THE TRANSITION FROM 2D TO 3D AND TO IMRT

-

RATIONALE AND CRITICAL ELEMENTS

ICTP SChool On MEdical PHysics For RAdiation THerapy

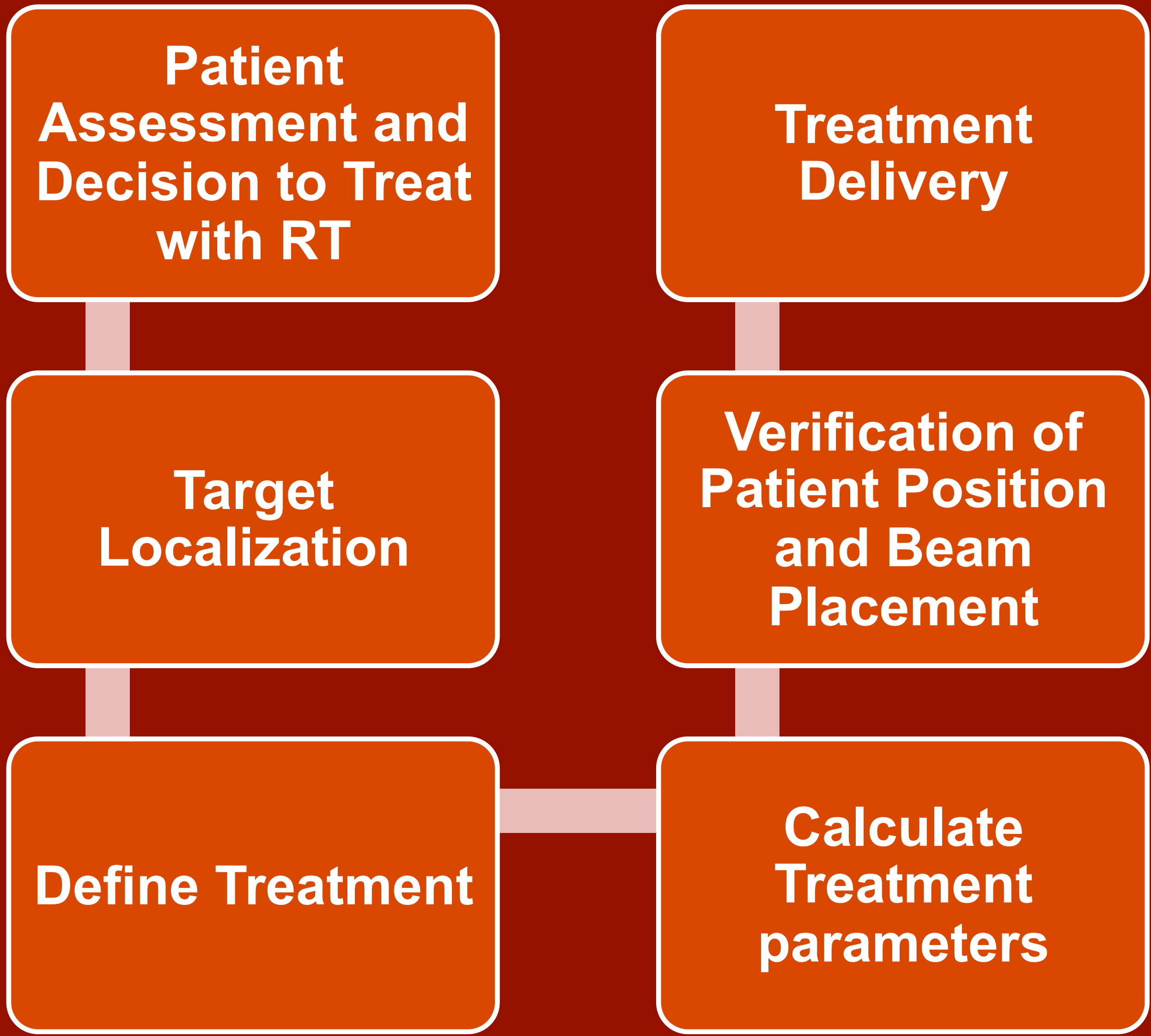
DOsimetry And TReatment PLanning For BAsic And ADvanced APplications

13 - 24 April 2015

Miramare, Trieste, Italy

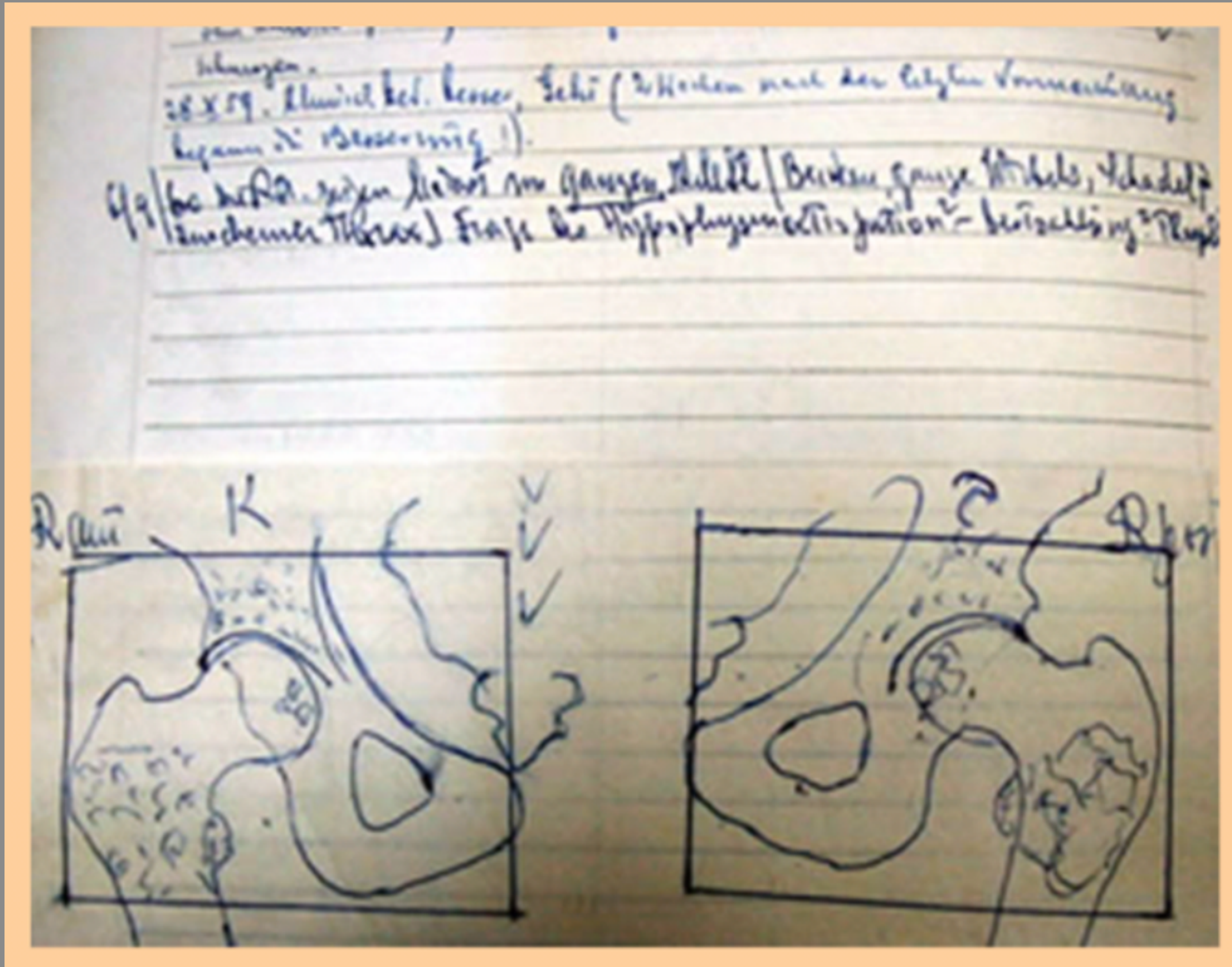
Yakov Pipman, D.Sc.

The Radiotherapy Process
…in the beginning…



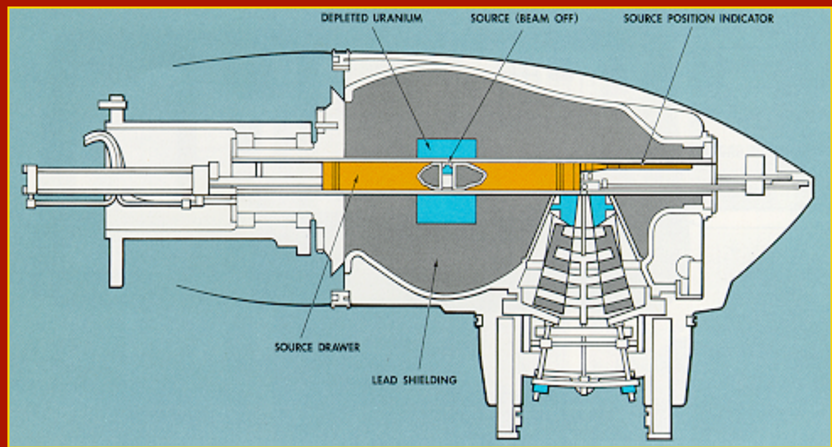
Radiotherapy 1-D

KV therapy for breast



Radiation therapy simulation… a note and a diagram in the chart

Radiotherapy 1-D and 2-D



Typical dosimetric calculation
=
Computation of Beam- ON time for a Co-60 treatment

$$BOT_i = PD_i/100 \times T_{100,d,FS}$$

April 1, 1969

Co-60 TREATMENT TIME and "SKIN" DOSAGE CHART
at
The Long Island Jewish Hospital
270-05 76th Avenue
New Hyde Park, N.Y. 11040

80 CM. S.S.D.

Time in Minutes to give 100 rads tumor dose at depth and Max.r "skin" dose for 100 Rads at depth
for period April 1, 1969 through June 30, 1969.

Output 104.8 r/Min. at 80 Cm. S.S.D.

	AREA IN SQ. CM.									
	25		50		100		200		400	
Depth in CM.	Max. Rads	Min.	Max. Rads	Min.	Max. Rads	Min.	Max. Rads	Min.	Max. Rads	Min.
.5	100	.97	100	.96	100	.96	100	.94	100	.94
1.0	103	1.00	102	.98	102	.97	102	.96	102	.95
2.0	110	1.06	108	1.00	107	1.02	107	1.00	106	.99
3.0	117	1.13	115	1.10	113	1.08	112	1.05	111	1.04
4.0	125	1.22	122	1.17	120	1.14	118	1.11	117	1.10
5.0	134	1.30	130	1.25	127	1.21	125	1.18	124	1.16
6.0	145	1.40	139	1.35	136	1.30	133	1.25	131	1.23
7.0	156	1.51	150	1.44	145	1.39	141	1.33	139	1.30
8.0	169	1.63	161	1.55	156	1.49	151	1.42	147	1.38
9.0	183	1.78	174	1.68	167	1.59	161	1.52	156	1.46
10.0	198	1.92	188	1.82	180	1.72	172	1.62	165	1.55
11.0	215	2.08	202	1.90	193	1.84	184	1.74	176	1.65
12.0	233	2.25	218	2.11	207	1.98	197	1.84	188	1.76
13.0	252	2.44	236	2.29	223	2.12	210	1.98	200	1.87
14.0	273	2.64	254	2.47	239	2.28	225	2.10	212	1.99
15.0	296	2.86	275	2.66	257	2.45	239	2.25	226	2.12
16.0	319	3.08	298	2.87	276	2.63	256	2.40	240	2.25
17.0	345	3.33	320	3.08	296	2.83	274	2.57	257	2.40
18.0	371	3.59	345	3.33	318	3.03	293	2.74	272	2.55
19.0	402	3.90	373	3.66	343	3.27	313	2.93	289	2.71
20.0	436	4.23	402	3.88	368	3.51	334	3.12	306	2.87

Lillian E. Jacobson

Radiotherapy 1-D +

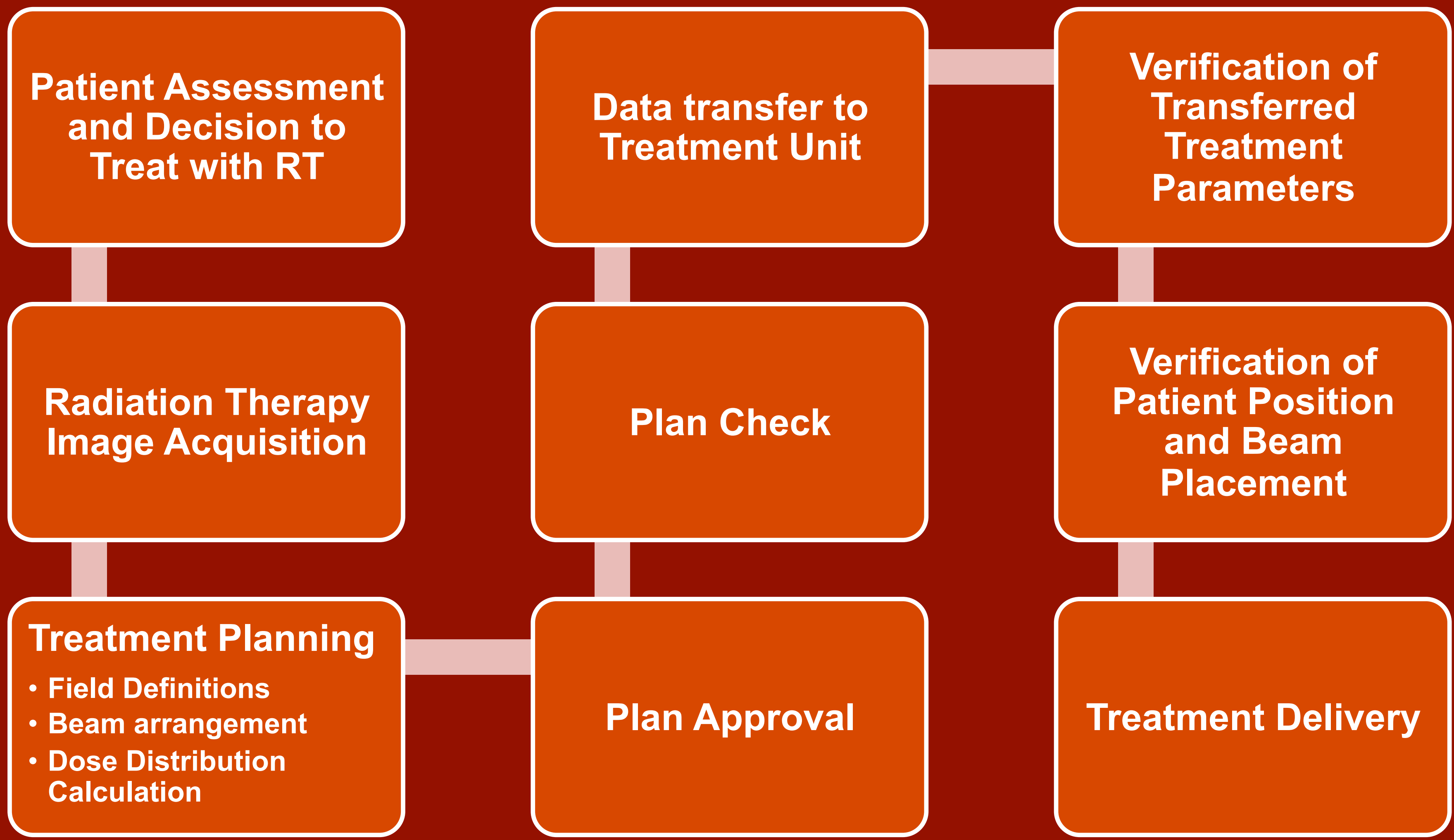
Planning

- Simple beam arrangements
- Prescription to a point

Calculations

- Standard condition tables (PDD and BOT)
- Corrections for SSD and field size
- Blocked field corrections = > Equivalent Square
- Point of interest calculations

The Radiotherapy Process – in 2-D



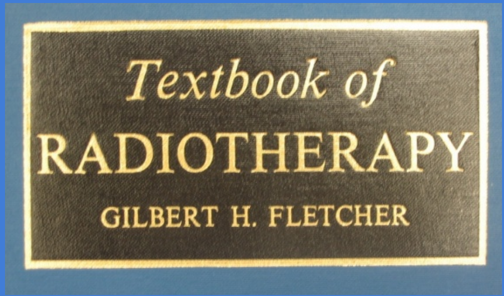


FIG. 11–37. A. Projection of vaginal disease onto the surface of the body. The cervical localizer, seen on the left side of the tray, consists of a plastic rod with a lead plug at its tip and a fluid level to assure its horizontal position. The plastic rod is introduced into the vagina, guided by the examining finger until contact is made with the lowest palpable vaginal disease. As the rod is then attached to the stand at exactly this level, the vertical pointer, which is in line with the tip of the rod, will project the location of the lowest palpable vaginal disease onto the surface of the body. The lower margin of the portal is drawn 2 cm below that projection. A verification film is taken immediately and adjustments are made until the field includes approximately 1 cm of tissue below the lead plug, which means that there will be at least 2 cm of normal vaginal tissues in the irradiated field.

Also seen on the tray are the compression cone for the 22-MeV betatron with the lead blocks to shield respectively 2 and 4 cm of tissue at 10-cm depth. The end of compression cone for the ^{60}Co unit is made of copper mesh to minimize secondary electron emission. The lead blocks can slide sideways to fit the isodose curves of the individual radium system.

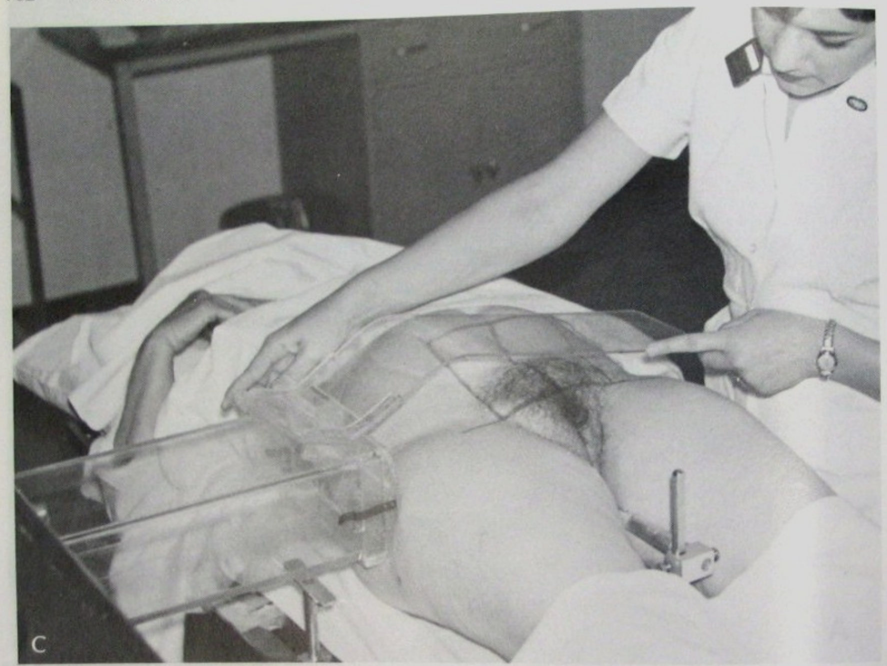
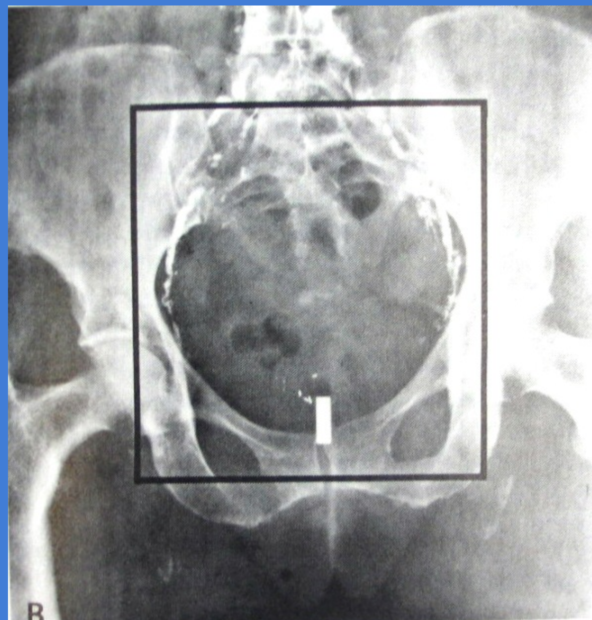
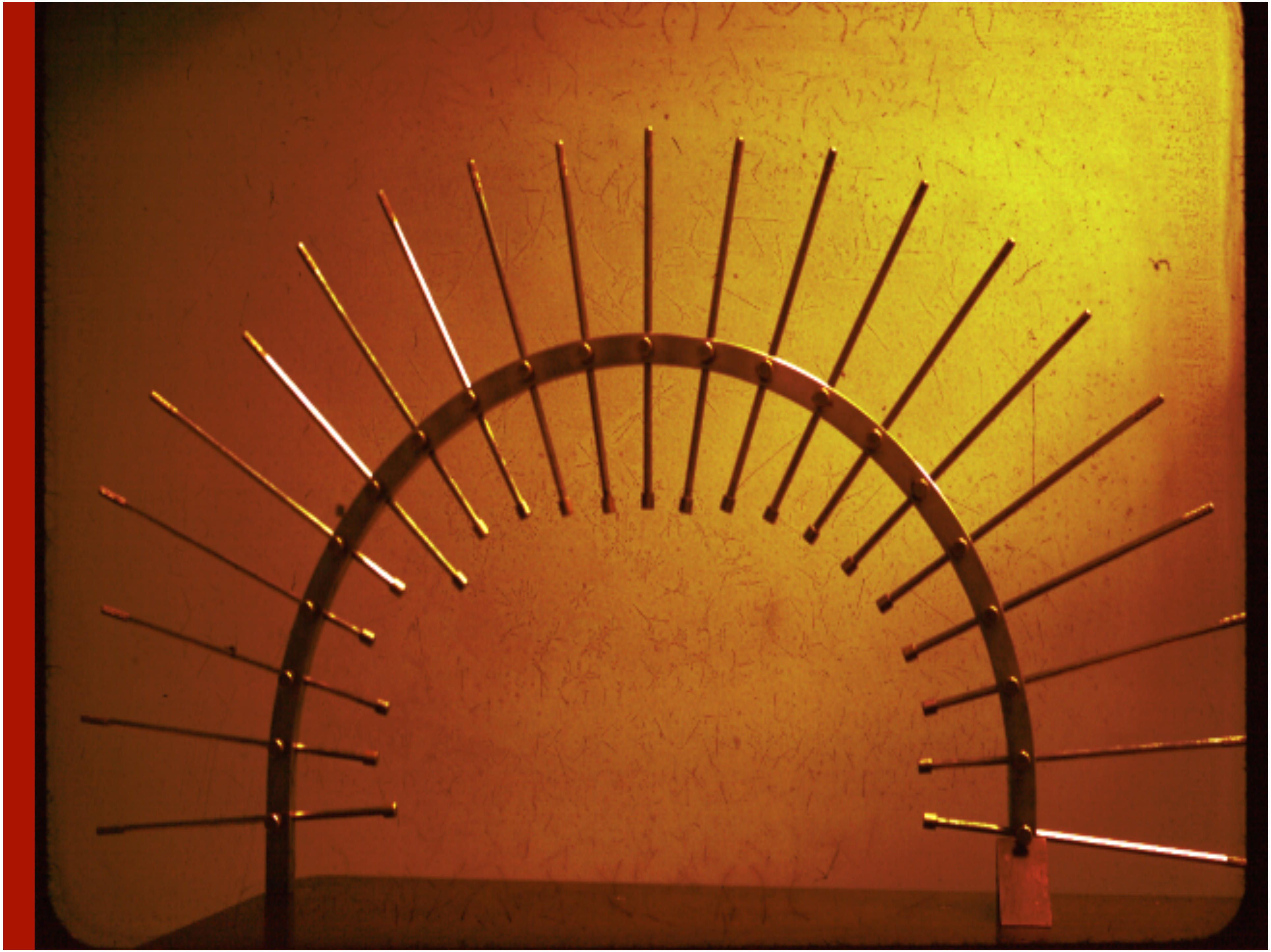
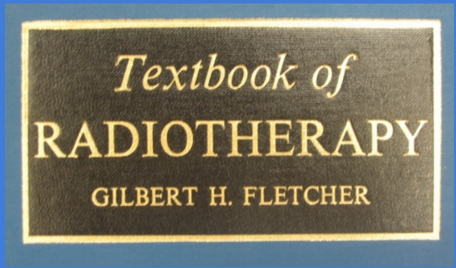


FIG. 11–37. C. The same procedure used for the localization of the lowest palpable disease is also used to determine the center of the lateral portals. A Lucite bridge used for daily treatment duplication is also shown.







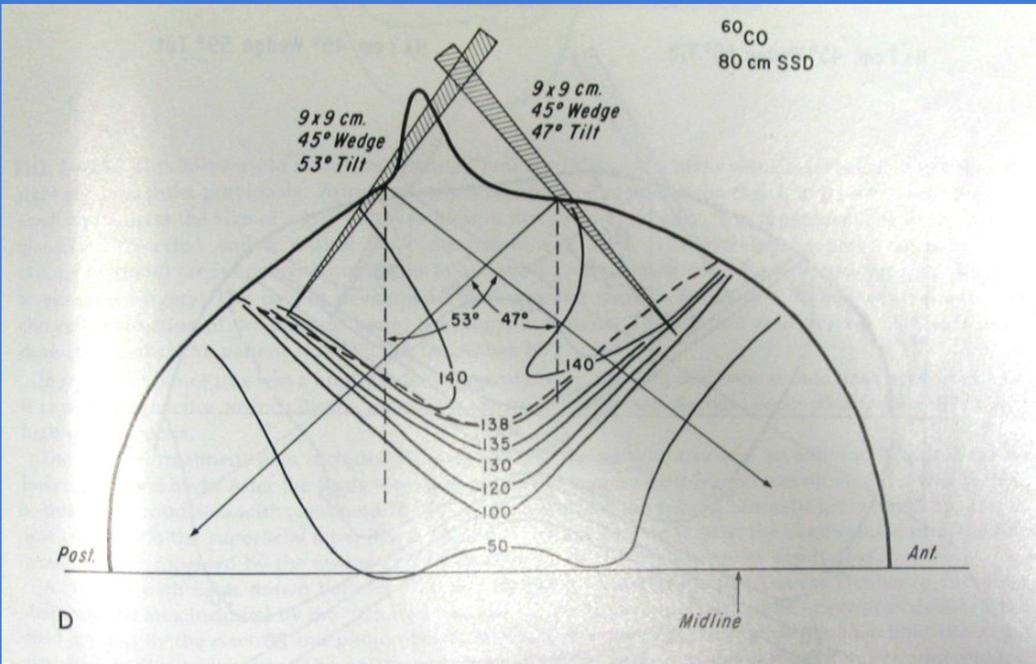


FIG. 3-124 (cont'd). C. Treatment for the ipsilateral neck. The anterior ^{60}Co field extends from the lower border of the parotid field.

D. Isodose distribution of ^{60}Co wedges. The tumor dose is taken at the 138% curve. The tissue volume included in the high dose range is not excessive.

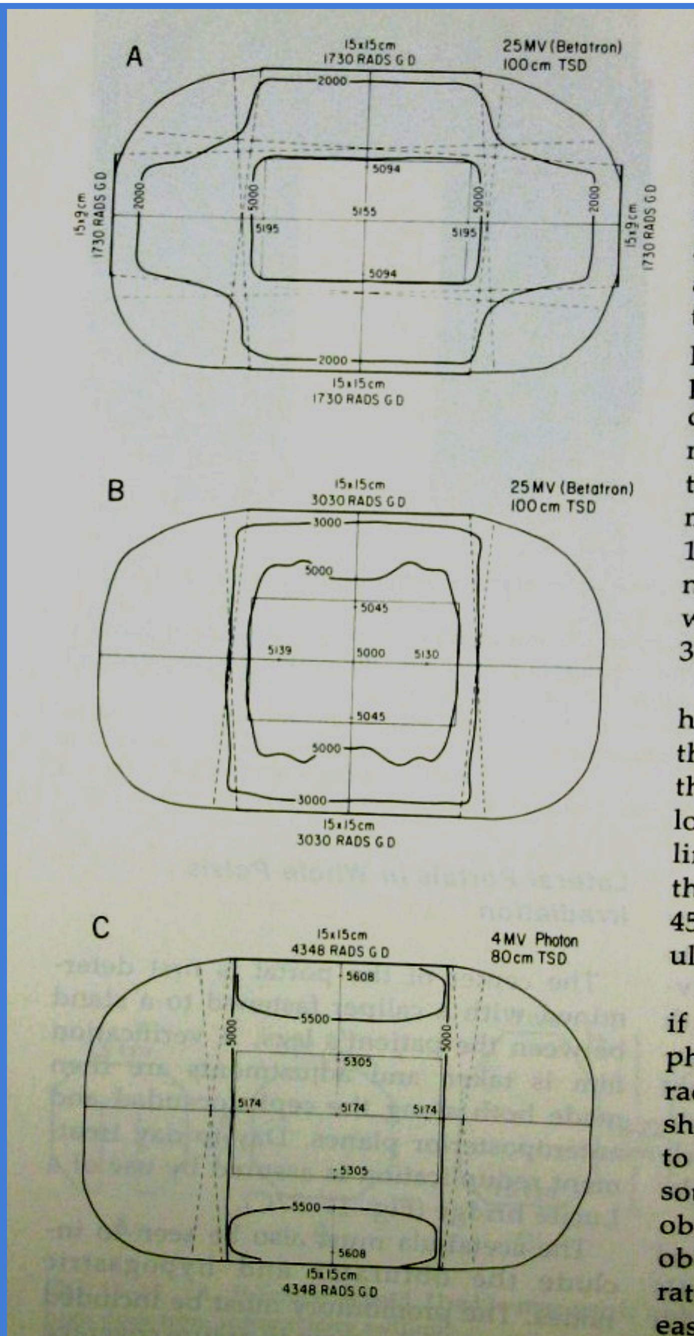
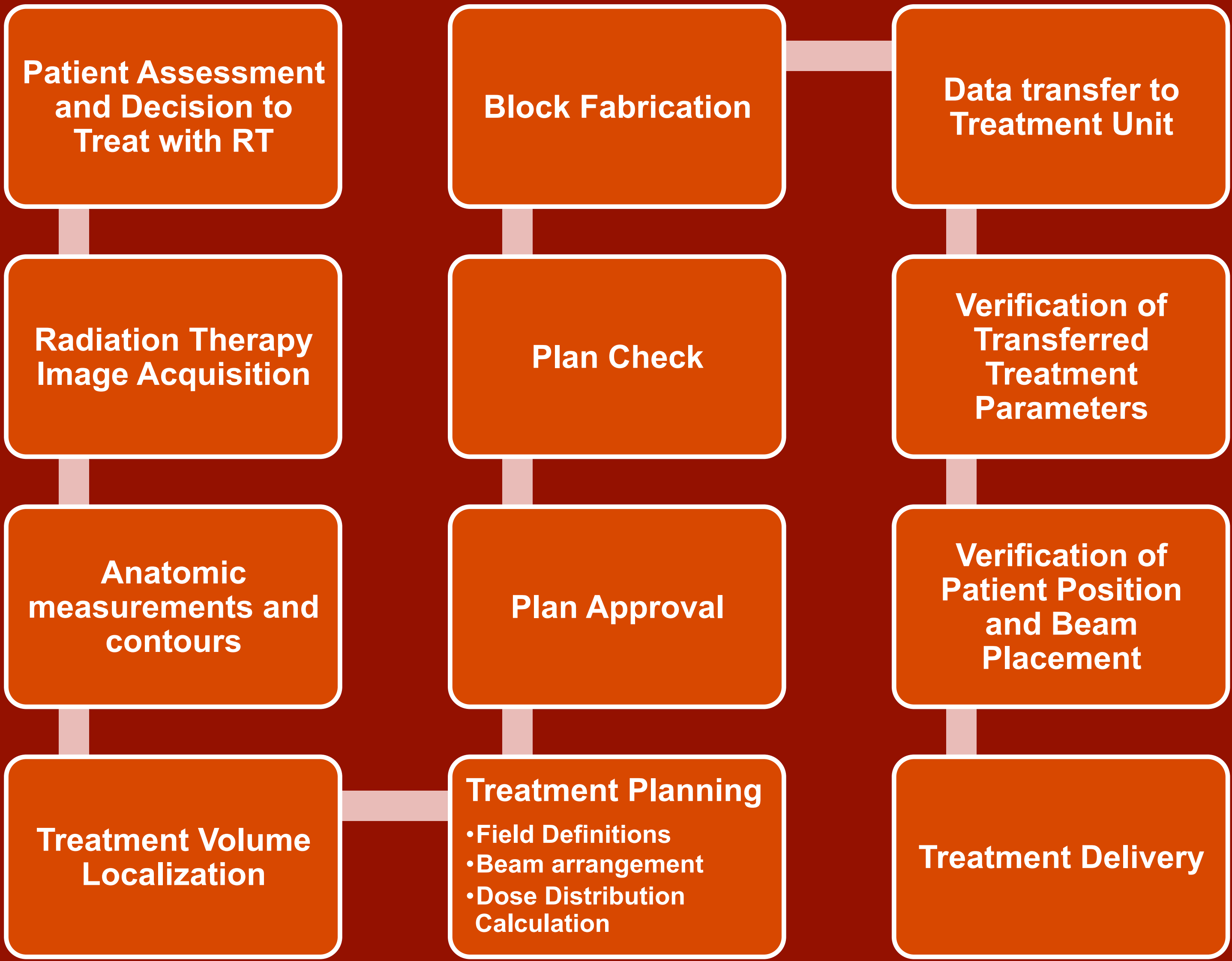


FIG. 11-36. A. Box pattern, 15 × 15 × 9 cm (approximately 2000 cm³) with 25 MeV. B. Parallel opposing 15 × 15 × 22 (AP diameter) cm (approxi-

In "2D" radiotherapy

- The target is defined in relation to anatomic landmarks – heavy reliance on bony anatomy
- The extent of fields is driven by knowledge of anatomy and by disease pathways
- Extensive use of physical examination, palpation and physical measurements of the patient.
- Dose distribution information limited to single plane of major significance in order to cover the target. Energy selection is very important.
- Protection of critical organs set by experience

The Radiotherapy Process in 2D with Radiographic Simulation



Radiotherapy 2-D with R/F simulation

Targeting

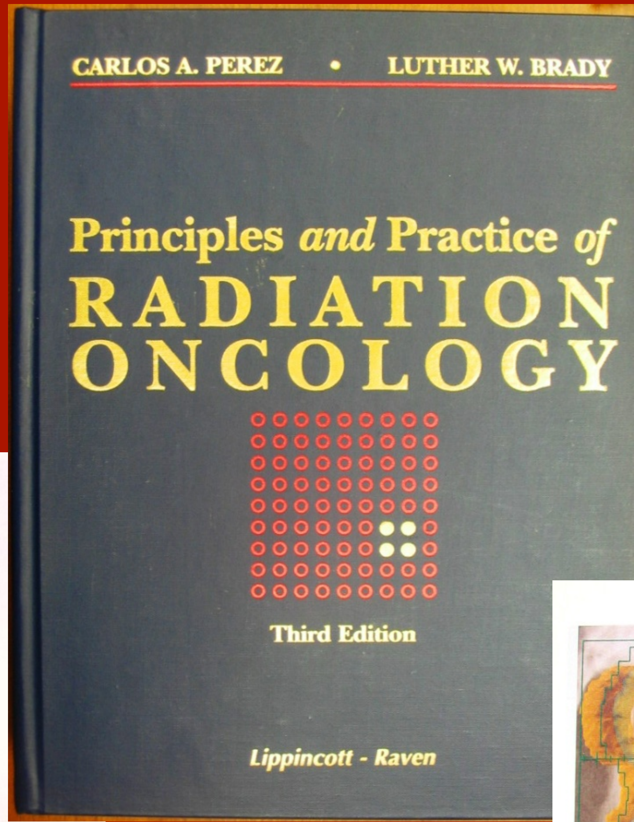
- Palpation
- Use of planar images
- Reference to Anatomical landmarks
- No Information on actual volumes
- Beam's eye-view of simple fields
- Choice of field size - usually by disease site rules

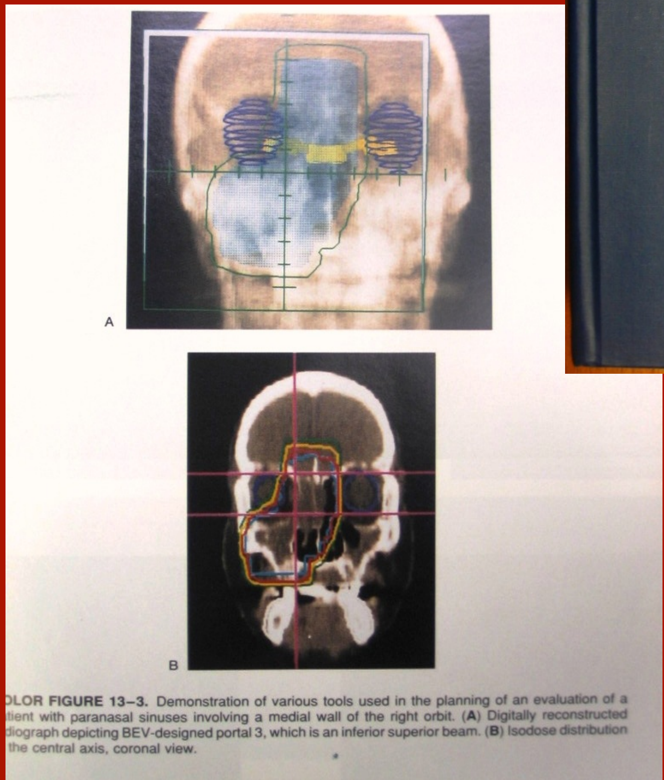
Blocking

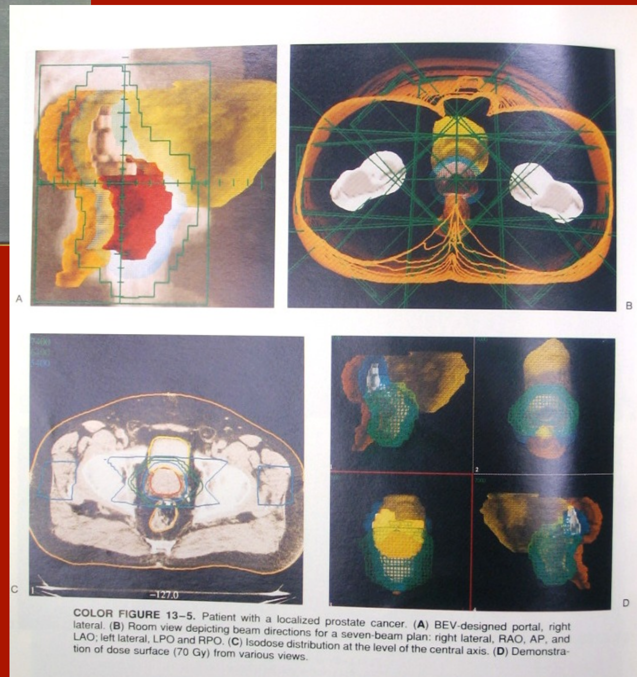
- Protection of critical structures rather than conformality.
- Based on clinical experience to avoid complications
- Treatment fields <u>not</u> conformal to <u>target</u>

- We never treated our patients with 2D RT…
- Our information was 2D
  - Radiographs collapsed all the anatomy unto a 2D radiographic film
  - We could only represent one plane at a time
- Our patients: All of them tri-dimensional !

