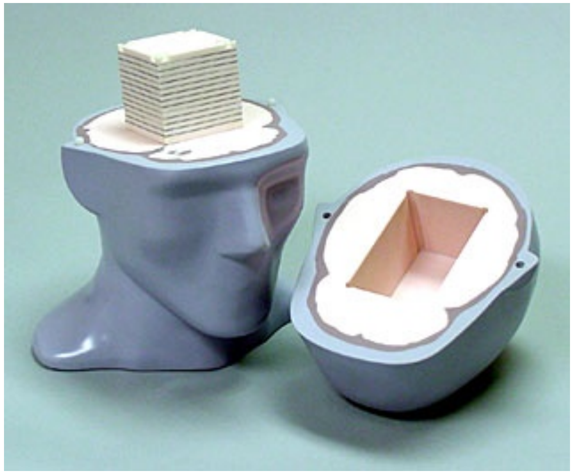




Dose verification





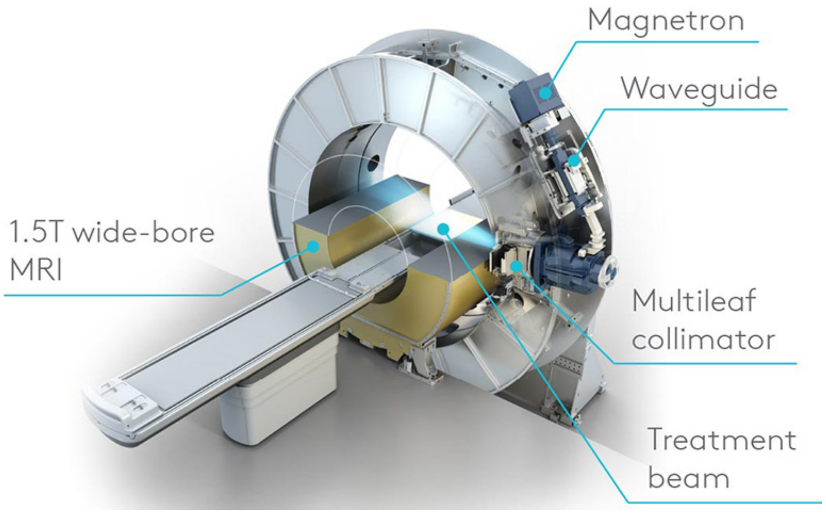


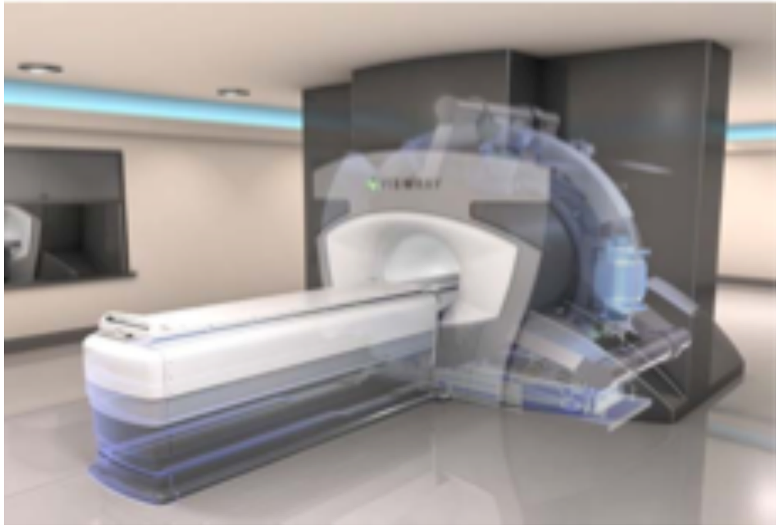
Dose verification and positioning

In vivo Dosimetry

Innovation in clinical medical imaging for treatment planning and delivery in precision oncology: MRI-Linac

Purpose:

