IMRT/VMAT: Practical Treatment Planning

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The University of Vermont

IMRT Planning: What you need to get started?

- Structures delineated on CT
  - CT with accurate CT numbers
  - Target structures (GTV, CTV, ITV, PTV)
  - Critical Structures
  - Planning organ at risk volumes
  - Planning structures to shape dose
  - Ability to remove (and replace couch) from image
- Clearly defined dose constraints

Clear Plan Objectives

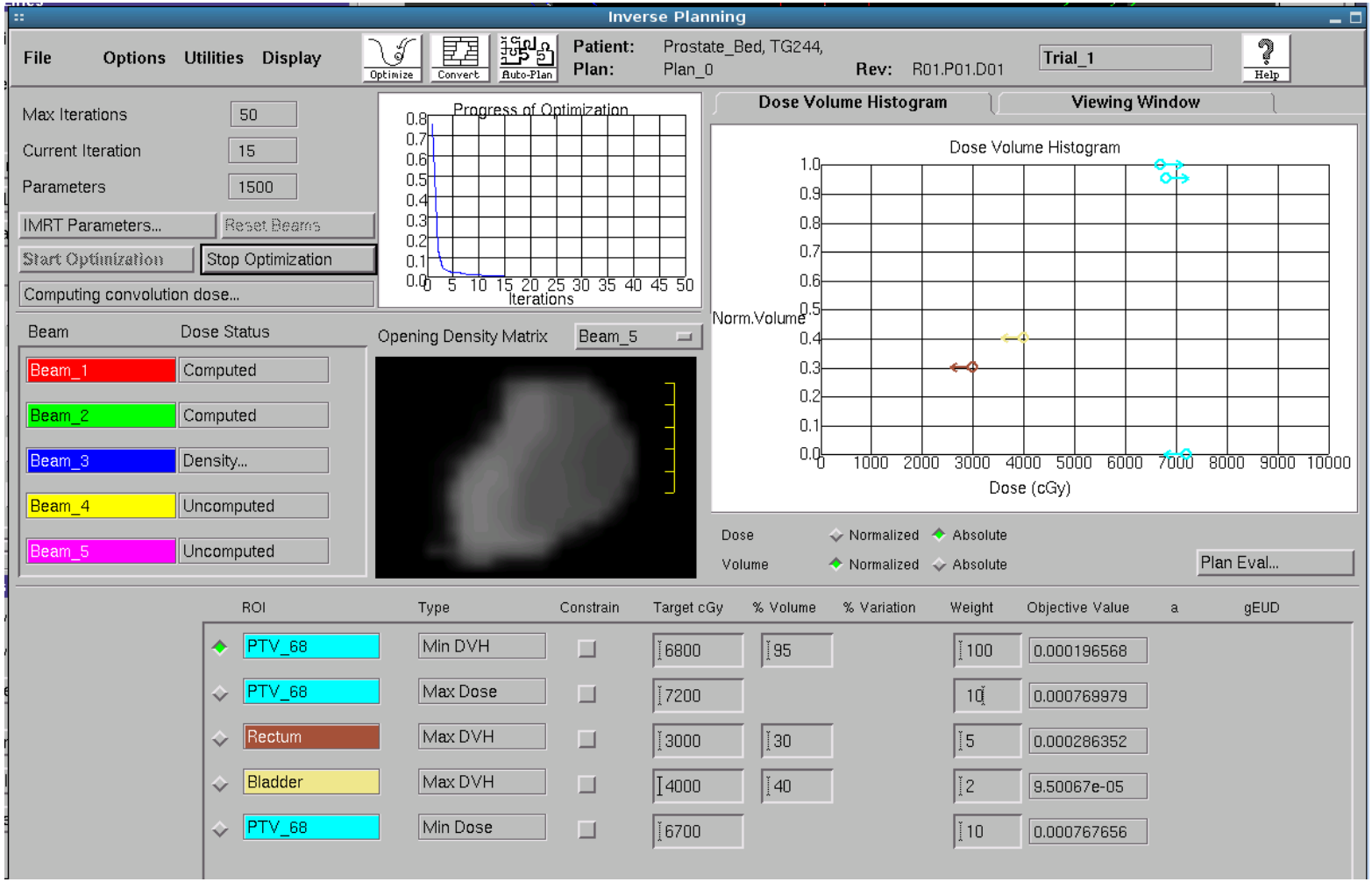
Organ	Plan Goals	Priority
PTV 6000	V98% ≥ 99% *	2
	V95% ≥ 95% *	1
PTV 5400	V98% ≥ 99% *	2
	V95% ≥ 95% *	1
PTV 4500	V98% ≥ 99% *	2
	V95% ≥ 95% *	1
COMPOSITE	V98% ≥ 99% *	2
	V95% ≥ 95% *	1
Rectum	V40Gy ≤ 35% &	3
	V65Gy ≤ 17% &	1
	V70Gy ≤ 10cc	3
Bladder (intact prostate) □	V65Gy ≤ 50% $	2
	V70Gy ≤ 35% $	2
	V75Gy ≤ 25% $	2
	V80Gy ≤ 15% $	2
Bladder-CTV (post-prostatectomy)	V40Gy ≤ 70% #	2
	V65Gy ≤ 50% #	2
Femoral Head L	V50Gy ≤ 10%	2
Femoral Head R	V50Gy ≤ 10%	2
Penile Bulb	Dmean Mean 52.5Gy *	Guideline only

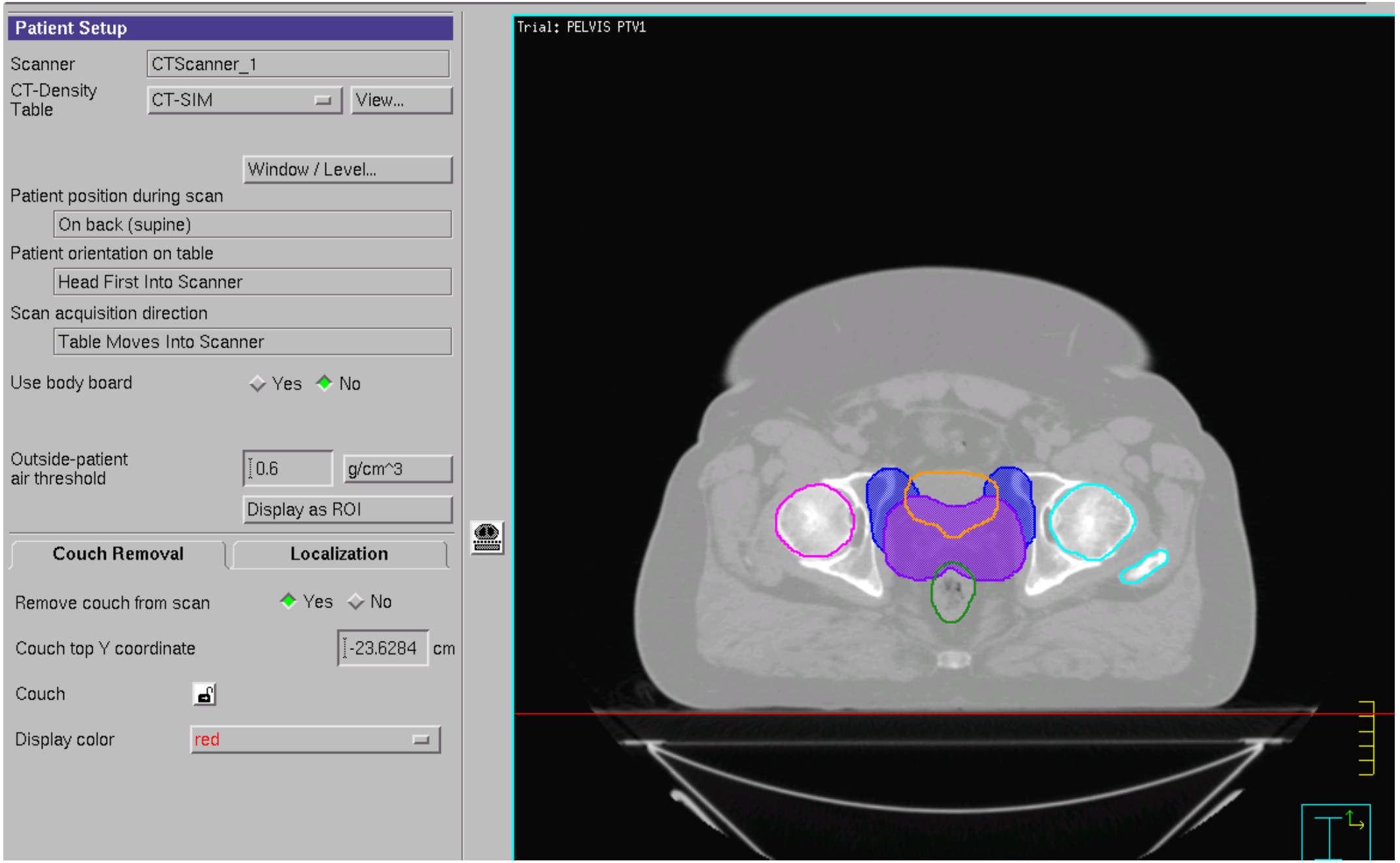
How to Determine Plan Objectives?

- Protocols
- Consensus Guidelines
- Population Based
  - Must know what you are able to achieve through rigorous data collection
- Patient specific factors
- Not all dose objectives have the same impact and should be weighted accordingly.

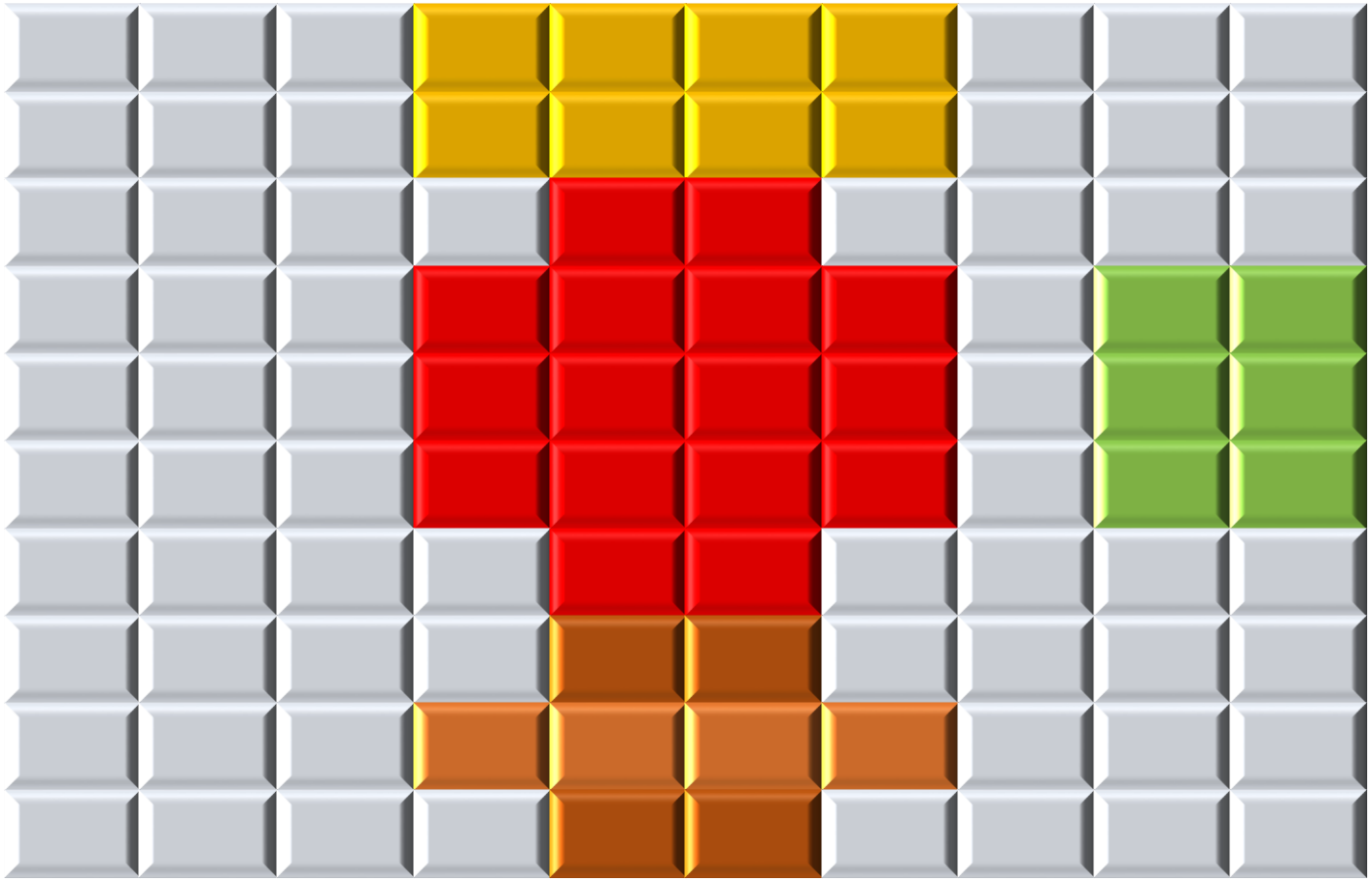
Planning Process

- Segment
- Enter constraints
- Determine Weights
- Optimize Fluence
- Segmentation
- Full Scatter Calculation
- Evaluate