The 90's – the era of 3D







Perez and Brady - Principles and Practice of Radiation Oncology-1998, and others…

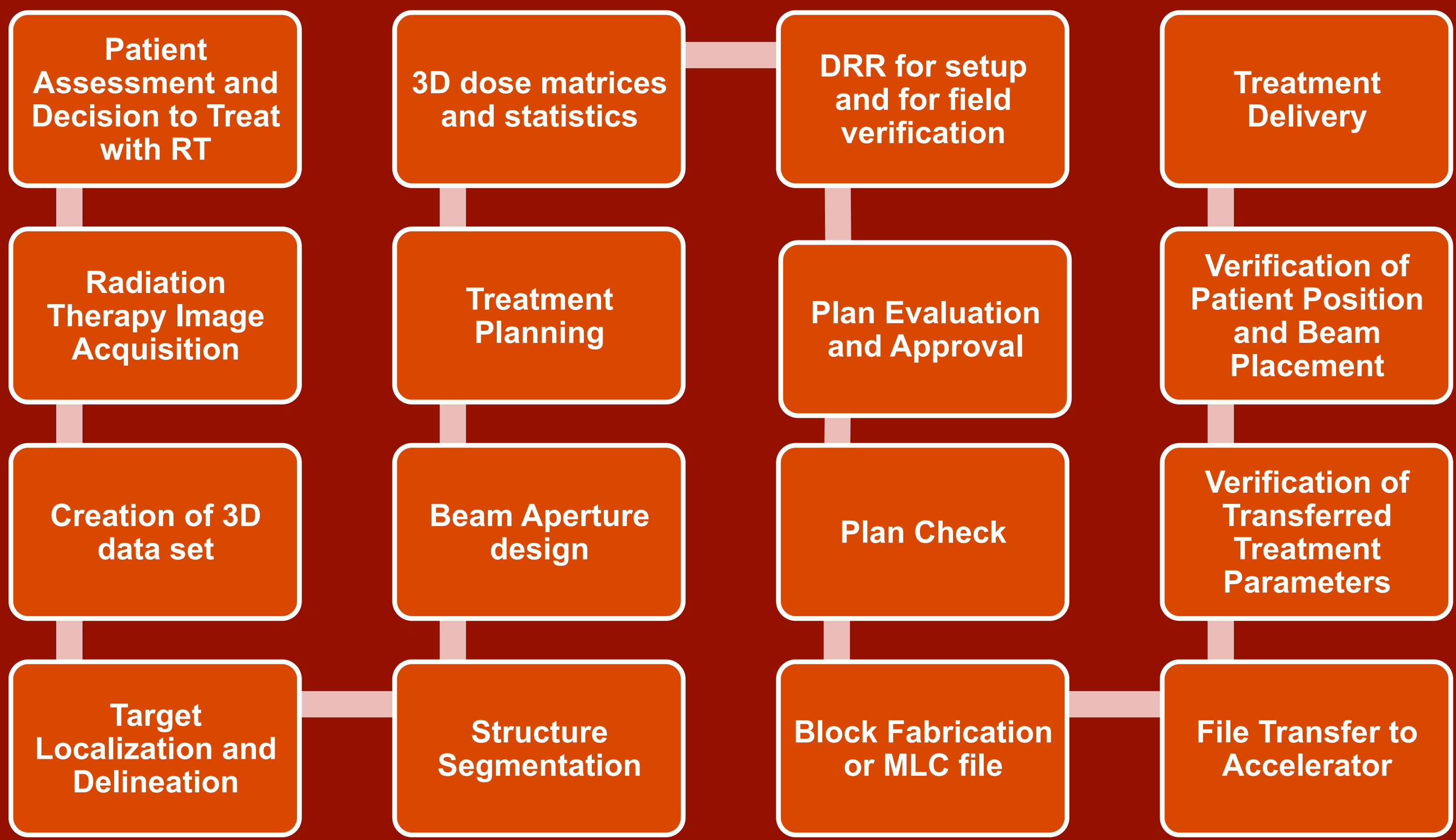
3-D Conformal Radiotherapy (3-D CRT)

- “The design and delivery of radiotherapy treatment plans based on 3-D image data with treatment fields individually shaped to treat only the target

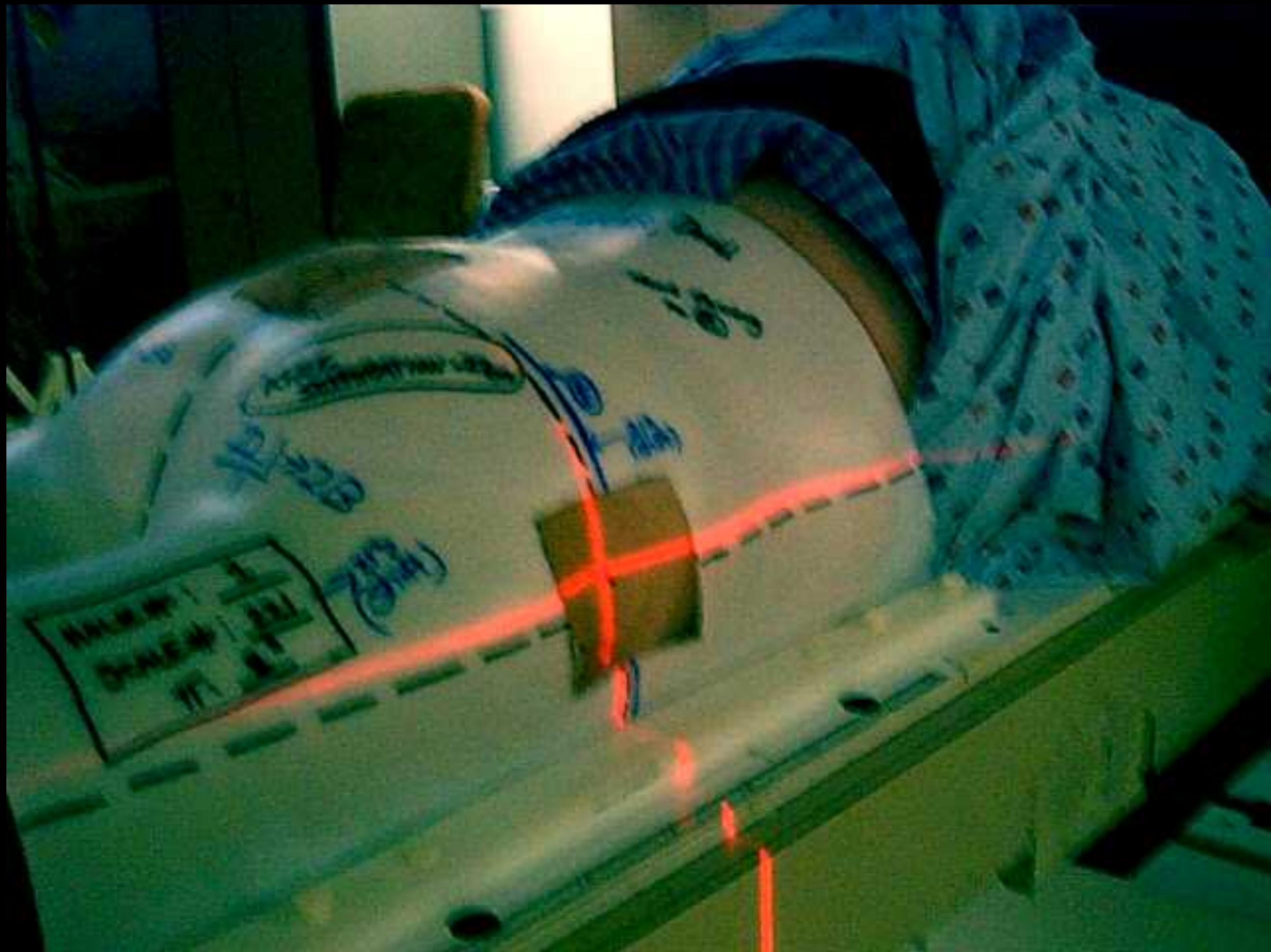
Tools in 3-D planning systems

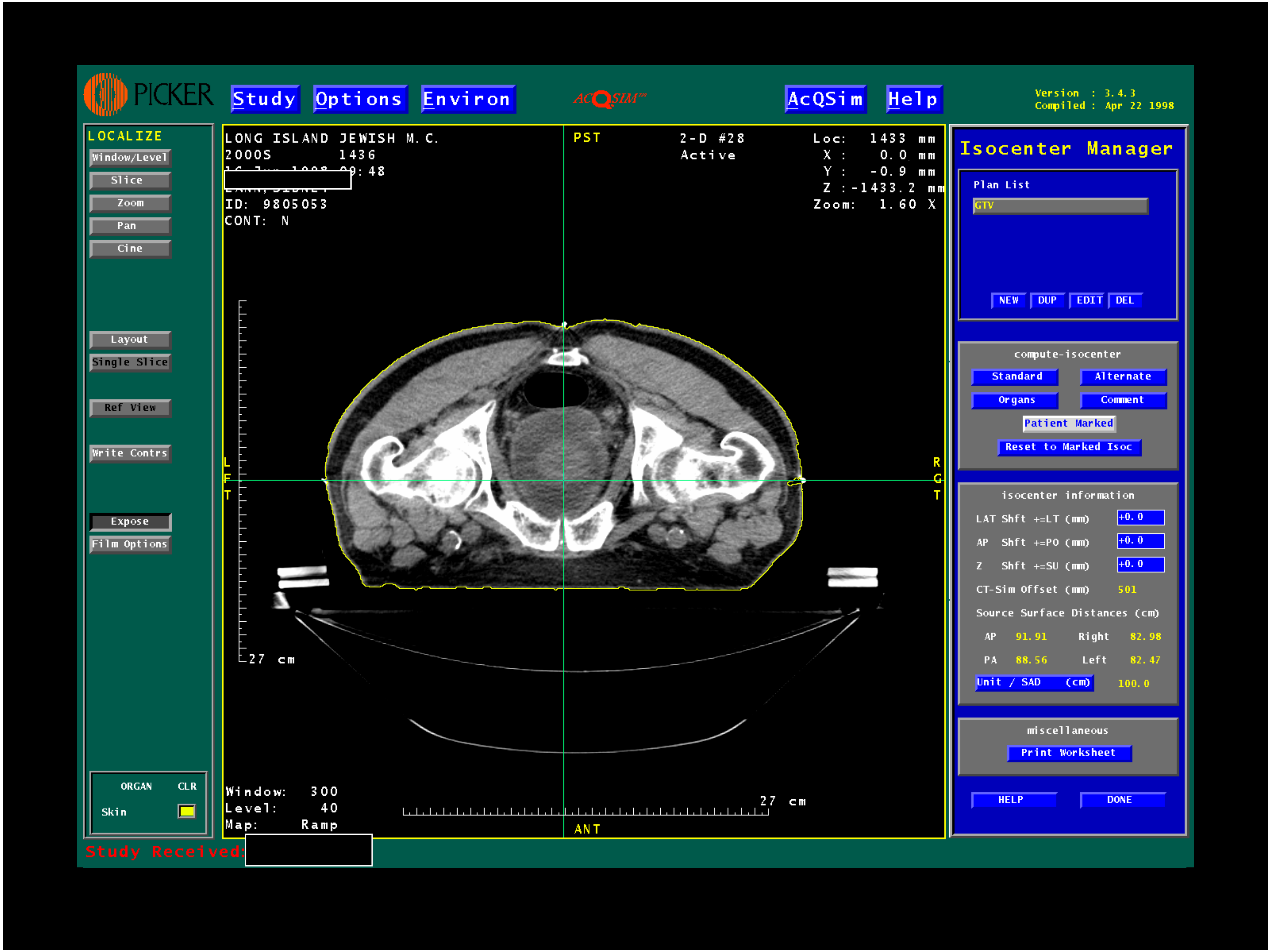
- design beam orientations
- display beam's-eye-views (BEVs)
- design of beam weights
- calculate dose distribution throughout patient volume
- computation of 3-D dose to the PTV and PRV
- evaluation of the dose plan using dose volume histograms (DVH)
- evaluation of the biological effect of the plan using tumor control probability (TCP) and normal tissue complication probability (NTCP)

The Radiotherapy Process – 3D-CRT



Immobilization Increasingly Important in 3D-CRT

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Study
Options
Environ
AcQSim
Help
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Zoom
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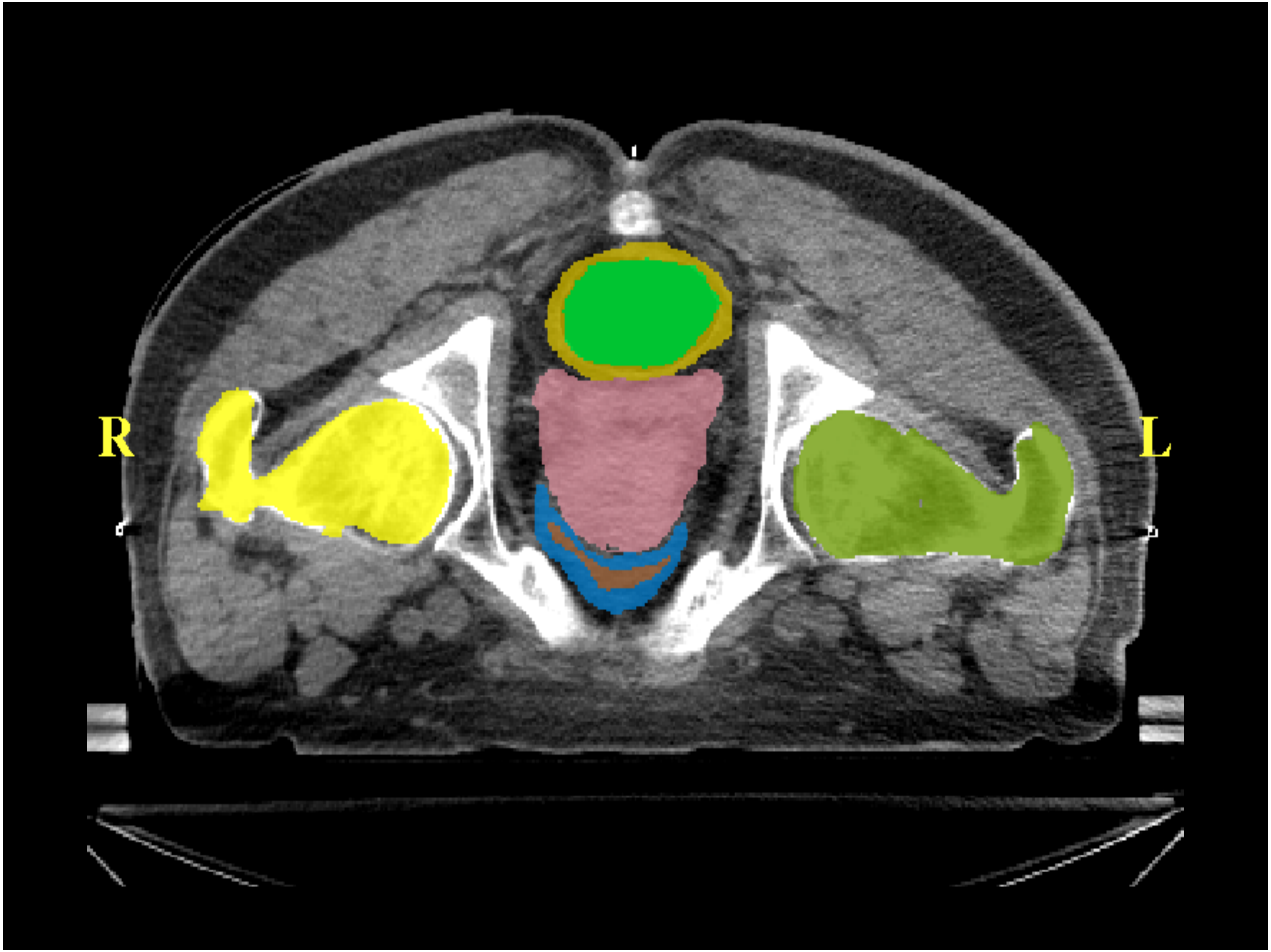
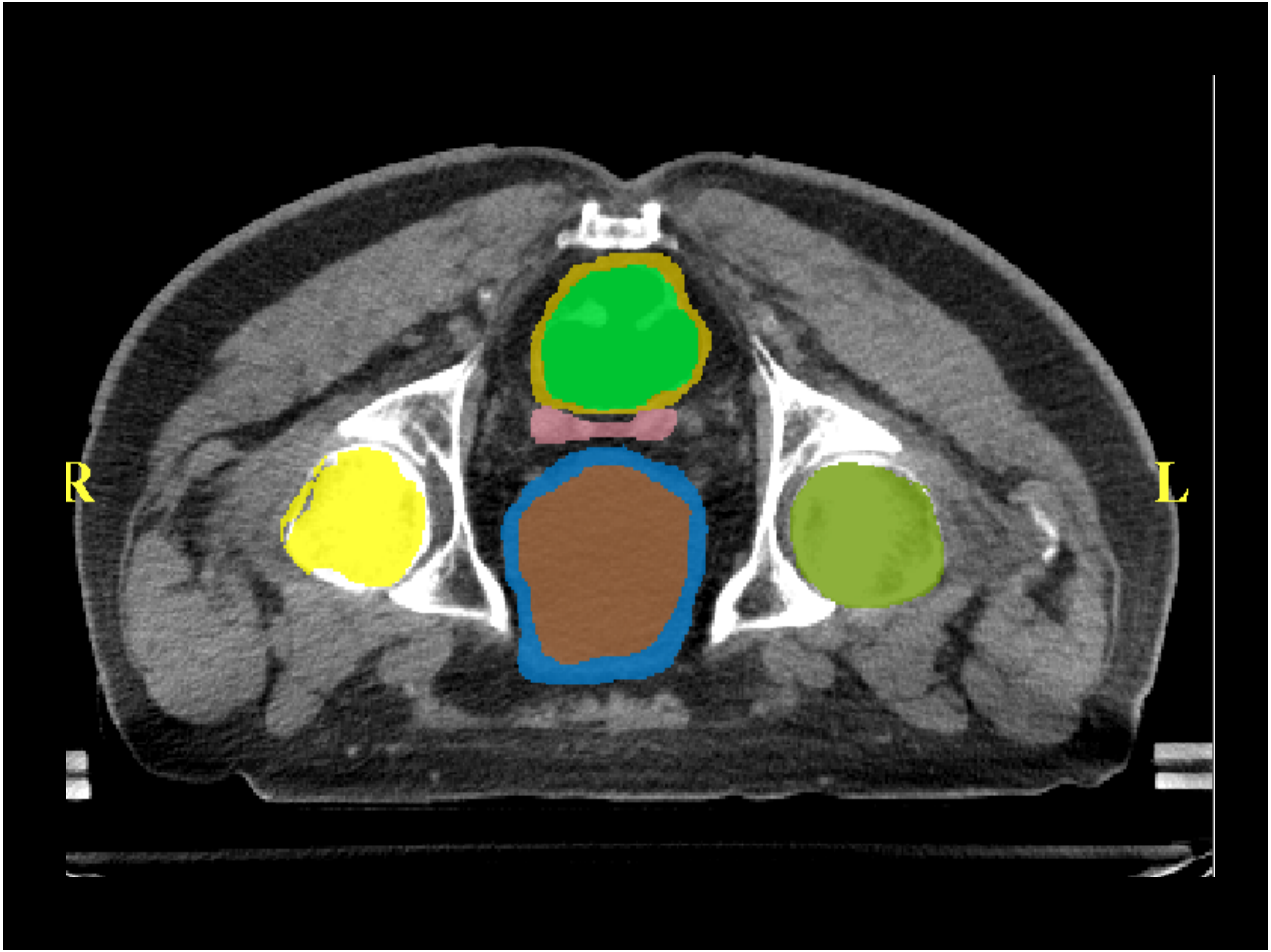
Cine
Layout
Single Slice
Ref View
Write Contrs
Expose
Film Options
ORGAN CLR
Skin
Study Received:
LONG ISLAND JEWISH M.C.
2000S 1436
[redacted]: 48
ID: 9805053
CONT: N
PST
2-D #28
Active
Loc: 1433 mm
X : 0.0 mm
Y : -0.9 mm
Z : -1433.2 mm
Zoom: 1.60 X
LFT
RGT
27 cm
Window: 300
Level: 40
Map: Ramp
27 cm
ANT
Isocenter Manager
Plan List
GTV
NEW
DUP
EDIT
DEL
compute-isocenter
Standard
Alternate
Organs
Comment
Patient Marked
Reset to Marked Isoc
isocenter information
LAT Shft +=LT (mm) +0.0
AP Shft +=PO (mm) +0.0
Z Shft +=SU (mm) +0.0
CT-Sim Offset (mm) 501
Source Surface Distances (cm)
AP 91.91 Right 82.98
PA 88.56 Left 82.47
Unit / SAD (cm) 100.0
miscellaneous
Print Worksheet
HELP
DONE

3D-CRT

high quality 3-D imaging to define :

- gross tumor volume (GTV)
- clinical target volume (CTV)
- planning target volume (PTV)
- planning organ at risk volume (PRV)


R
L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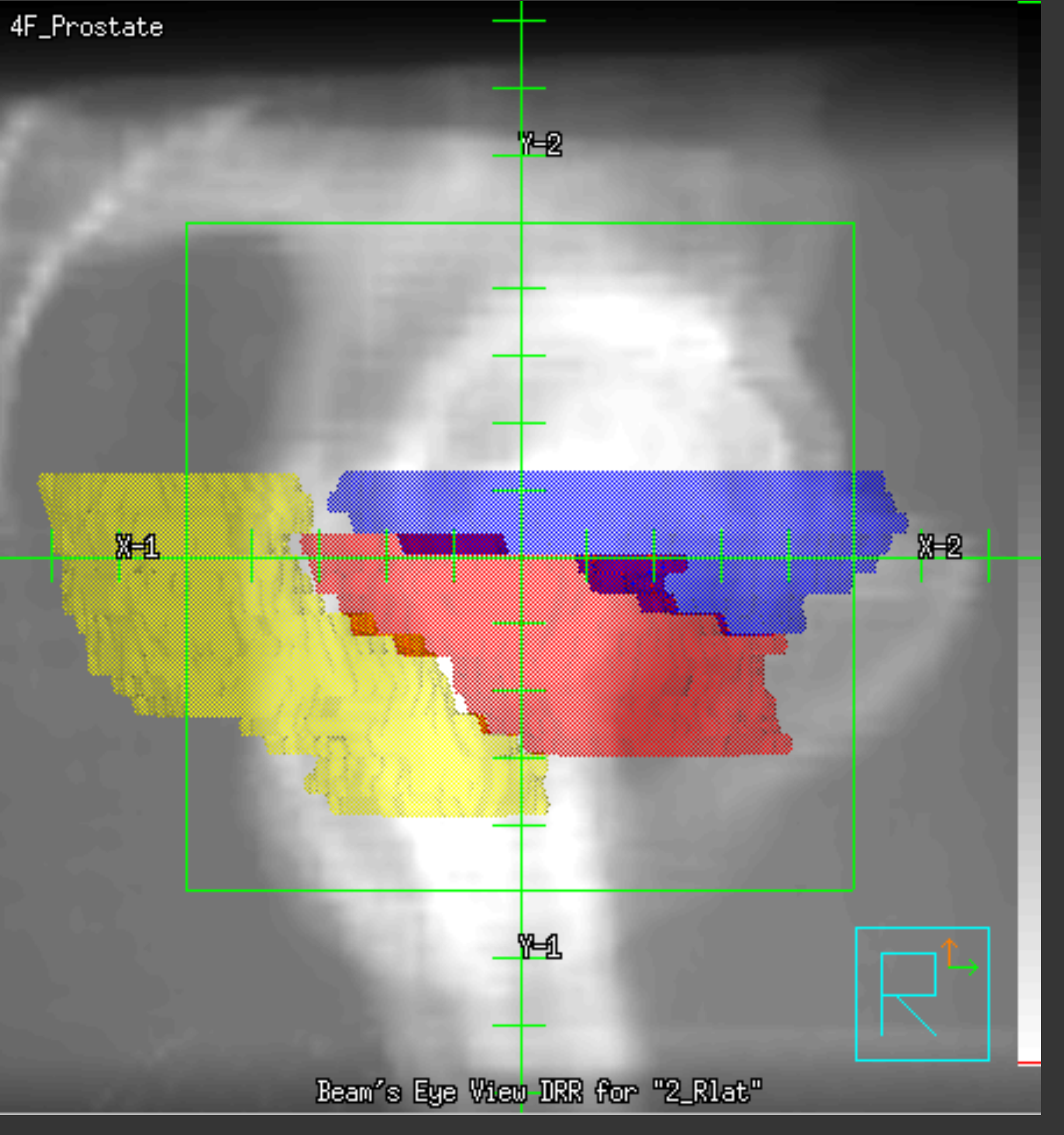
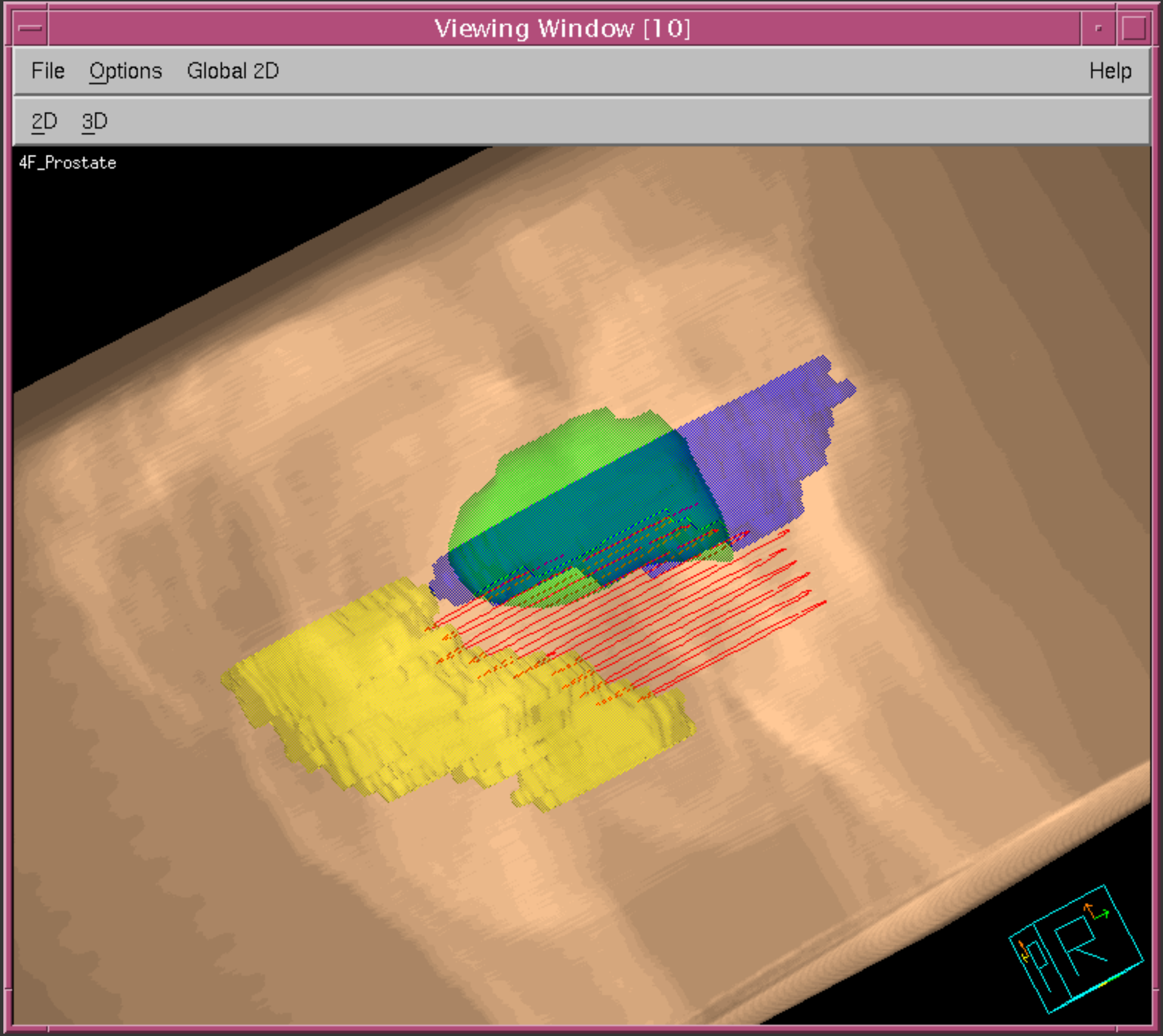
Four fields+arcs for a small Prostate EBT

Total prescription 65 Gy to Isocenter



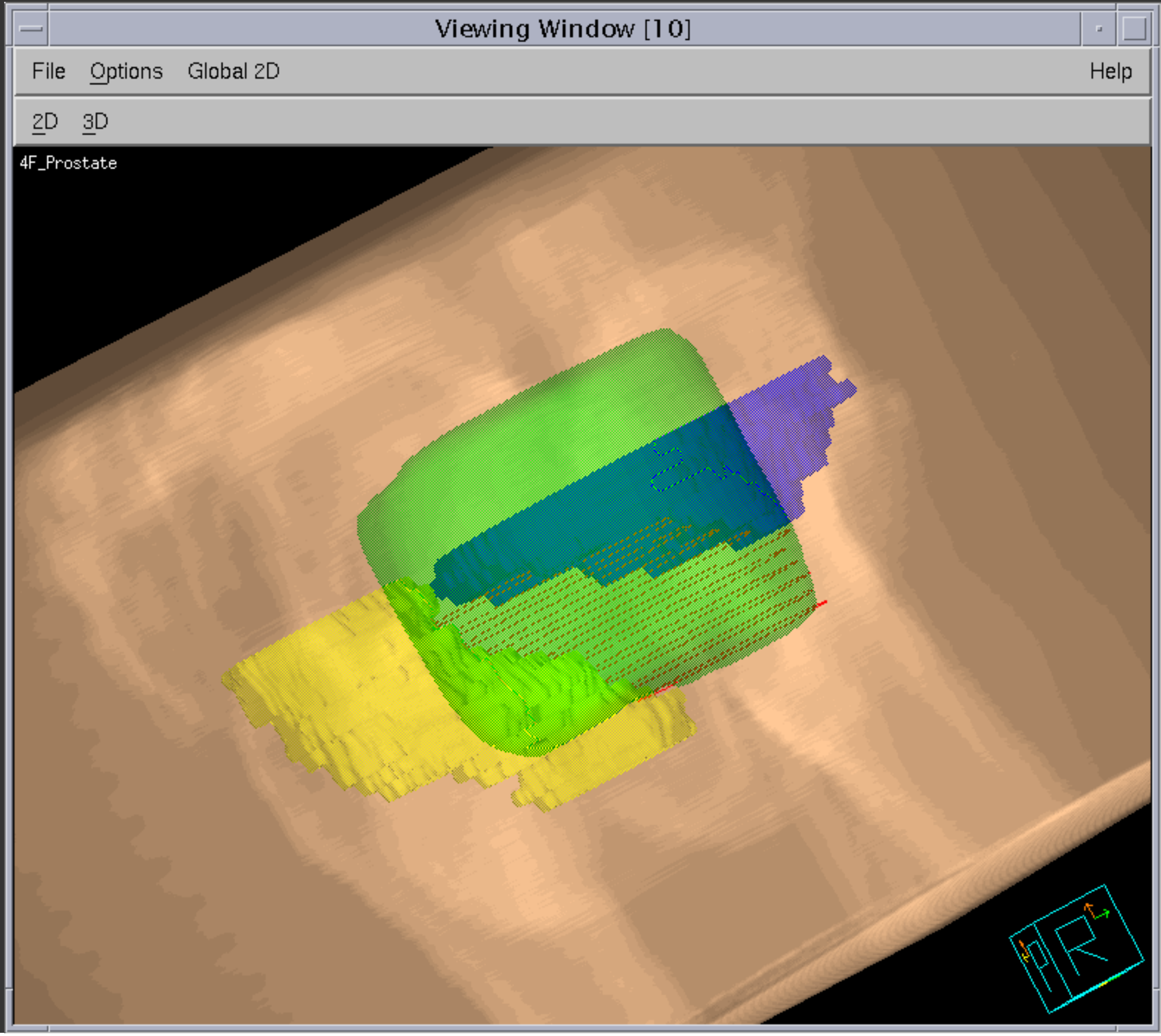
Green Dose Cloud for four fields plus arcs for the small prostate

Isodose is the 65 Gy prescription



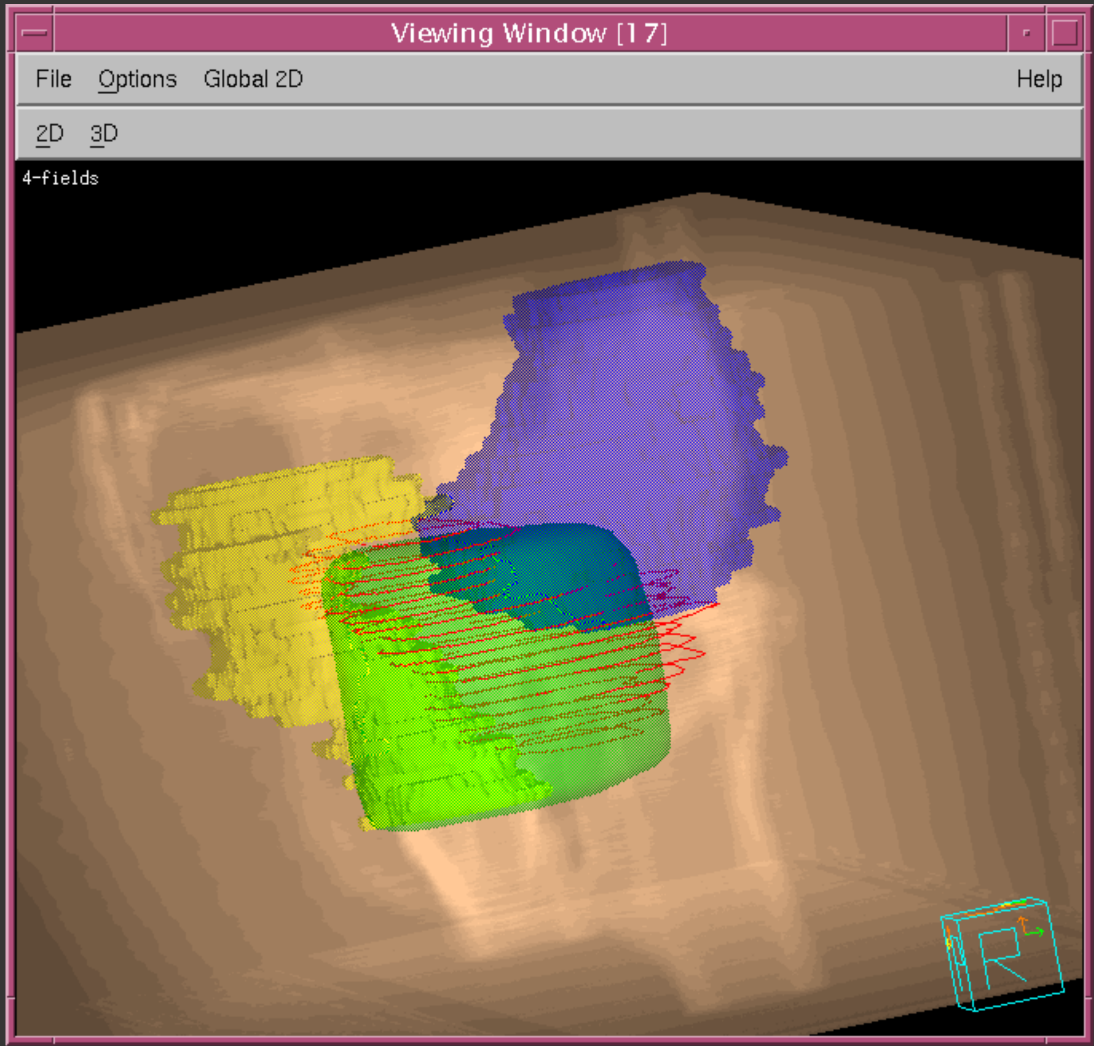
Dose Cloud for four fields plus arcs for the same small prostate PTV

Isodose is now 97% of isocenter prescription (63 Gy)

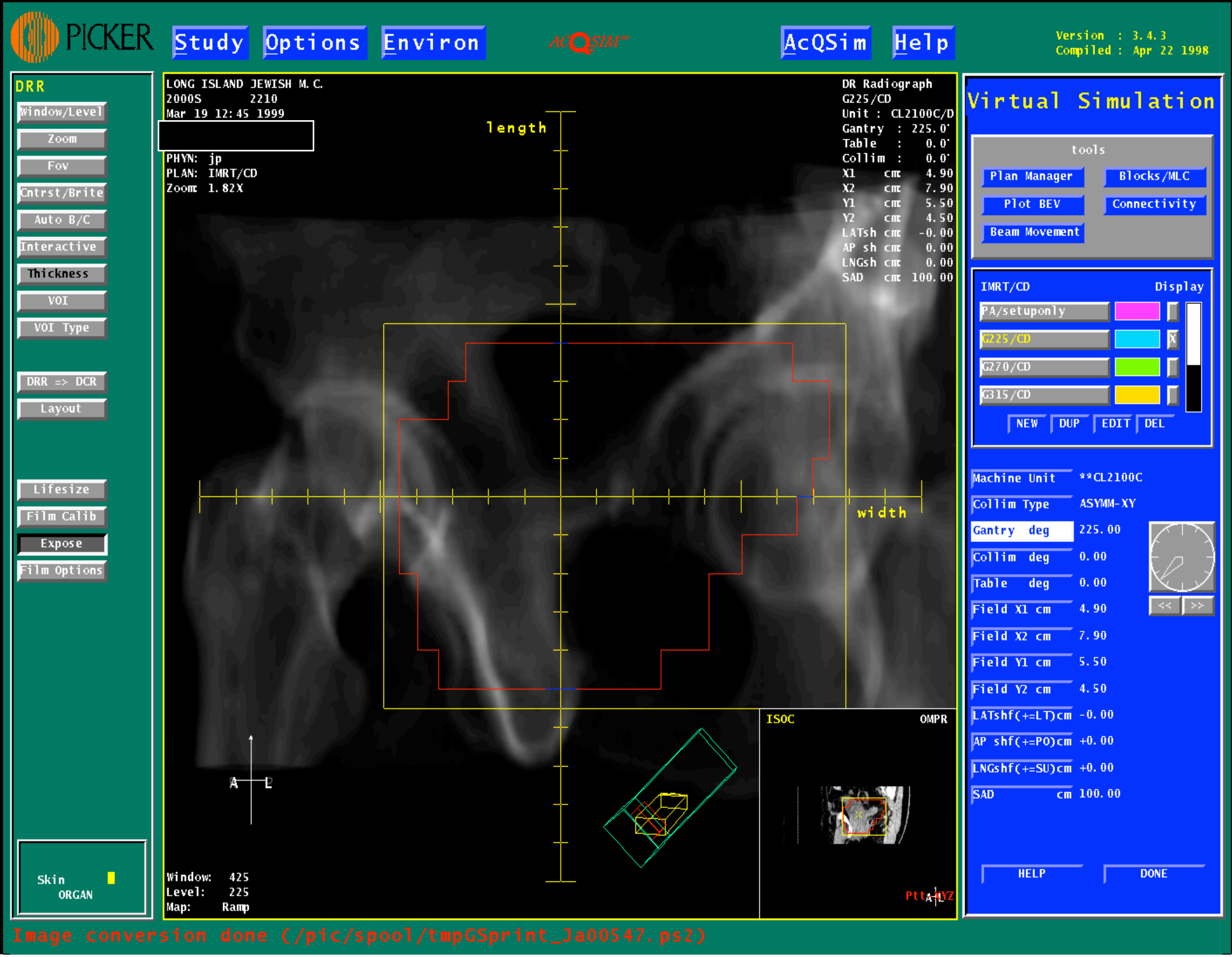


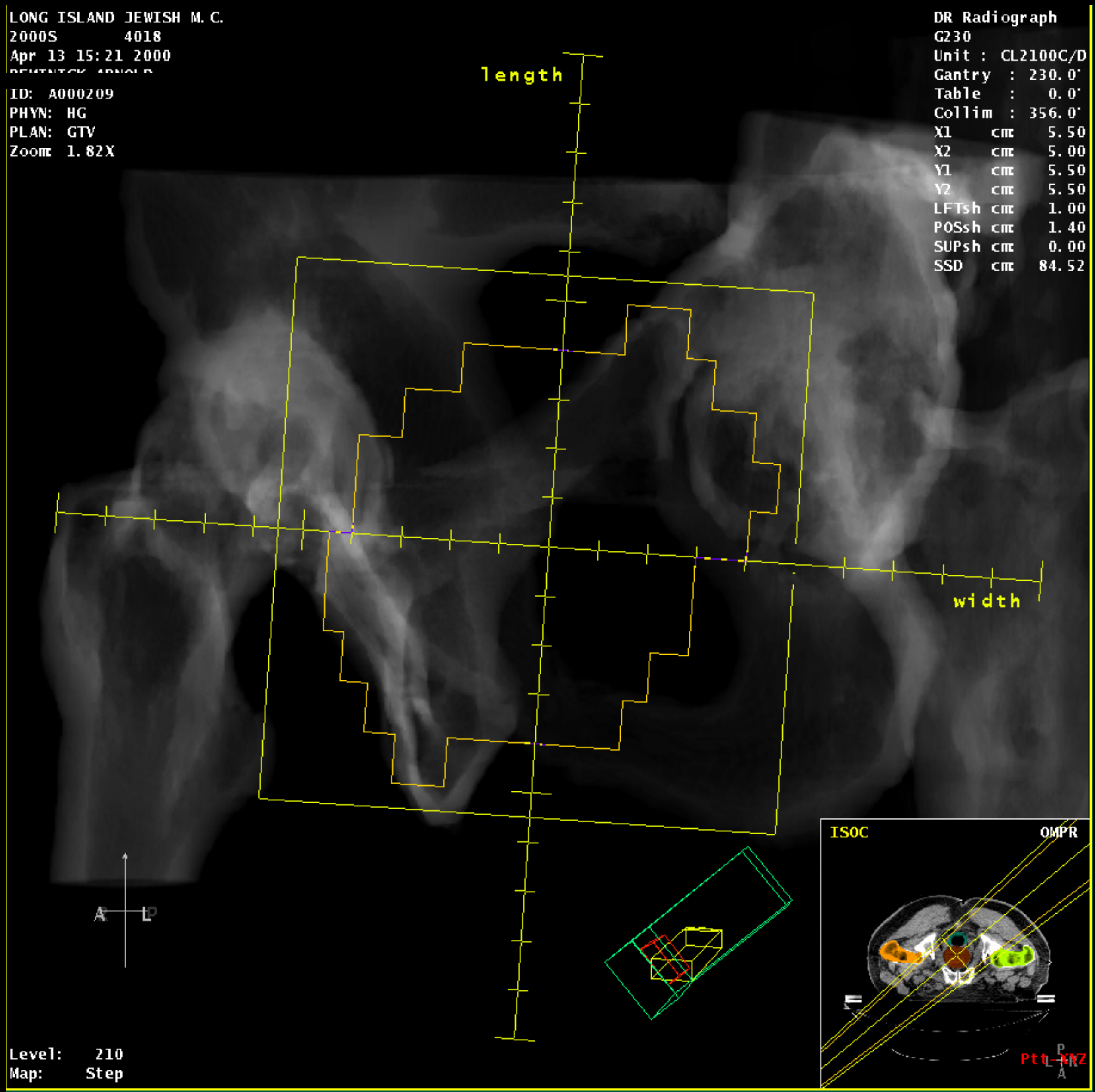
Same Green Dose Cloud for four fields plus arcs for the LARGE PTV