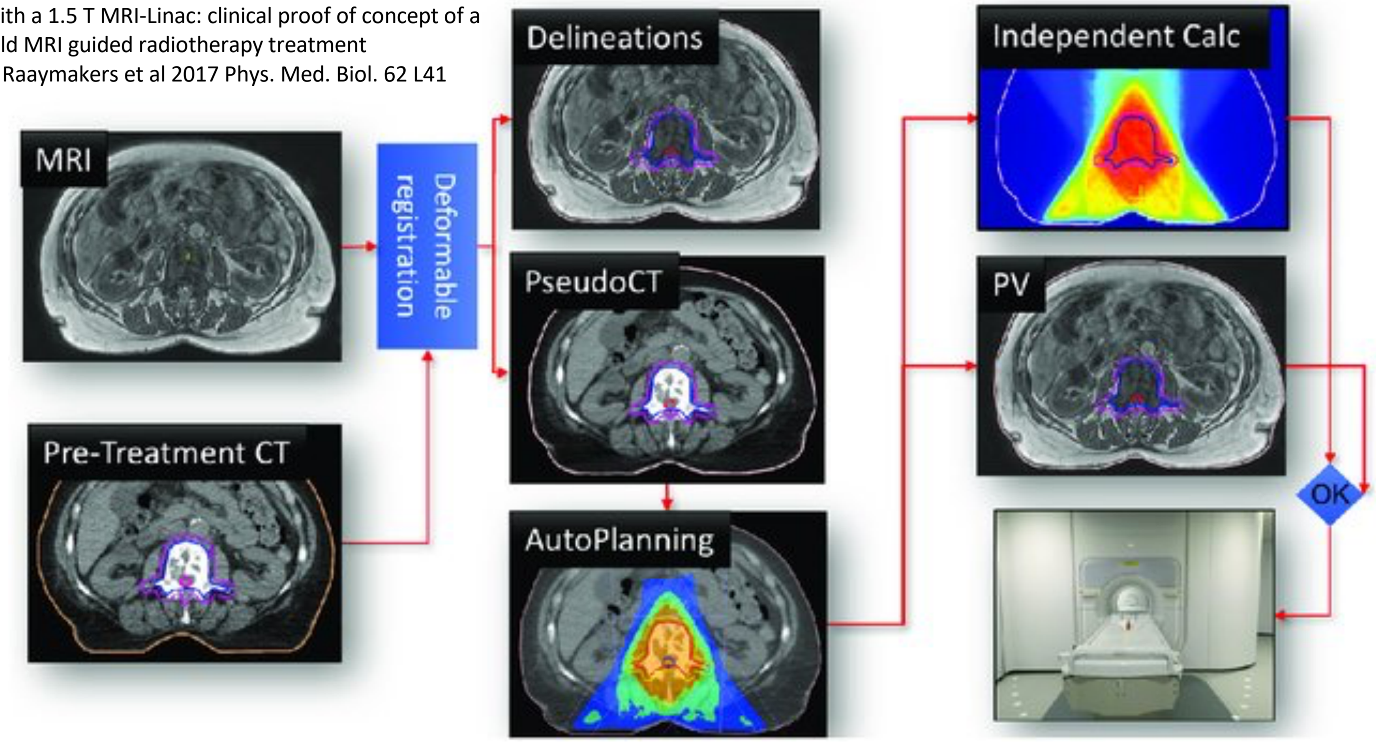




Innovation in clinical medical imaging for treatment planning and delivery in precision oncology: MRI-Linac

MRI Planning:

First patients treated with a 1.5 T MRI-Linac: clinical proof of concept of a high-precision, high- field MRI guided radiotherapy treatment
To cite this article: B W Raaymakers et al 2017 Phys. Med. Biol. 62 L41



Innovation in clinical medical imaging for treatment planning and delivery in precision oncology: MRI-Linac