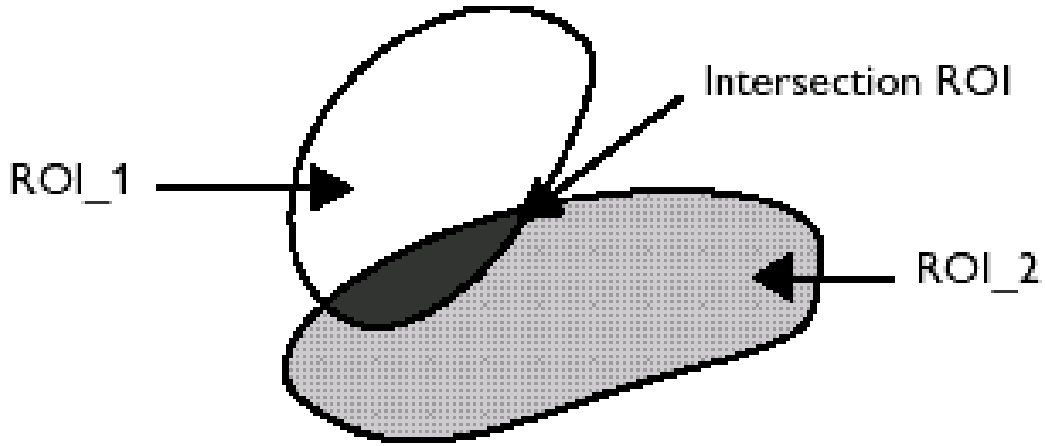



Patient Setup
Scanner
CTScanner_1
CT-Density Table
CT-SIM
View...
Window / Level...
Patient position during scan
On back (supine)
Patient orientation on table
Head First Into Scanner
Scan acquisition direction
Table Moves Into Scanner
Use body board
Yes
No
Outside-patient air threshold
0.6
g/cm^3
Display as ROI
Couch Removal
Localization
Remove couch from scan
Yes
No
Couch top Y coordinate
-23.6284
cm
Couch
Display color
red
Trial: PELVIS PTV1

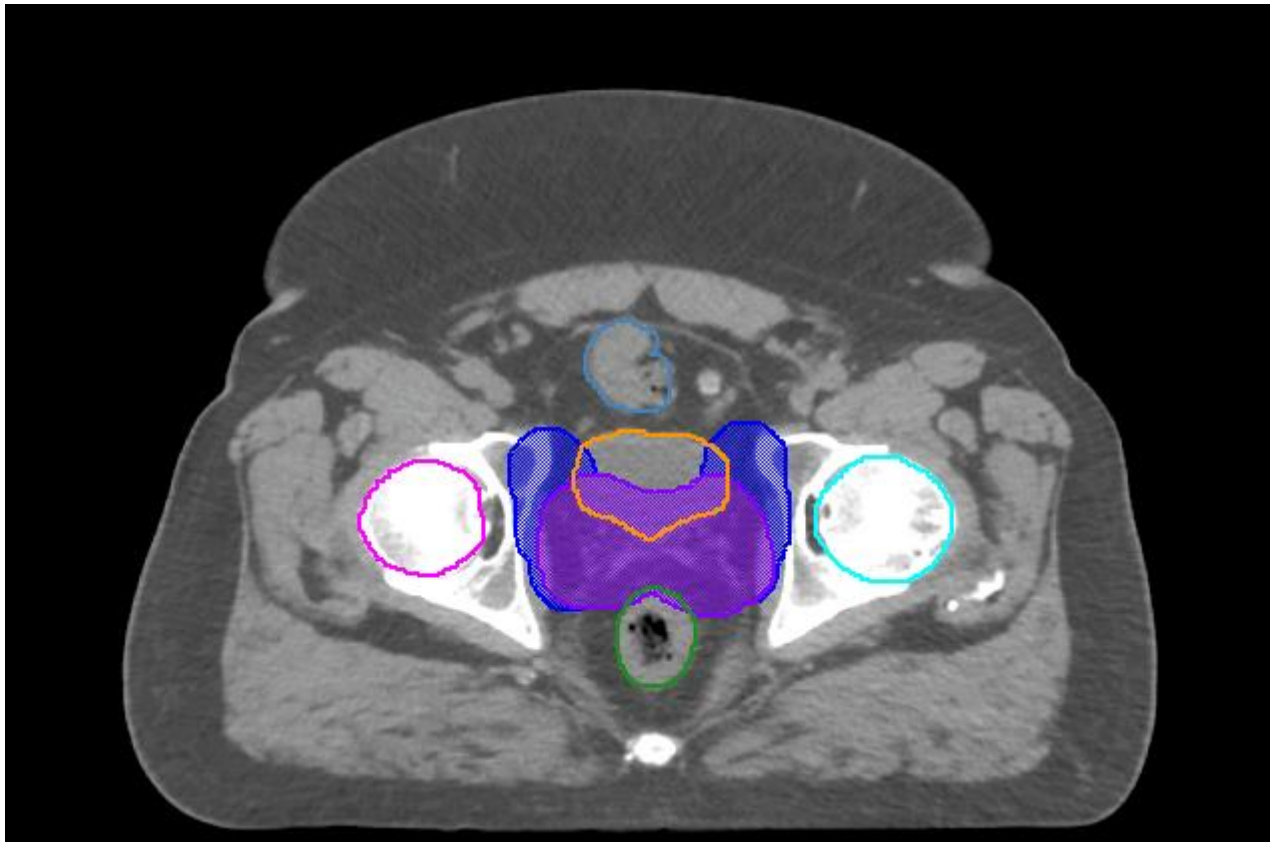
CT Segmentation

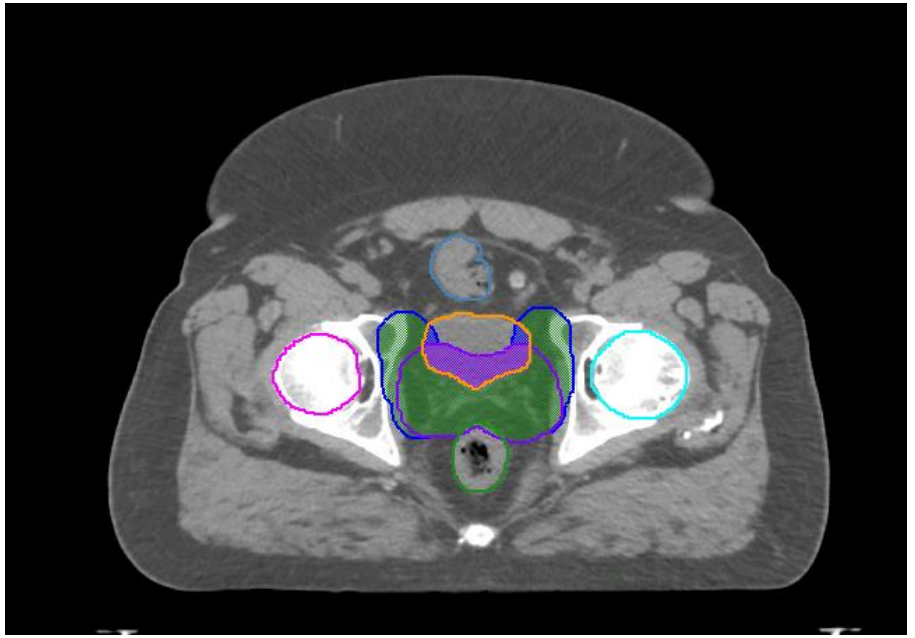


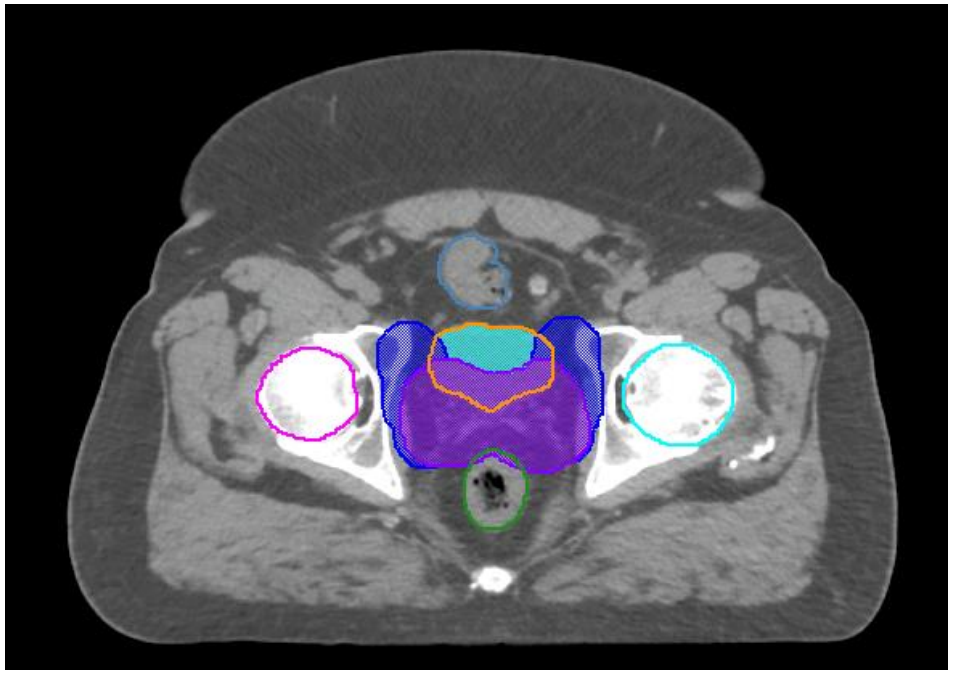
What if Structures Overlap?