Isodose is 97% of isocenter prescription – 63 Gy



Virtual Simulation

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2000S 4018
Apr 13 15:21 2000
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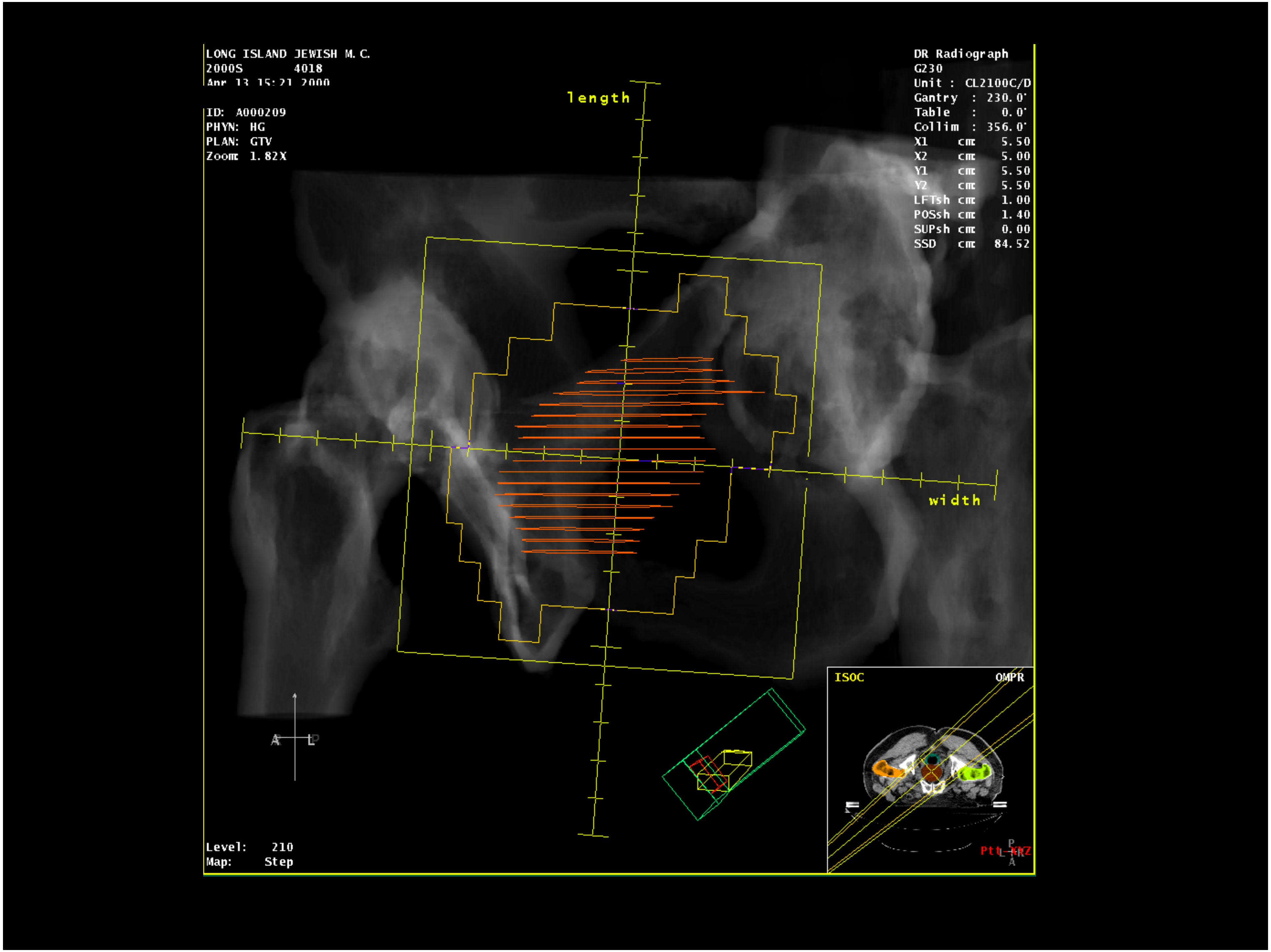
PHYN: HG
PLAN: GTV
Zoom: 1.82X
length
width
DR Radiograph
G230
Unit : CL2100C/D
Gantry : 230.0°
Table : 0.0°
Collim : 356.0°
X1 cm 5.50
X2 cm 5.00
Y1 cm 5.50
Y2 cm 5.50
LFTsh cm 1.00
POSsh cm 1.40
SUPsh cm 0.00
SSD cm 84.52
ISOC
OMPR
Level: 210
Map: Step


LONG ISLAND JEWISH M.C.
2000S 4018
Apr 13 15:21 2000
ID: A000209
PHYN: HG
PLAN: GTV
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DR Radiograph
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X1 cm 5.50
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LFTsh cm 1.00
POSsh cm 1.40
SUPsh cm 0.00
SSD cm 84.52
length
width
ISOC
OMPR
Level: 210
Map: Step

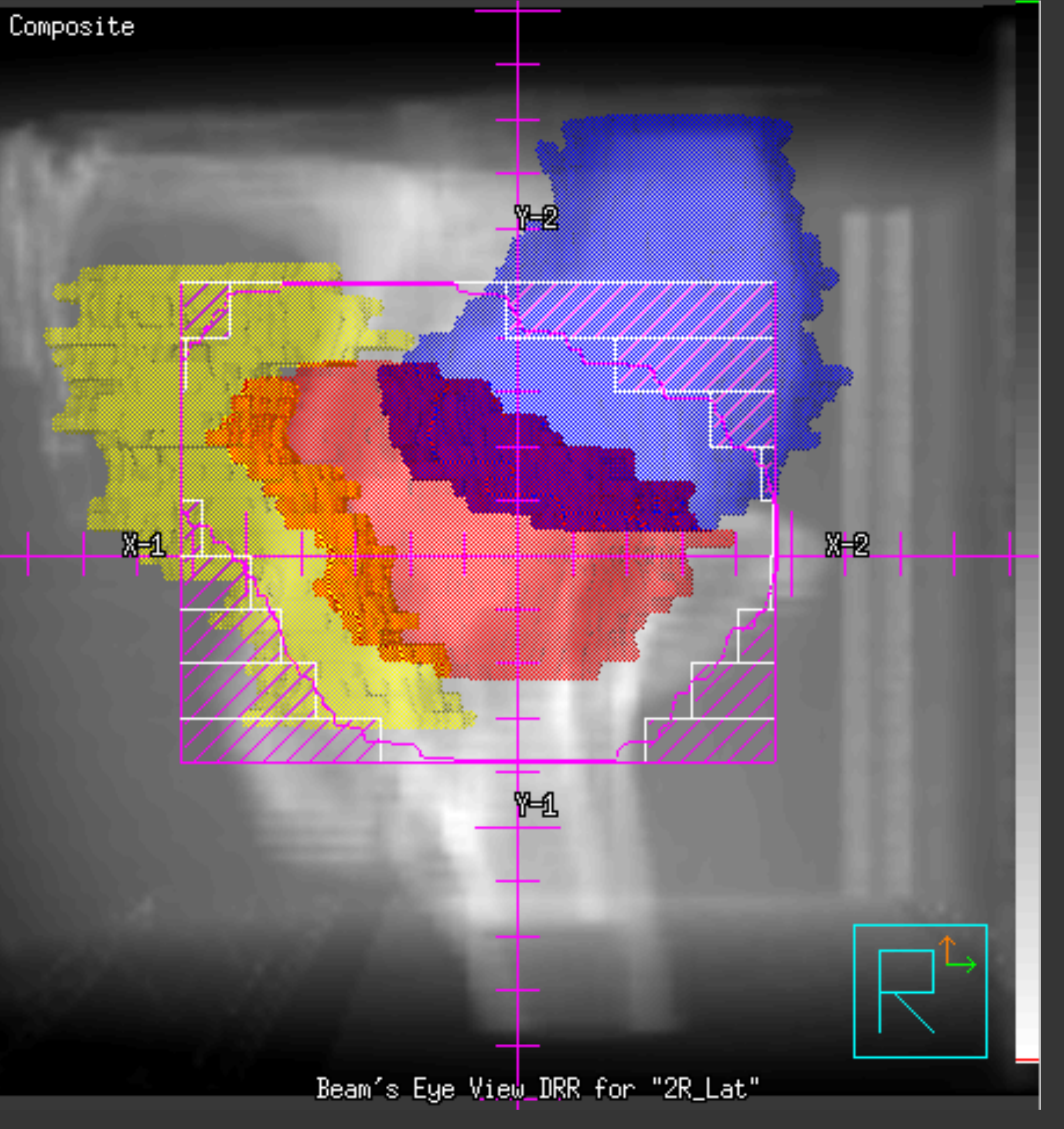
Treatment Portal Evaluation Tools

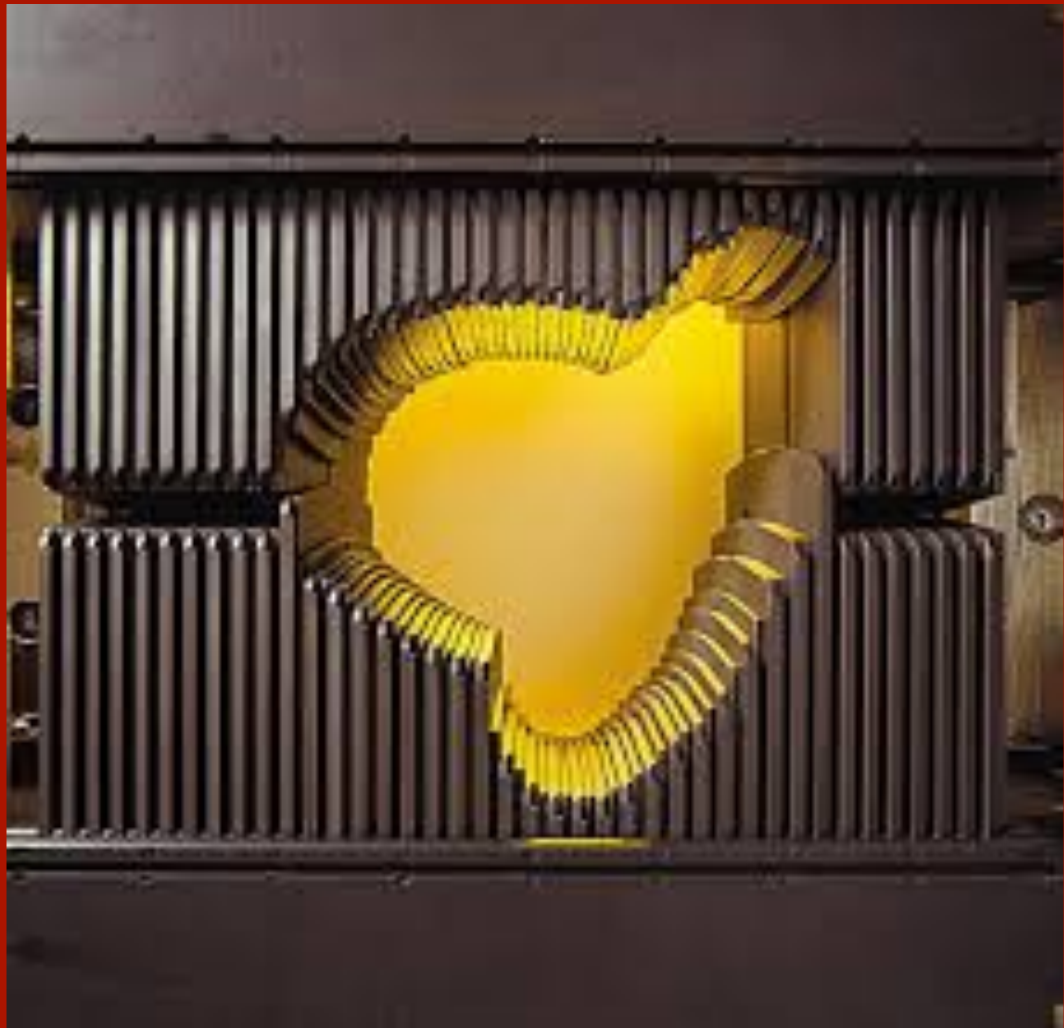
- Digitally Reconstructed Radiographs (DRR)
- Port verification films
- Electronic Portal Imaging Devices (EPID)
- On Board Imagers (OBI)
- Port comparison Software

CT guided Conformal Plan

One of Six fields

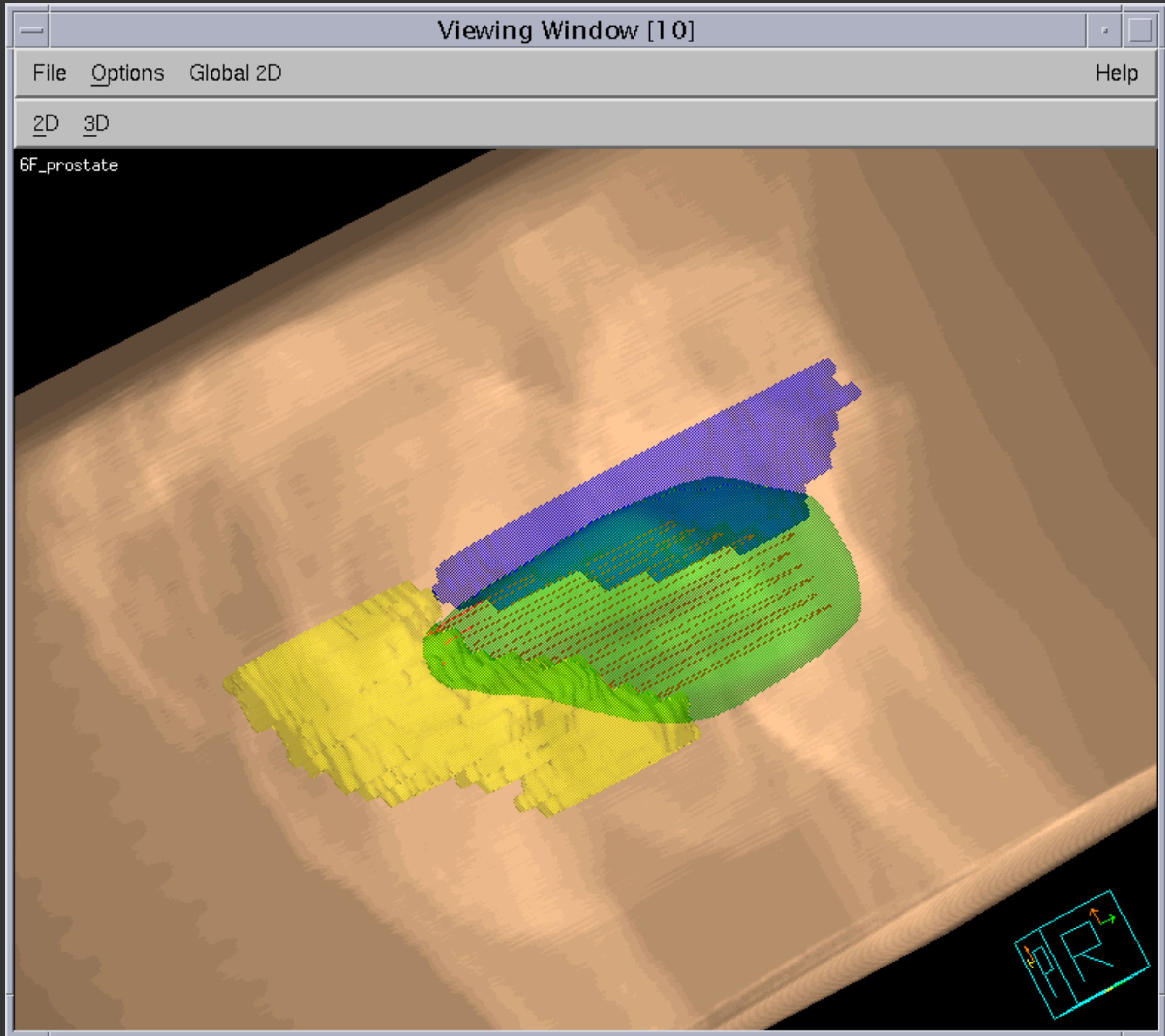
Prescription 77.4Gy to PTV





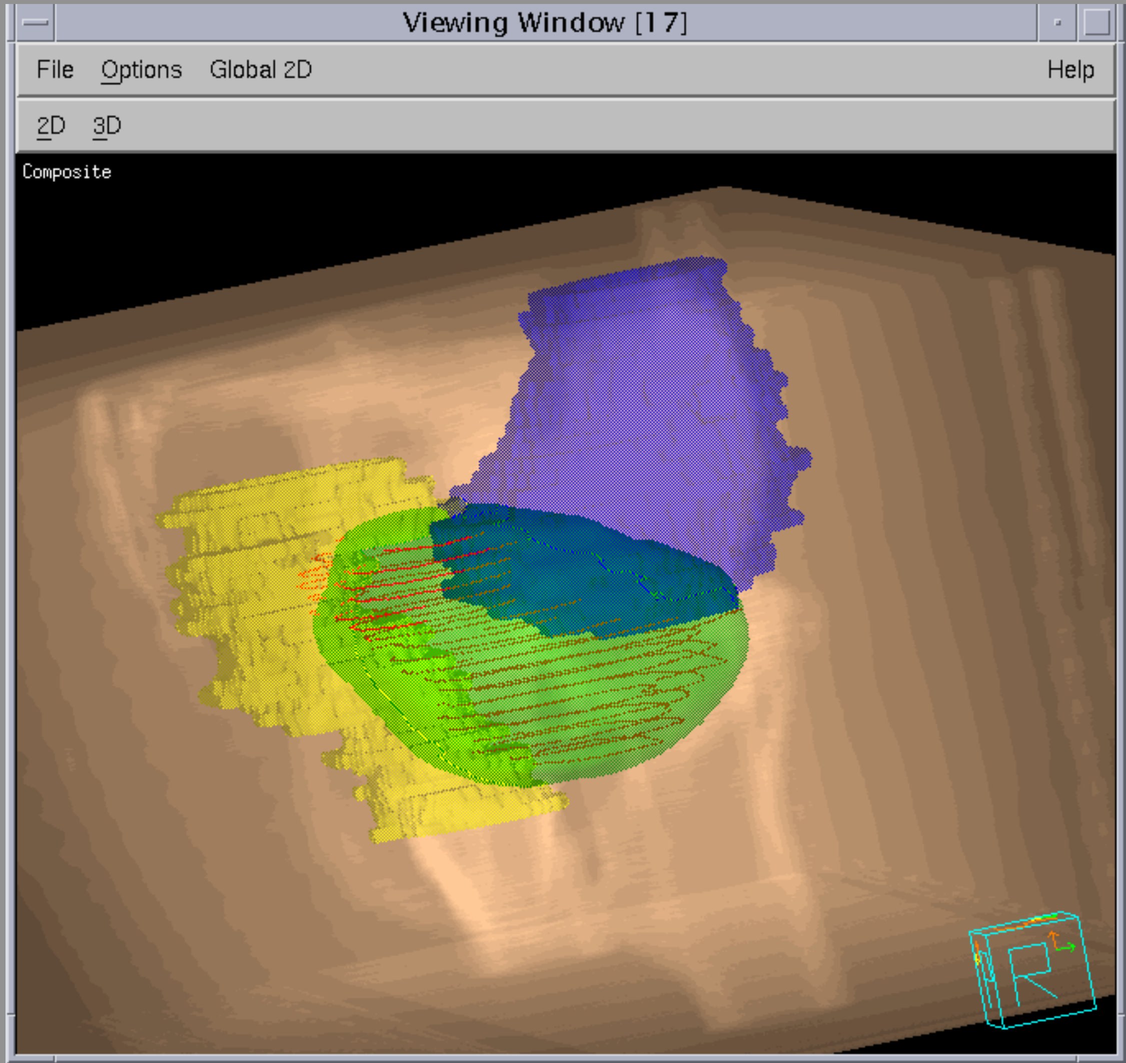
Dose Cloud for a Six Fields CRT

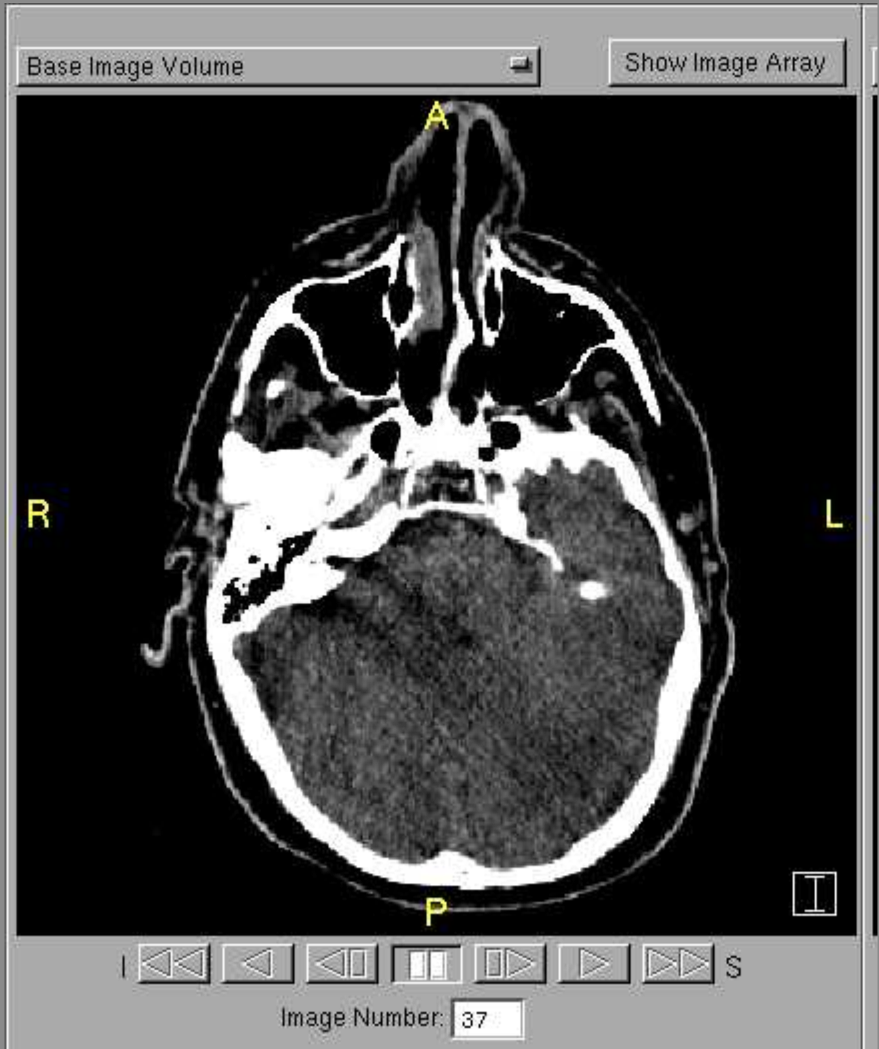
Prescription Isodose 77.4 Gy – small PTV



Dose Cloud for Six Fields CRT

Prescription Isodose 77.4 Gy – LARGE PTV

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Show Image Array
A
R
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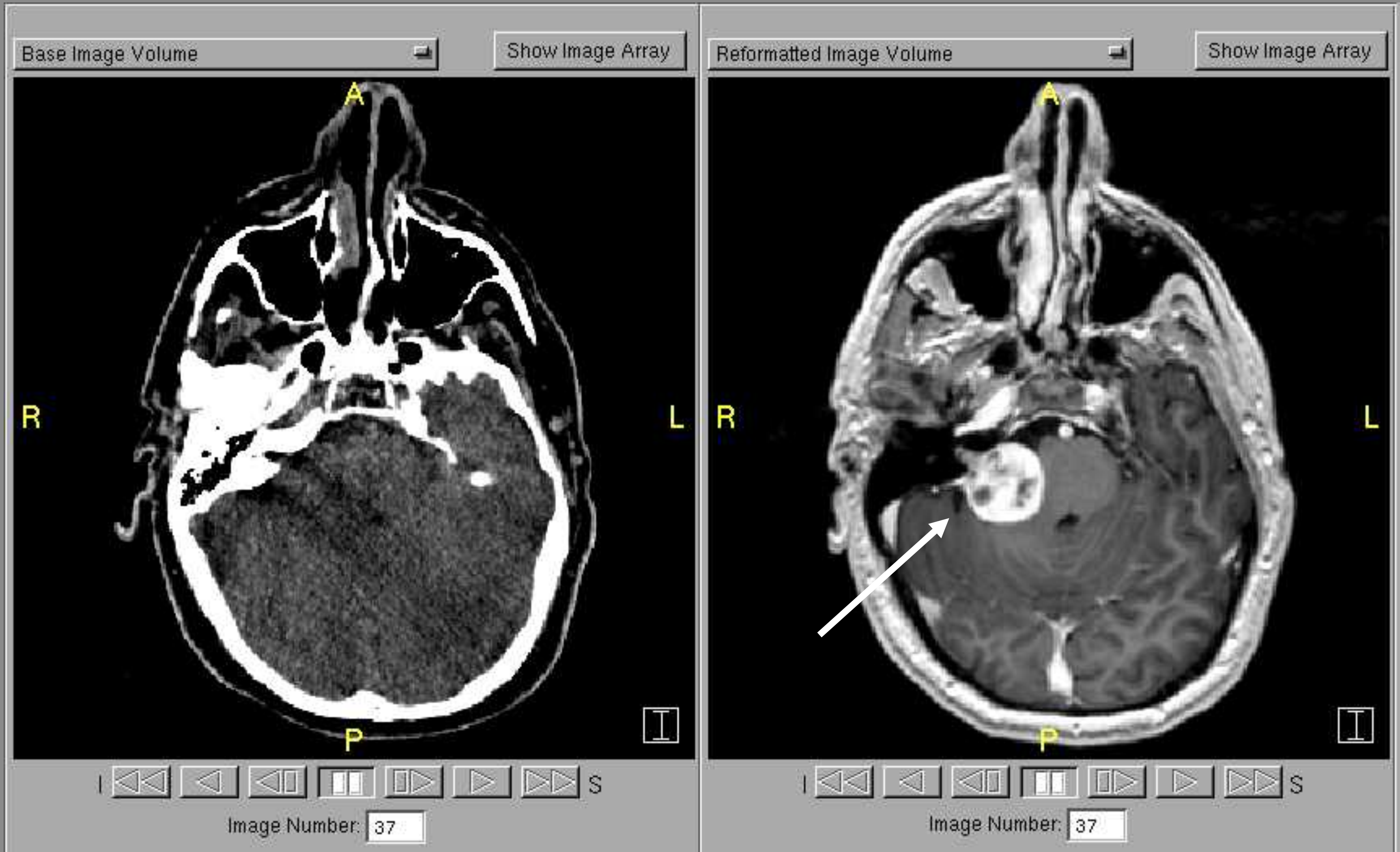
S
Image Number: 37

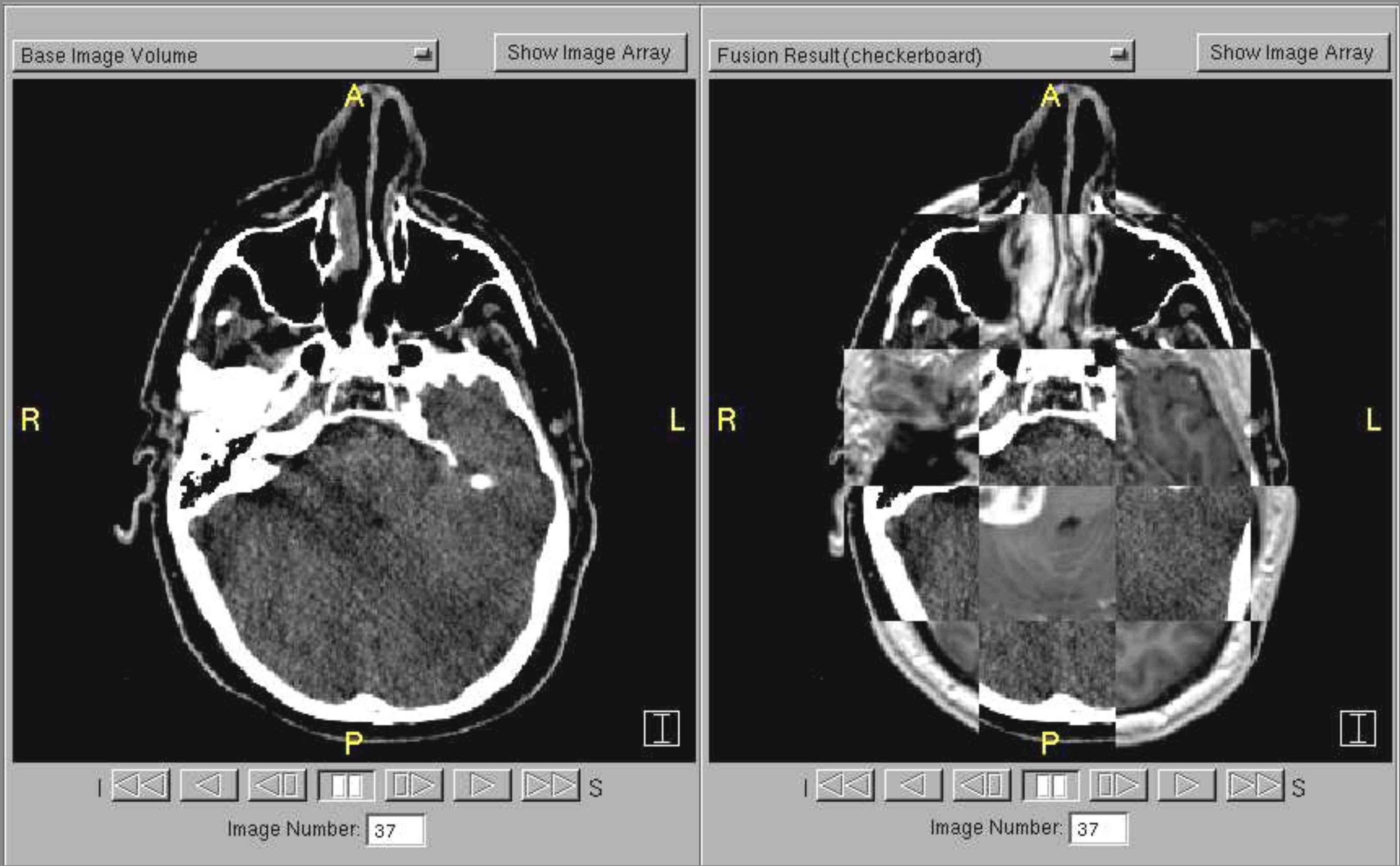
Multimodality image registration



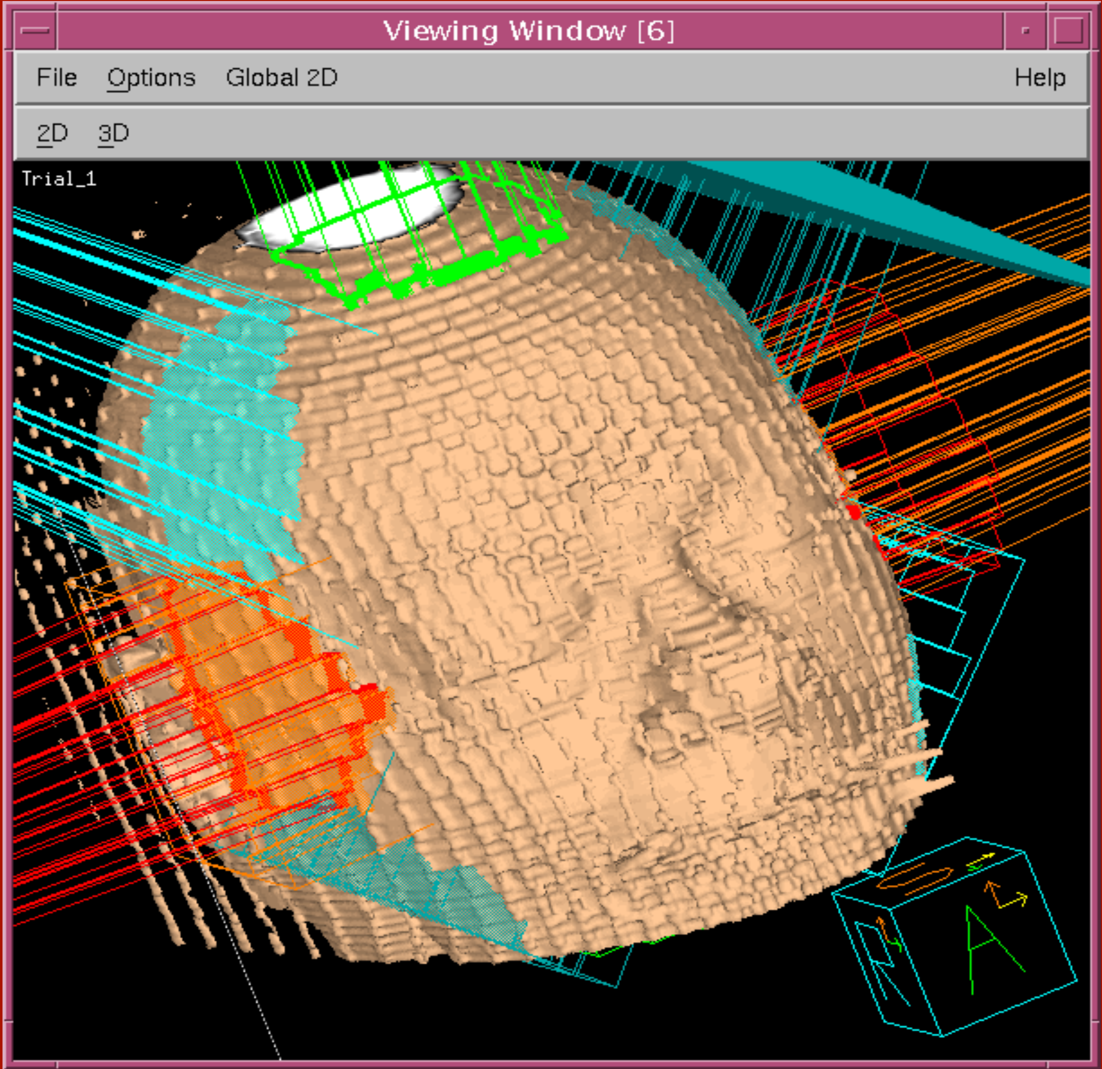
Acoustic neuroma not clearly visible on CT image

Mass clearly seen on reformatted MRI image after fusion with CT

Multimodality image registration- verification

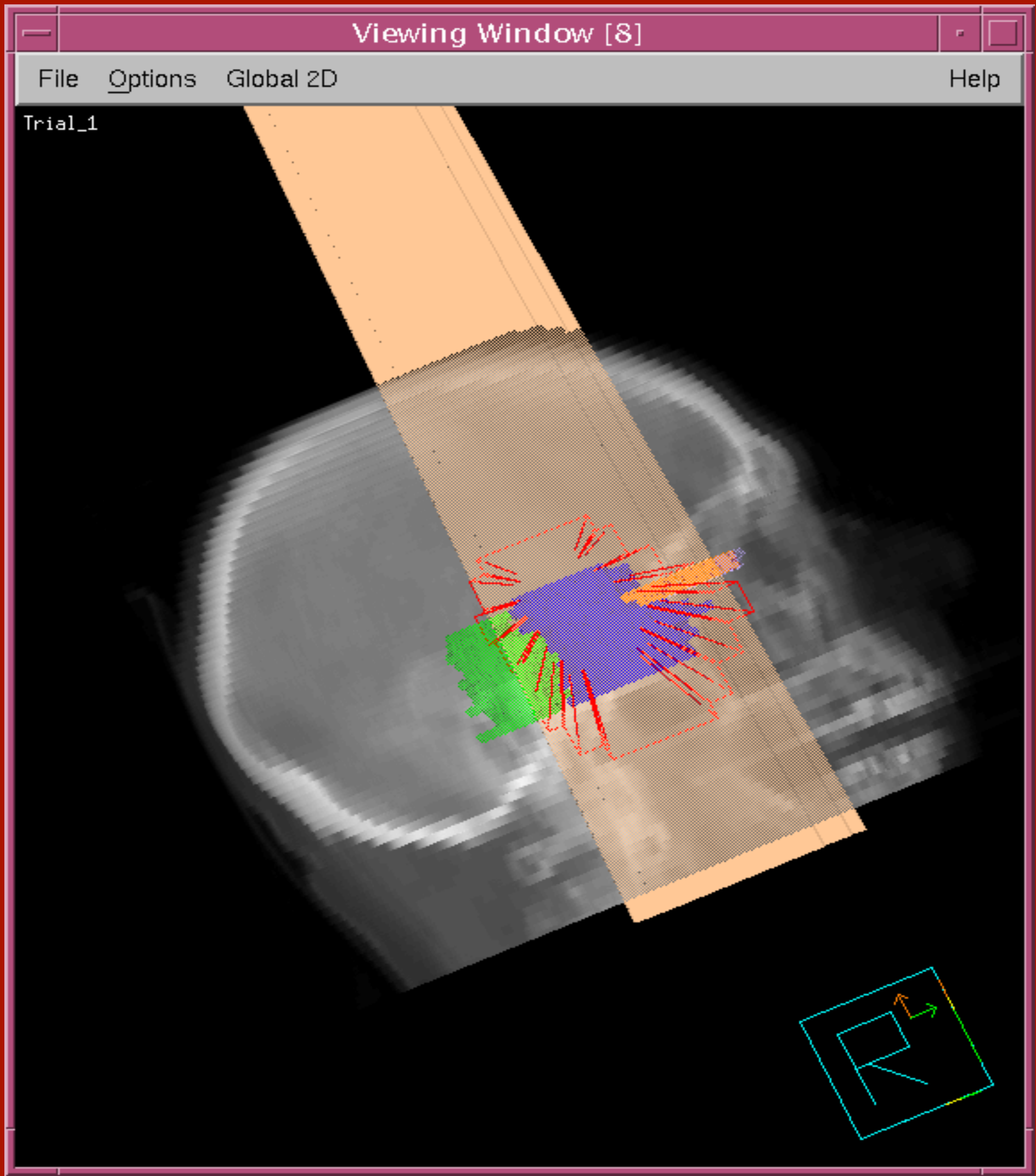


a-CT image **b-CT - MRI checkerboard combination**



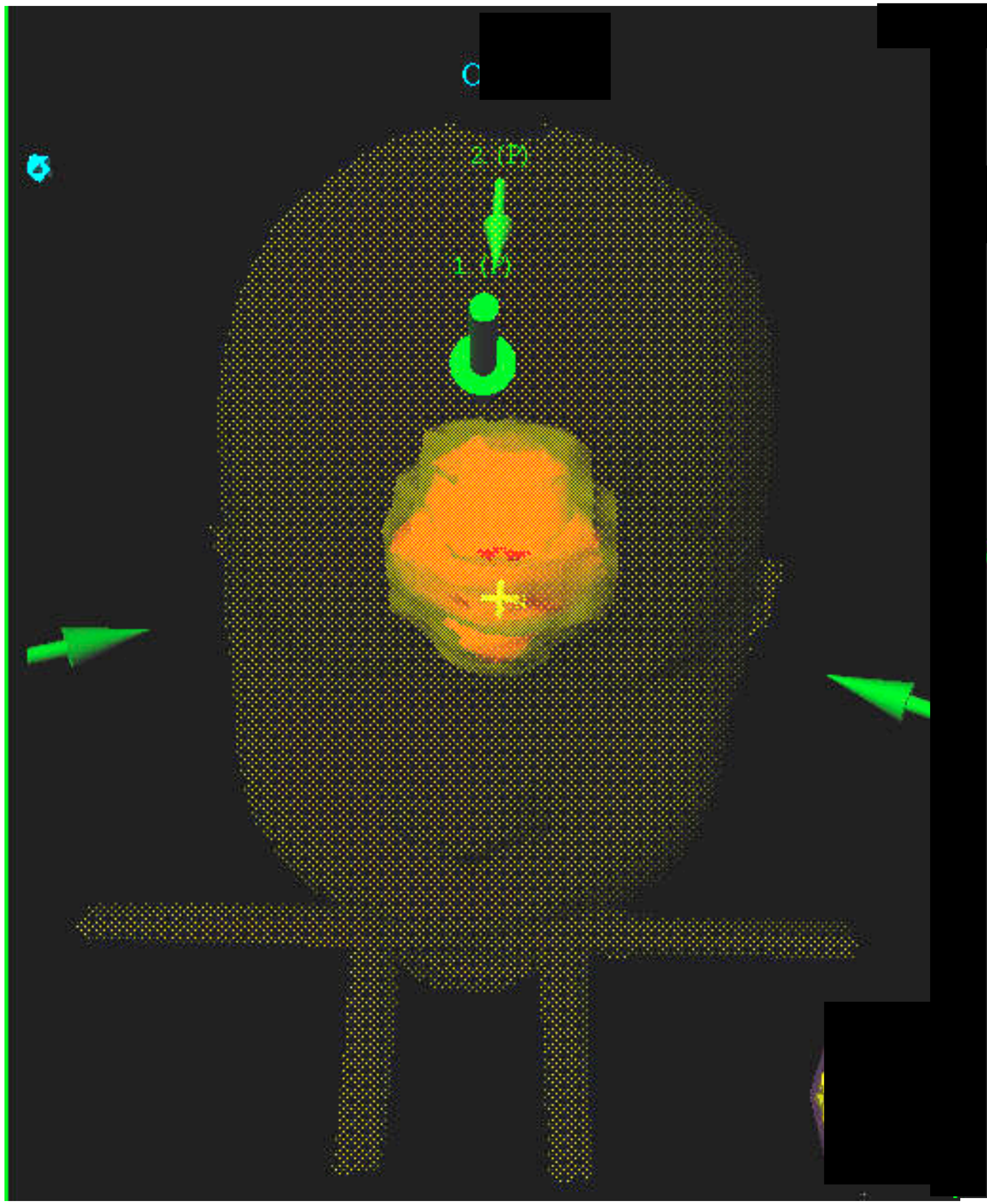
Multiple beams projected on a surface rendering of the patient facilitate setting the patient up for treatment. The puckered surface represents the mask used to immobilize the patient's head in the correct treatment position.