<u>Physical Challenges:</u>

Electrons beams in magnetic fields

Measurement tools

Dose calculation

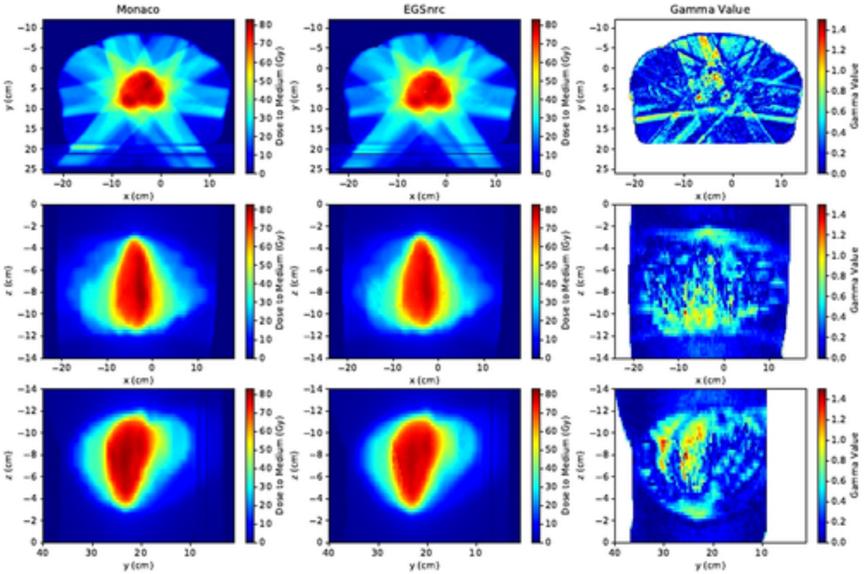
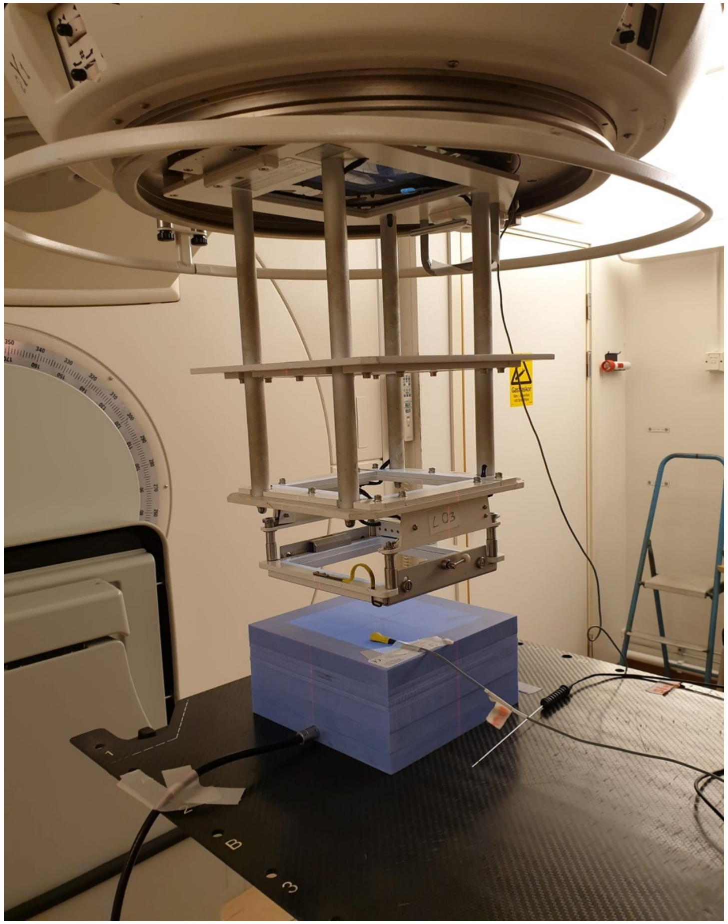
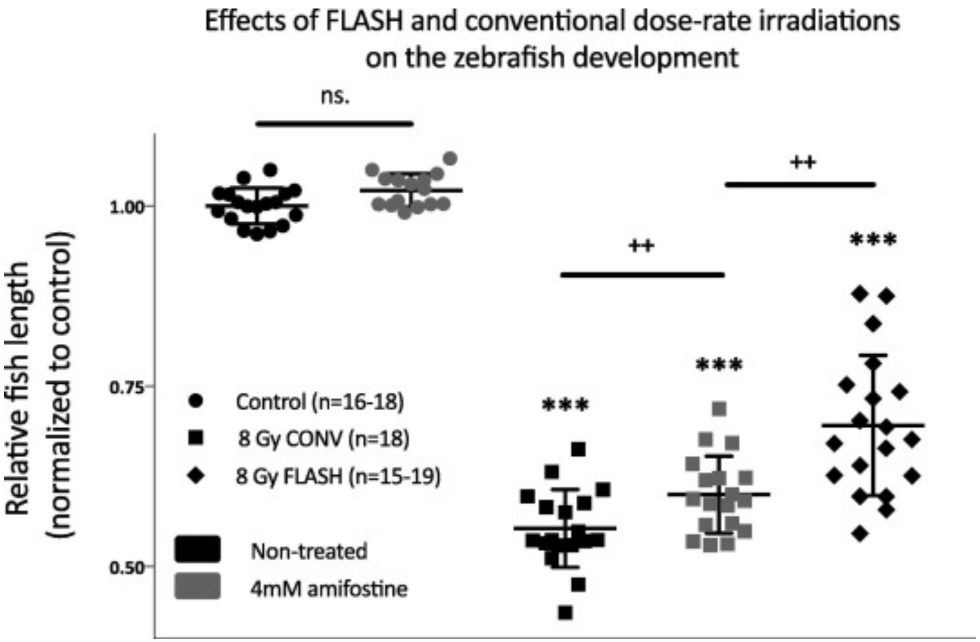