Subtract Voxels



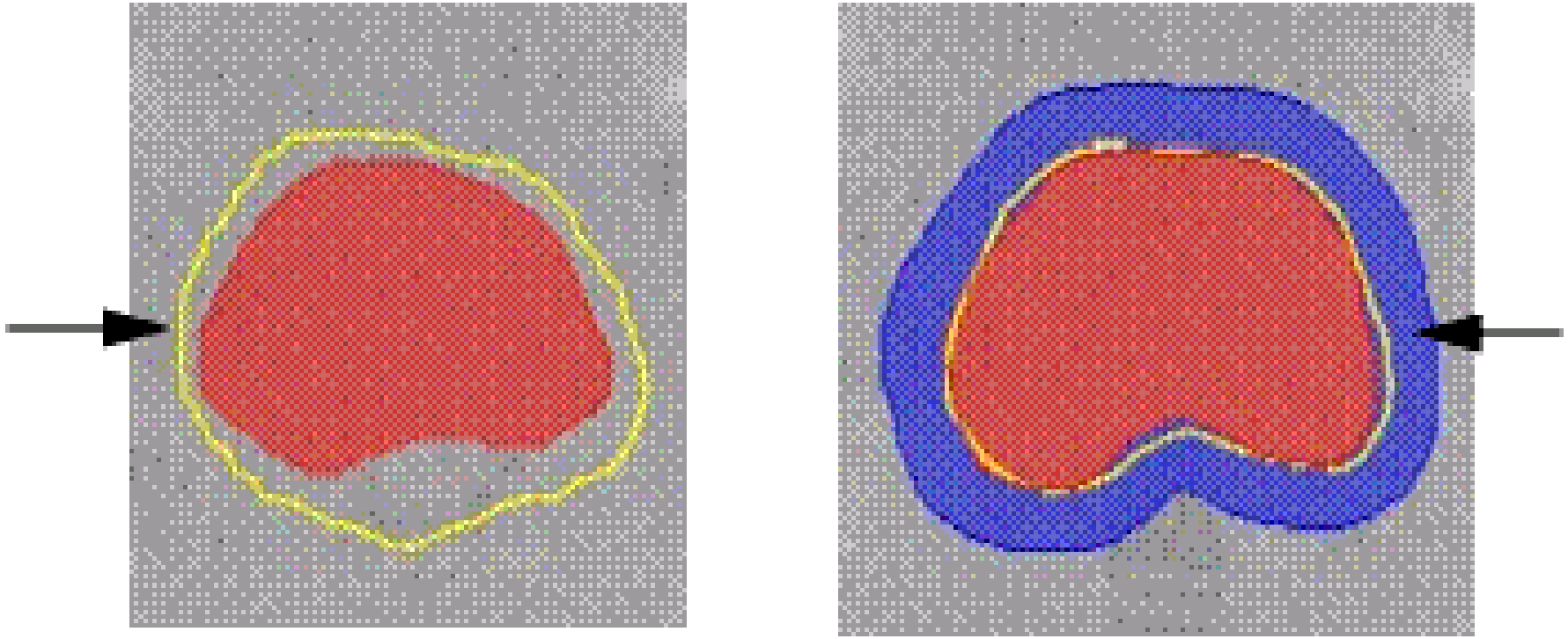




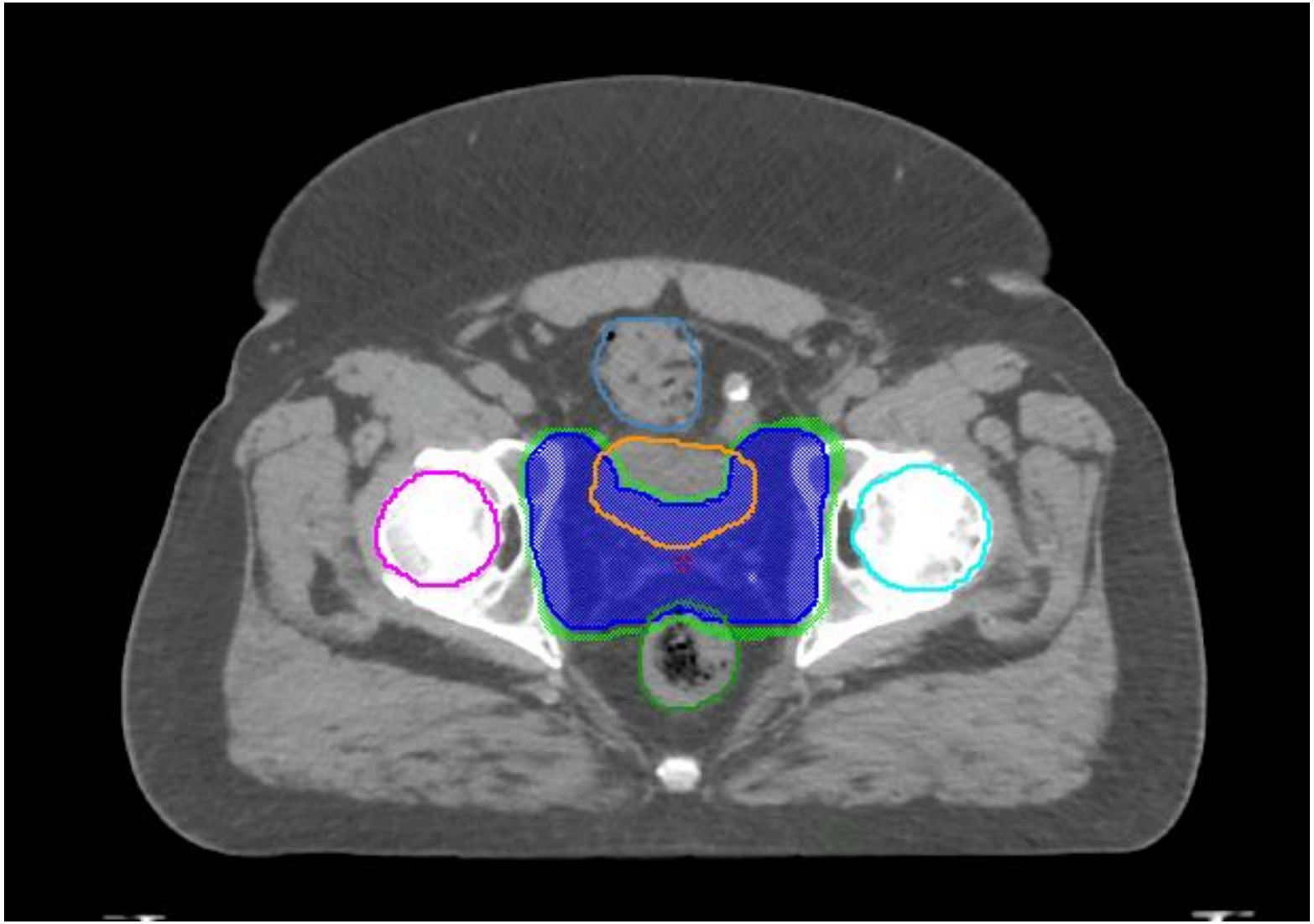
Ways to Account for Overlap

- Manually adjust contours to simplify the problem
- Overlap Priority
  - Number in order of priority
  - Set a fraction of the weight to one structure versus another
- Clarifying the overlap is one way that you avoid conflicting goals

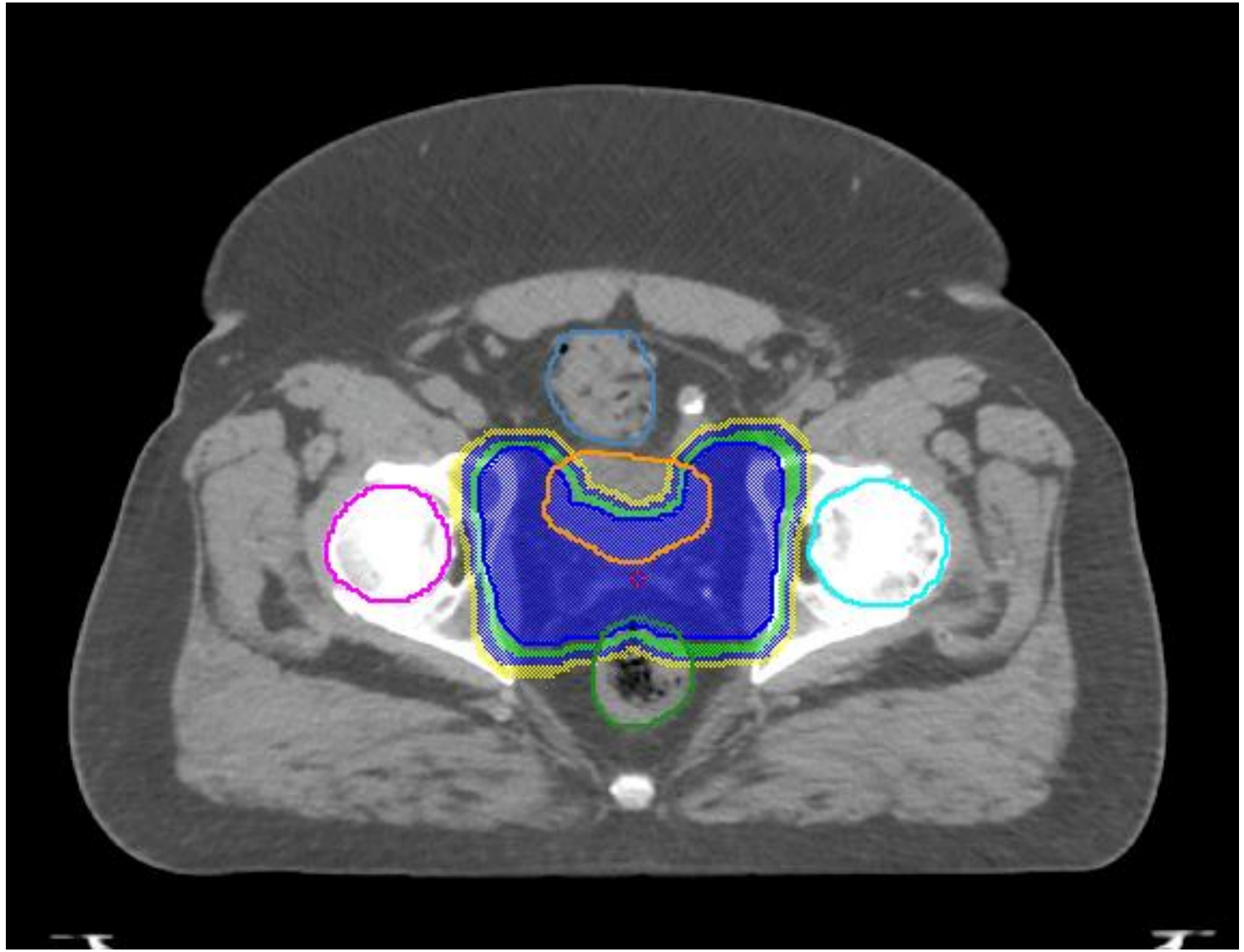
Structures to Improve Conformity



Pictures from Philips Pinnacle3 Training Manual

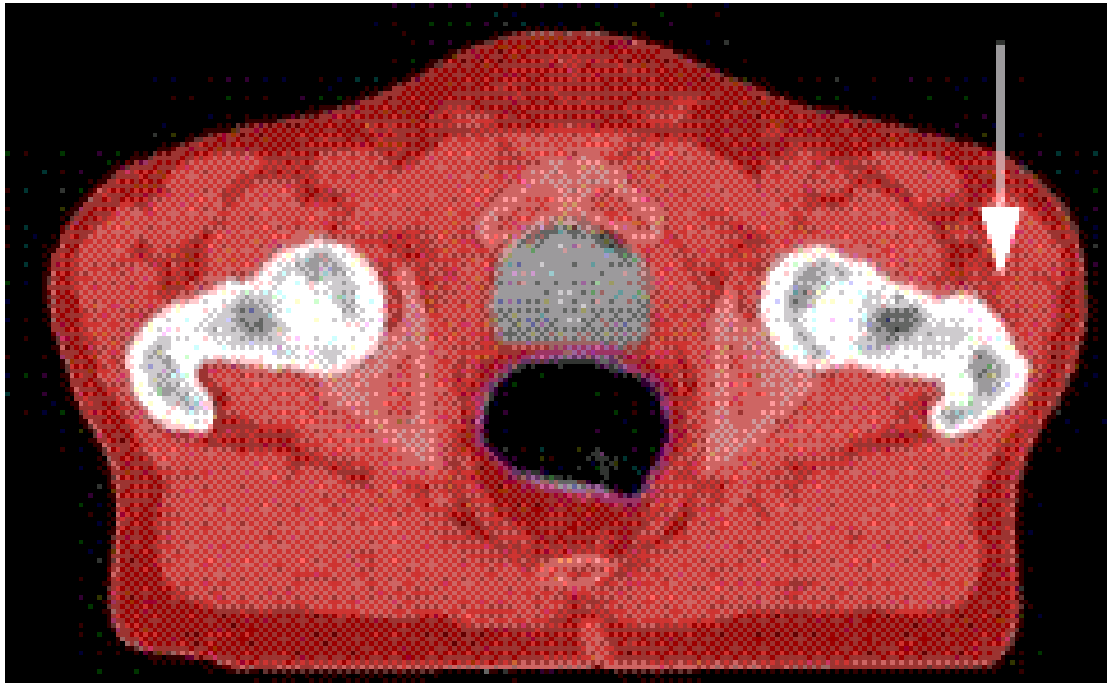


Disclaimer: This is not an endorsed planning method, only an example taken from a clinical plan.

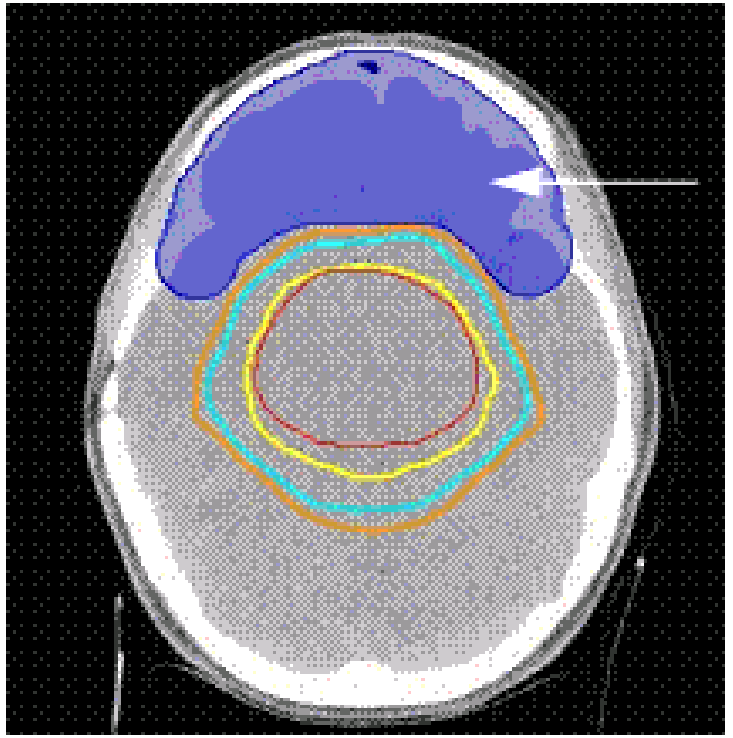


Disclaimer: This is not an endorsed planning method, only an example taken from a clinical plan.