Dosimetric effects caused by couch tops and immobilization devices: Report of AAPM Task Group 176 - Med. Phys. 41 (6), June 2014

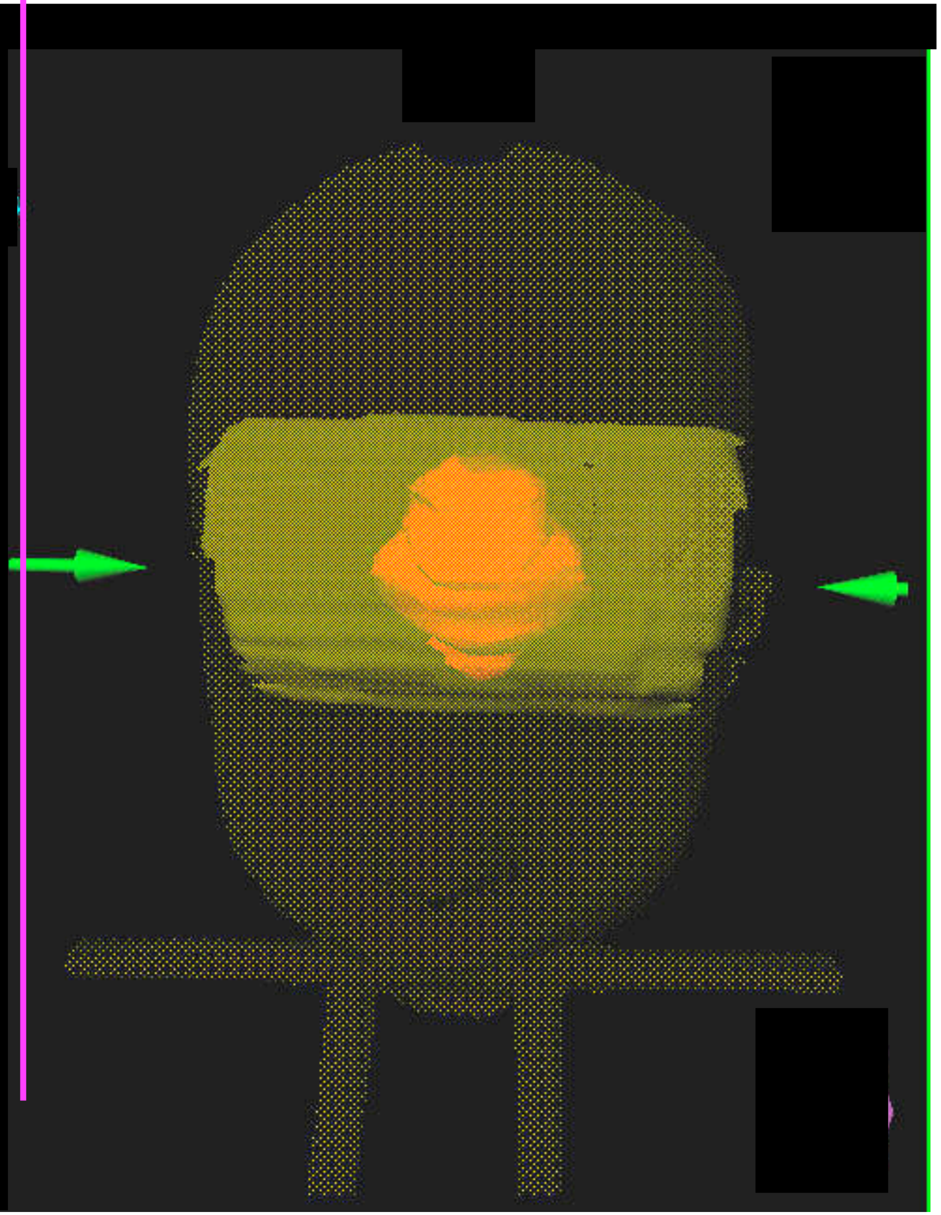


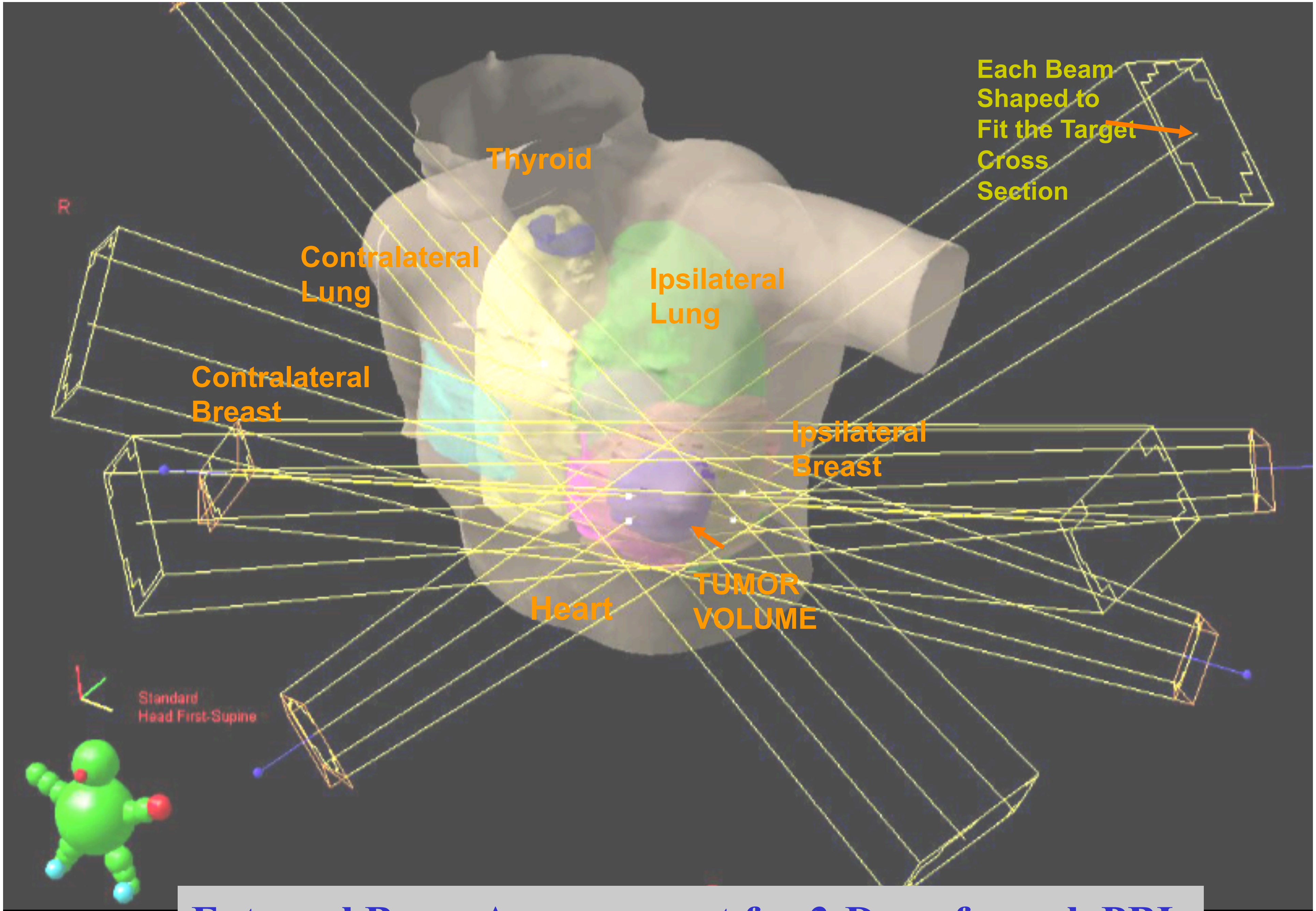
Non-coplanar beams (peach and red) aimed at a brain tumor (purple), displayed on a digitally reconstructed radiograph. The brain stem (green) and the optic chiasm (orange) are spared using conformal shaping of the beams

Conformal Dose Distribution



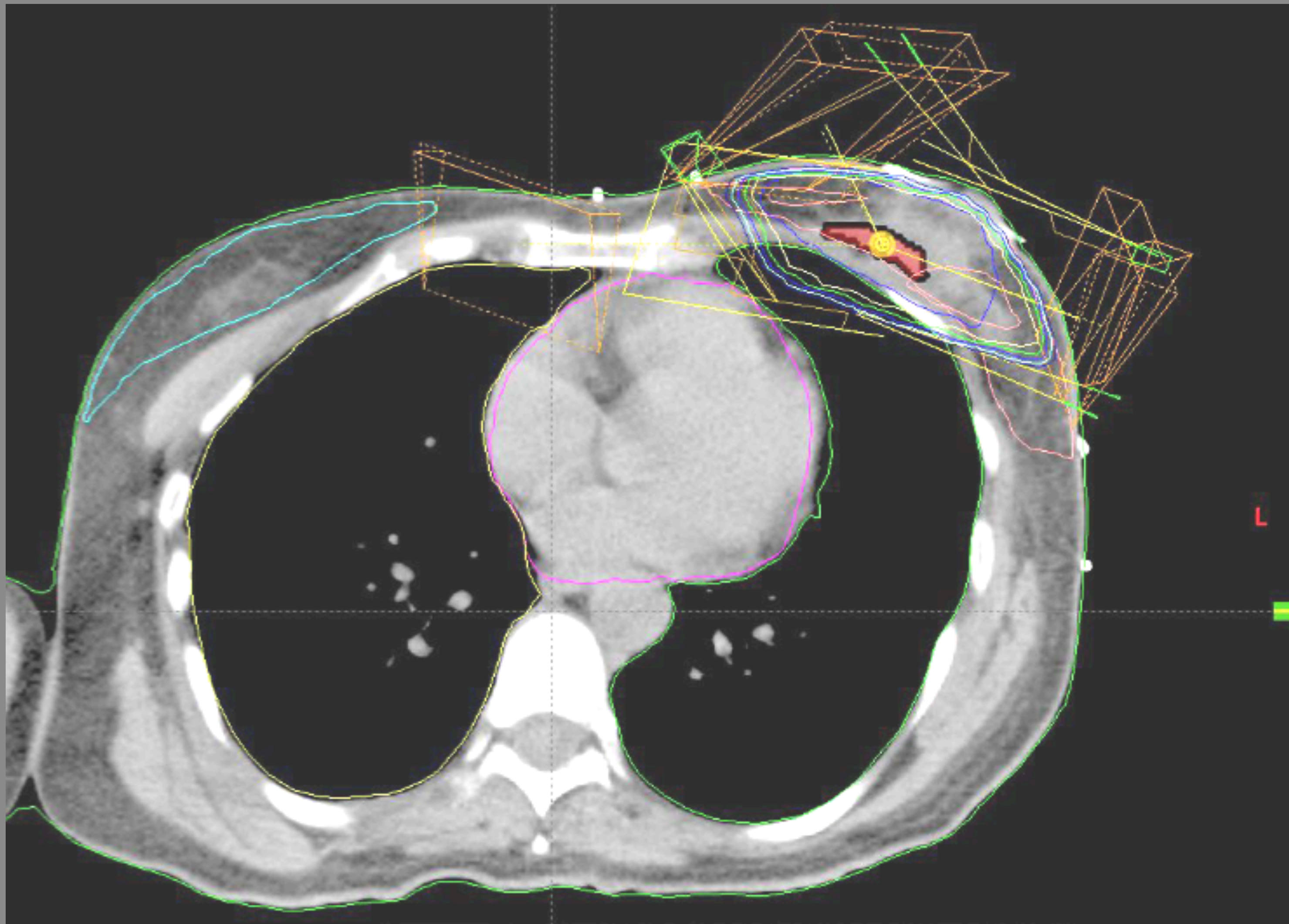
Non conformal 2D dose Distribution



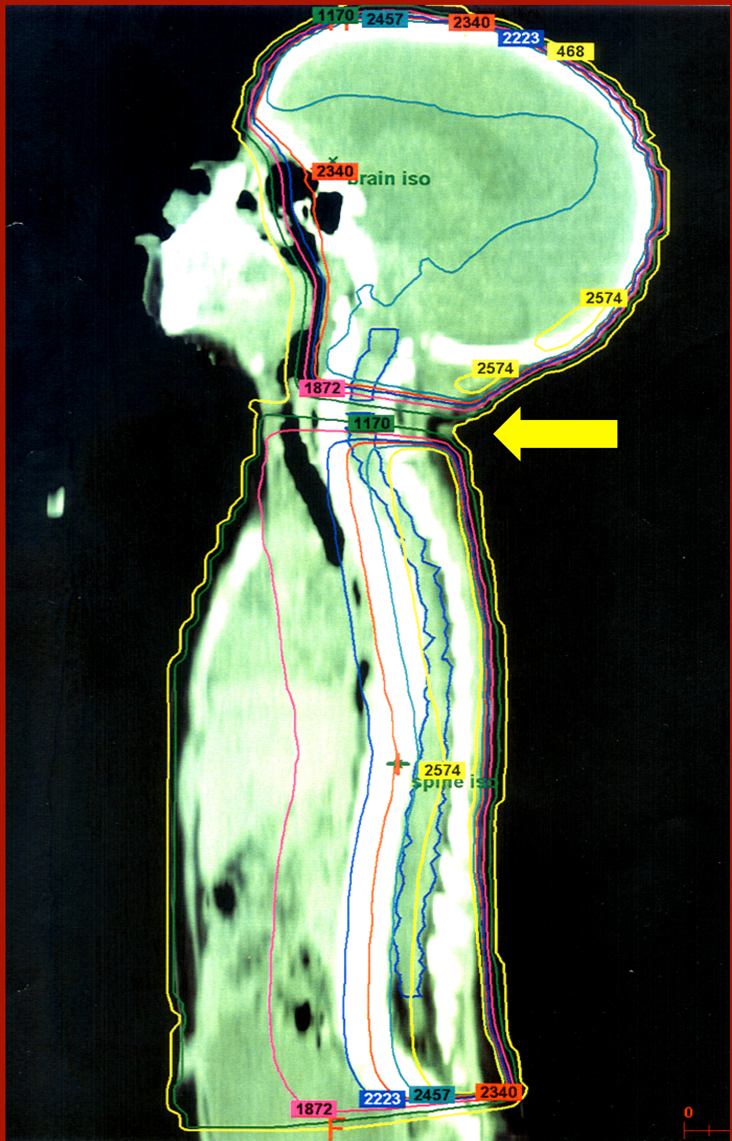


External Beam Arrangement for 3-D conformal PBI

Dose distribution for External 3-D conformal PBI



Cranio- spinal Irradiacion



3-D Conformal RT
Essential use of CT information

- Major increase in the use of CT information enables the construction of volumetric data sets

- The targets are constructed slice by slice from knowledge of anatomy and by disease pathways but aided by visualization of organs and boundaries between them and the targets. Physical examination, palpation and other tests are complemented with cross sectional images.

- The fields outlines are "conformed" to the BEV of the targets

- Physical measurements of the patient are substituted by digital image measurements tools.

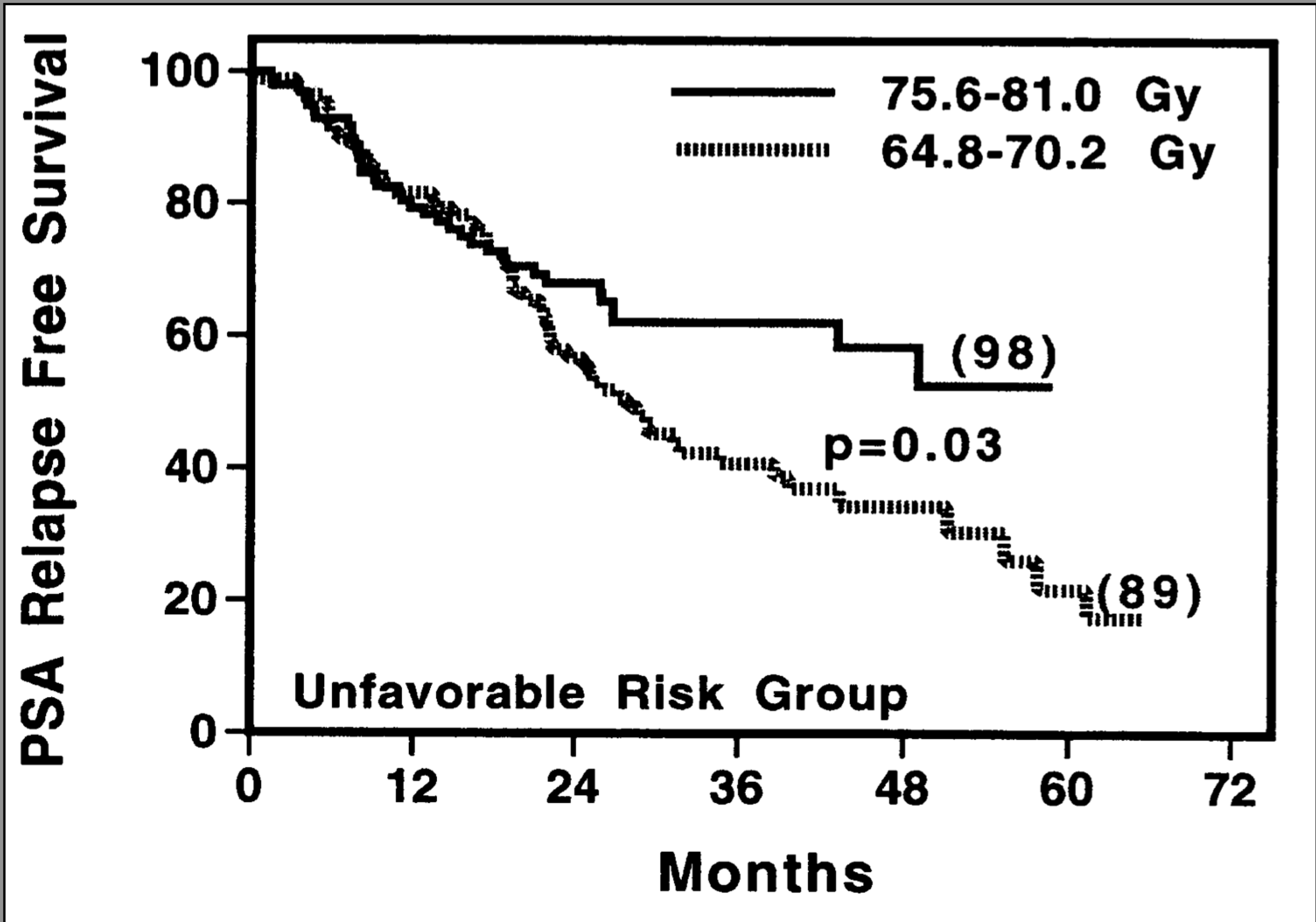
- The target is still defined in relation to anatomic landmarks – significant reliance on bony anatomy. Use of DRR's

3-D Conformal RT - cont

- Dose distribution information expanded to multiple planes
- Multiple beam directions and non-coplanar arrangements reduce the dependence on beam energy
- Accounting for dose contributions from other planes is made possible by better beam models. Increased weight given to doses to critical organs
- New tools required to describe target and critical organ doses (DVH) and for plan evaluation
- DVH's of critical organs started to generate Organ dose tolerance information and partial volume dose tolerance

Comparative Dose-Volume Histograms
Dose escalation for Prostate Ca.

RFS vs. DOSE - RT alone



From: M.J.Zelefsky et. al.; IJROBP June 1998

RFS vs. DOSE - RT alone

657 patients treated in 1994-95

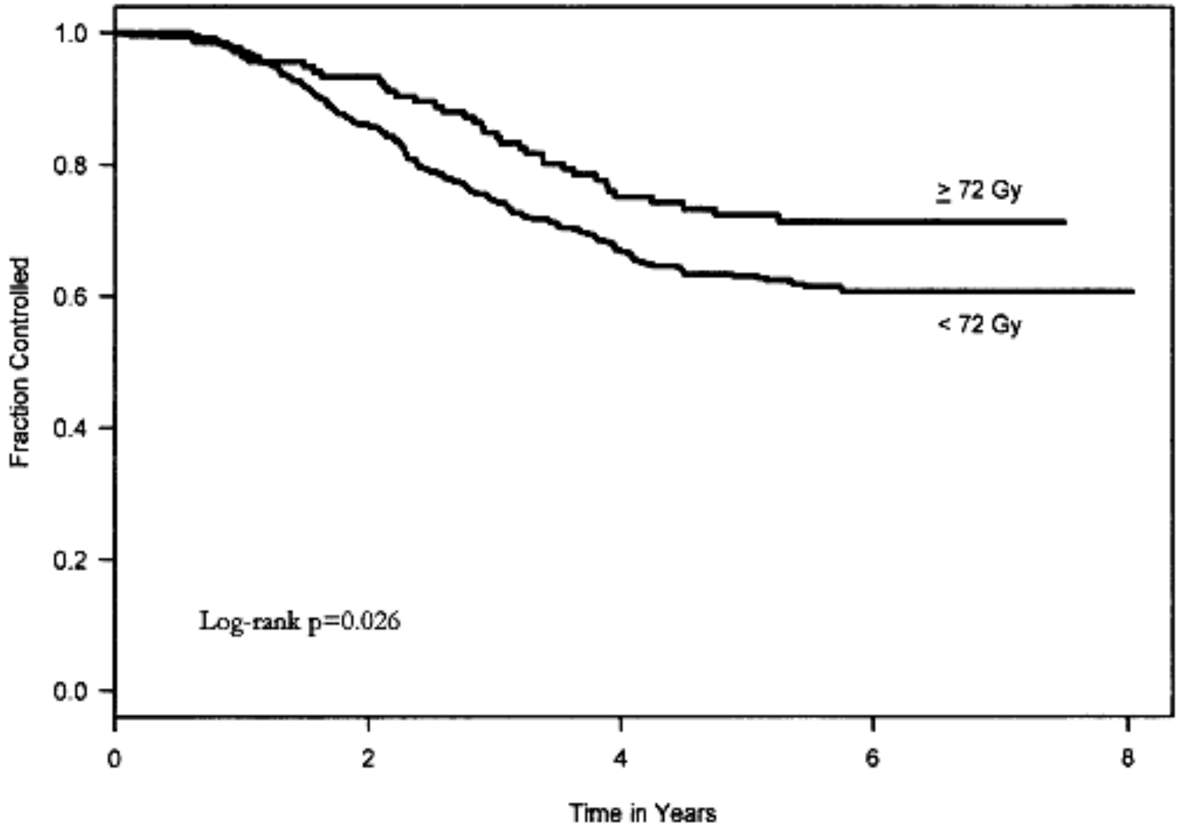


Fig. 2. Kaplan-Meier prostate-specific antigen (PSA) disease-free survival curves of patients with intermediate-risk tumors (T1b, T1c, T2a, GS ≤6 and PSA >10 ng/mL but ≤20 ng/mL or T2b, GS ≤6 and PSA ≤20 ng/mL or GS 7 and PSA ≤20 ng/mL).

From: P. Kupelian et. al.; IJROBP Feb 2005

Dose Response

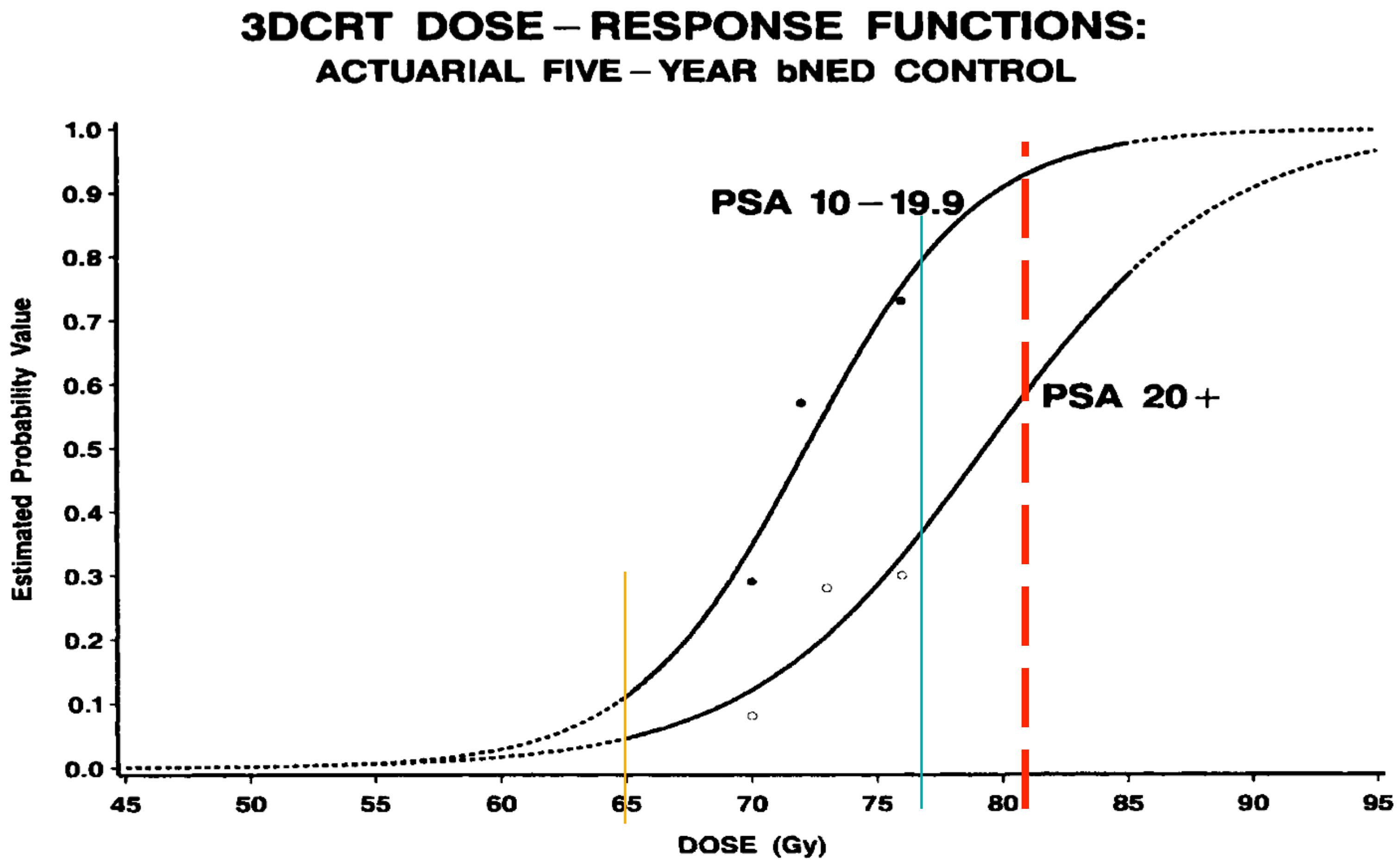


Fig. 2. Logistic response models for bNED for two pretreatment PSA groups.

- **From: G.E.Hanks et. al., IJROBP, June 1998**

Morbidity vs. Dose

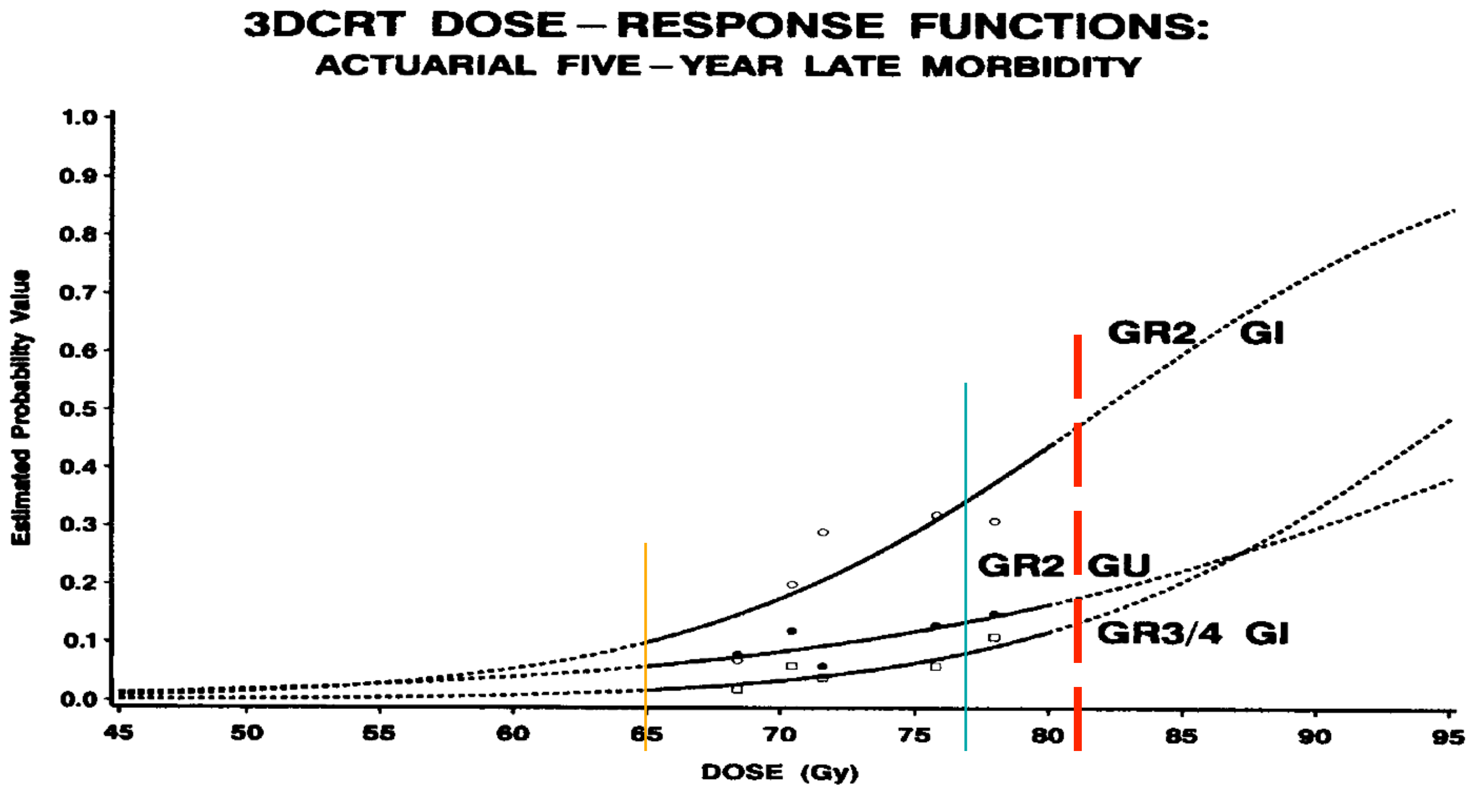
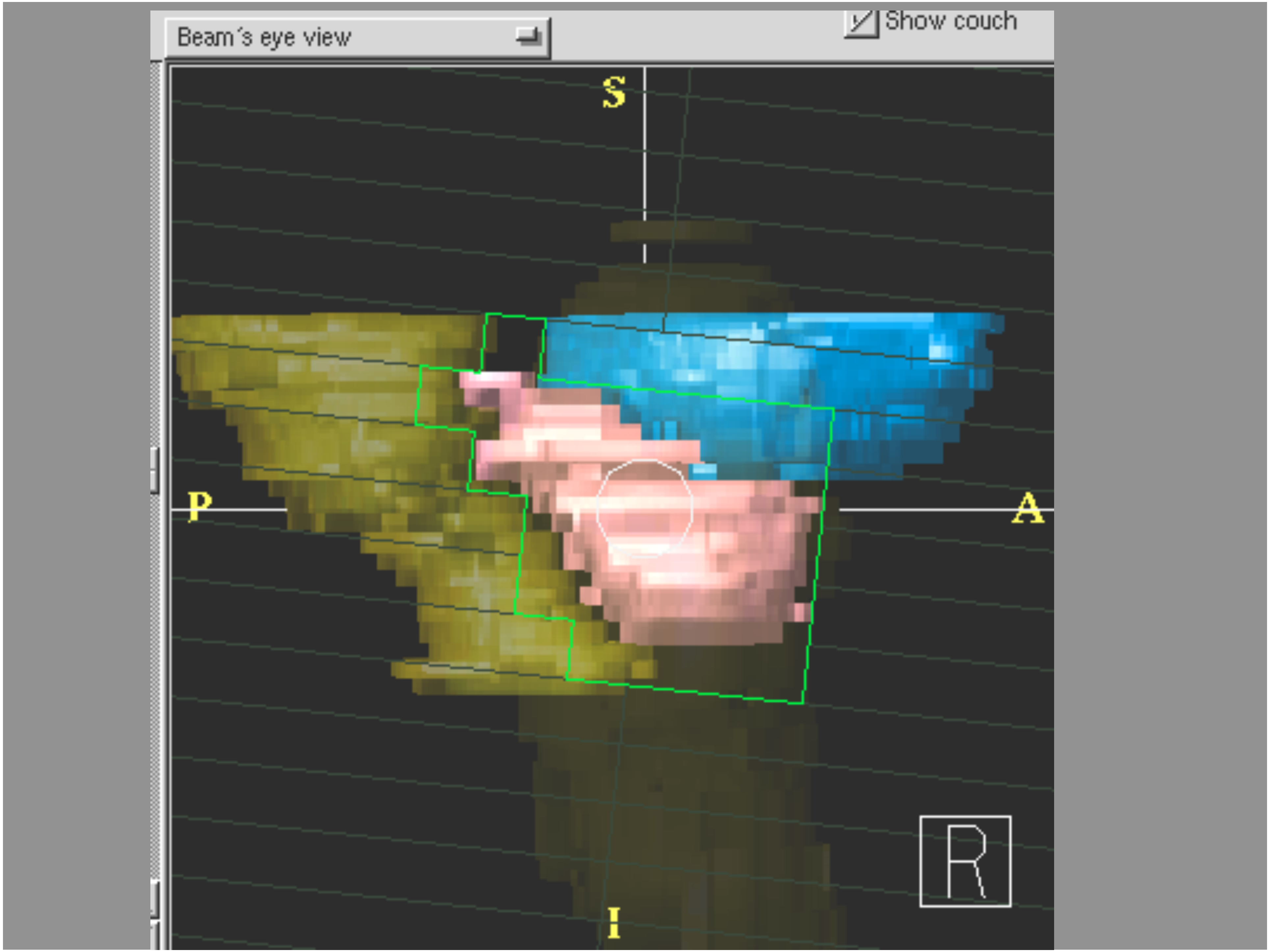


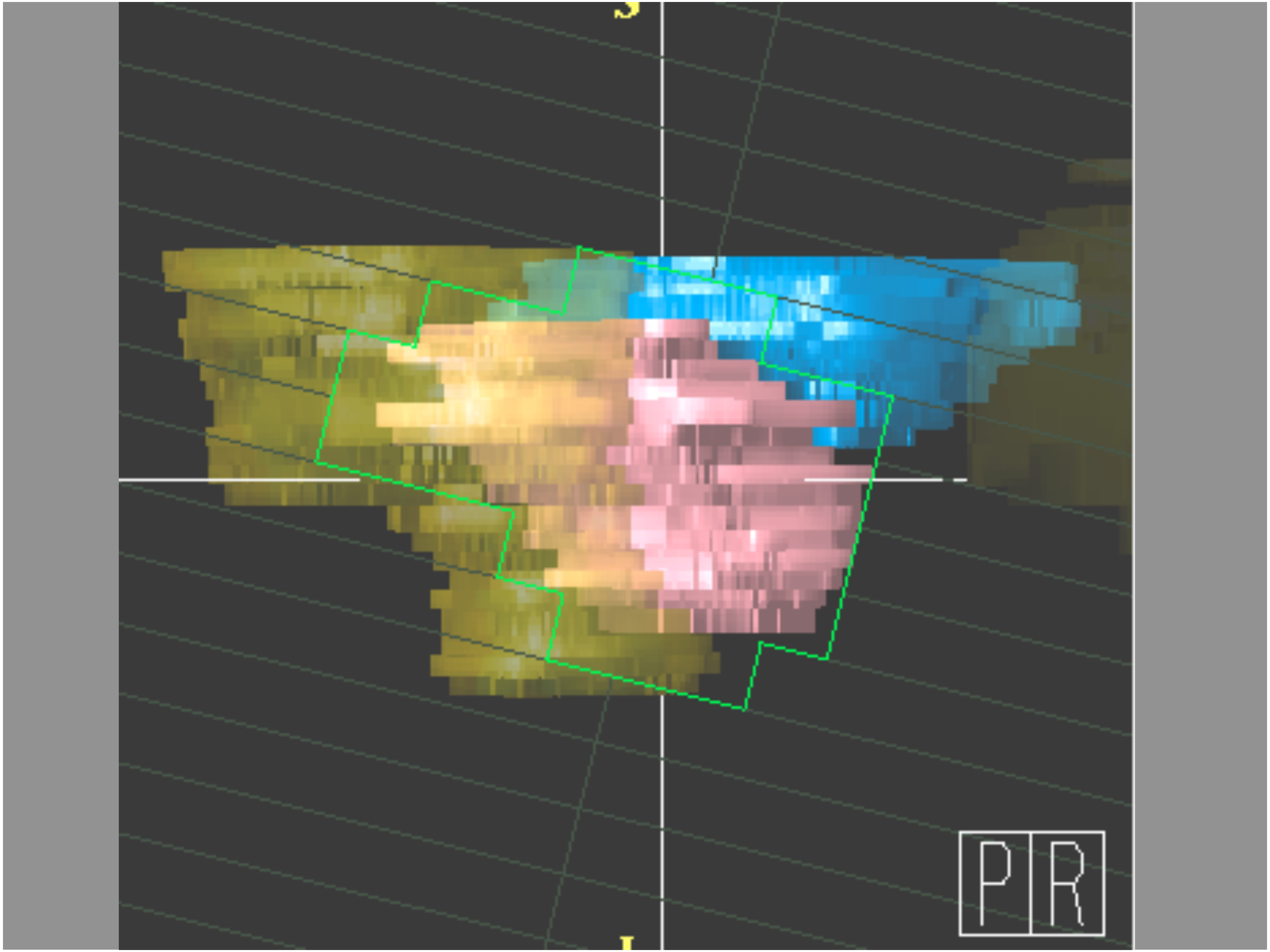
Fig. 5. Logistic response models for gastrointestinal and genito-urinary radiation sequelae.