Figure 1: PTW prototype MR-compatible MP1 waterphantom at the MRI-linac with (picture insert) PTW prototype holder, with PTW30013 chamber and CC13 monitor chamber.

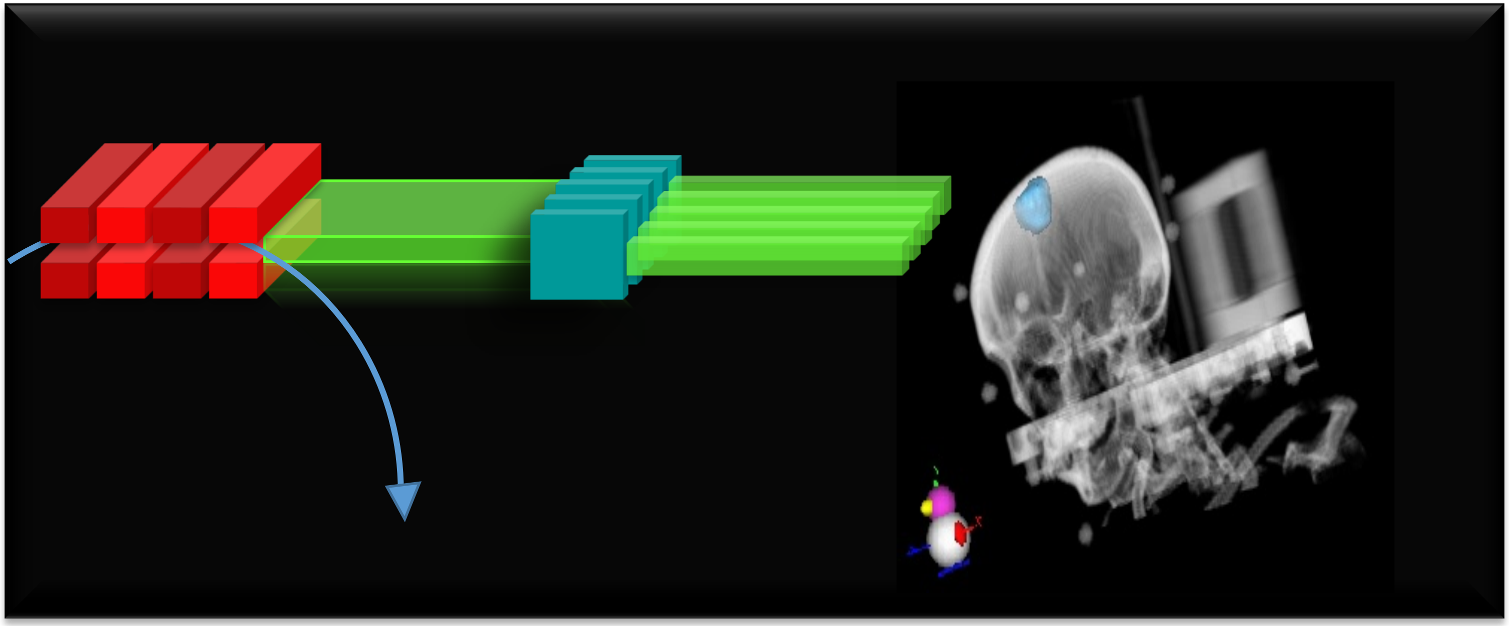
Innovation in Radiotherapy: Flash radiotherapy