Structures to Limit Dose to Non-Delineated Structures

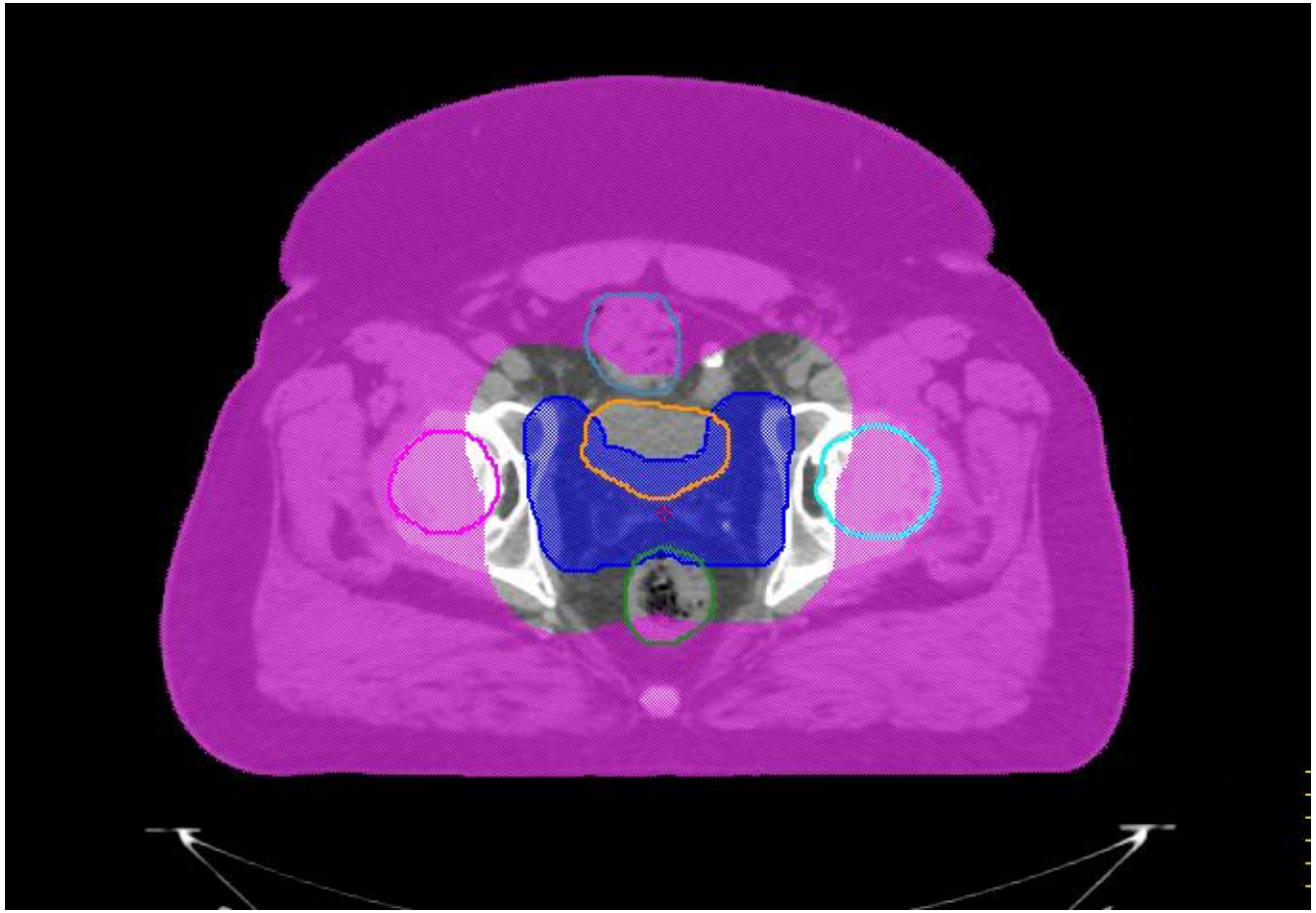


Contours for external – PTV or external – (PTV + Margin)