From:G.E.Hanks et. al., IJROBP, June 1998

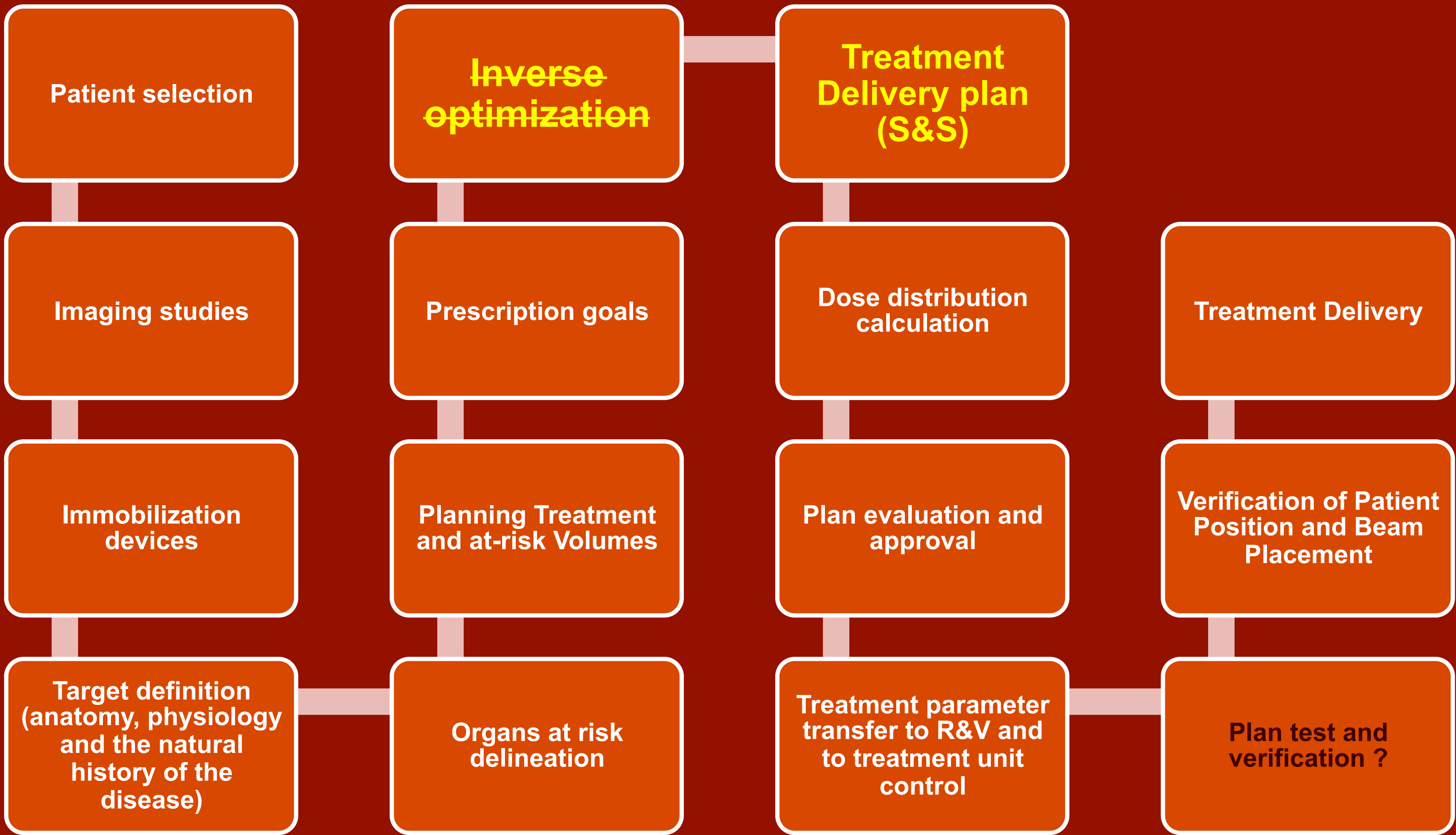
The "drama" of Radiotherapy

- We can give radiation doses so high that they can sterilize any tumor… and "cure" any localized cancer
- If it were not for those inopportune organs and tissues that get in our way and prevent us from doing the best of jobs…


Beam's eye view
Show couch
S
P
A
I
R


P R

The Radiotherapy Process - IMRT



Classic Methods of Intensity Modulation

- **Wedge** *(1-D linear)*
- **Compensator** *(2-D)*
- **Coned-down boost field** *(bi-level)*

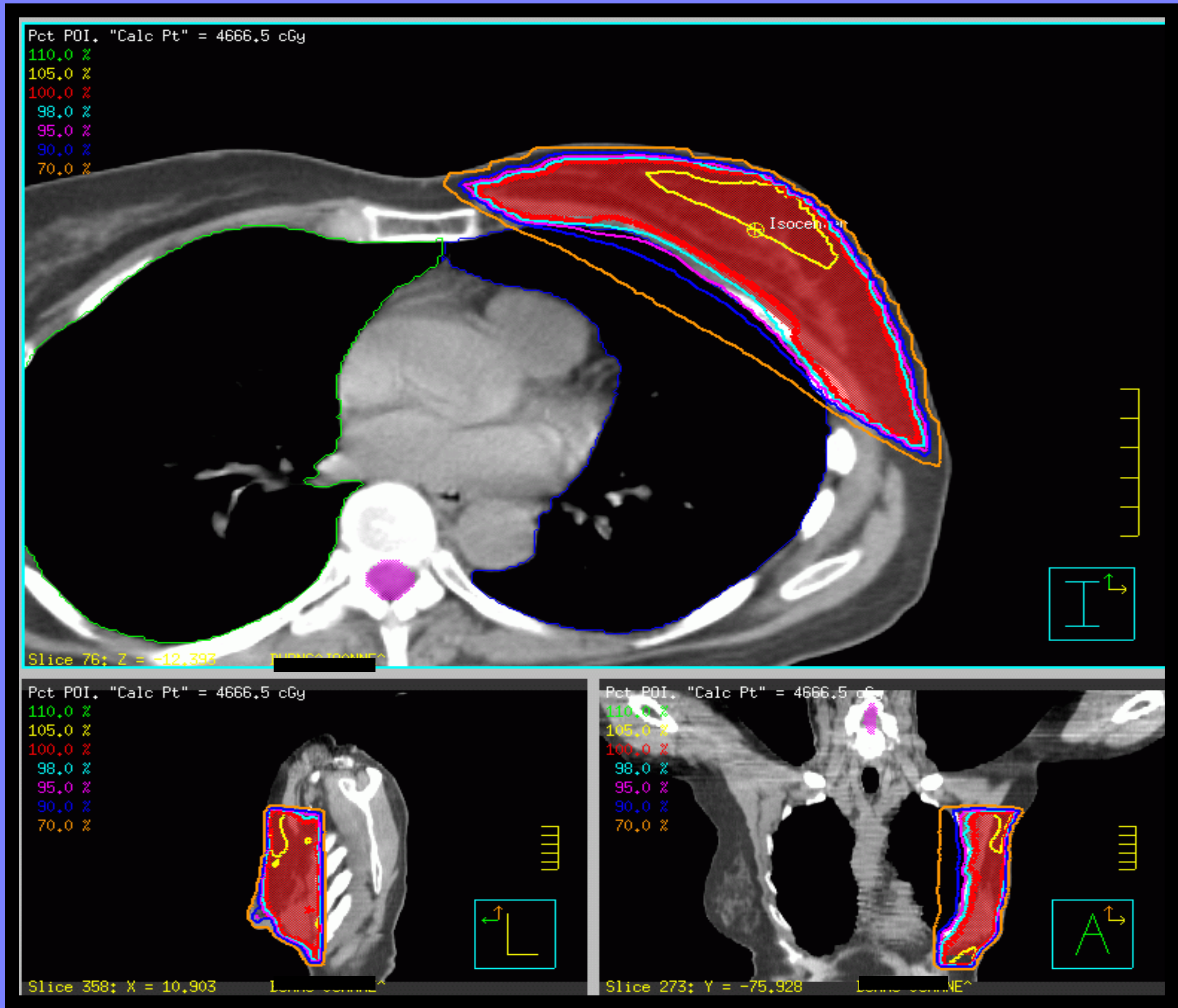
Dynamic Methods of Intensity Modulation

Independent Jaws: ***Dynamic wedges***

Multileaf: ***discrete, continuous***

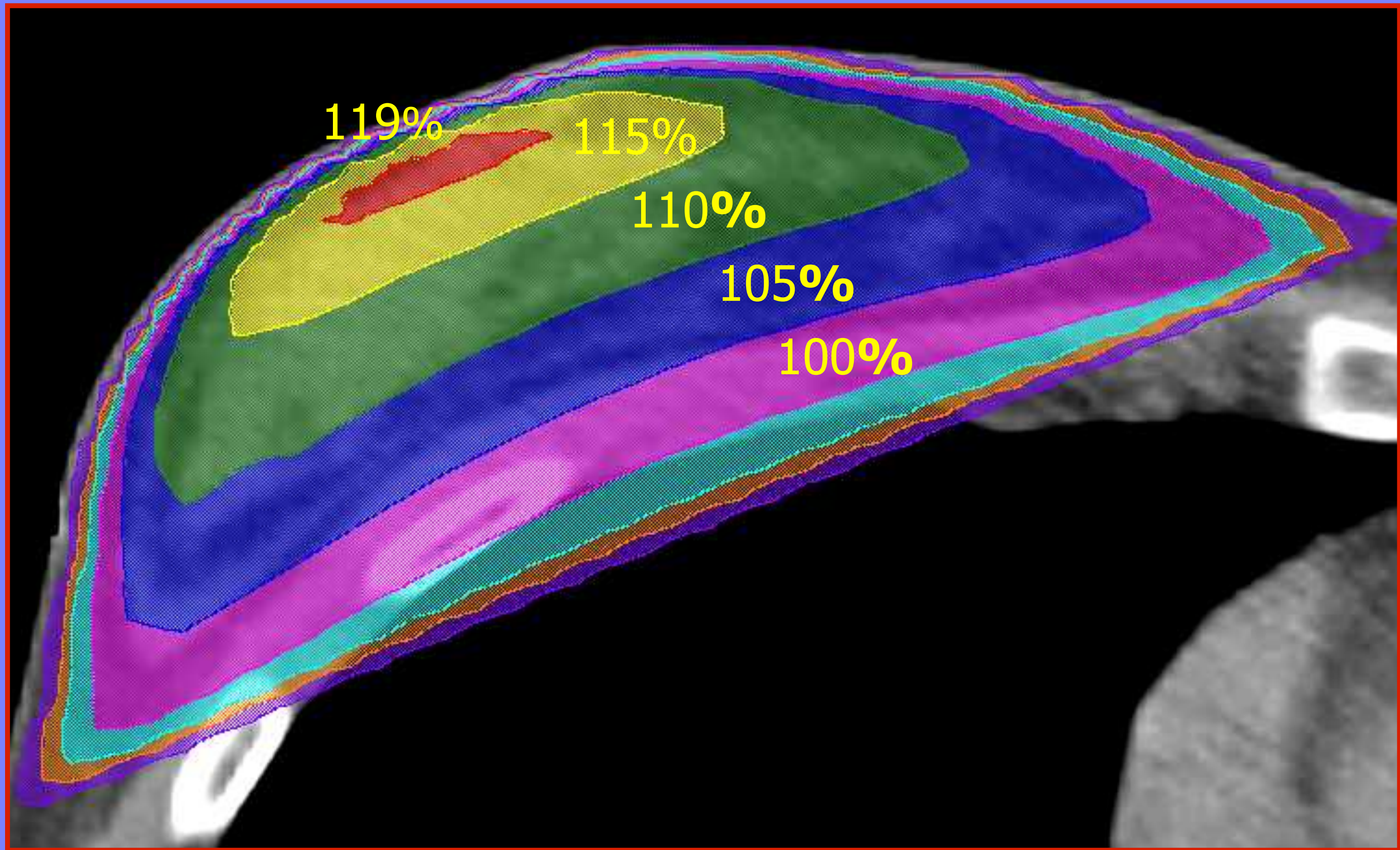
Slit field: ***Peacock, Tomotherapy***

Forward Planning (Poor Man's IMRT)



DPF, NSUH_LIJ,NY,USA

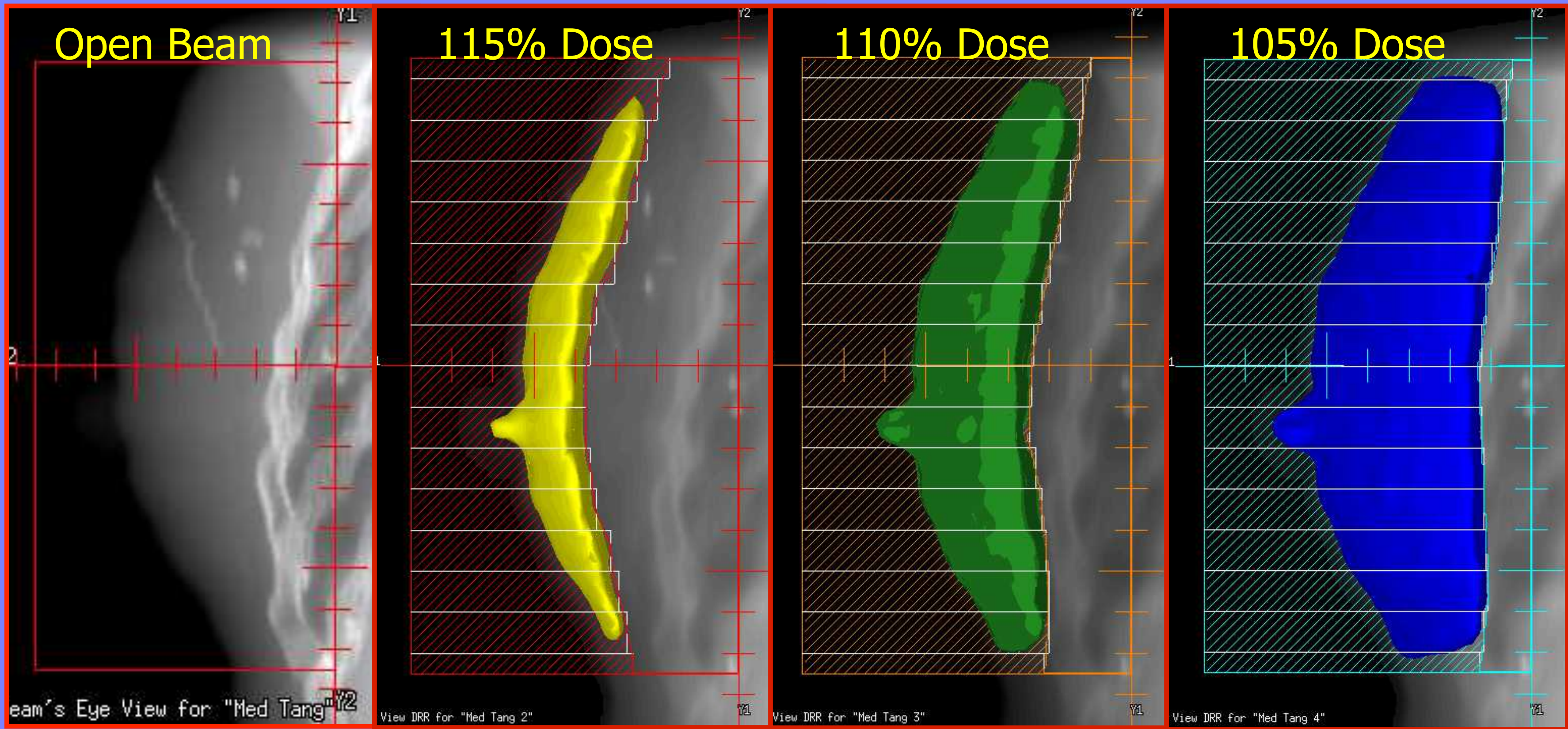
Initial Dose Distribution (No Wedges)



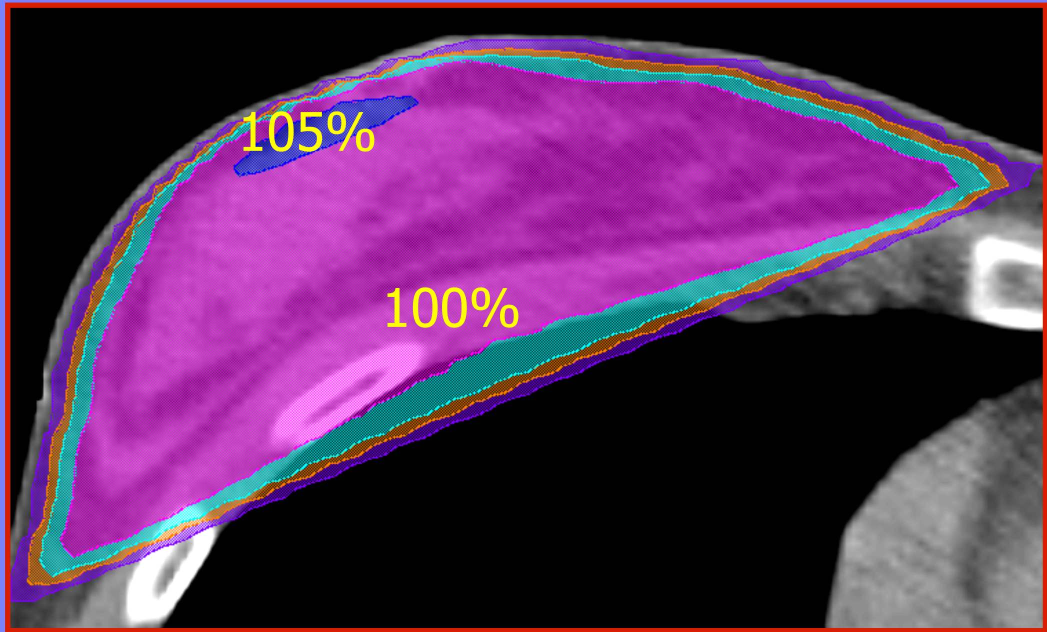
DPF, NSUH_LIJ,NY,USA

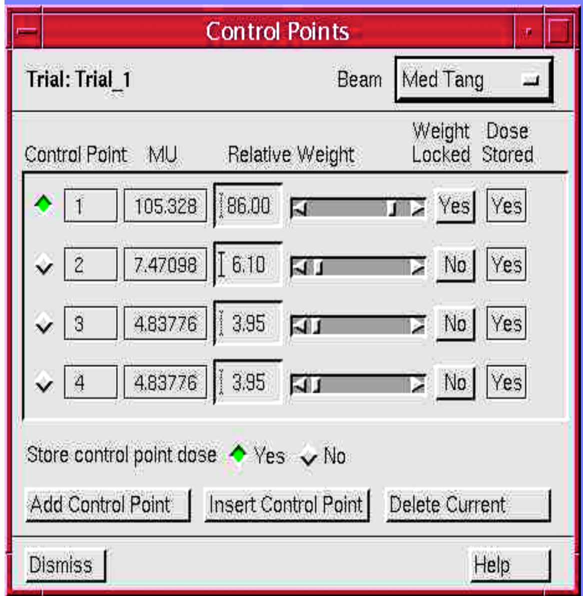
Create Three New MLC Segments

Draw new segments directly on DRRs



Interactively Adjust Control Point (Segment) Weights to Optimize Plan





DPF, NSUH_LIJ,NY,USA

IMRT *is* CONFORMAL THERAPY

Conforms (high) dose to the target volume for improved tumor control

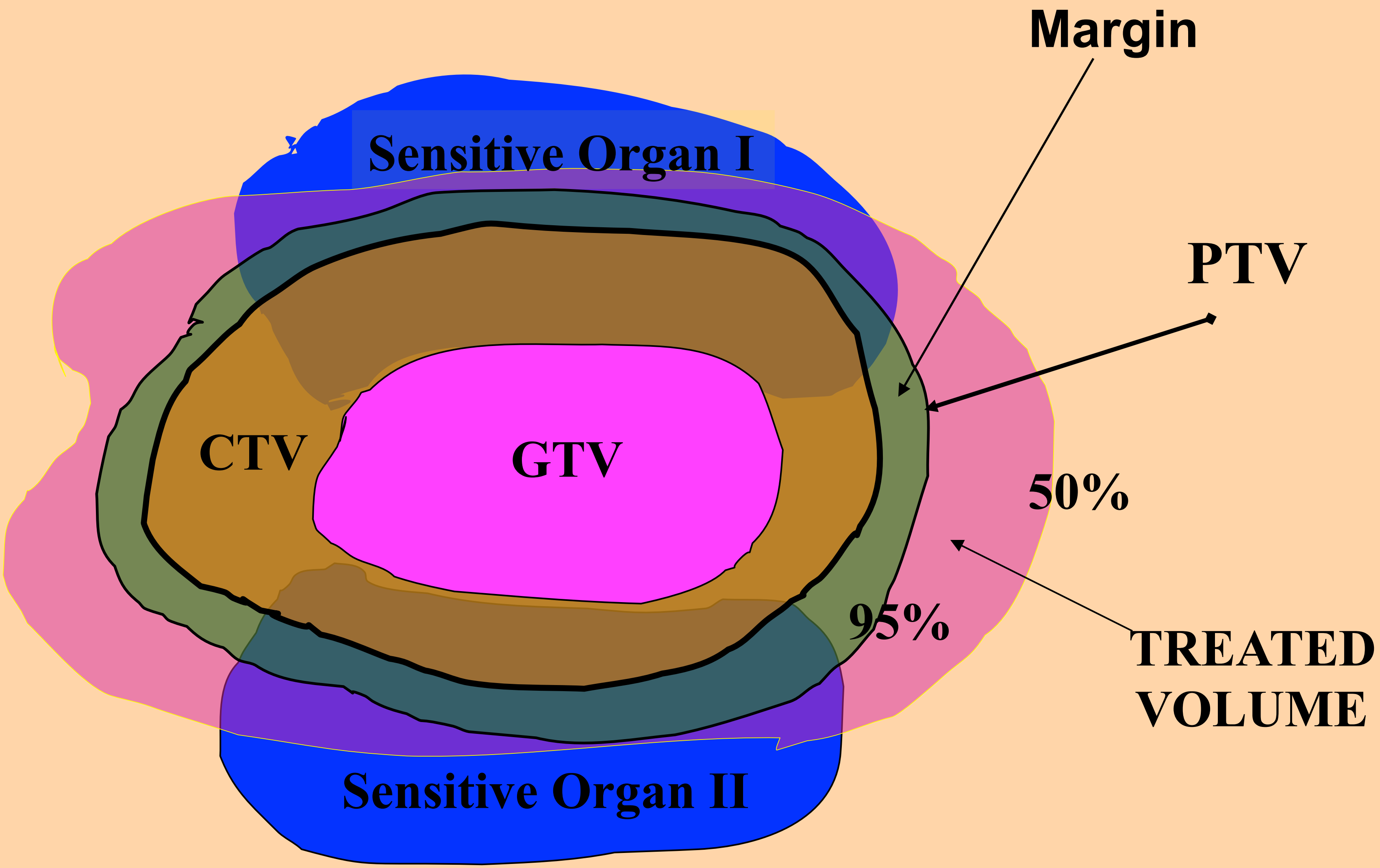
Conforms (low) dose to sensitive structures to reduce complications

AND

Adds modulation to the geometric shaping of the beam

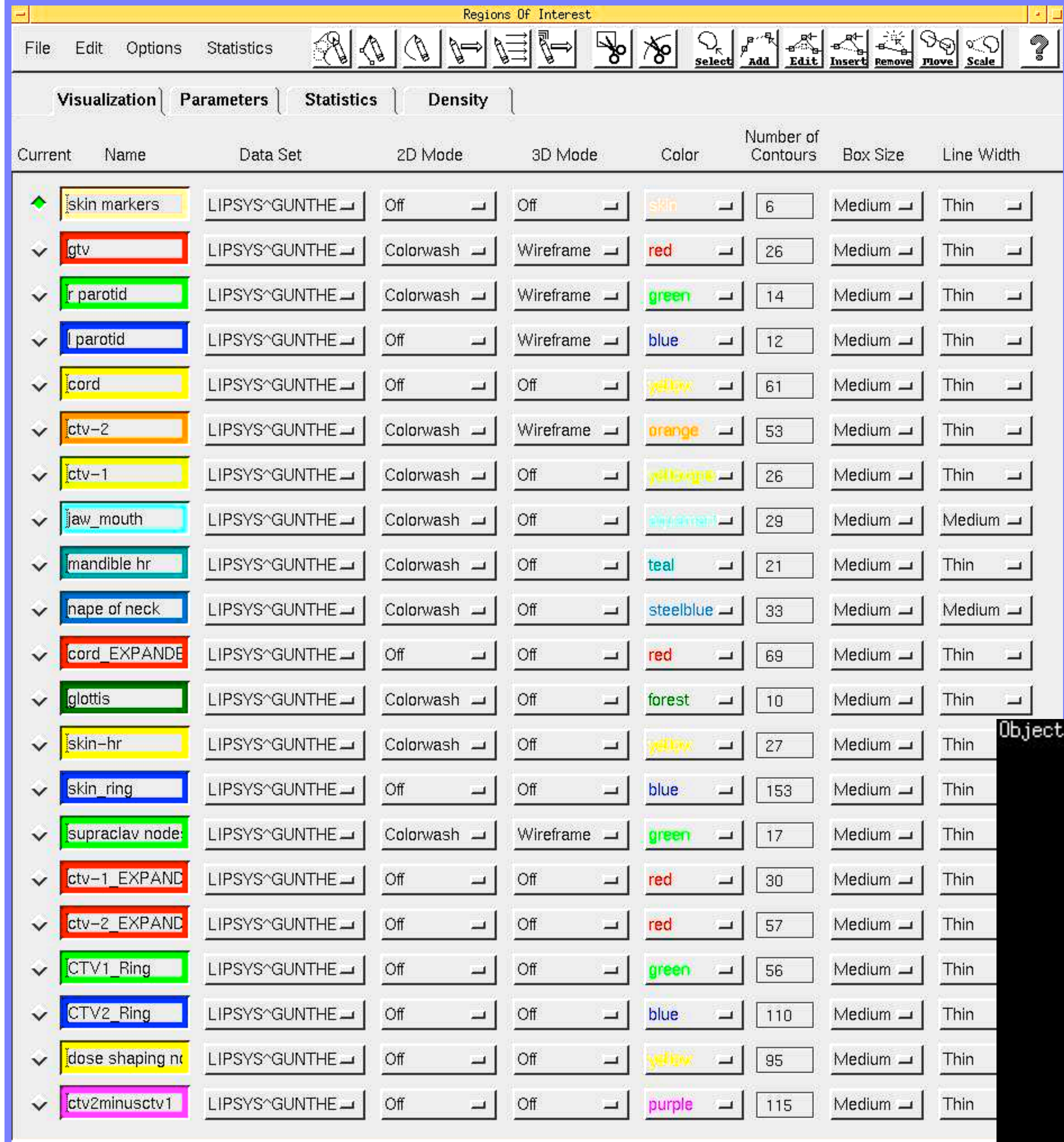
The Radiotherapy Process - IMRT

Relation between Volumes



ICRU-50 and ICRU-62

Structure Definitions Typical of an Head and Neck IMRT Treatment Design

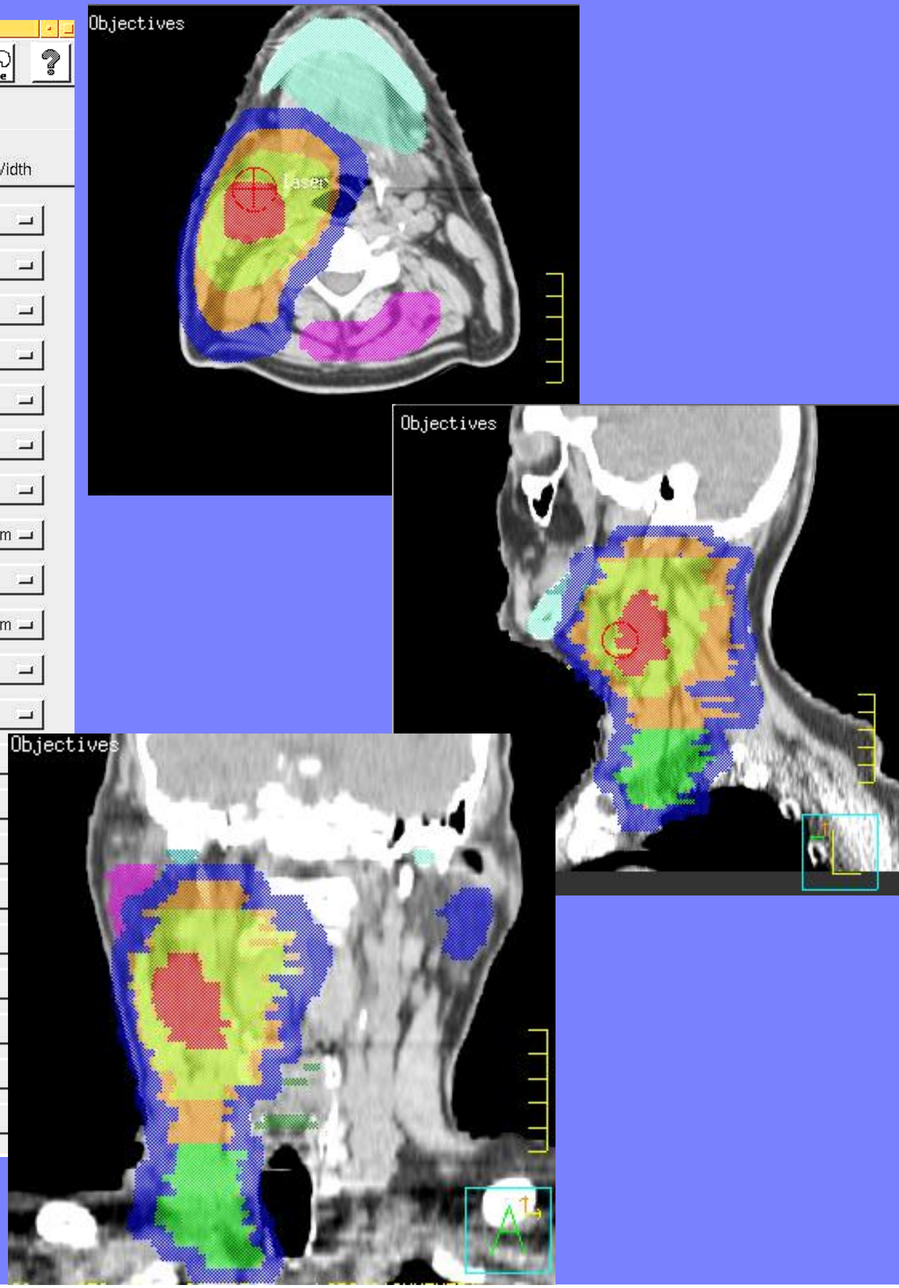


Regions Of Interest

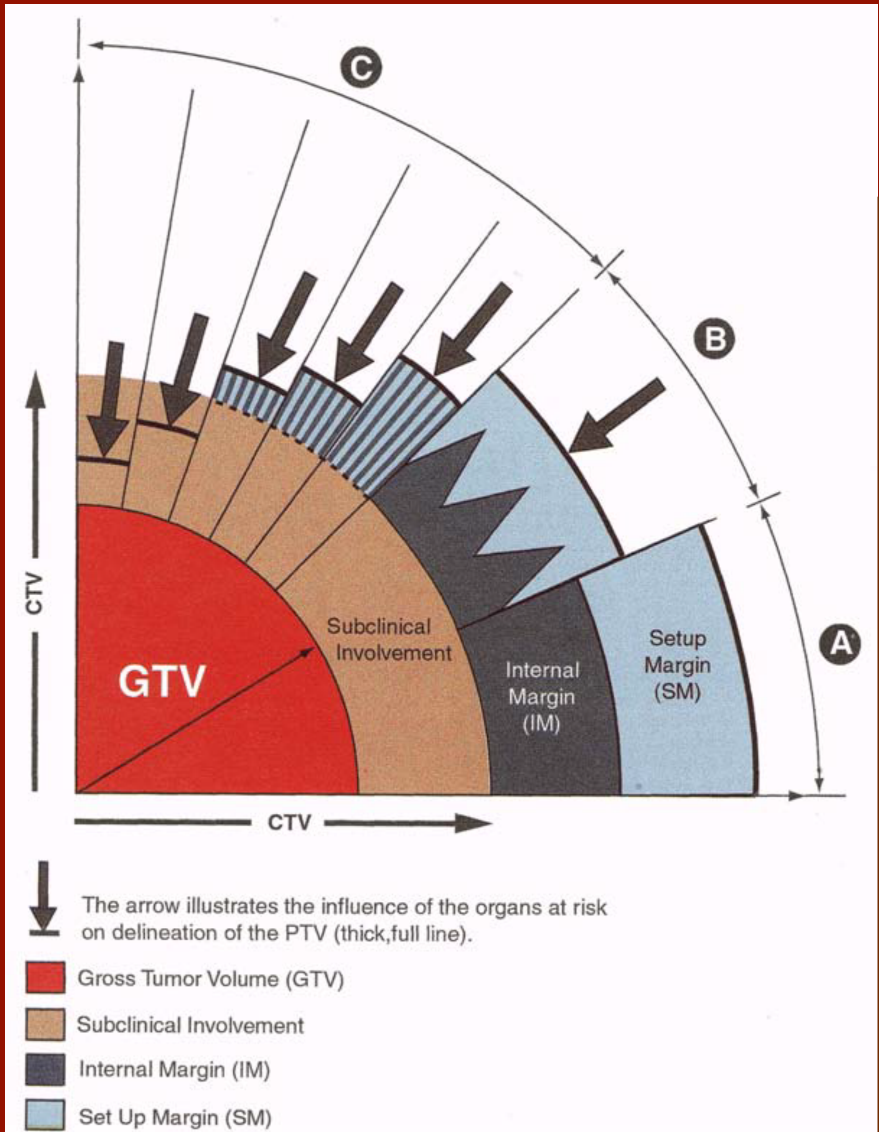
File | Edit | Options | Statistics

Visualization | Parameters | Statistics | Density

Current	Name	Data Set	2D Mode	3D Mode	Color	Number of Contours	Box Size	Line Width
◆	skin markers	LIPSYS^GUNTHE	Off	Off	skin	6	Medium	Thin
✓	gtv	LIPSYS^GUNTHE	Colorwash	Wireframe	red	26	Medium	Thin
✓	r parotid	LIPSYS^GUNTHE	Colorwash	Wireframe	green	14	Medium	Thin
✓	l parotid	LIPSYS^GUNTHE	Off	Wireframe	blue	12	Medium	Thin
✓	cord	LIPSYS^GUNTHE	Off	Off	yellow	61	Medium	Thin
✓	ctv–2	LIPSYS^GUNTHE	Colorwash	Wireframe	orange	53	Medium	Thin
✓	ctv–1	LIPSYS^GUNTHE	Colorwash	Off	yellowgre	26	Medium	Thin
✓	jaw_mouth	LIPSYS^GUNTHE	Colorwash	Off	aquamari	29	Medium	Medium
✓	mandible hr	LIPSYS^GUNTHE	Colorwash	Off	teal	21	Medium	Thin
✓	nape of neck	LIPSYS^GUNTHE	Colorwash	Off	steelblue	33	Medium	Medium
✓	cord_EXPANDE	LIPSYS^GUNTHE	Off	Off	red	69	Medium	Thin
✓	glottis	LIPSYS^GUNTHE	Colorwash	Off	forest	10	Medium	Thin
✓	skin–hr	LIPSYS^GUNTHE	Colorwash	Off	yellow	27	Medium	Thin
✓	skin_ring	LIPSYS^GUNTHE	Off	Off	blue	153	Medium	Thin
✓	supraclav node:	LIPSYS^GUNTHE	Colorwash	Wireframe	green	17	Medium	Thin
✓	ctv–1_EXPAND	LIPSYS^GUNTHE	Off	Off	red	30	Medium	Thin
✓	ctv–2_EXPAND	LIPSYS^GUNTHE	Off	Off	red	57	Medium	Thin
✓	CTV1_Ring	LIPSYS^GUNTHE	Off	Off	green	56	Medium	Thin
✓	CTV2_Ring	LIPSYS^GUNTHE	Off	Off	blue	110	Medium	Thin
✓	dose shaping nc	LIPSYS^GUNTHE	Off	Off	yellow	95	Medium	Thin
✓	ctv2minusctv1	LIPSYS^GUNTHE	Off	Off	purple	115	Medium	Thin