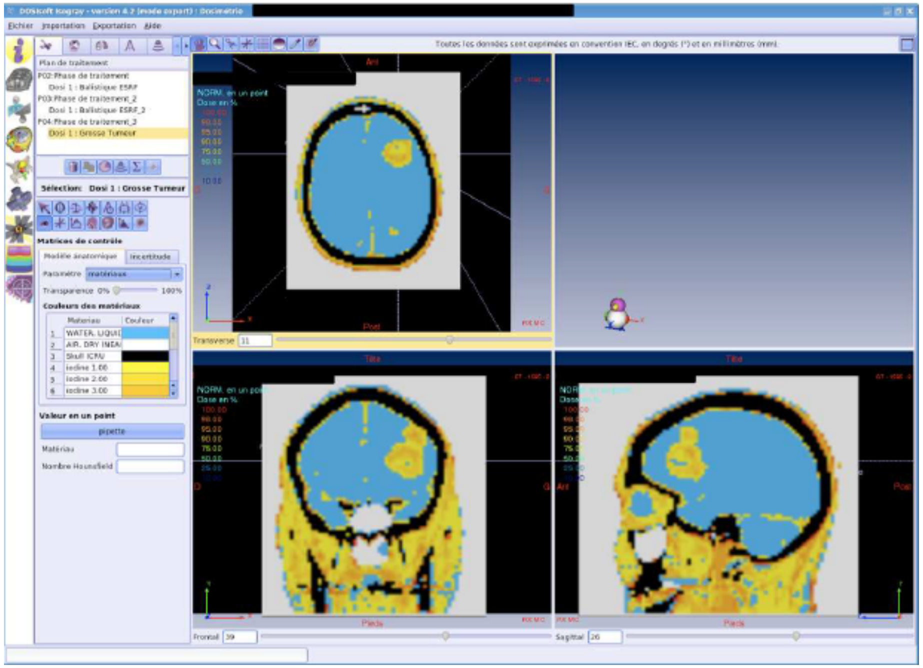


https://physicsworld.com/a/clinical-linear-accelerator-delivers-flash-radiotherapy/

Innovation in Radiotherapy: microbeam radiotherapy



Innovation in Radiotherapy: combined radiotherapy



DOSIsoft Isogray - version 4.2 (mode expert) : Dosimétrie [redacted]

Plan de traitement
P02:Phase de traitement
Dosi 1 : Balistique ESRF
P03:Phase de traitement_2
Dosi 1 : Balistique ESRF_2
P04:Phase de traitement_3
Dosi 1 : Grosse Tumeur