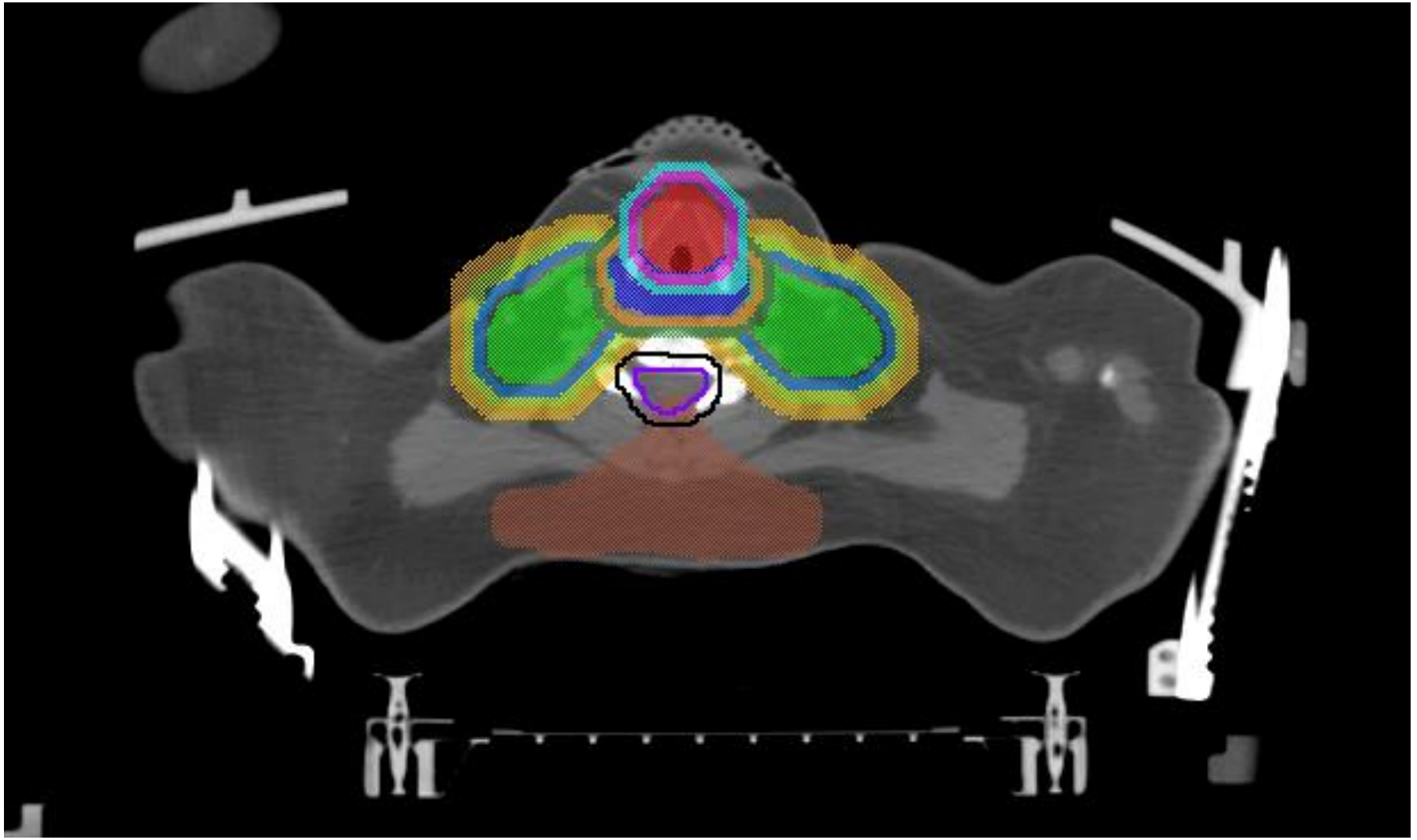


Large avoidance regions in sensitive areas

Pictures from Philips Pinnacle3 Training Manual



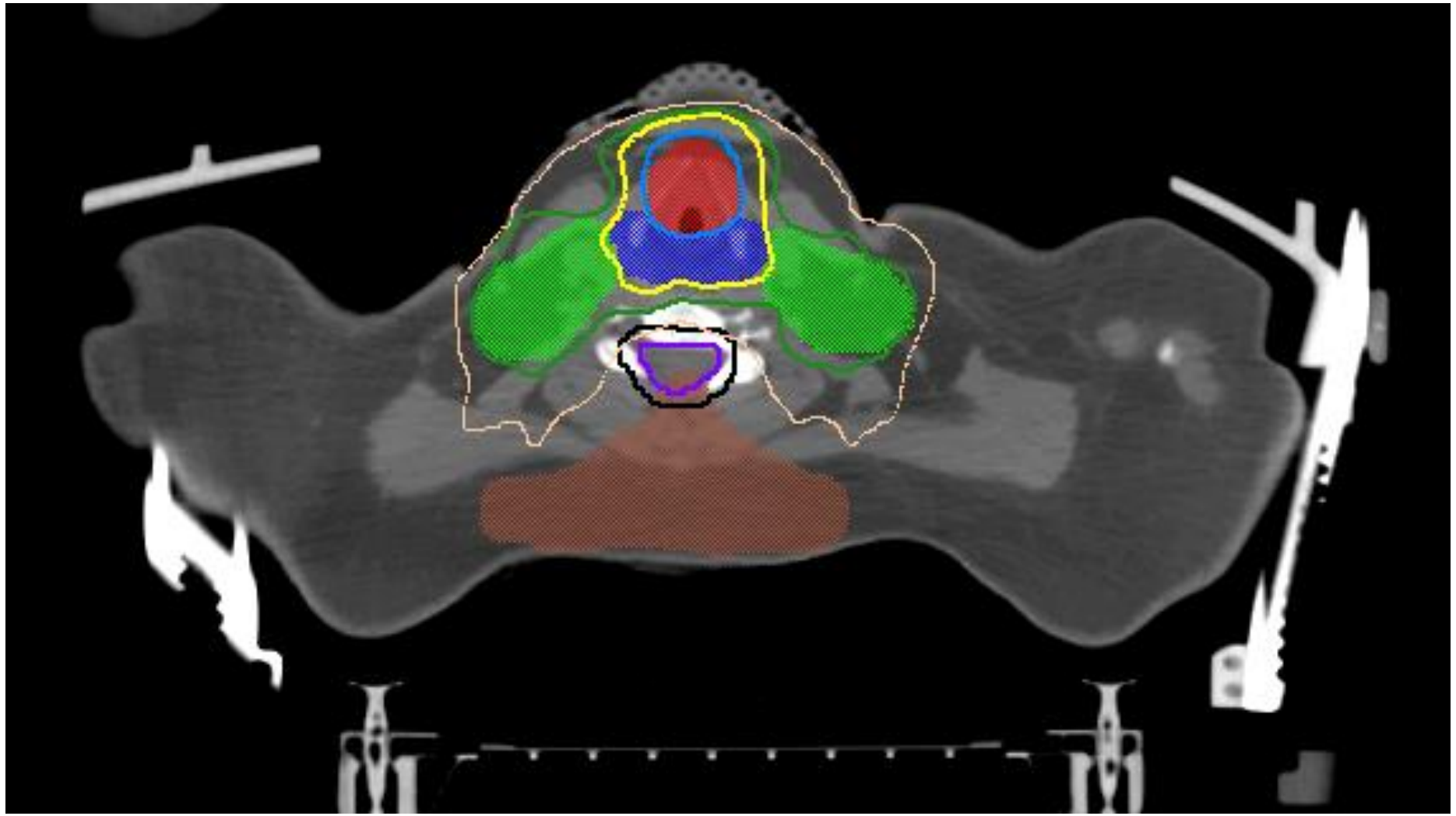
Rings multiple dose Levls

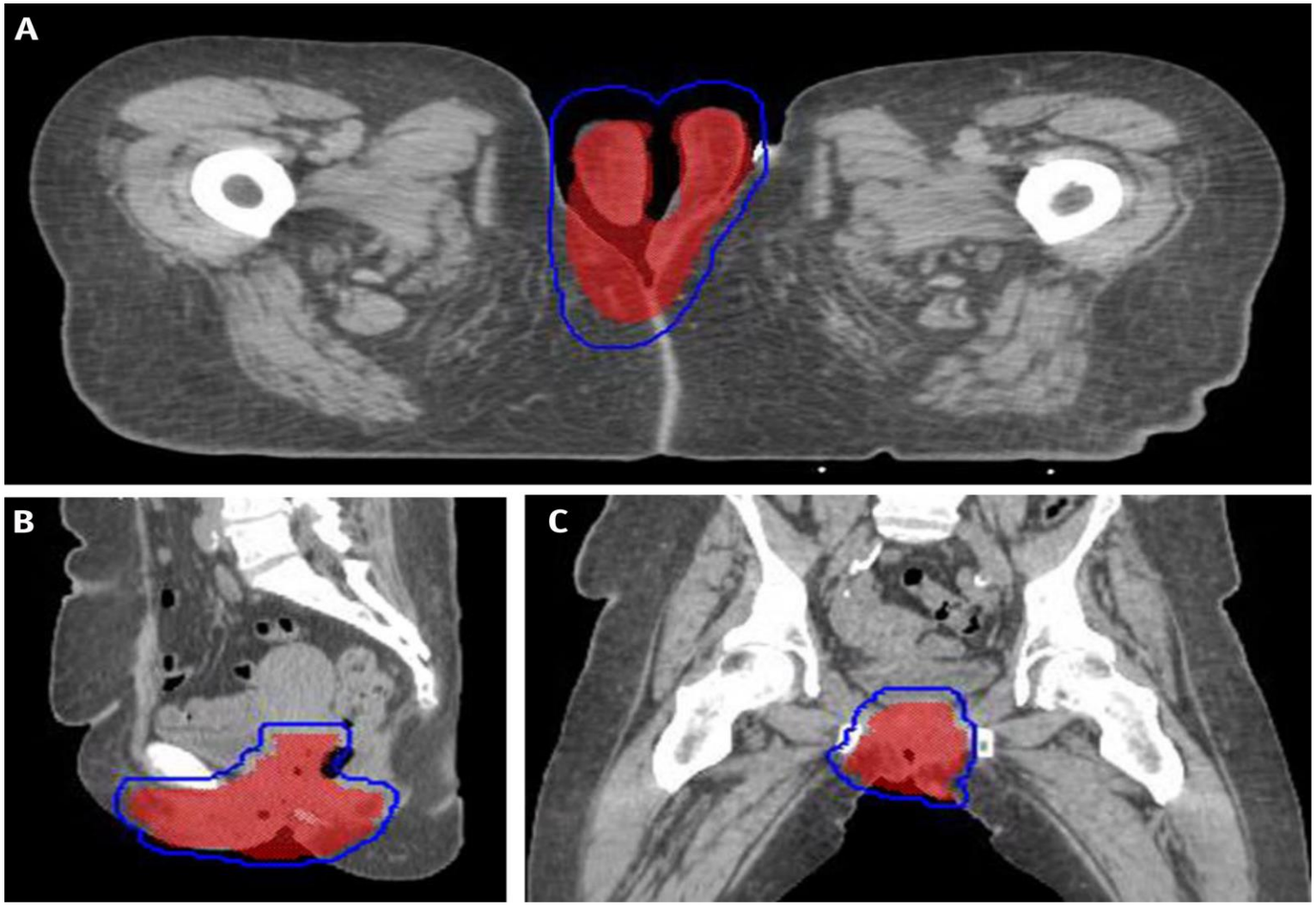


7 Rings

Planning Organ at Risk Volumes

Cord PRV for 3 Dose Levels
6996cGy – Blue
5940cGy – Yellow
5412cGy – Green

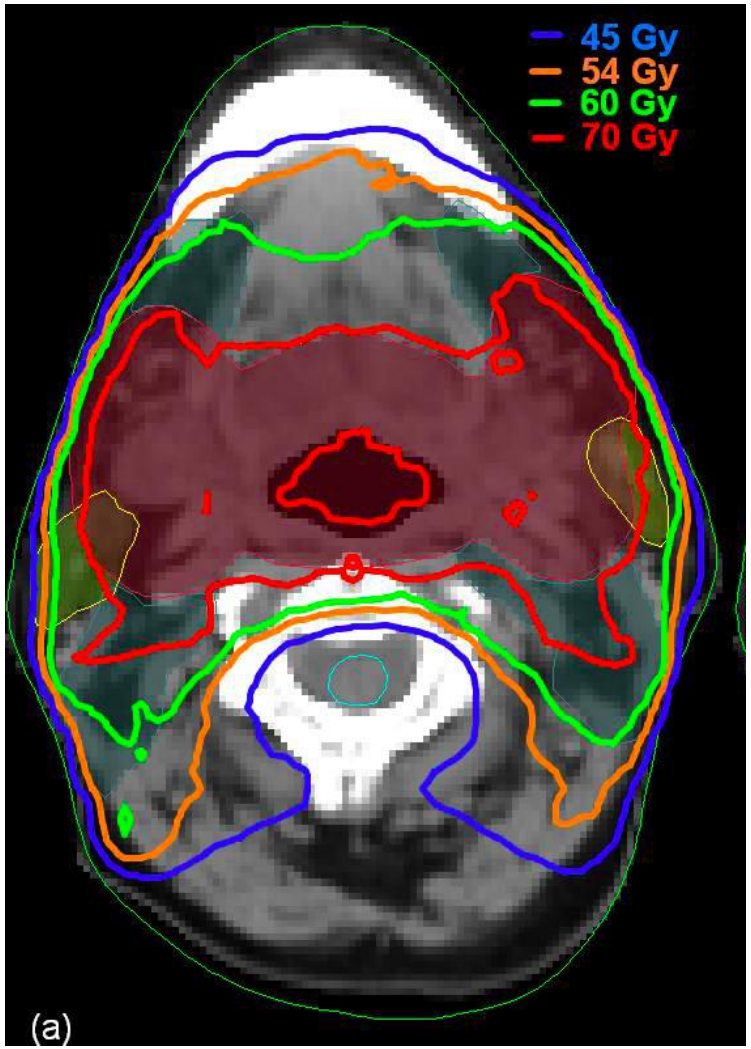




International Journal of Radiation Oncology • Biology • Physics 2018 101, 1025-1026DOI: (10.1016/j.ijrobp.2018.03.019)

The Air Out There: Treatment Planning When Target Volumes Extend Beyond the Skin

Optimization PTV (PTV opt)



- Modify the PTV that the optimizer sees if coverage will be impossible
- PTVs should be cropped from the skin surfact to avoid focing a very high fluence in air
  - Dangerous for moving targets
- Patient can be scanned with bolus if full dose is desired at the surface.
- Reporting should be clear

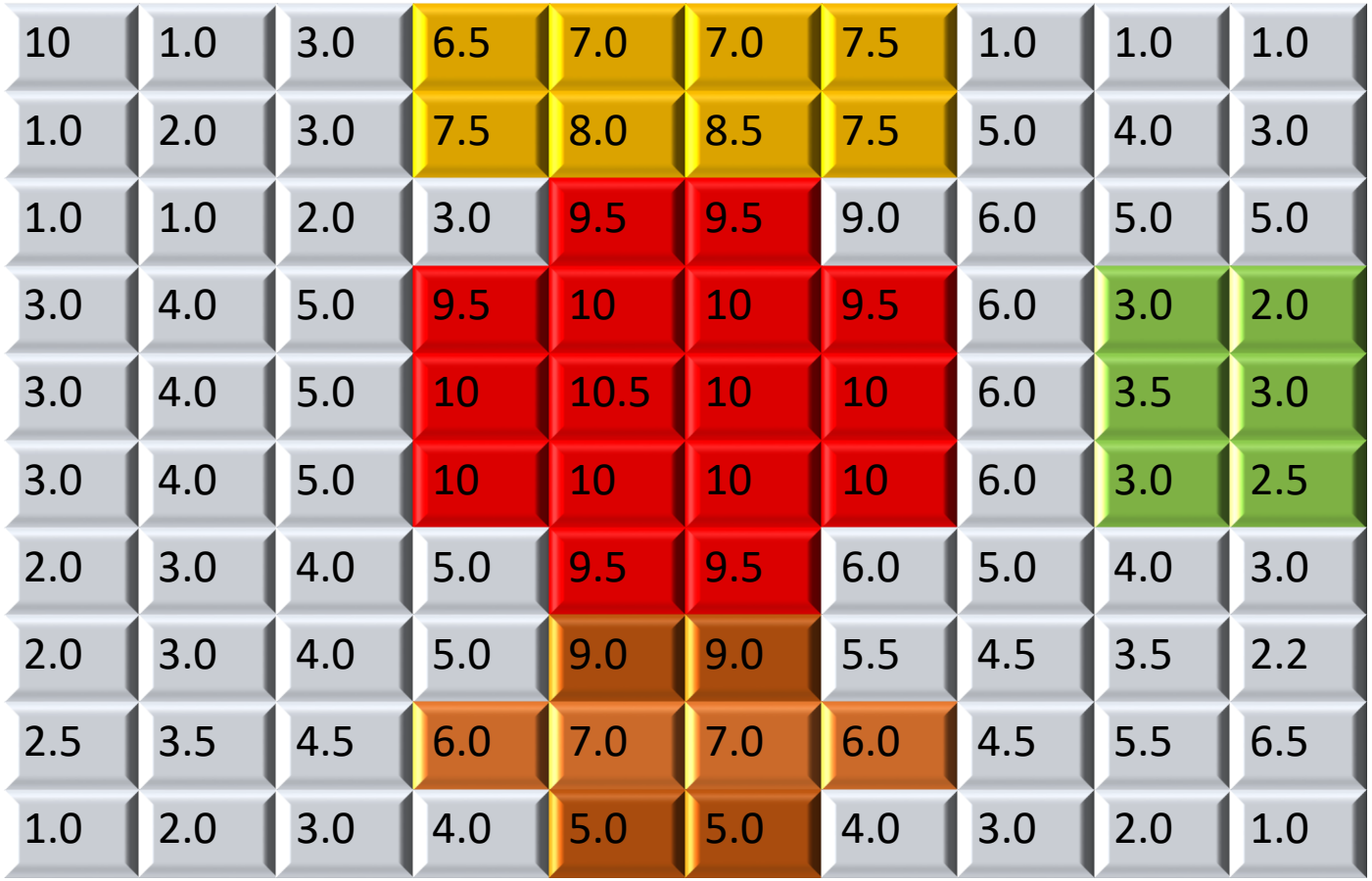
How many structures do you need?

- Recommendations from vendor (manual?) or vendor training
- Trial and error
- Create templates/standardize
- Will vary based on the planning system and patient specific factors
- Generally use PRVs around serial organs

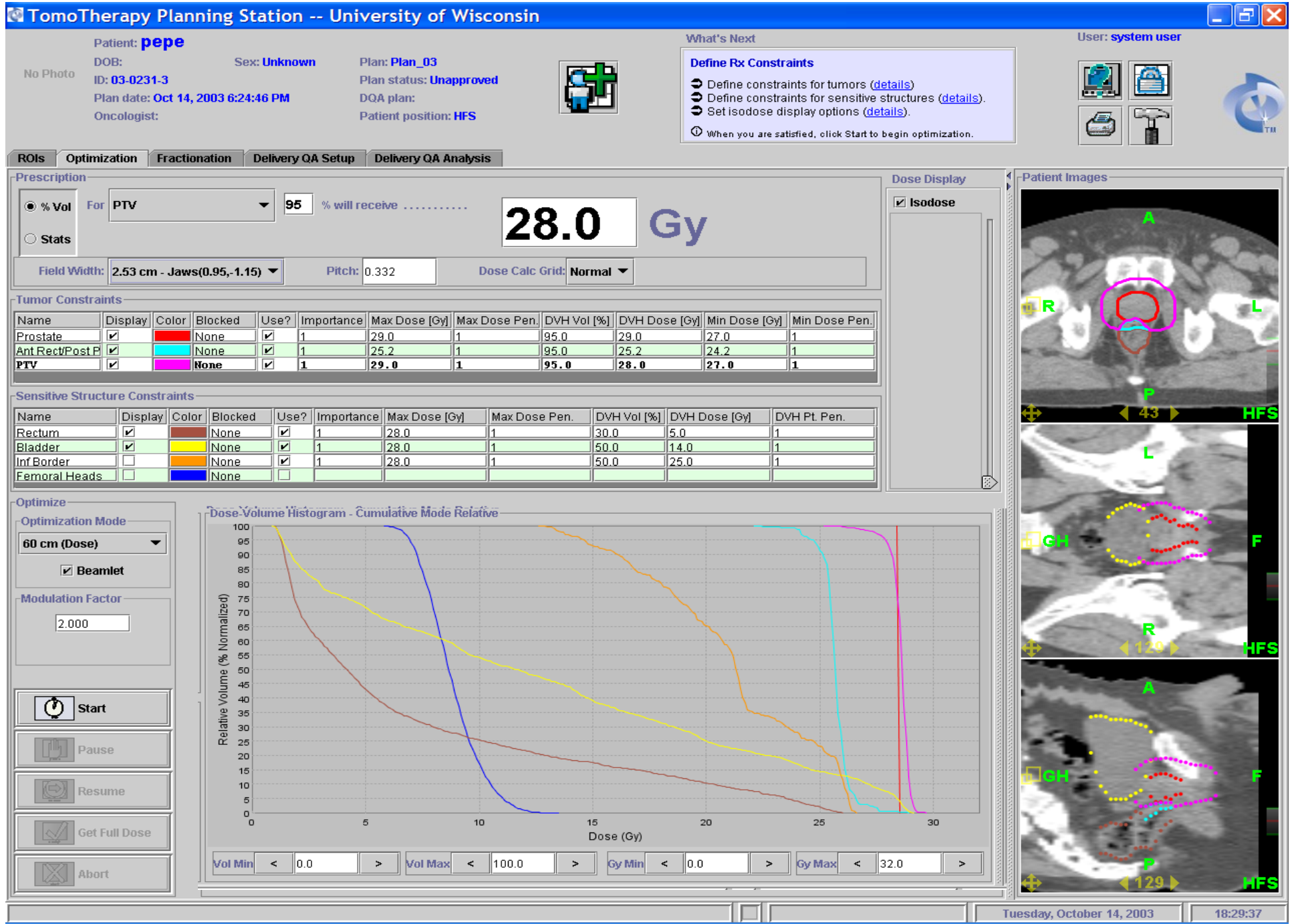
Adding Objectives

- Goals should be realistic and not conflicting
- Some structures may require more than one objective

Let's say these are the objectives:
Prostate –V10Gy ≥ 99%
Rectum – Max dose 4Gy **X**
Femoral Head – V5Gy<10%
Bladder – V2Gy<5% **X**



It will be harder to ask for things that are not achievable. These conflicts would be worse in the PTV were to overlap with the bladder and rectum.