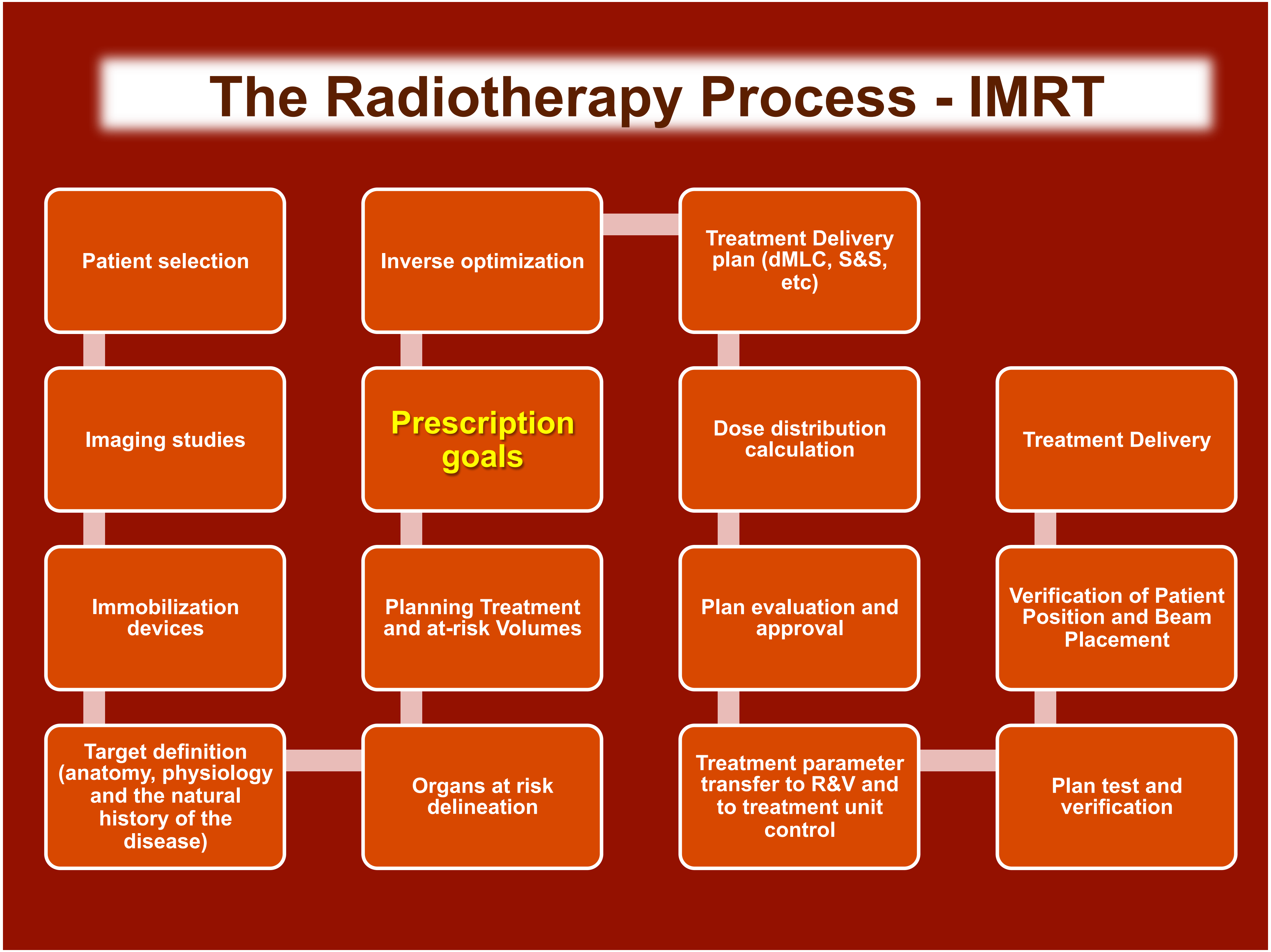
DPF, NSUH_LIJ,NY,USA



Uncertainties
(ICRU 62)

- Combined uncertainties to define the PTV from the GTV
  - (A)=linear addition of margins
  - (B)=probabilistic addition of IM and SM
  - (C)=global safety margin (empirical compromise between adequate coverage of GTV and unacceptable irradiation of organs at risk (OARs)

Immobilization is of major importance to reduce setup margins (SM)


The Radiotherapy Process - IMRT
Patient selection
Imaging studies
Immobilization devices
Target definition (anatomy, physiology and the natural history of the disease)
Organs at risk delineation
Planning Treatment and at-risk Volumes
Prescription goals
Inverse optimization
Treatment Delivery plan (dMLC, S&S, etc)
Dose distribution calculation
Plan evaluation and approval
Treatment parameter transfer to R&V and to treatment unit control
Plan test and verification
Verification of Patient Position and Beam Placement
Treatment Delivery

A new perspective on what is “the prescription”

- Identification of the Target is a “must”
- Definition of the desired Target DVH
- Determine the desired DVH’s for Sensitive Structures
- Assign Uncertainties to the Volumes
- Set *Goals* and *Priorities* or *Penalties*

The new “fashion” in prescriptions

Optimization

Structures and Constraints

Structure	Constraint						
CTV		**Volume [cc]:**	**142**	**Points:**	**7150**	**Resolution [mm]:**	**3.00**
	Upper	Volume [%]:	10.0	Dose [cGy]:	5700.0	Priority:	80
	Upper		5.0		5950.0		90
	Lower	Volume [%]:	100.0	Dose [cGy]:	5400.0	Priority:	110
Cooling Ring		Volume [cc]:	657	Points:	33574	Resolution [mm]:	3.00
	Upper	Volume [%]:	10.0	Dose [cGy]:	2600.0	Priority:	85
	Upper		0.0		3000.0		95
Cord		Volume [cc]:	11	Points:	2876	Resolution [mm]:	1.72
	Upper	Volume [%]:	2.0	Dose [cGy]:	4200.0	Priority:	85
External		Volume [cc]:	3213	Points:	135528	Resolution [mm]:	3.00
L cochlea		Volume [cc]:	1	Points:	1314	Resolution [mm]:	1.00
	Upper	Volume [%]:	50.0	Dose [cGy]:	2050.0	Priority:	100
	Upper		10.0		4300.0		75
L optic nerve		Volume [cc]:	1	Points:	1287	Resolution [mm]:	1.00
	Upper	Volume [%]:	20.0	Dose [cGy]:	4000.0	Priority:	75
LT Eye		Volume [cc]:	8	Points:	2552	Resolution [mm]:	1.52
	Upper	Volume [%]:	20.0	Dose [cGy]:	1500.0	Priority:	80
PTV 3mm		Volume [cc]:	185	Points:	8965	Resolution [mm]:	3.00
	Upper	Volume [%]:	10.0	Dose [cGy]:	5950.0	Priority:	80
	Upper		5.0		5950.0		90
	Lower	Volume [%]:	95.0	Dose [cGy]:	5400.0	Priority:	100
	Lower		98.0		5100.0		95
R cochlea		Volume [cc]:	1	Points:	646	Resolution [mm]:	1.00
	Upper	Volume [%]:	50.0	Dose [cGy]:	2050.0	Priority:	100
	Upper		10.0		4300.0		85
R optic nerve		Volume [cc]:	1	Points:	941	Resolution [mm]:	1.00
	Upper	Volume [%]:	20.0	Dose [cGy]:	4000.0	Priority:	75

DVH limits – reference values

E45 | Xerostomia

	Structure	Volume (cc)	Total Dose (Gy)	Max Dose (Gy)	Endpoint	Notes	Reference
34	Kidney	10%	18	20	Renal insufficiency		Spalding
35	Lens			25	Cataracts		RTOG 0615
36	Lens				Cataracts	Avoid direct beam exposure	RTOG 0513
37	Liver	50%	35		Clinical hepatitis		RTOG 0436
38	Liver	100%	30		Clinical hepatitis		RTOG 0436
39	Lung minus GTV	37%	20		Clinical pneumonitis		RTOG 0623
40	Lung minus GTV	Mean	20		Clinical pneumonitis		RTOG 0623
41	Mandible	1	75	70		Use either limit	RTOG 0225
42	Optic nerves	1%	60	54		1% of PTV, use either limit	RTOG 0225
43	Oral cavity (exclude PTV)	Mean	40				RTOG 0615
44	Parotid gland (both)	20	20		Xerostomia	Only if sparing both glands	RTOG 0912
45	Parotid gland (one)	50%	30		Xerostomia	Only if sparing one gland	RTOG 0912
46	Parotid gland (one)	Mean	26		Xerostomia	Only if sparing one gland	RTOG 0912
47	Penile bulb	Mean	52.5				RTOG 0126
48	Rectum	15%	75				RTOG 0126
49	Rectum	25%	70				RTOG 0126
50	Rectum	35%	65				RTOG 0126
51	Rectum	50%	60				RTOG 0126
52	Small bowel	65	45	50			RTOG 0822
53	Small bowel	100	40	50			RTOG 0822
54	Small bowel	180	35	50			RTOG 0822
55	Spinal cord			45	Myelitis		RTOG 0623
56	Spinal cord	0.03	48		Myelitis		RTOG 0619
57	Stomach	2%	50	54			Spalding

Conventional | SRS, SBRS, 1 fx | SBRT, 3 fx | SBRT, 5 fx | BED | Info

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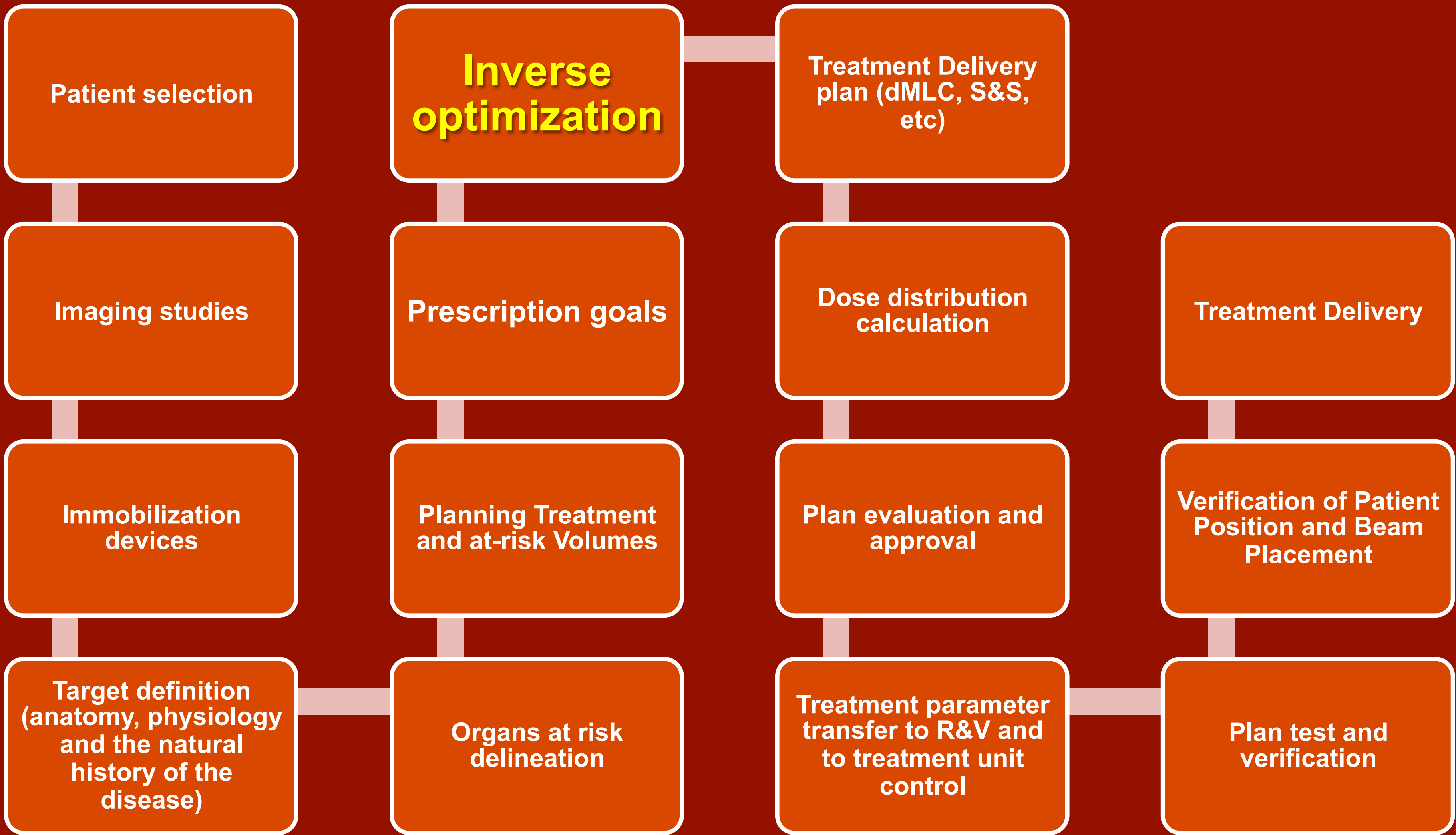
The Radiotherapy Process - IMRT



Inverse Planning Problem

Dose to point i:

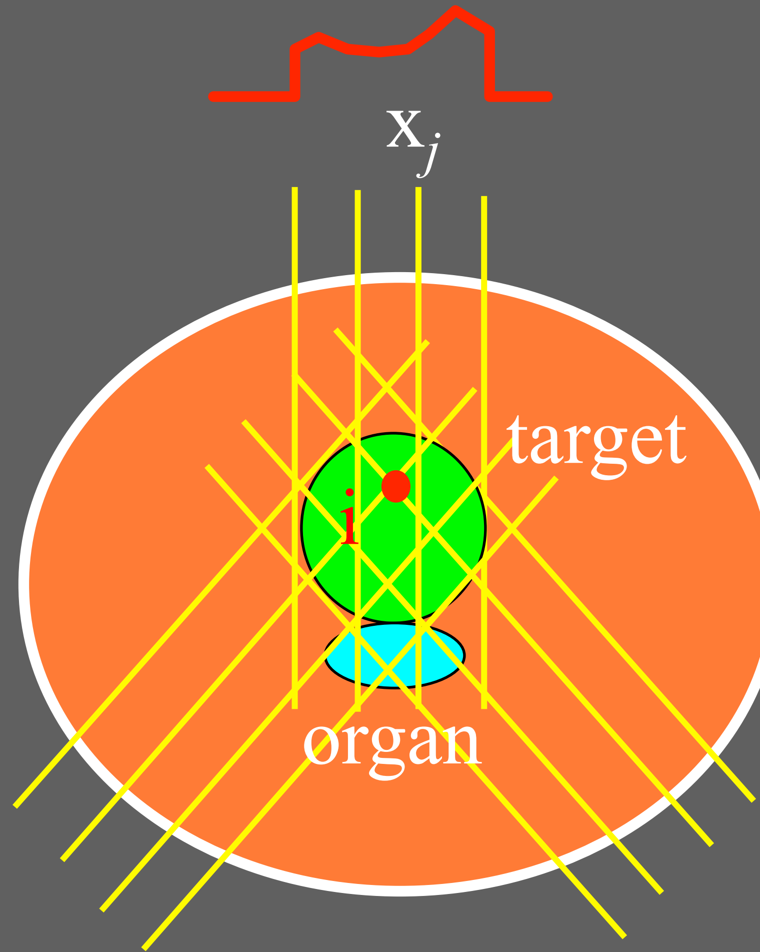
$$D_i = x_1 d_{1i} + \bullet\bullet\bullet + x_J d_{Ji}$$
$$= \mathbf{x} \bullet \mathbf{d}_i$$

Objective function:

$$F(\mathbf{x}) = \sum_i w_i \bullet (D_i - P_i)^2$$

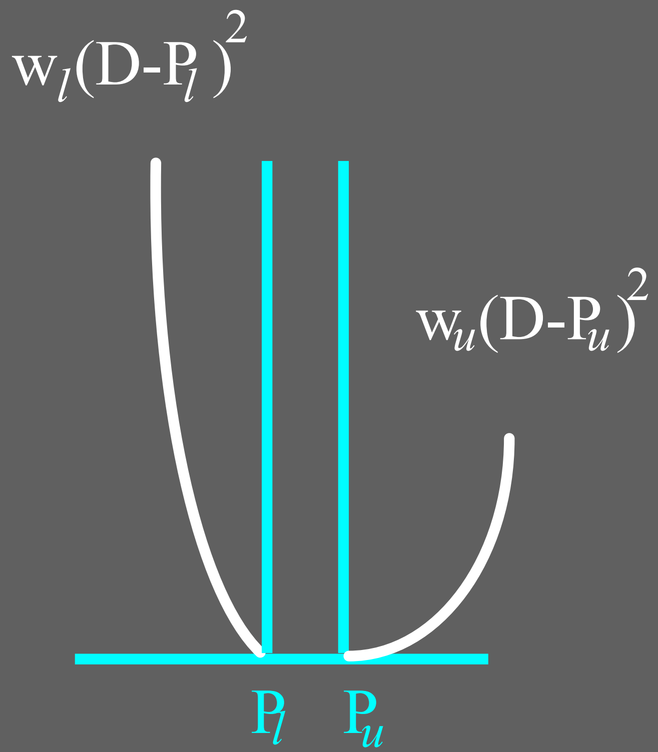
Minimize F(**x**):

$$\nabla F(\mathbf{x}) = 2 \sum_i w_i \bullet (D_i - P_i)\, \mathbf{d}_i = 0$$

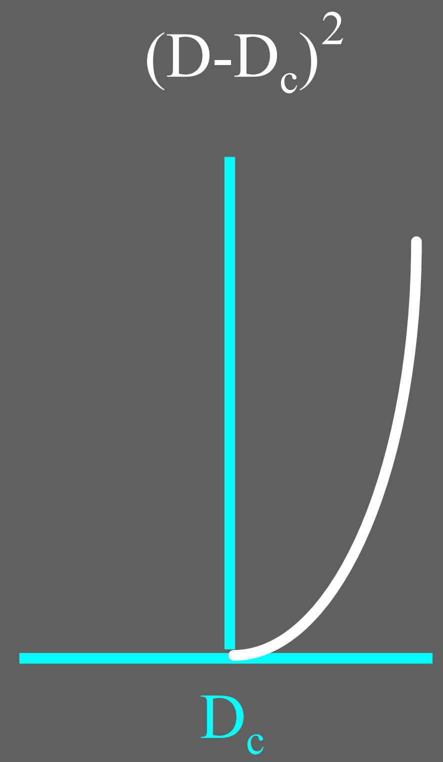


Types of Objective Functions

target



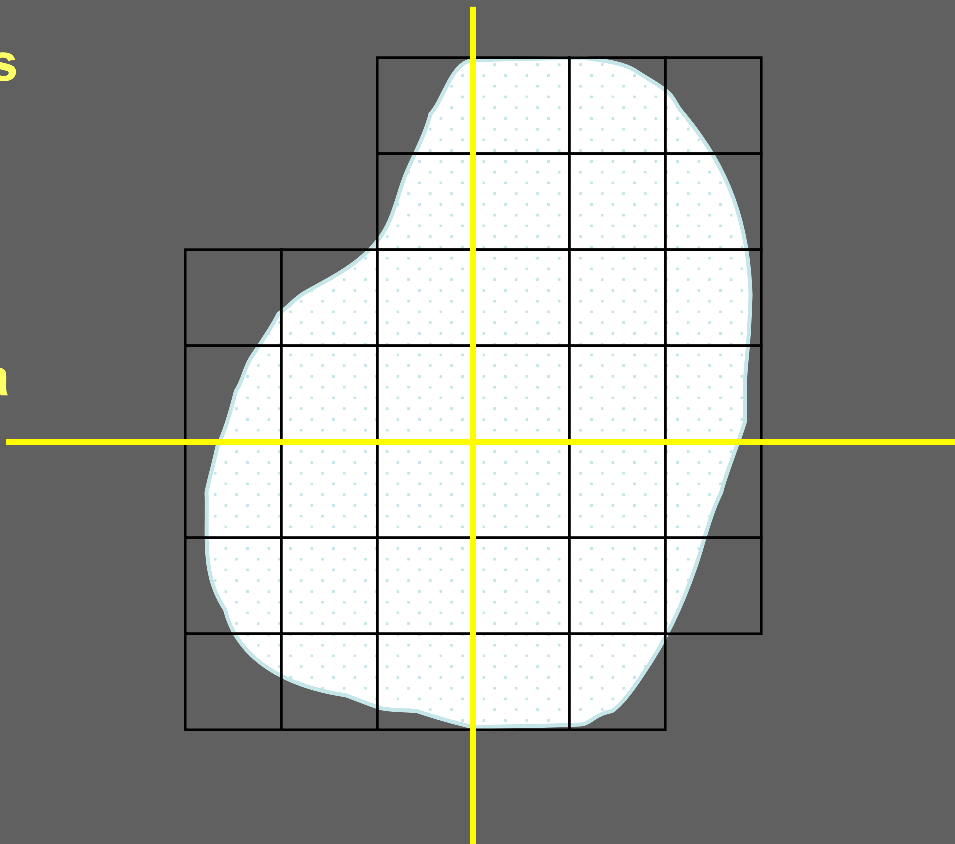
organ at risk



Plan Optimization

Conceptually, plan optimization proceeds as follows:

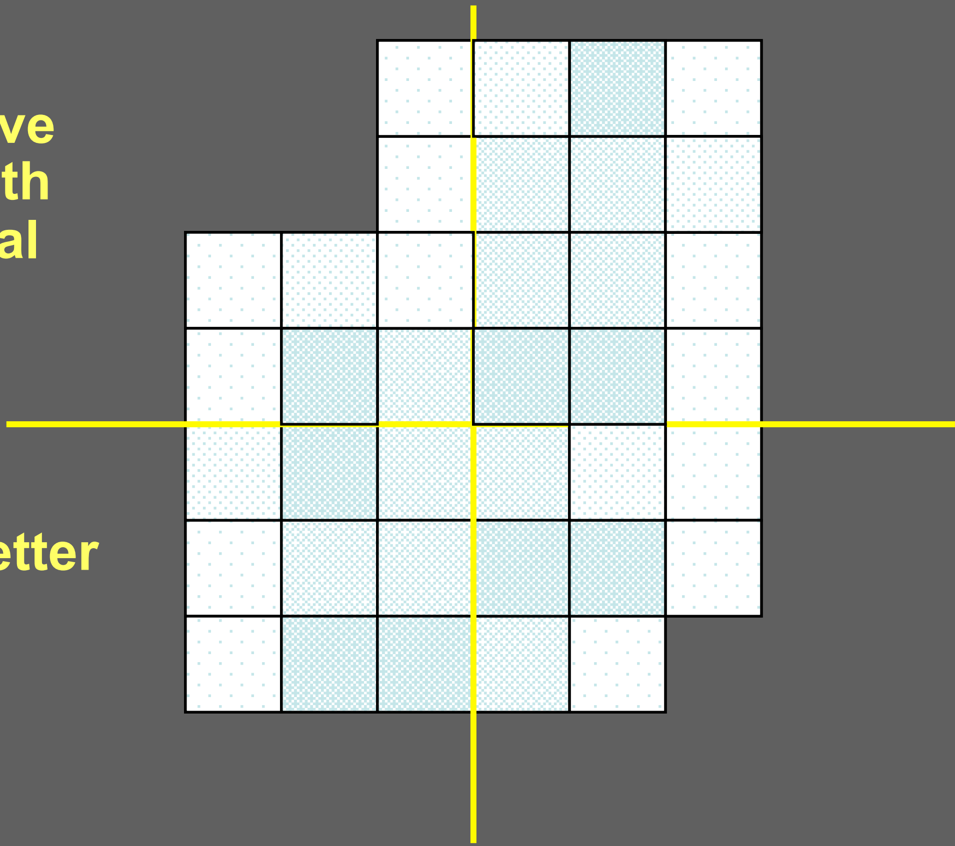
- For each treatment field, a beam's-eye-view of the target is used to divide the field into pencil-beams.
- For simplicity, assume the pencil-beams are centered on a 1 cm x 1 cm grid.

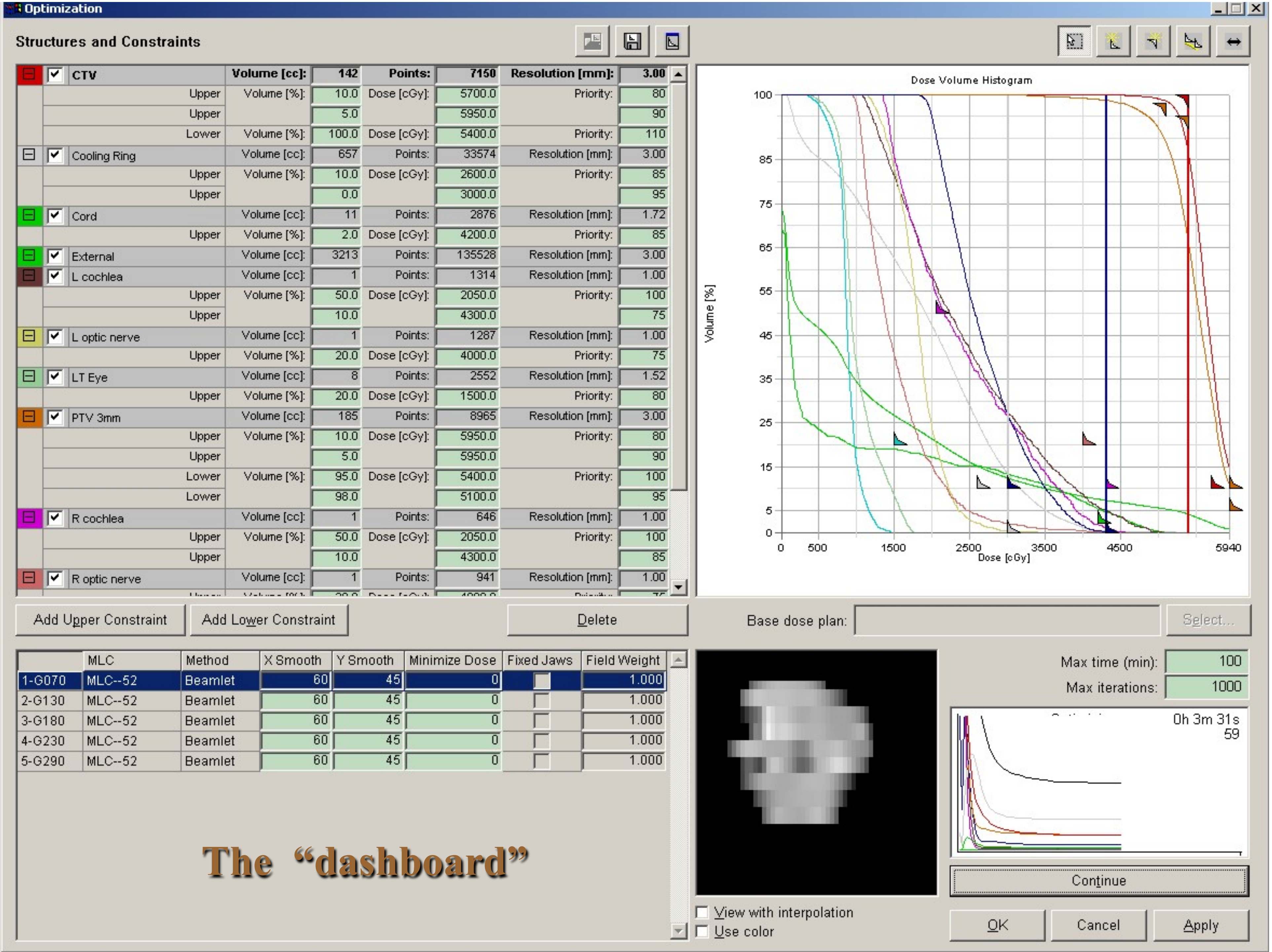


Plan Optimization

During optimization:

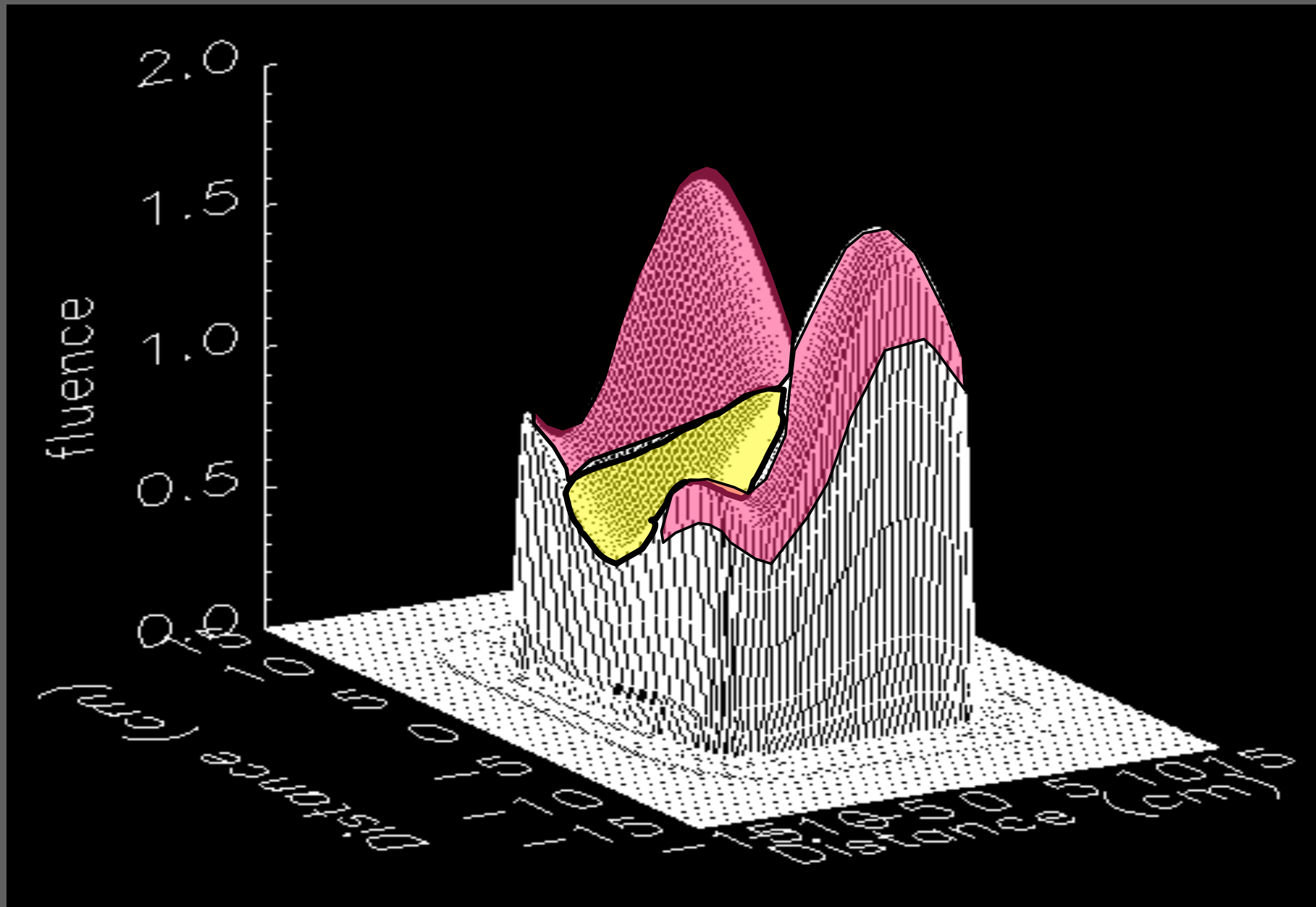
- **The weight of each pencil beam in each field is changed during each iteration.**
- **After each iteration, the objective function is calculated, along with the DVH of the target and critical structures.**
- **The optimization iterations continue until the objective function is no-longer getting better or the maximum number of iterations has been achieved.**





The “dashboard”

Posterior Field Intensity Profile - Prostate

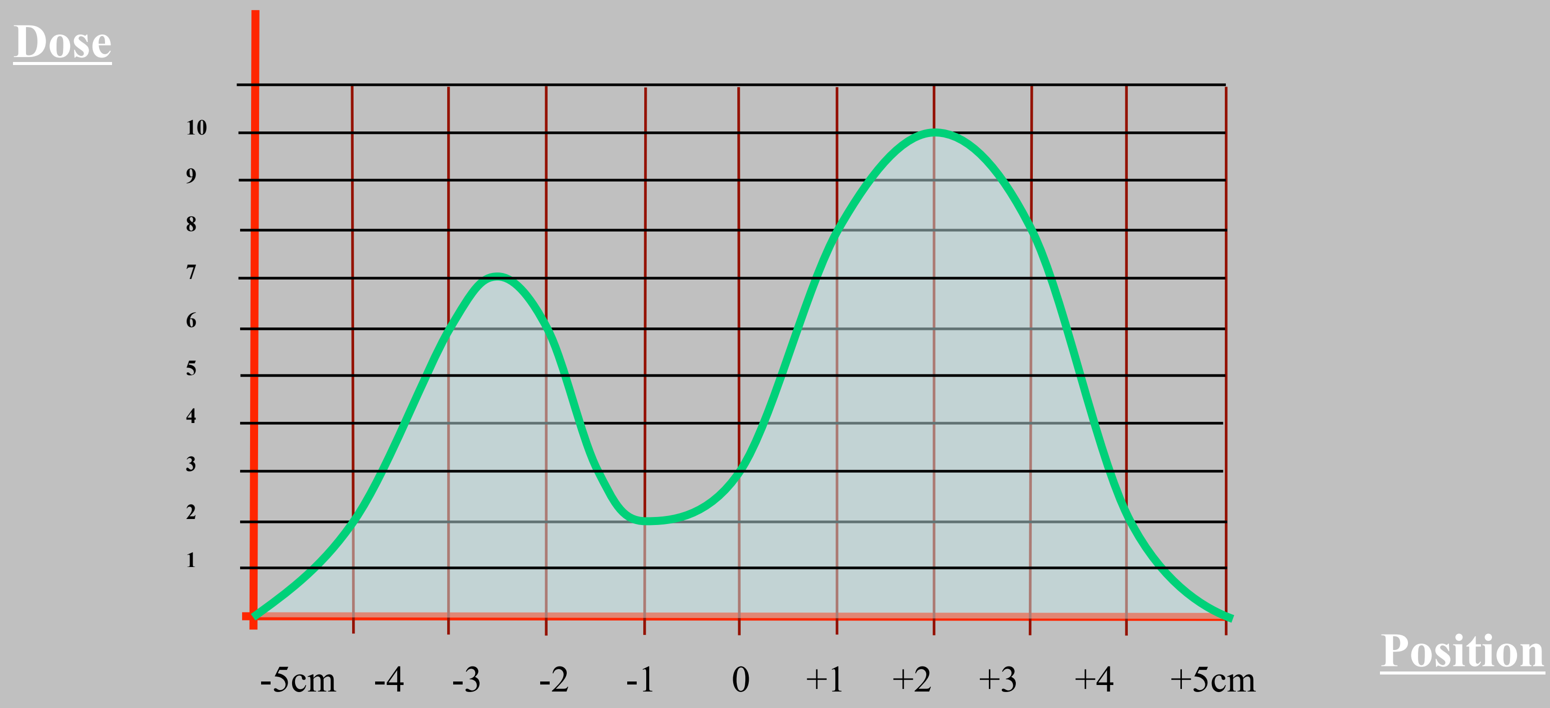


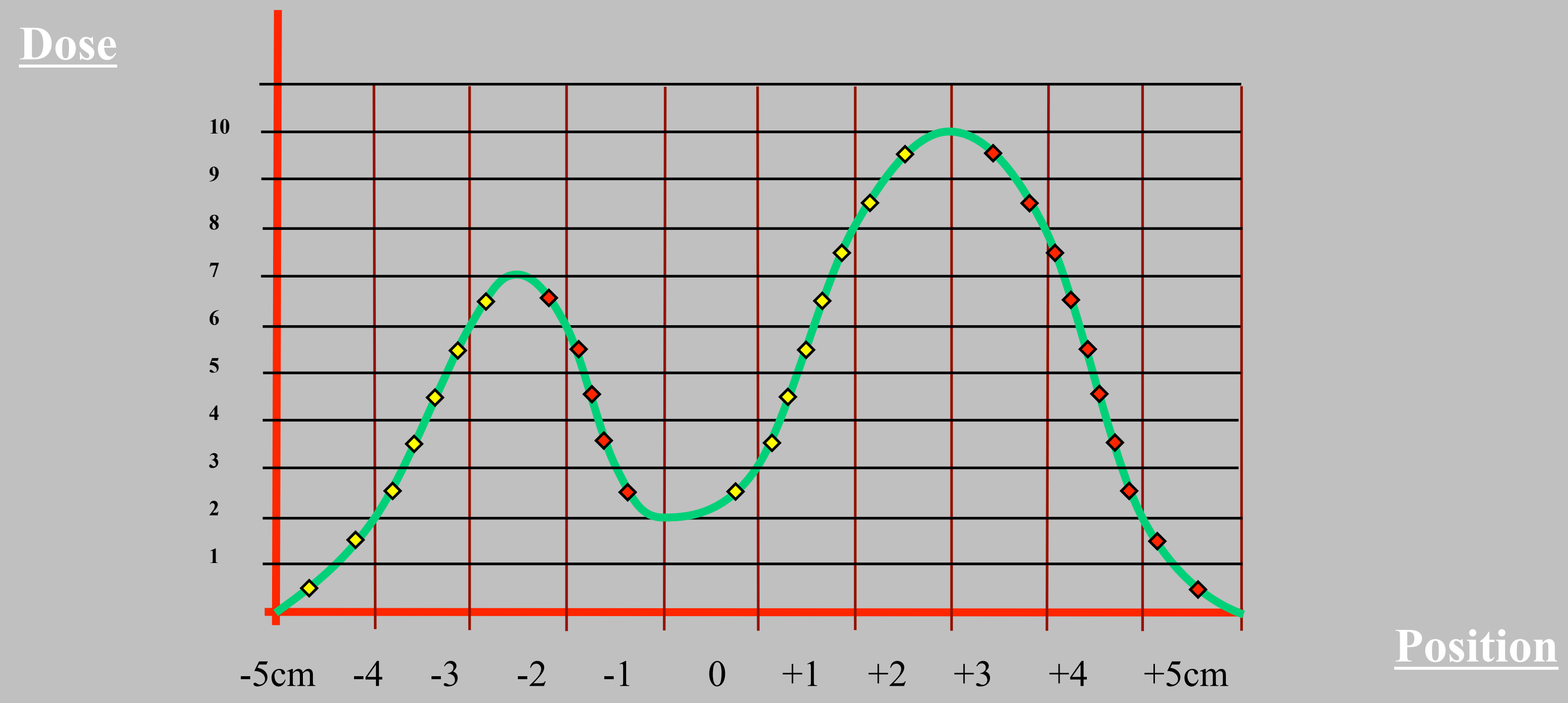
Delivery Methods to Modulate the Intensity

- **Custom physical compensators**
- **Sliding Window with d-MLC**
- **“Step and Shoot” with MLC**
- **Slit Arc with binary MLC (Tomotherapy)**
- **VMAT**
- **RapidArc**

- **After the ‘optimization’ all require a final calculation of fluence and dose distribution !**

How Can We Make Any Intensity Shape with an MLC?