Sélection: Dosi 1 : Grosse Tumeur

Matrices de contrôle

Paramètre: matériaux

Transparence 0% 100%

Couleurs des matériaux

	Materiau	Couleur
1	WATER, LIQUID	
2	AIR, DRY (NEA	
3	Skull ICRU	
4	iodine 1.00	
5	iodine 2.00	
6	iodine 3.00	

Valeur en un point

Matériau

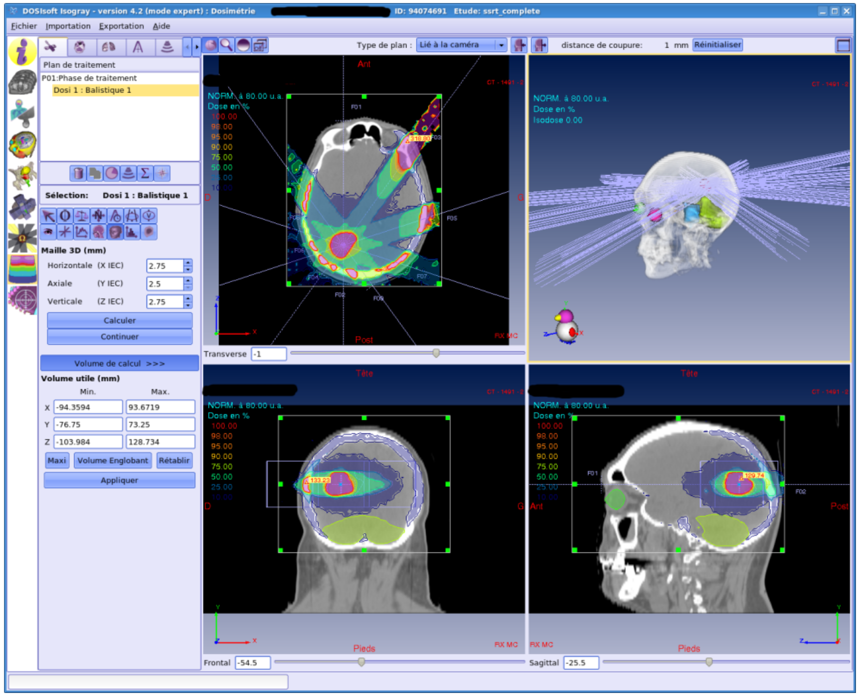
Nombre Hounsfield

Toutes les données sont exprimées en convention IEC, en degrés (°) et en millimètres (mm)

Transverse 11

Frontal 39

Sagittal 26



DOSIsoft Isogray - version 4.2 (mode expert) : Dosimétrie [redacted] ID: 94074691 Etude: ssrt_complete

Type de plan : Lié à la caméra

distance de coupure: 1 mm

Plan de traitement
P01:Phase de traitement
Dosi 1 : Balistique 1

Sélection: Dosi 1 : Balistique 1

Maille 3D (mm)

Horizontale (X IEC) 2.75
Axiale (Y IEC) 2.5
Verticale (Z IEC) 2.75

Volume utile (mm)

	Min.	Max.
X	-94.3594	93.6719
Y	-76.75	73.25
Z	-103.984	128.734

Transverse -1

Frontal -54.5

Sagittal -25.5

NORM. à 80.00 u.a.
Dose en %
Isodose 0.00

[redacted]

[redacted]

[redacted]

Conclusion

Innovation in radiation therapy

Strong needs from diagnostic Imaging for treatment accuracy

Innovation in radiotherapy : Flash Radiotherapy ; micro and minibeams ; combined therapies

Opens new possibilities for personnalised disease management.

Innovations in instrumentation (source and detectors)

Articficial intelligence can help but needs to be carefully checked as bias can be easily introduced

Beam Monitoring for Flash RT (Y Arnoud)
Challenges in in vivo dosimetry and mdern RT QA (P Pittet)
Combined RT (E Porcel)

Thanks a lot for your attention