TomoTherapy Planning Station -- University of Wisconsin
Patient: pepe
No Photo
DOB:
Sex: Unknown
ID: 03-0231-3
Plan date: Oct 14, 2003 6:24:46 PM
Oncologist:
Plan: Plan_03
Plan status: Unapproved
DQA plan:
Patient position: HFS
What's Next
Define Rx Constraints
Define constraints for tumors (details)
Define constraints for sensitive structures (details).
Set isodose display options (details).
When you are satisfied, click Start to begin optimization.
User: system user
ROIs
Optimization
Fractionation
Delivery QA Setup
Delivery QA Analysis
Prescription
% Vol
Stats
For PTV
95 % will receive .....
28.0 Gy
Field Width: 2.53 cm - Jaws(0.95,-1.15)
Pitch: 0.332
Dose Calc Grid: Normal
Dose Display
Isodose
Patient Images
Tumor Constraints
Name | Display | Color | Blocked | Use? | Importance | Max Dose [Gy] | Max Dose Pen. | DVH Vol [%] | DVH Dose [Gy] | Min Dose [Gy] | Min Dose Pen.
Prostate | None | 1 | 29.0 | 1 | 95.0 | 29.0 | 27.0 | 1
Ant Rect/Post P | None | 1 | 25.2 | 1 | 95.0 | 25.2 | 24.2 | 1
PTV | None | 1 | 29.0 | 1 | 95.0 | 28.0 | 27.0 | 1
Sensitive Structure Constraints
Name | Display | Color | Blocked | Use? | Importance | Max Dose [Gy] | Max Dose Pen. | DVH Vol [%] | DVH Dose [Gy] | DVH Pt. Pen.
Rectum | None | 1 | 28.0 | 1 | 30.0 | 5.0 | 1
Bladder | None | 1 | 28.0 | 1 | 50.0 | 14.0 | 1
Inf Border | None | 1 | 28.0 | 1 | 50.0 | 25.0 | 1
Femoral Heads | None
Optimize
Optimization Mode
60 cm (Dose)
Beamlet
Modulation Factor
2.000
Start
Pause
Resume
Get Full Dose
Abort
Dose-Volume Histogram - Cumulative Mode Relative
Relative Volume (% Normalized)
Dose (Gy)
Vol Min 0.0
Vol Max 100.0
Gy Min 0.0
Gy Max 32.0
A
R
L
P
43
HFS
GH
F
129
Tuesday, October 14, 2003
18:29:37

What about unassigned voxels

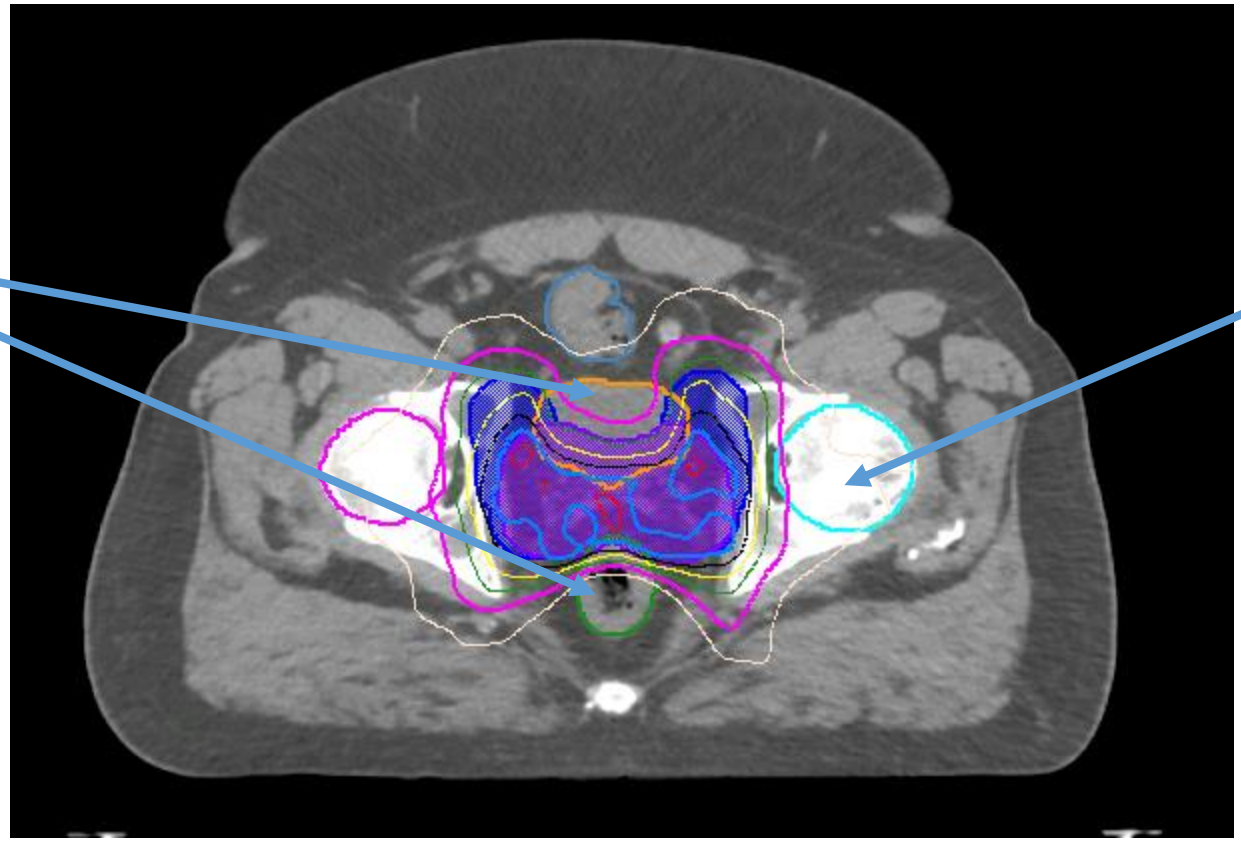
Normal
Tissue Objective
or
BodyExternal Etc.

Ring

Ring and Structure will overlap

Final Distribution

Avoids bladder and rectum



More low dose laterally

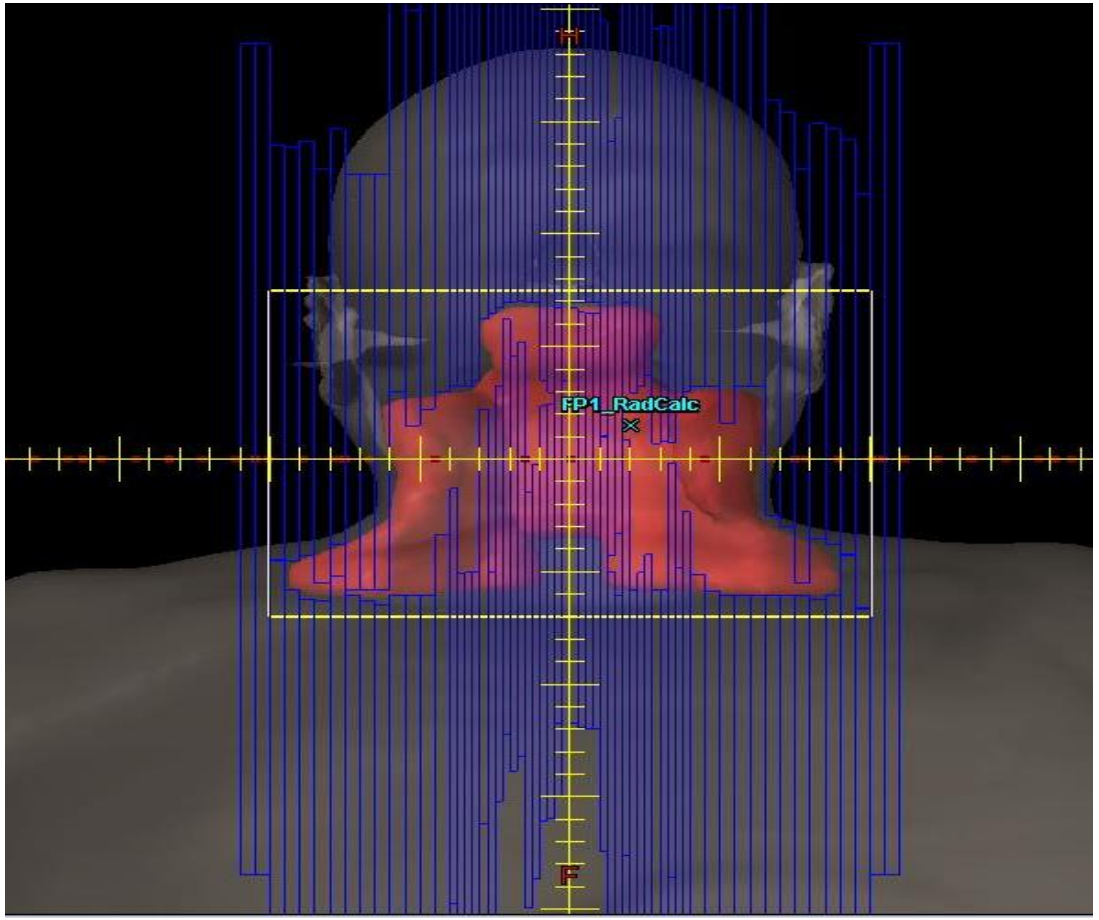
Planning Strategies

- The order that the objectives are introduced and their weighting may matter
- Read user manual and talk to the vendor
- If you are stuck in a solution of the optimization that is unacceptable, major changes may be required to get out of it (some system require resetting beams)

Modulation

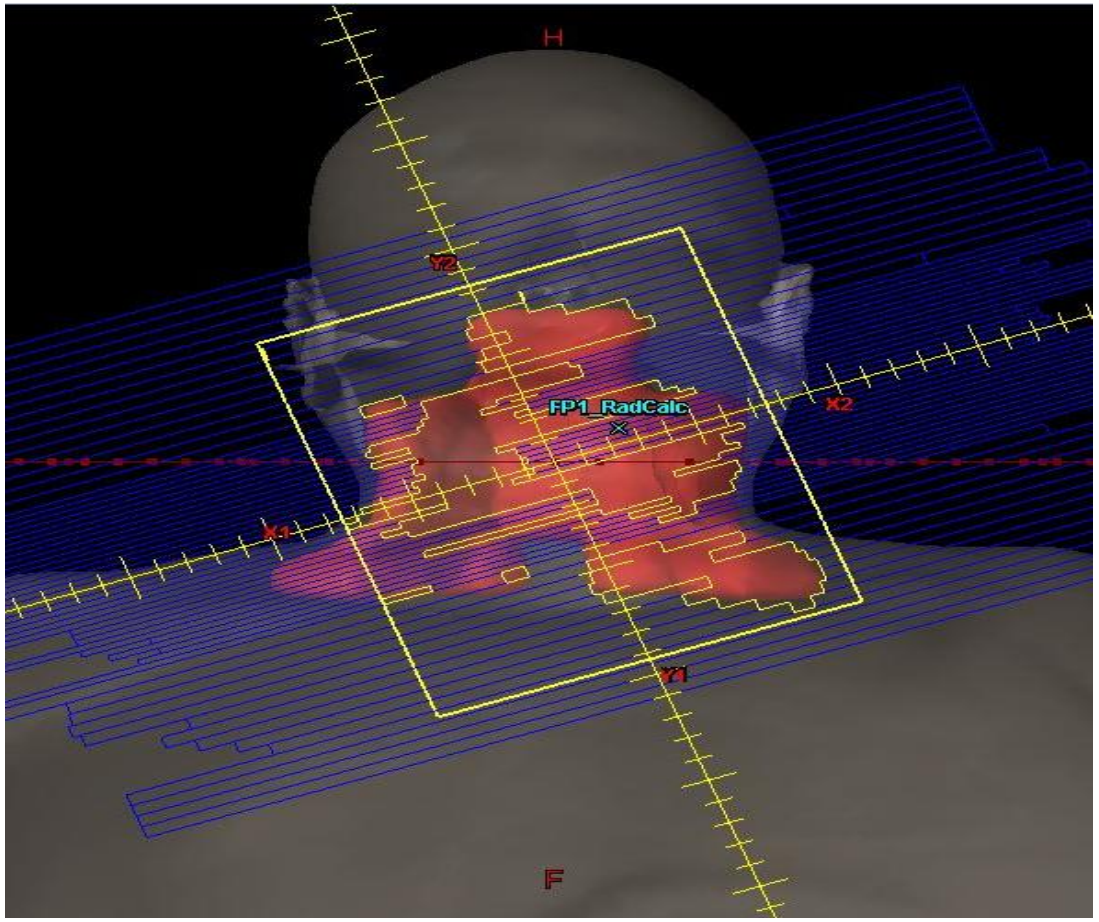
- Tomotherapy defines a modulation factor (maximum divide by average leaf opening for all non-zero leaf openings) but modulation varies in all systems
  - In Tomo, diminishing returns over a MF of 3.0
- High modulation makes delivery verification more difficult and slows treatment time
- May be able to come up with a less modulated solution by limiting intensity levels or simplifying the problem