Dose
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-5cm
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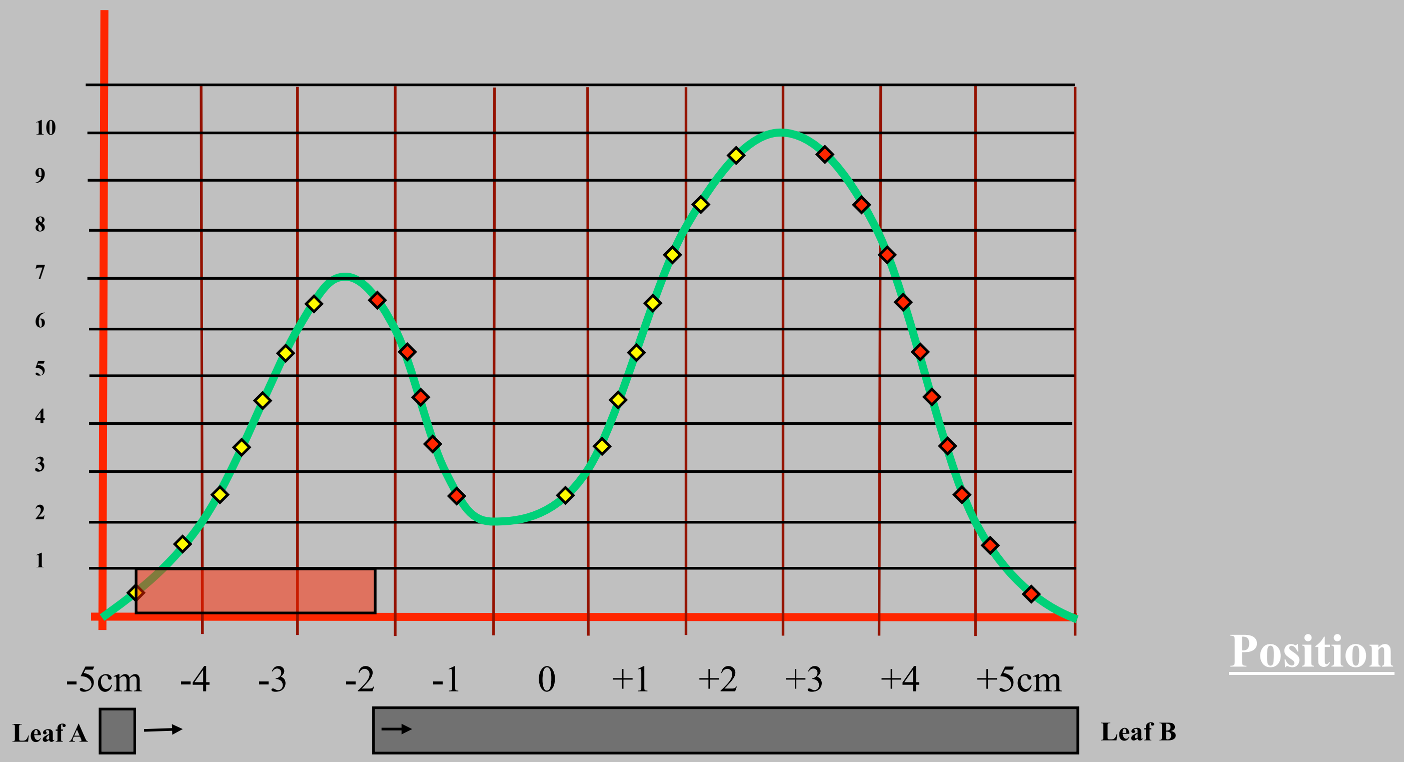
0
+1
+2
+3
+4
+5cm
Position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-2
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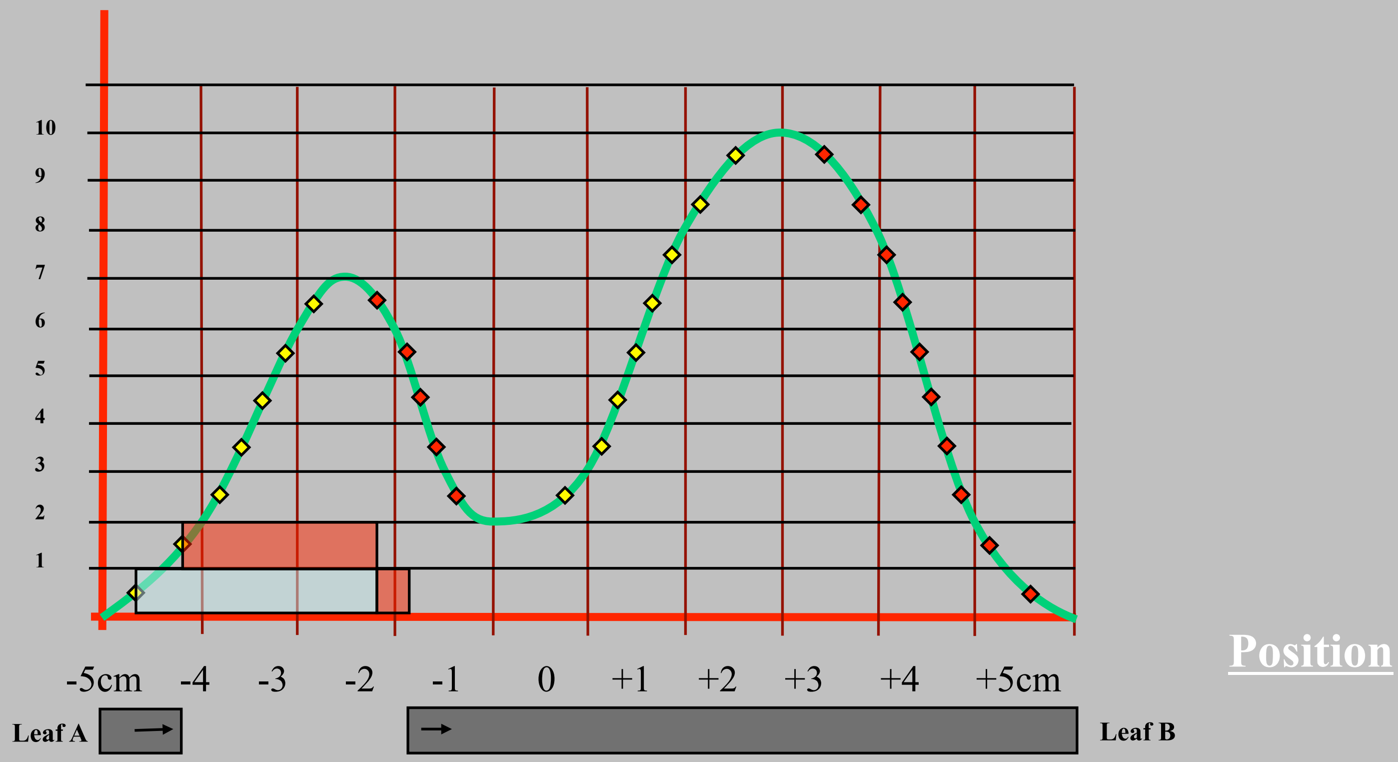
0
+1
+2
+3
+4
+5cm
Position
Leaf A
Leaf B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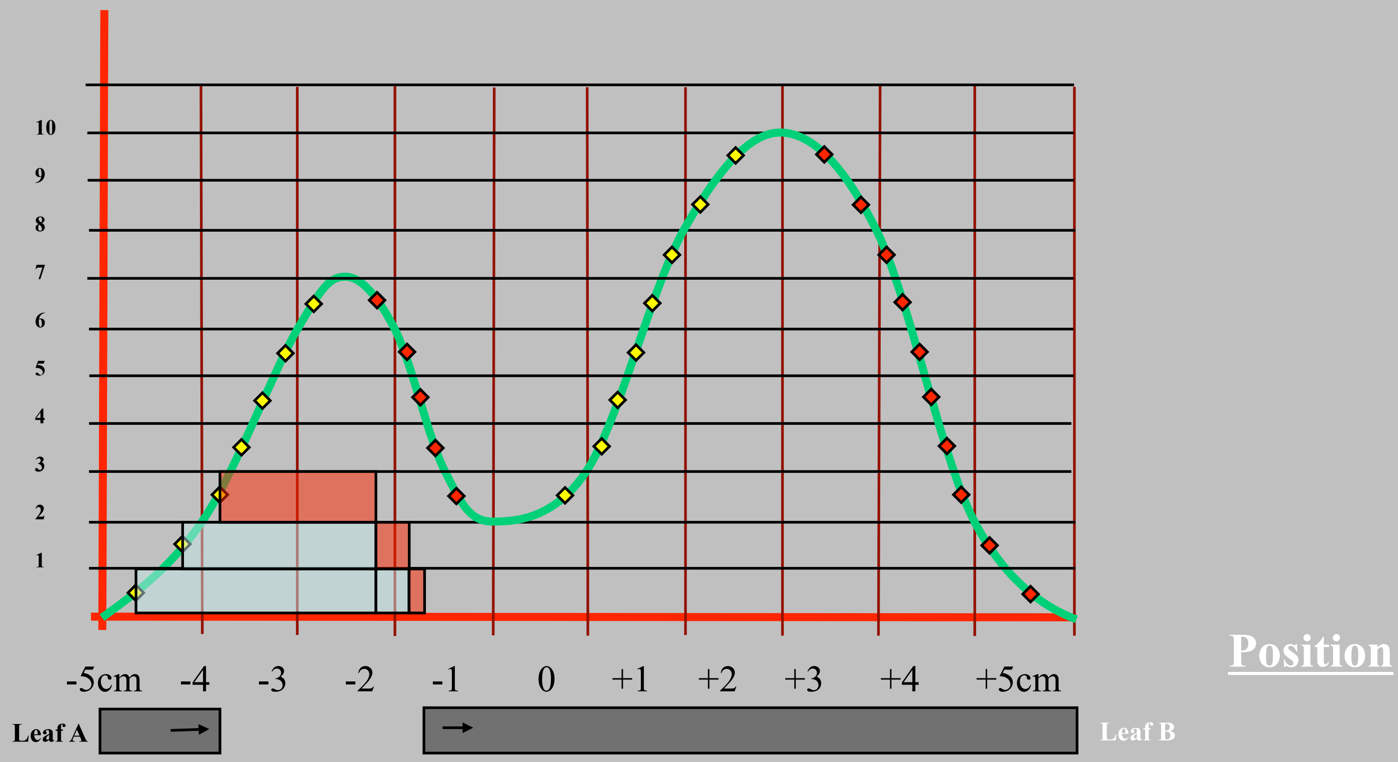
Position
Leaf A
Leaf B



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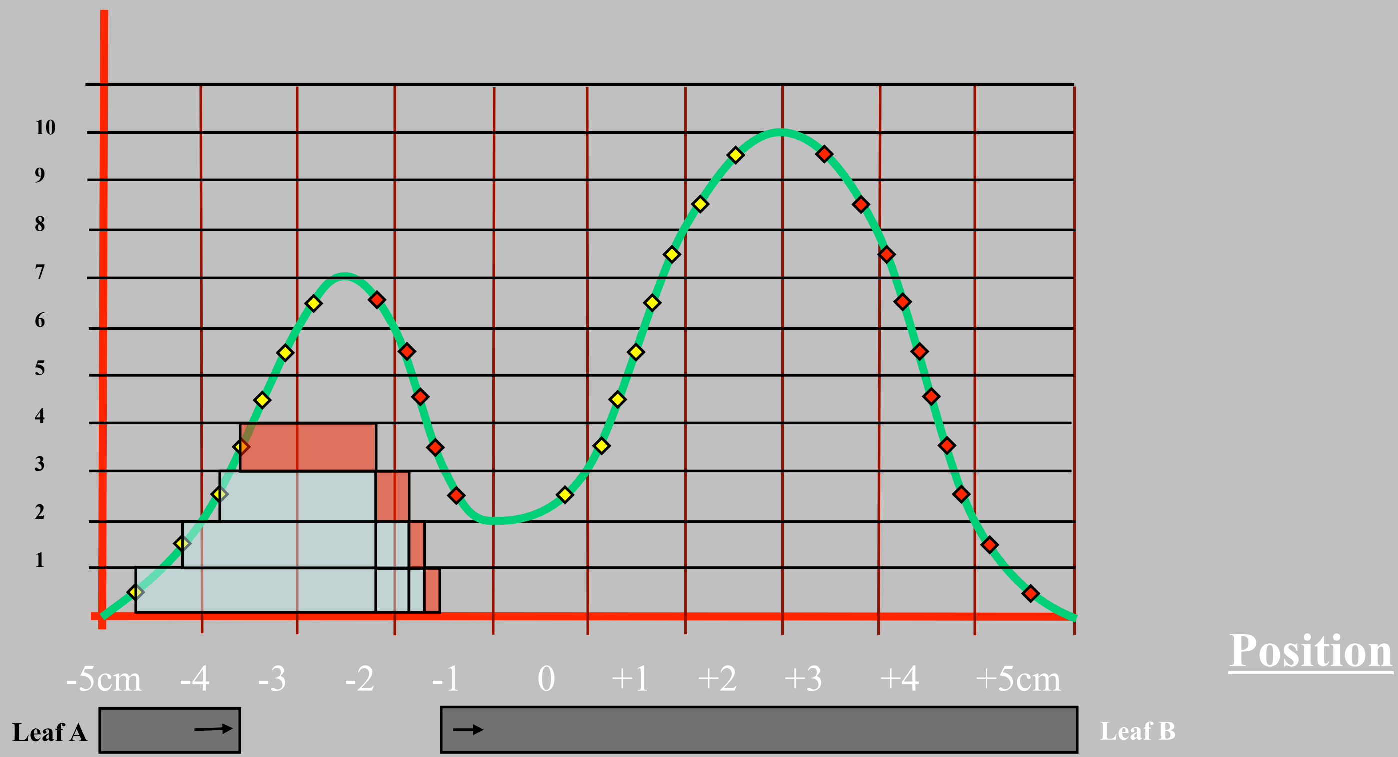
Position
Leaf A
Leaf B



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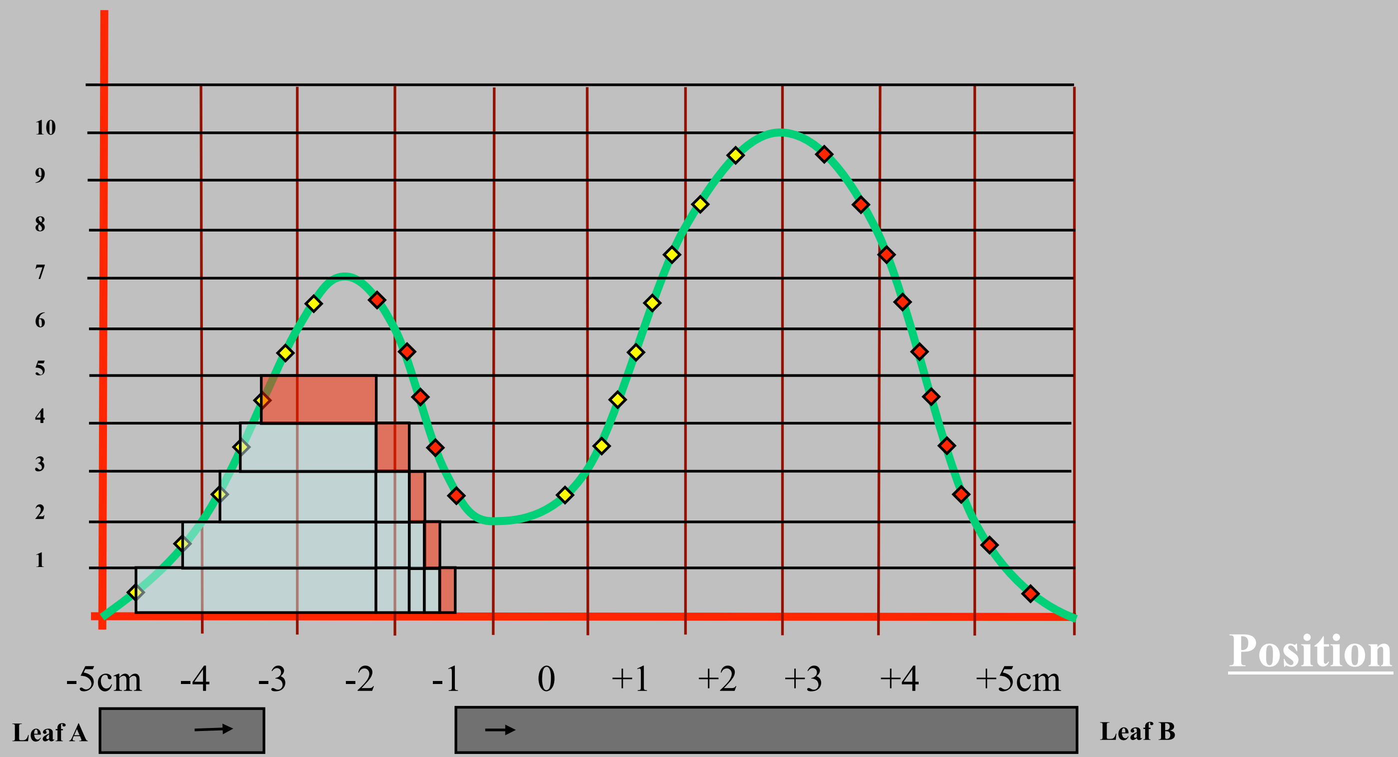
Position
Leaf A
Leaf B



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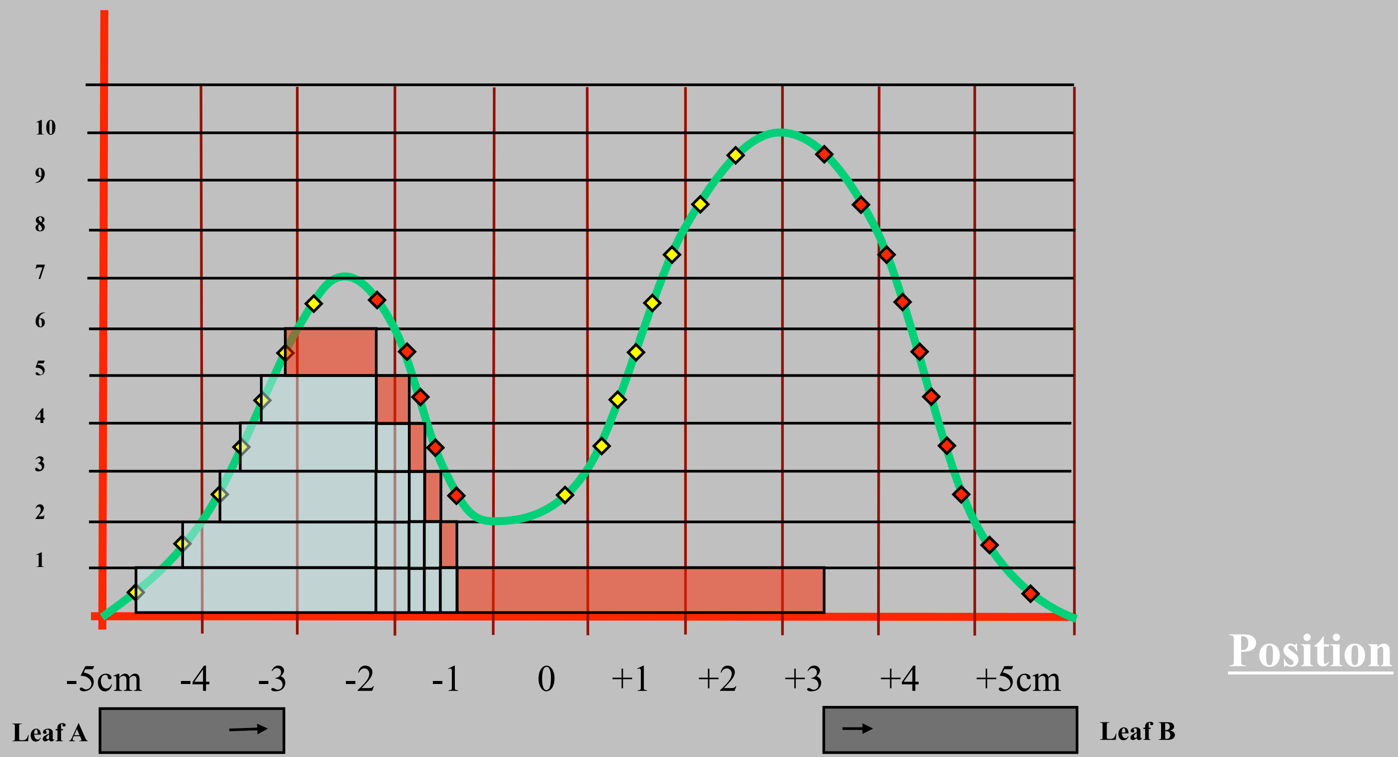
+5cm
Position
Leaf A
Leaf B



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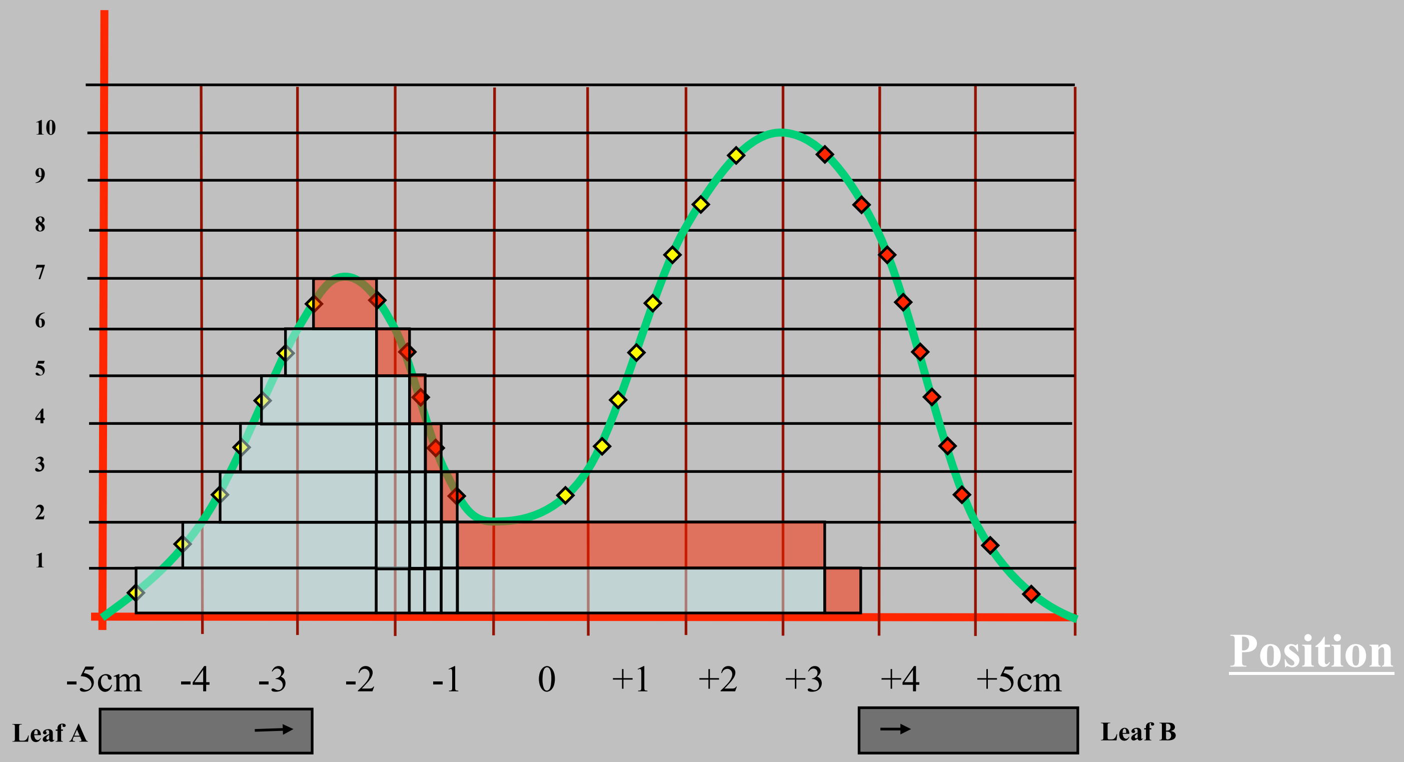
+5cm
Position
Leaf A
Leaf B



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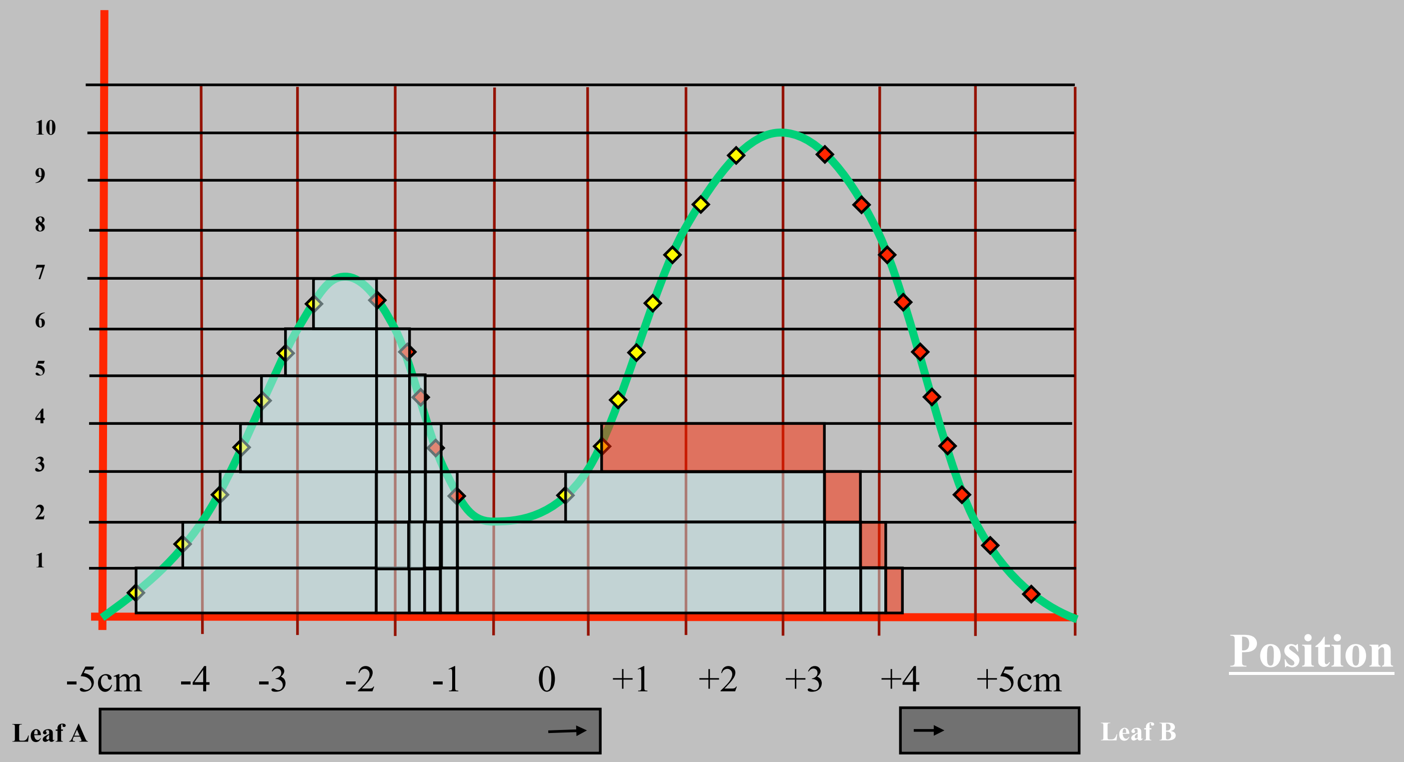
+1
+2
+3
+4
+5cm
Position
Leaf A
Leaf B



10
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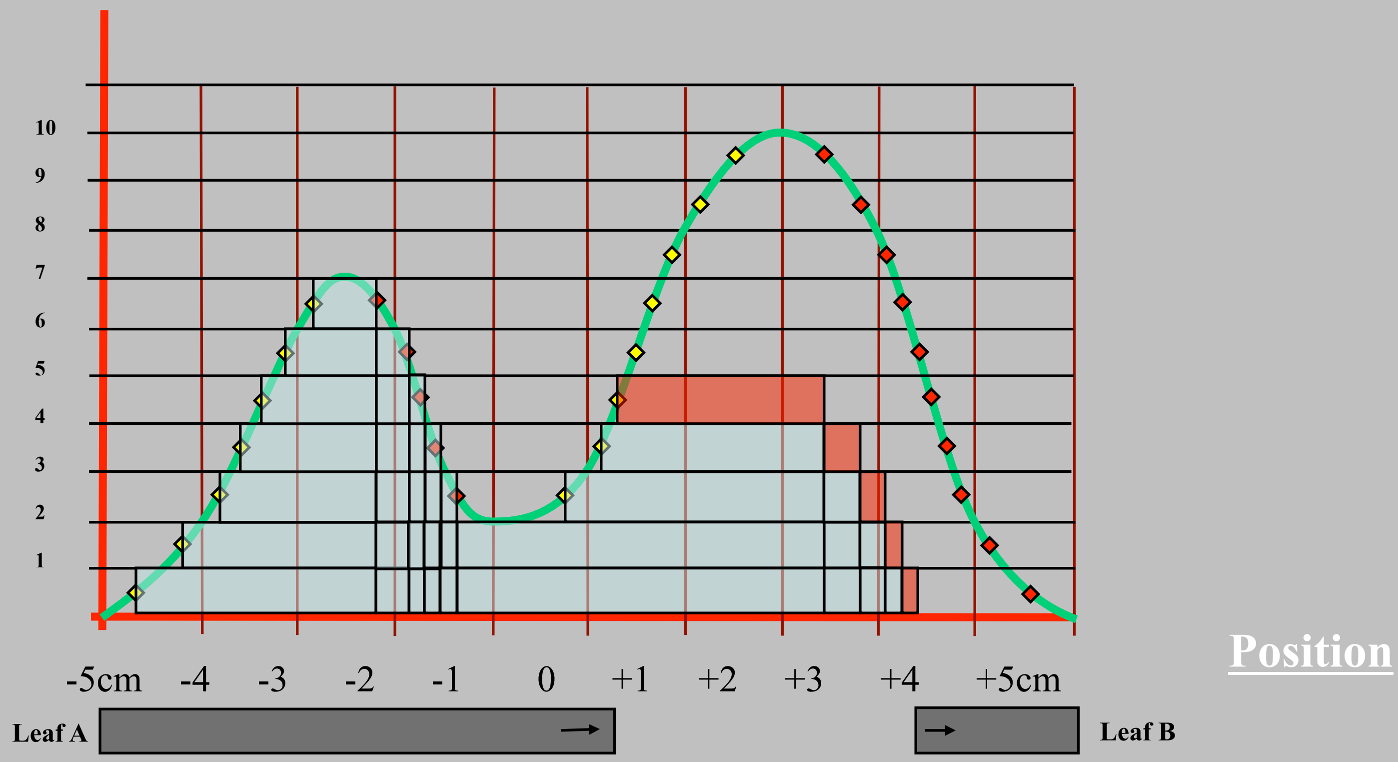
-5cm -4 -3 -2 -1 0 +1 +2 +3 +4 +5cm
Position
Leaf A
Leaf B



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-5cm
-4
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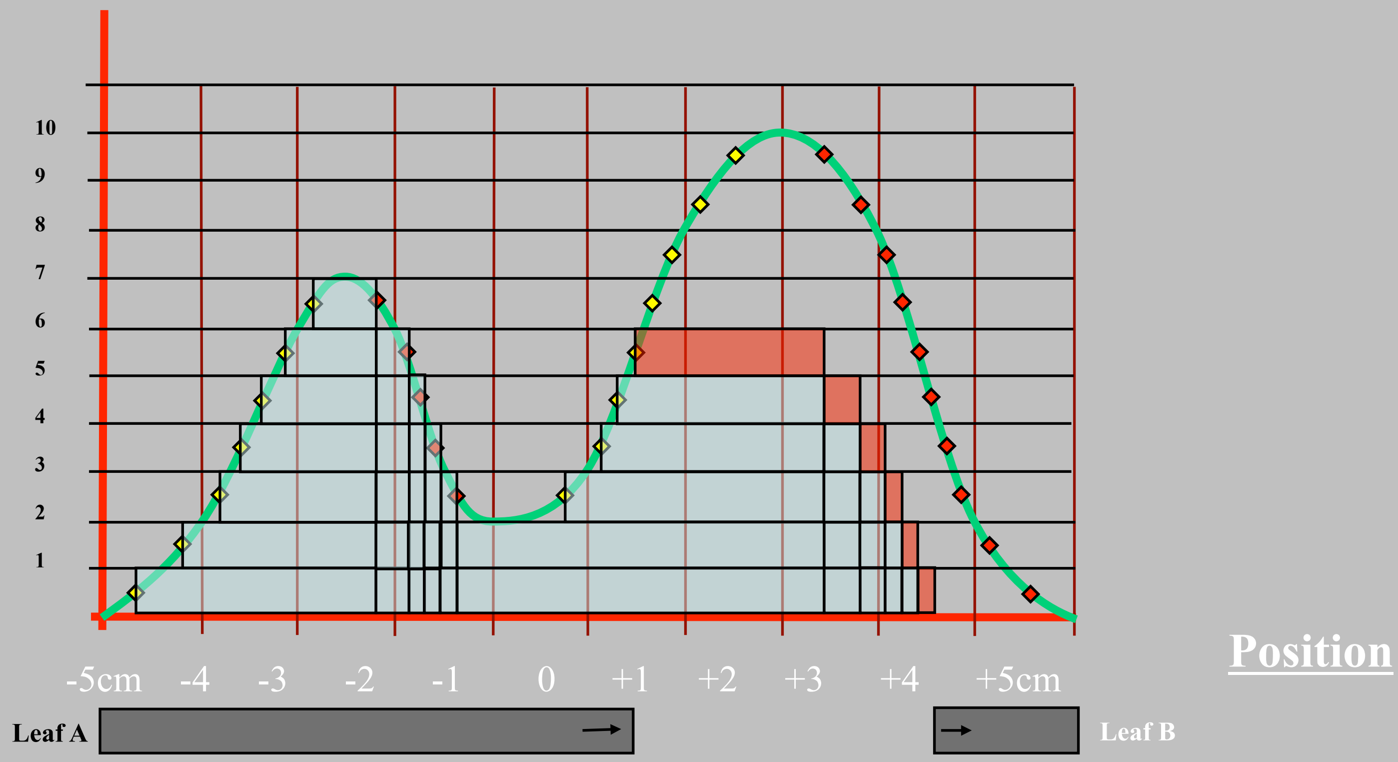
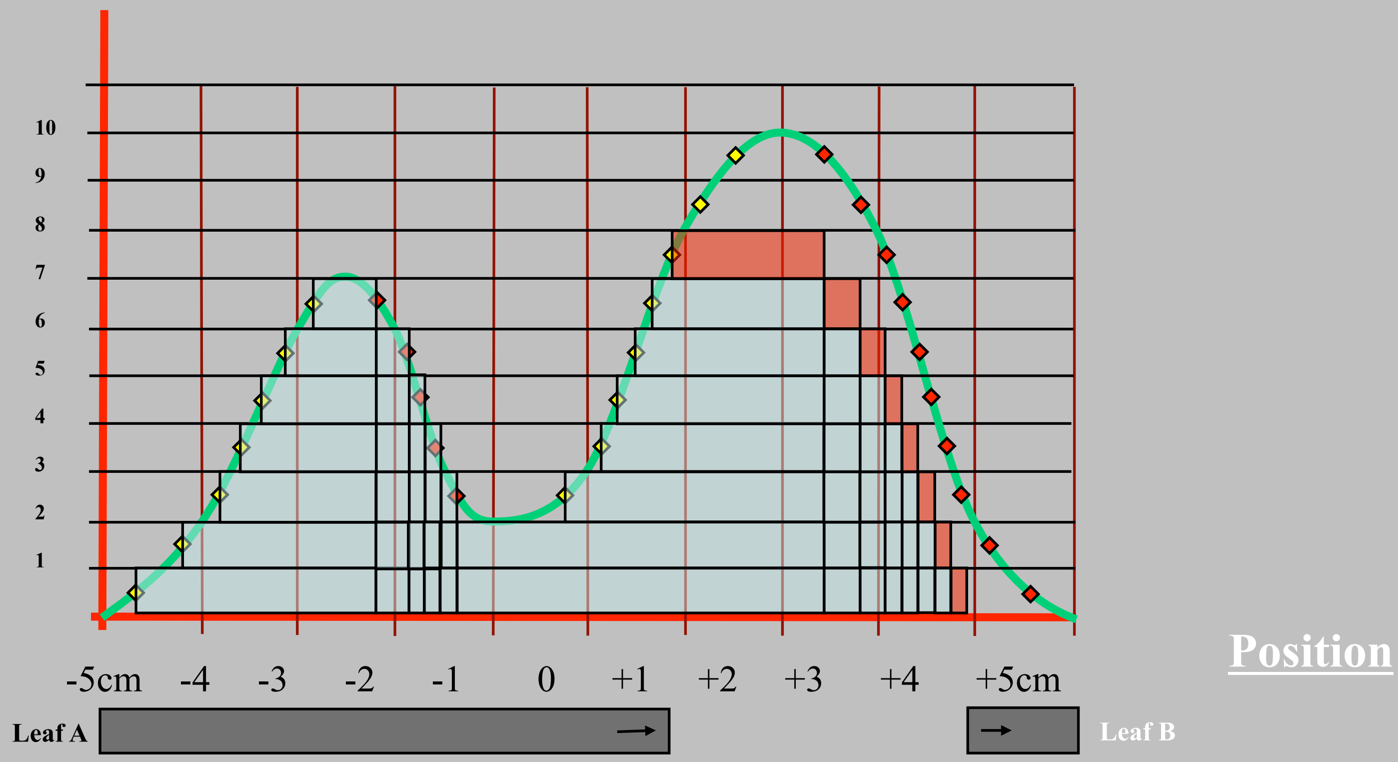
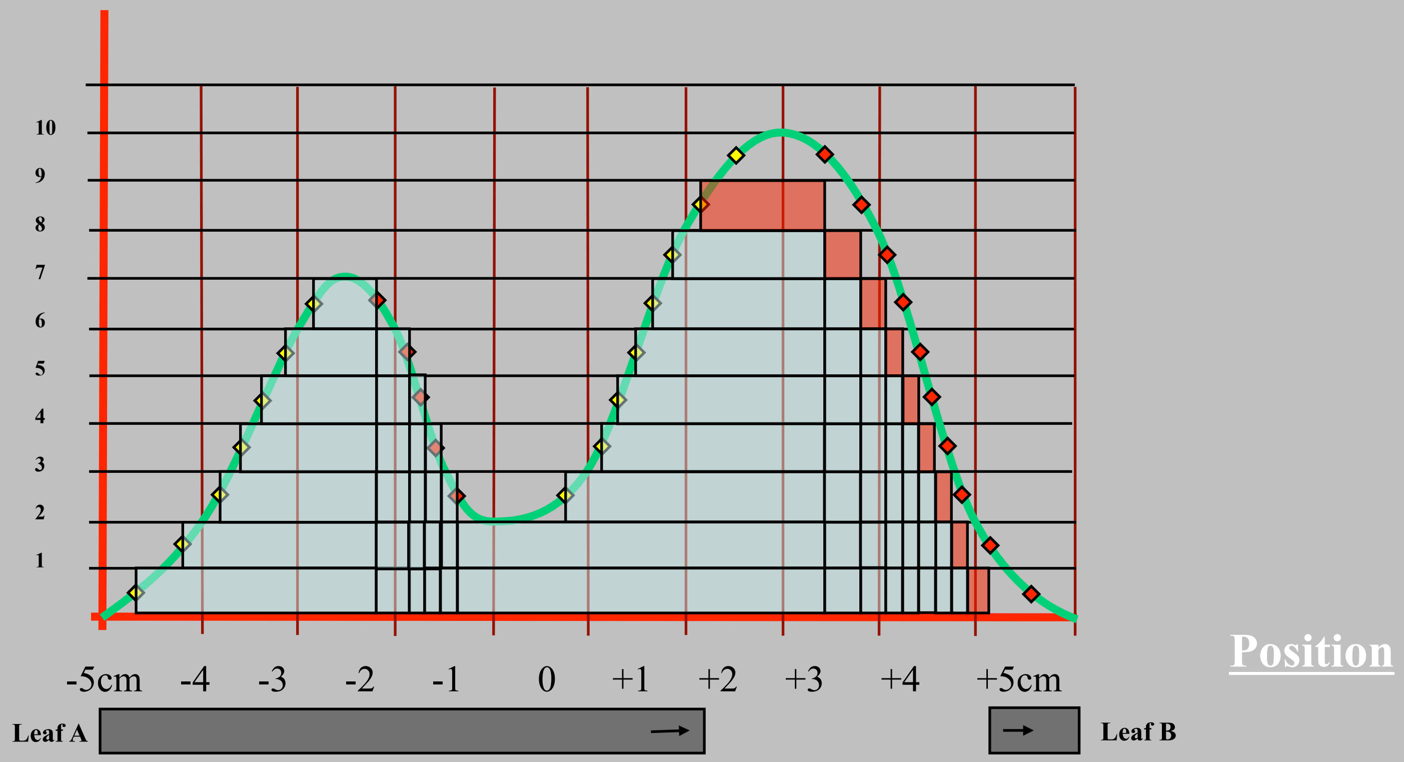
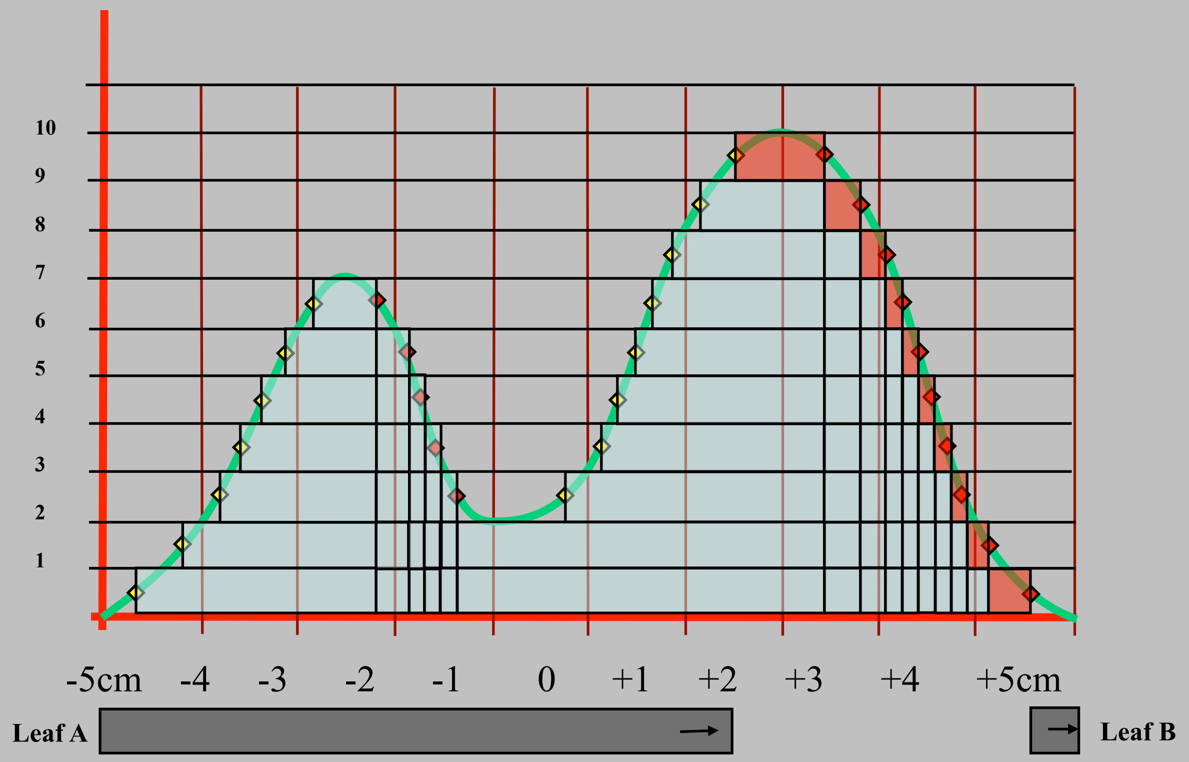
-2
-1
0
+1
+2
+3
+4
+5cm
Leaf A
Leaf B
Position