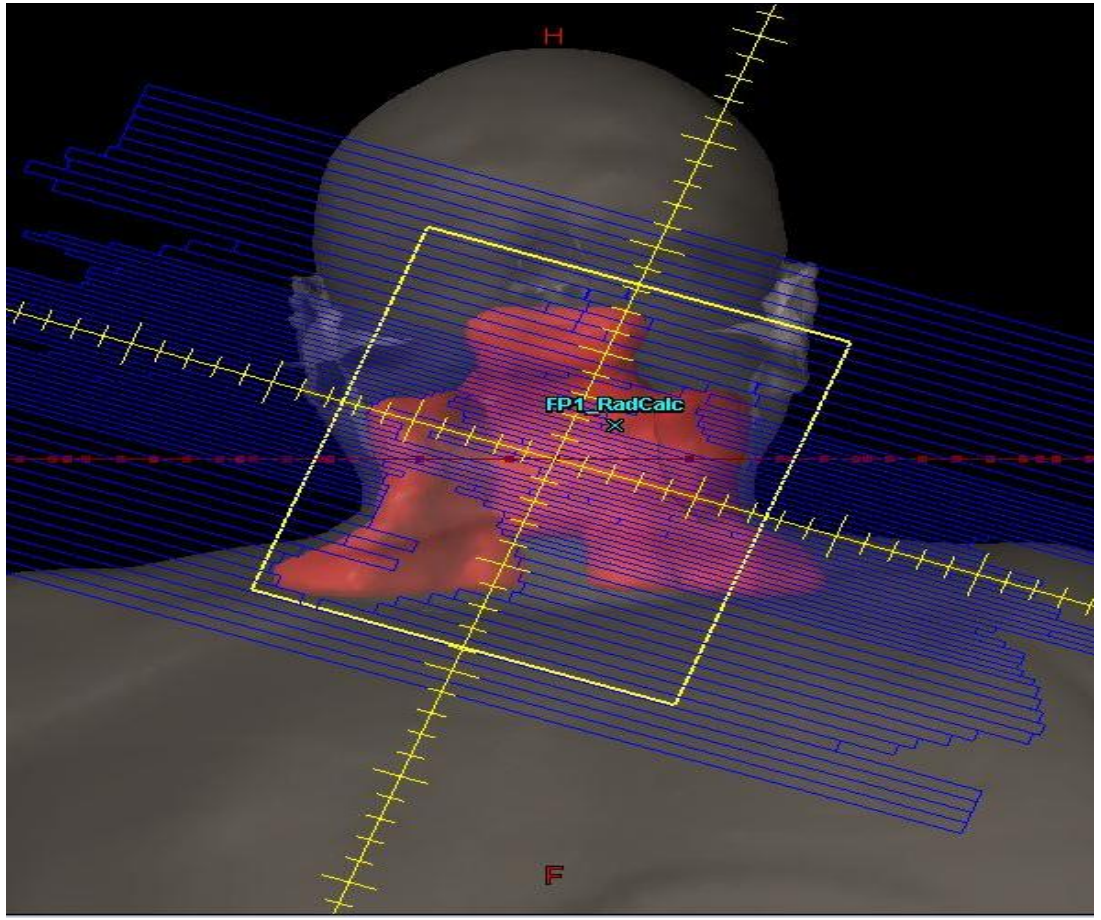
Field Limits



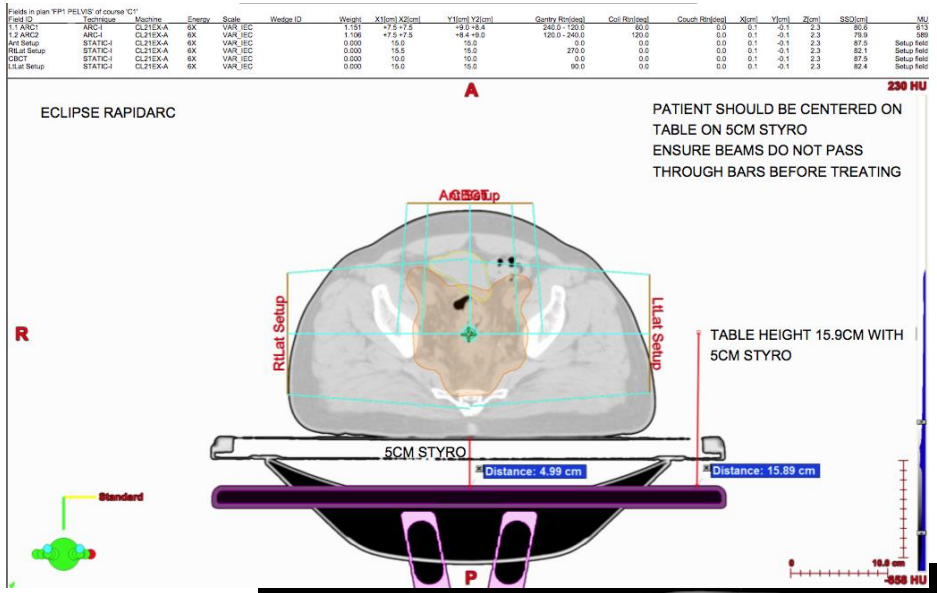
- Max leaf span is usually limited
- Modulation may be compromised for wider fields
- Can change collimator angles to better cover fields

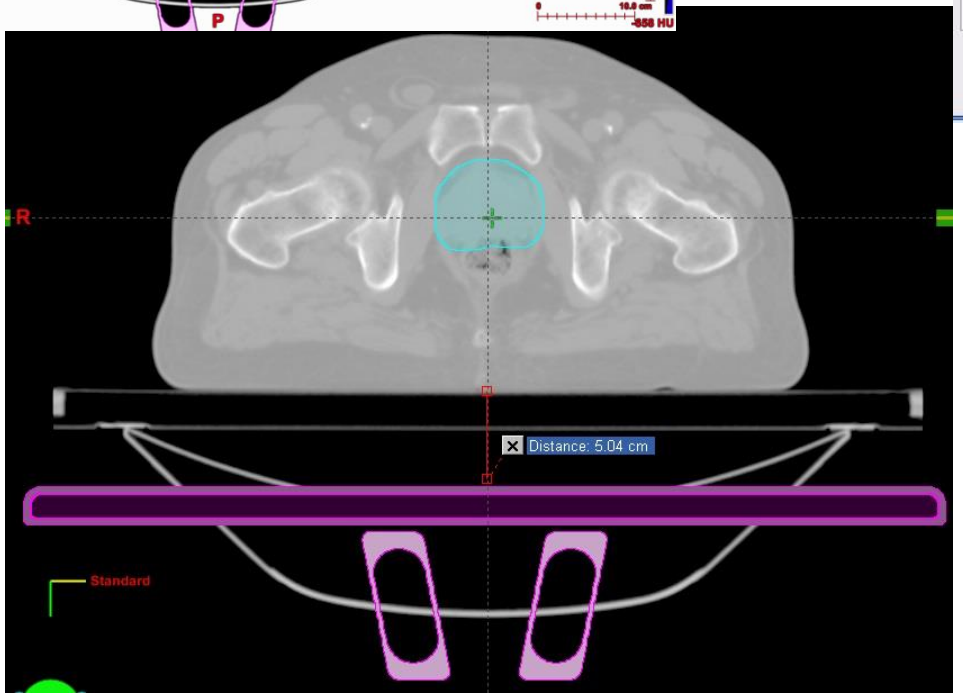
Interleaf Leakage Consierations

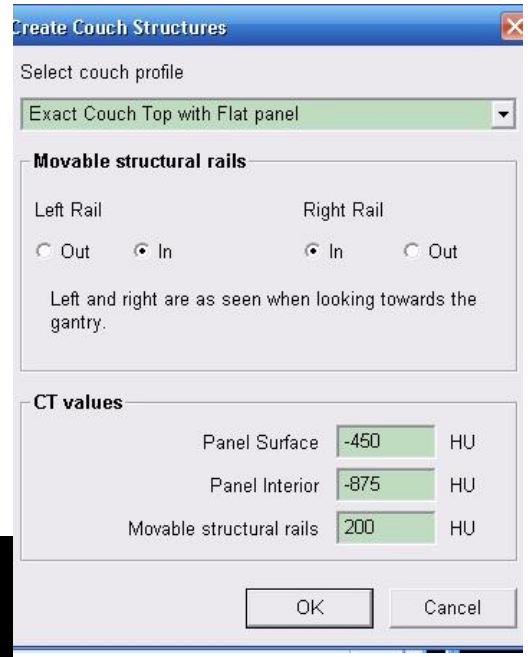




Treatment Couch







How do you know you have the best plan

- You don’t!
- Planner experience and training matters
- Must be able to compare solutions from different optimization attempts
- Planner should be able to compare against other planners (plan challege/plan scoring)
- Peer review

Commissioning

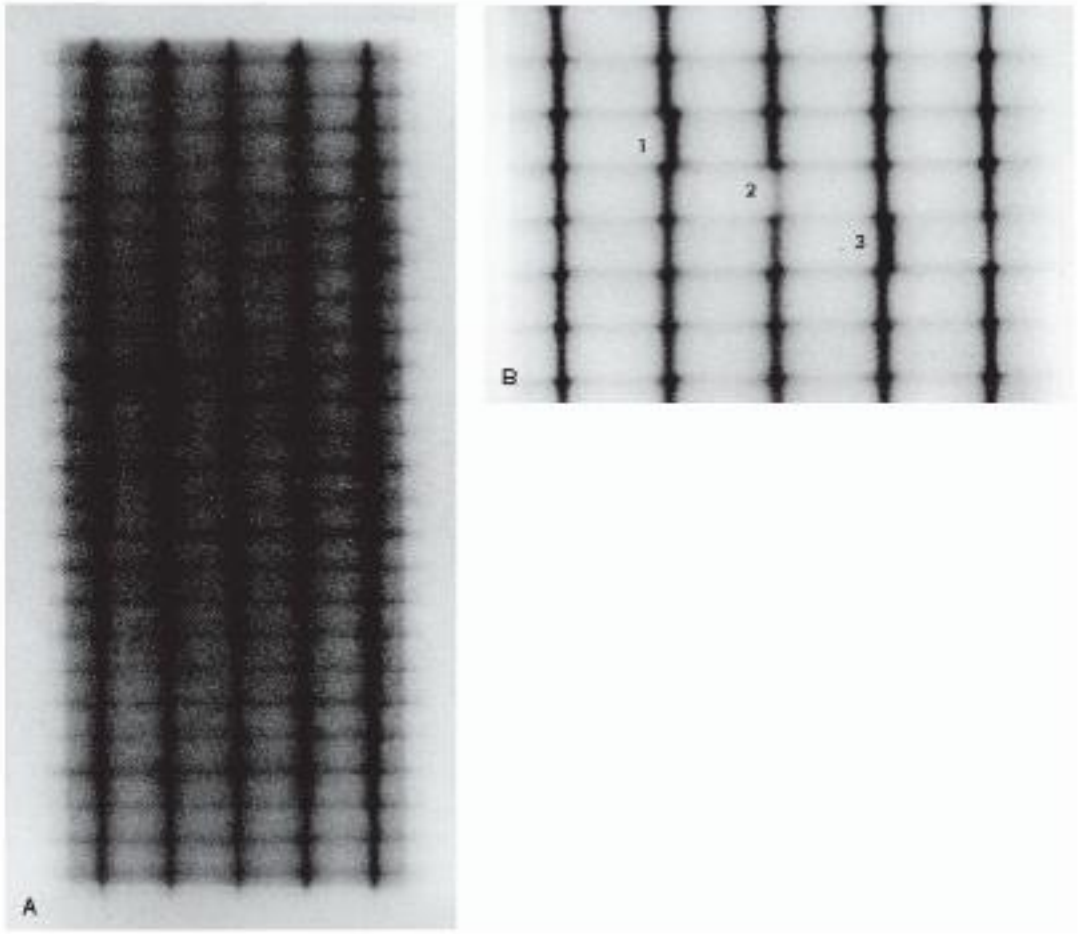
- IMRT and VMAT can be available usually with small hardware and software upgrades
- Validation can be challenging
- Commissioning is require for both planning and delivery