10
9
8
7
6
5
4
3
2
1
-5cm
-4
-3
-2
-1
0
+1
+2
+3
+4
+5cm
Position
Leaf A
Leaf B

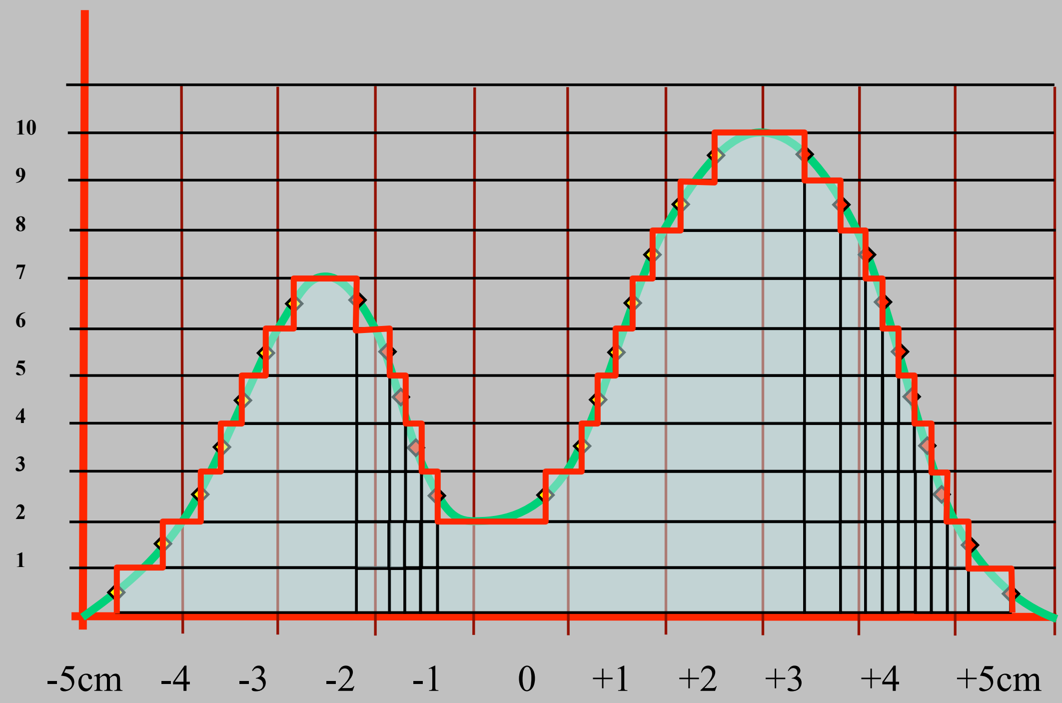


10
9
8
7
6
5
4
3
2
1
-5cm
-4
-3
-2
-1
0
+1
+2
+3
+4
+5cm
Position
Leaf A
Leaf B


10
9
8
7
6
5
4
3
2
1
-5cm -4 -3 -2 -1 0 +1 +2 +3 +4 +5cm
Leaf A
Leaf B
Position


10
9
8
7
6
5
4
3
2
1
-5cm
-4
-3
-2
-1
0
+1
+2
+3
+4
+5cm
Leaf A
Leaf B

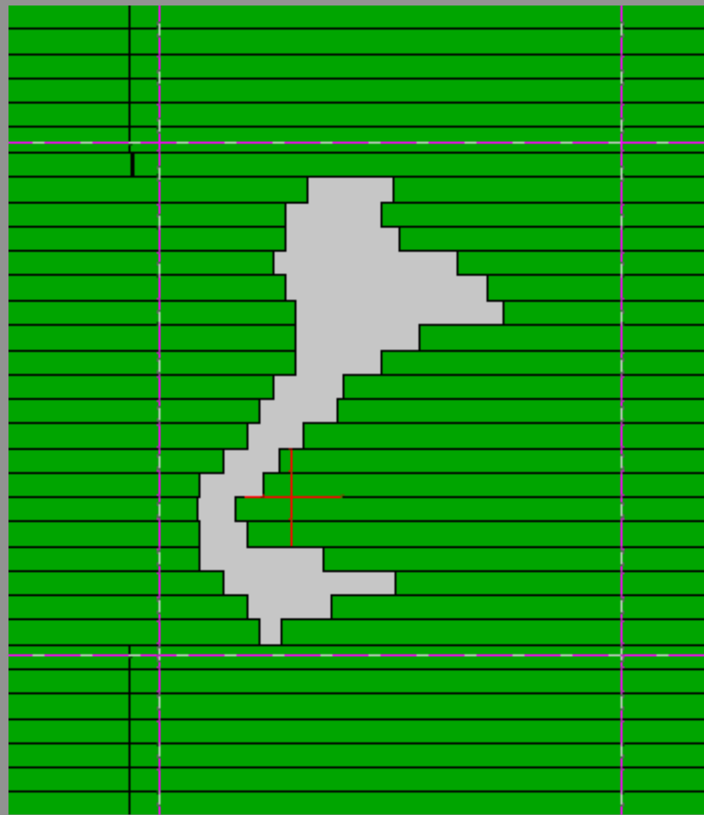
Done!



The Leaf Motion Calculator™

Creates the control file that orchestrates the dance between the beam control and the motion of the MLC leaves

"Step and Shoot"

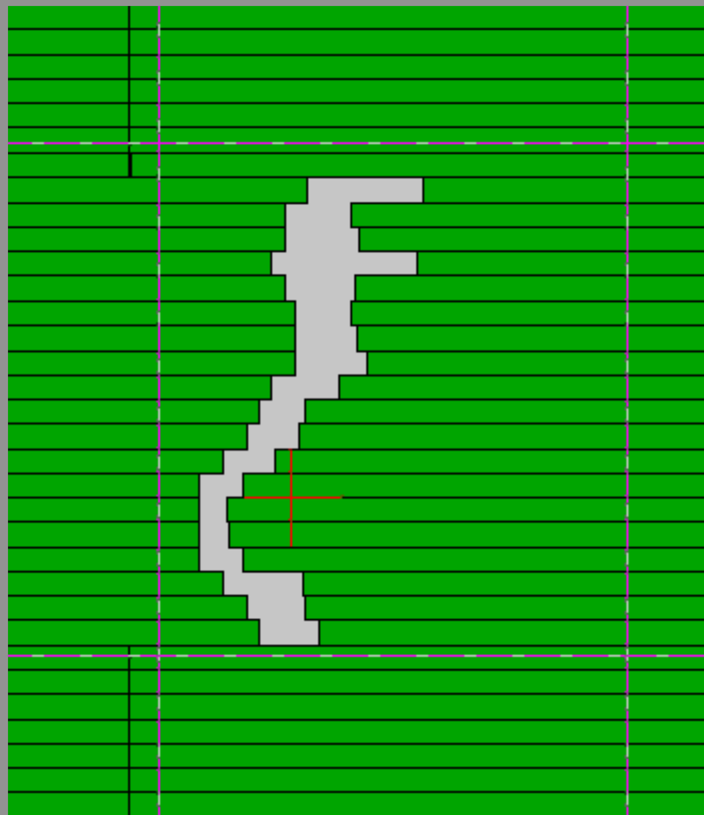


- **Leaf end shape (geometric penumbra)**
- **Leaf Transmission**
- **"Tongue and Groove" effect**
- **Jaw transmission**

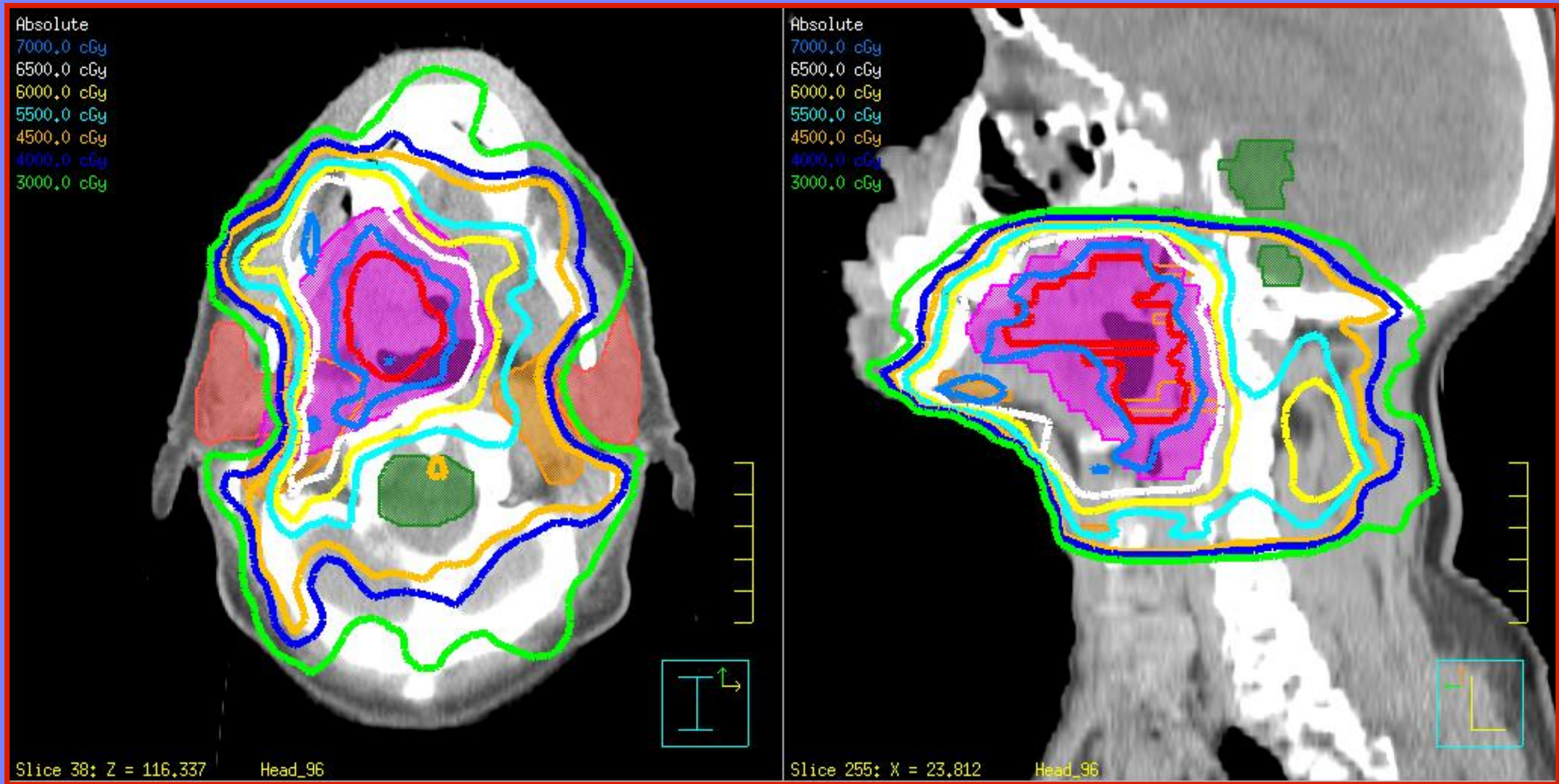
The Leaf Motion Calculator™

- Leaf end shape (geometric penumbra)
- Leaf Transmission
- “Tongue and Groove” effect
- Jaw transmission
- Leaf speed and acceleration

“Sliding Window”



Plan Review



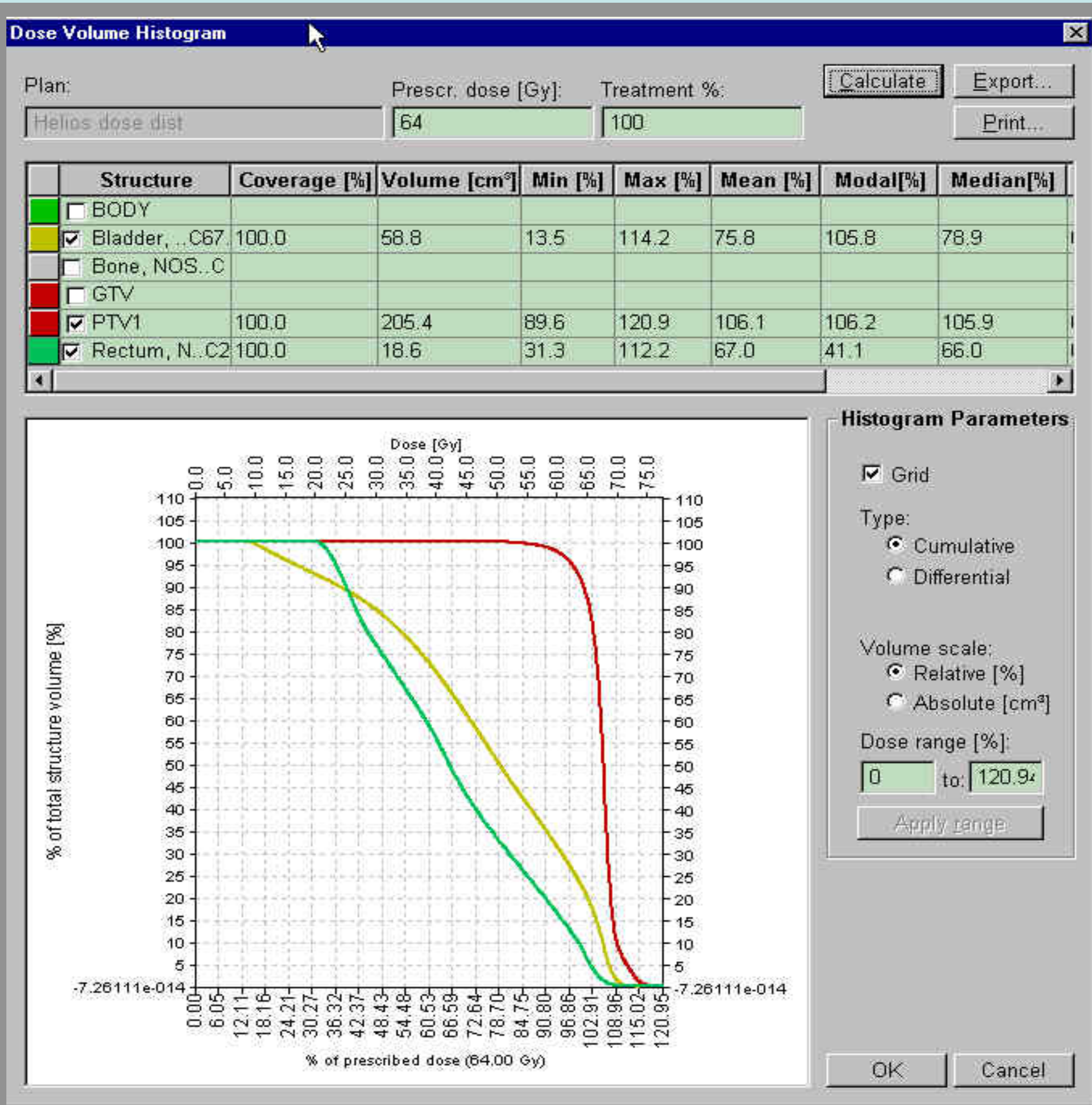
GTV (red), CTV (purple), Parotids (tomato), Brain Stem (green)

DPF, NSUH_LIJ,NY,USA

Plan Review: Dose Volume Histograms

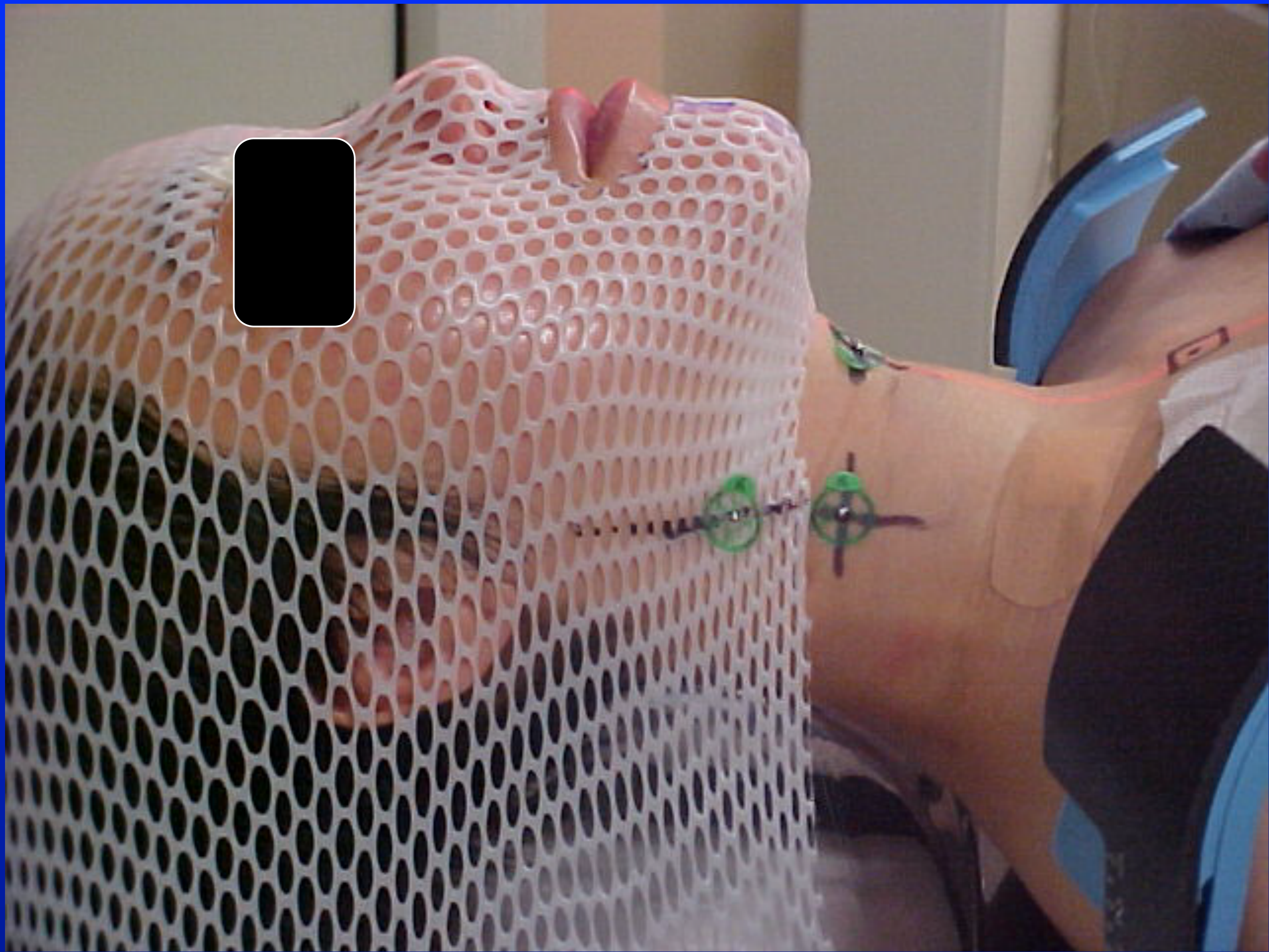
- **Dose Volume Histograms of the target and critical structures must be reviewed**

- ***The same as you would for a 3-D plan, but more structures***

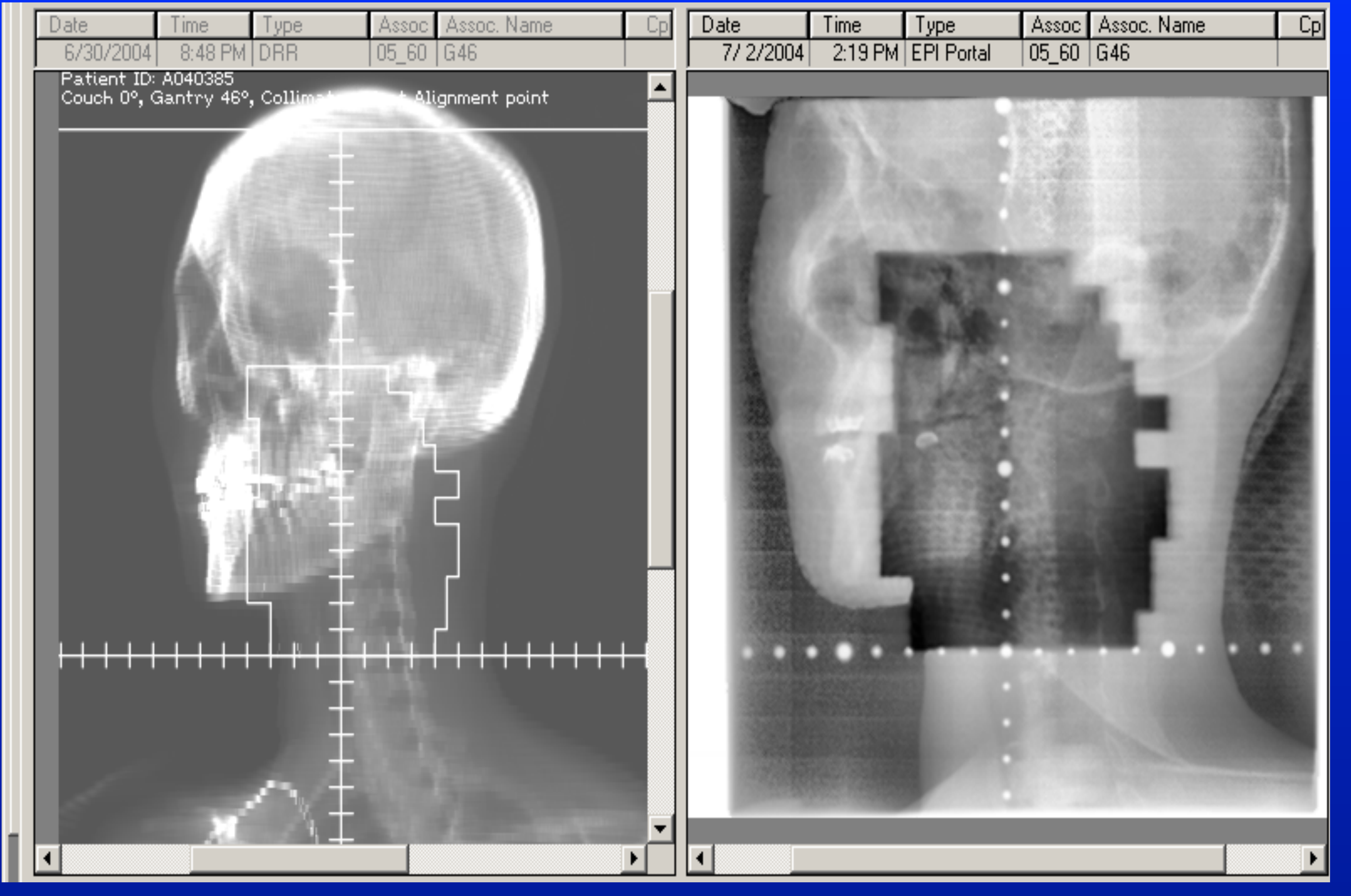


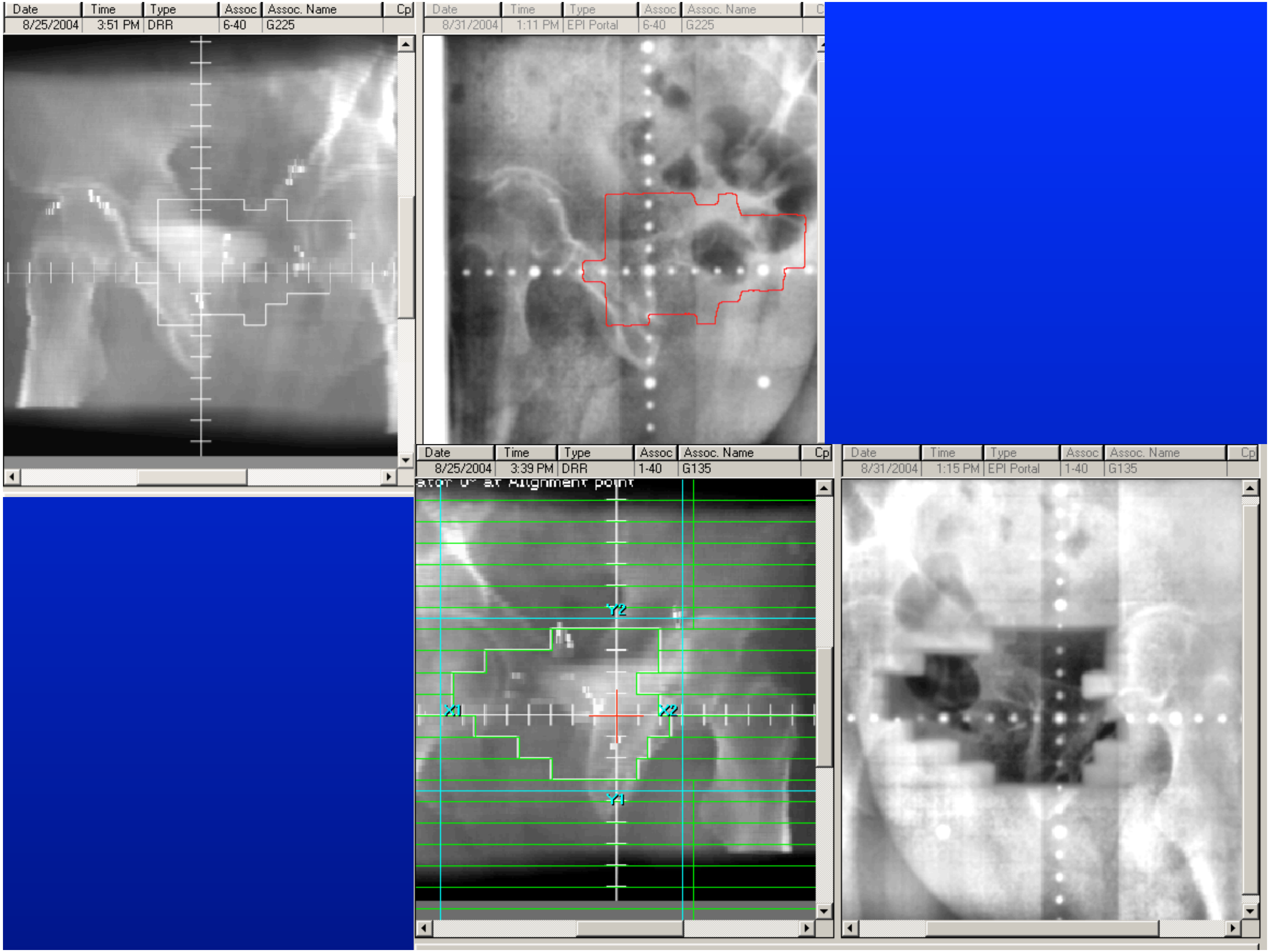
Do We Deliver the Correct Dose Distribution for Treatment the first time ?

- Associate the d-MLC files to the fields in the Record and Verify system
- Verify start MLC positions for each field
- Verify modality and other parameters of each field against the reference plan.



DPF, NSUH-LIJ HS-NY-USA


Date | Time | Type | Assoc | Assoc. Name | Cp
6/30/2004 | 8:48 PM | DRR | 05_60 | G46
Patient ID: A040385
Couch 0°, Gantry 46°, Collima... Alignment point
Date | Time | Type | Assoc | Assoc. Name | Cp
7/ 2/2004 | 2:19 PM | EPI Portal | 05_60 | G46



Date Time Type Assoc Assoc. Name Cp
8/25/2004 3:51 PM DRR 6-40 G225
Date Time Type Assoc Assoc. Name
8/31/2004 1:11 PM EPI Portal 6-40 G225
Date Time Type Assoc Assoc. Name Cp
8/25/2004 3:39 PM DRR 1-40 G135
Y2
X1
X2
Y1
Date Time Type Assoc Assoc. Name Cp
8/31/2004 1:15 PM EPI Portal 1-40 G135

Do We Deliver the Correct Fluence for Treatment every time ?

- Periodic QA of the d-MLC
- Audit the d-MLC motion history for the treatment
- Audit the patients electronic records

Do We Deliver the Same Treatment Every Time ?

With an 80 leaf MLC,there are about 2,000 parameters and 15,000 leaf positions per day, that have to be "just right"…. …every day.

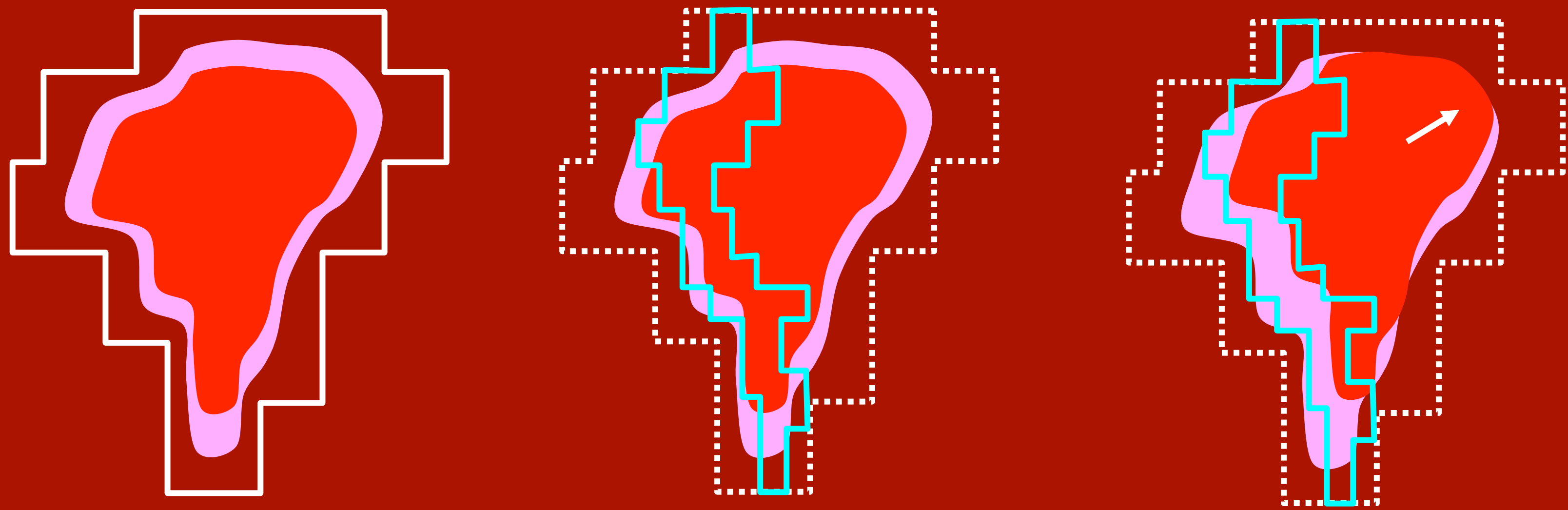
Record and Verify systems should be an integral part of IMRT delivery !

http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1607_web.pdf

Do We Deliver the Correct Dose Distribution for Treatment every time ?

- For many anatomical sites we have limited control of the internal organ motion.

Effects of Intra-Fraction Organ Motion on the Delivery of IMRT with an MLC



Conventional treatment

Effect of organ motion on GTV is accounted for by PTV, which is always inside the beam aperture.

IMRT treatment: summation of small beams

No organ motion
delivered = planned

with organ motion
delivered ≠ planned

Courtesy of Dr C. S. Chui

Targeting Accuracy and Localization

- Targets Move
  - Patient positioning
  - Limits on delivery system
- Implication:
  - Increased risk of complications seen with dose escalation
- Solutions
  - Minimize Uncertainty in Target Organ Location, perhaps on a daily basis
  - Use Image guided localization of the target or a reliable surrogate
  - Use gated beam delivery

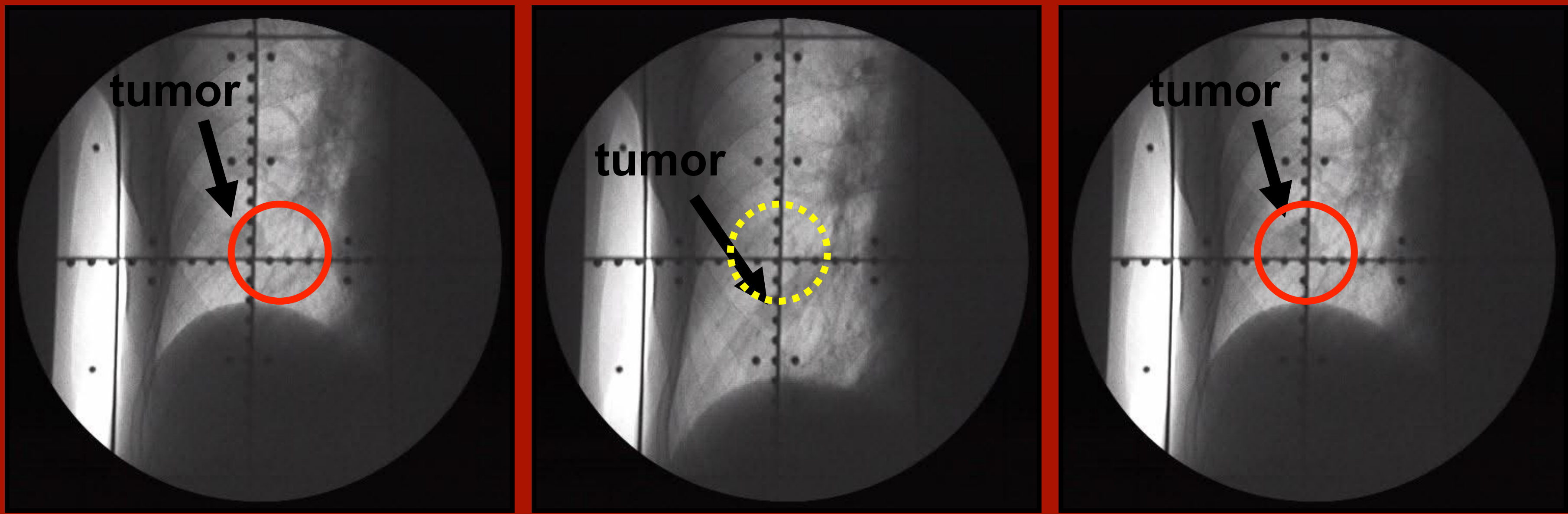
Synchronization of radiation treatment with respiration

An implicit assumption is that the tumor and organ motions are correlated to the respiration motion.

Motion range of up to 3 cm with respiration possible

- PTV increases significantly with motion
- Increased PTV limits use of radiotherapy for some disease sites

Respiratory gating is ...



Beam ON | **Beam OFF** | **Beam ON**

...synchronizing the radiation beam with the respiratory cycle

The great challenge!

- The better we can "fix" the target and be sure where we deliver the dose, the more we can reduce the margin required to convert CTV to PTV, and spare dose to sensitive structures!
- However…
- The tighter the dose distribution, the better we must know where the target is at all times!
- If not…
- We will achieve the exact opposite of our goal!

How is IMRT different from 3D-CRT?

- **Definition of the prescription**
- **Optimization (Inverse Planning)**
- **Delivery Method**
- **Dose Calculation**
- **Quality Assurance requirements**
- **Treatment Delivery and Verification**

AAPM Report No. 82: Guidance Document on Delivery, Treatment Planning, and Clinical Implementation of IMRT. (2003)
http://www.aapm.org/pubs/reports/RPT_82.pdf.

Guidance document on delivery, treatment planning, and clinical implementation of IMRT: Report of the IMRT subcommittee of the AAPM radiation therapy committee

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IAEA-TECDOC-1588

Transition from 2-D Radiotherapy to 3-D Conformal and Intensity Modulated Radiotherapy

IAEA
International Atomic Energy Agency

TABLE 1. CLASSIFICATION OF CONFORMAL THERAPY ACCORDING TO THE METHODOLOGY AND TOOLS ASSOCIATED WITH EACH STEP OF THE PROCEDURE

	Level 1 Basic CRT	Level 2 3-D CRT	Level 3 Advanced 3-D CRT
1. Patient data acquisition			
Immobilization	Desirable	Customized to the patient	Customized to the patient
Imaging system	Localization films, few CT slices optional	Thin adjacent CT slices, MR optional	Co-registered CT with MR or PET
Anatomical data			
Reference marks for setup	Height above table and skin marks	External markers or frame	Implanted markers or frame
Critical organs	Contour individual slices	3-D segmentation	3-D segmentation
Inhomogeneities	Optional	Contouring every slice or voxel based correction	Voxel based correction
Gross tumour volume (GTV)	May not be formally defined	Contouring every slice	3-D segmentation
Clinical target volume (CTV)	May not be formally defined	Grown from GTV using auto-margin growing	Margin growing from GTV + functional imaging
Internal target volume (ITV)	May not be formally defined	Based on standard decision rules	4-D CT data to define ITV customized to patient

TECDOC No. 1588. (2008)
www.pub.iaea.org/MTCD/Publications/PDF/TE_1588_web.pdf

APPENDIX A
SELF ASSESSMENT QUESTIONNAIRE

This questionnaire is designed to assist centres that plan to embark on a programme of 3-D conformal radiotherapy to check that they have all the necessary requirements. By the time the first patient is to be treated the answers to all the questions should be "**Yes**". Where gaps are identified they will need to be corrected. The questionnaire begins with the staffing and equipment requirements and then looks at the process of conformal radiotherapy planning and treatment to identify the issues that need to be addressed. Items indicated with an asterisk (*) are optional for 3-D CRT. Questions 50-62 cover additional issues required for IMRT, for which the items marked with an asterisk should be regarded as essential.

Reference of References

- "The Modern Technology of Radiation Oncology: A Compendium for Medical Physicists and Radiation Oncologists" - Volume 3 - J. Van Dyk, editor. Madison, WI: Medical Physics Publishing, (2013)

- Chapter 16: Radiation Oncology Resources for Working, Teaching, and Learning

- http://www.medicalphysics.org/vandykch16.pdf.

IMRT is a powerful and sharp tool in the treatment of cancer with radiation!

We must use it with great care and respect !!!