IMRT/VMAT – MLC tests

- Additional MLC tests may be required

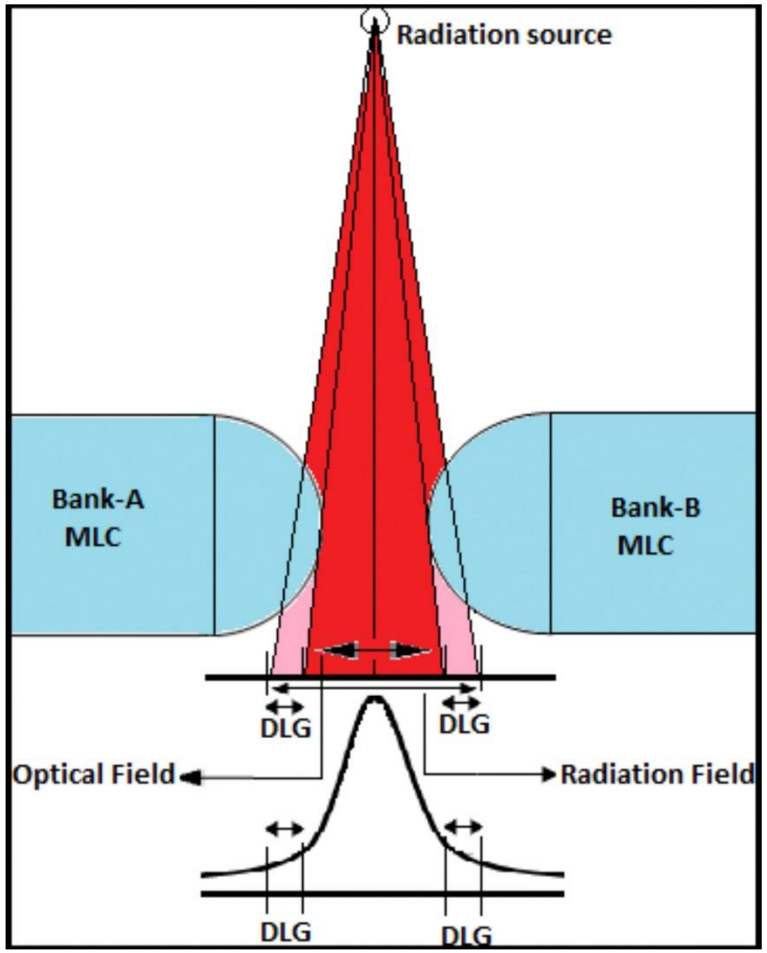
  Dosimetry
  - Leaf gap
  - Transmission

  Mechanical
  - Speed
  - Positioning



Chui CS, Spirou S, LoSasso T. Testing of dynamic multileaf collimation. Med Phys. 1996;23:635-641

MLC Characteristics



From Shende et al. Reports of Practical Oncology & Radiotherapy Volume 22, Issue 6, November–December 2017, Pages 485-494

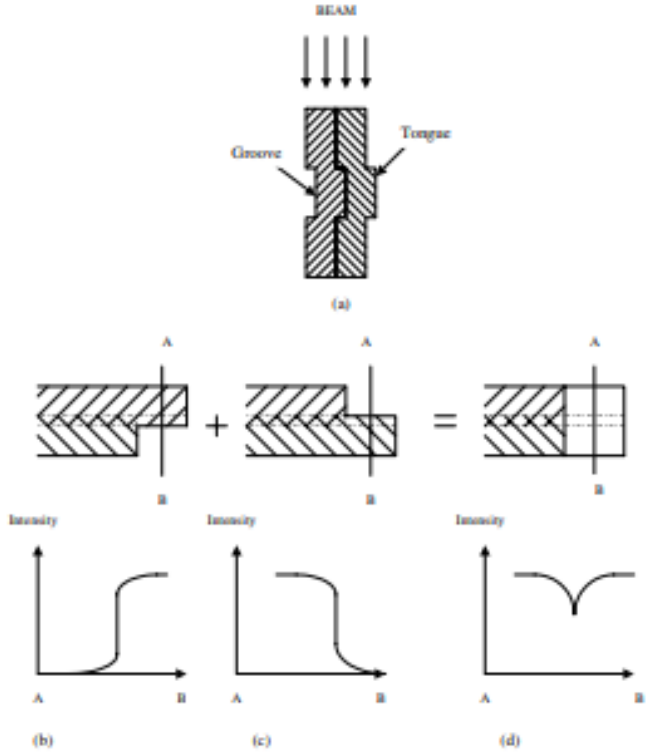
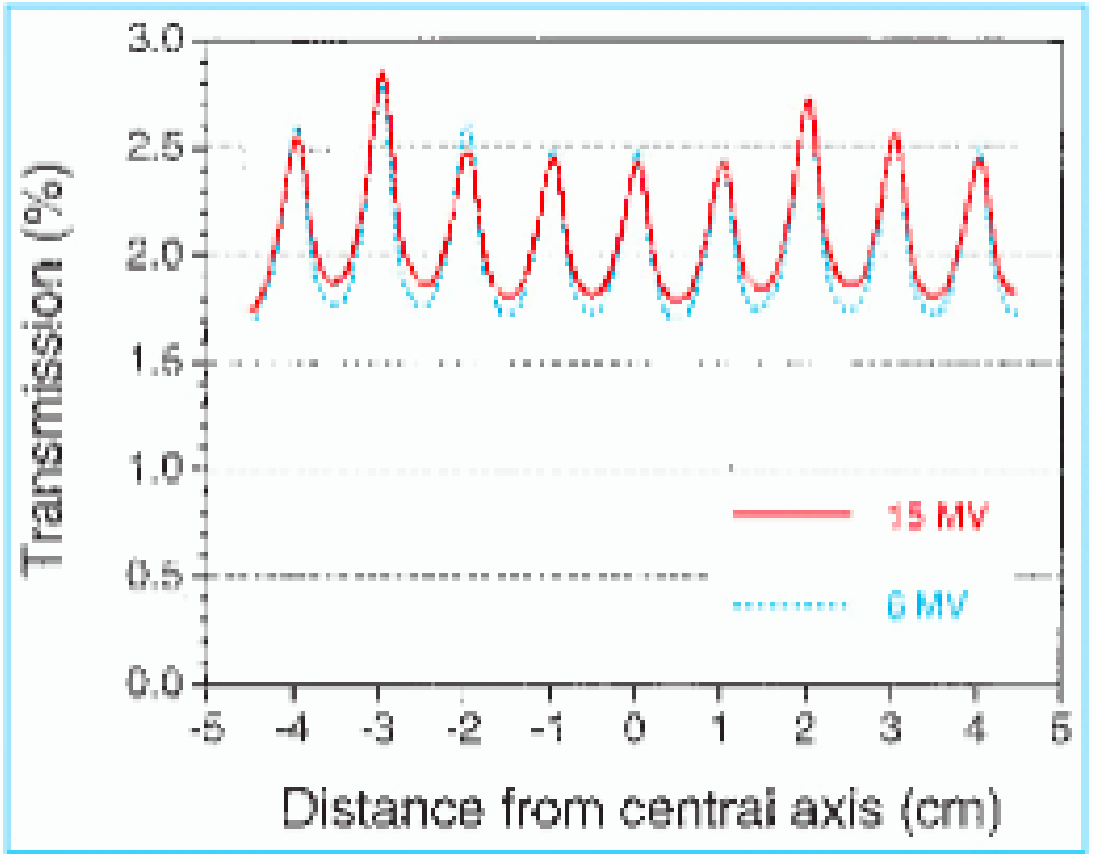
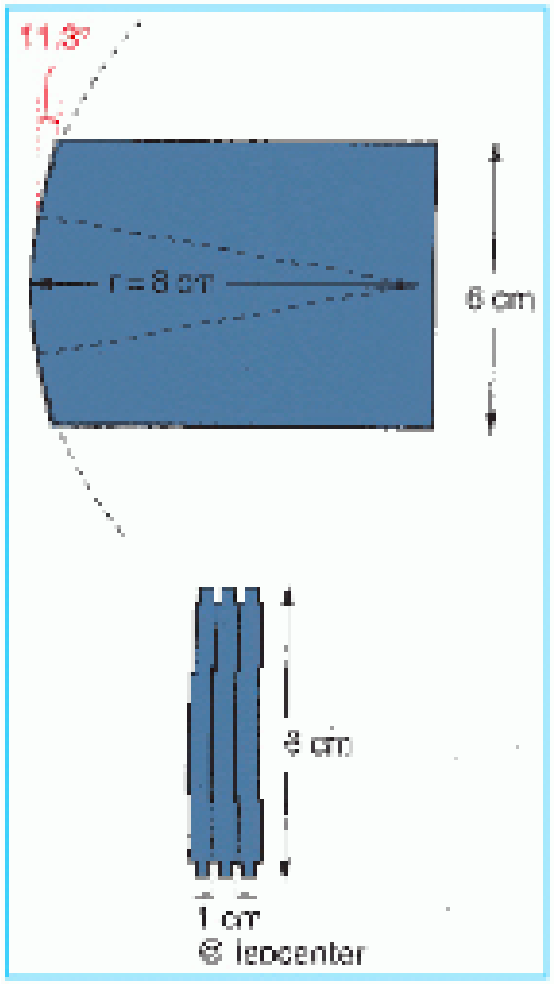


Figure 1. Schematic diagram of the tongue-and-groove effect in an MLC. (a) The design of the MLC tongue and groove is to reduce inter-leaf leakage. (b)–(d) Schematic diagrams of two fields and their superposition defined by two adjacent leaves. The region centred between two leaves in (d) is underdosed.

From Deng et al. The MLC tongue-and-groove effect on IMRT dose distributions. Phys. Med. Biol. 46 (2001) 1039–1060

Inter and Intraleaf Leakage



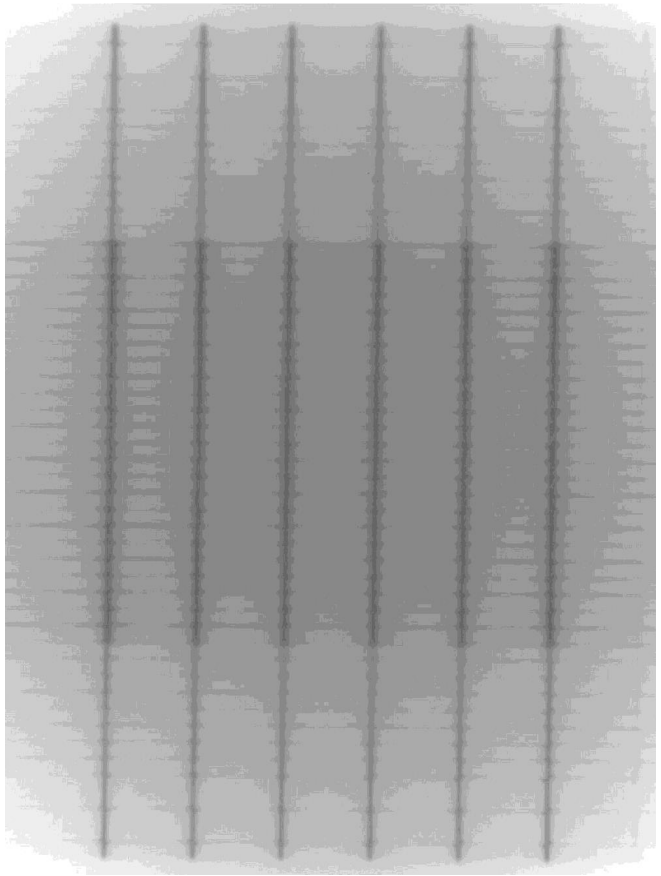


LoSasso T, Chui CS, Ling CC. Physical and dosimetric aspects of a multileaf collimation system used in the dynamic mode for implementing intensity-modulated radiotherapy. Med Phys. 1998;25:1919-1927

Commissioning and Quality Assurance of RapidArc Radiotherapy Delivery System

C. Clifton Ling, Ph.D., Pengpeng Zhang, Ph.D., Yves Archambault, M.Sc., Jiri Bocanek, M.Sc., Grace Tang, M.Phil., Thomas LoSasso, Ph.D.

International Journal of Radiation Oncology • Biology • Physics
Volume 72, Issue 2, Pages 575-581 (October 2008)
DOI: 10.1016/j.ijrobp.2008.05.060



A film exposed to the 1-mm-wide picket fence pattern with “intentional” errors in fence width and position.

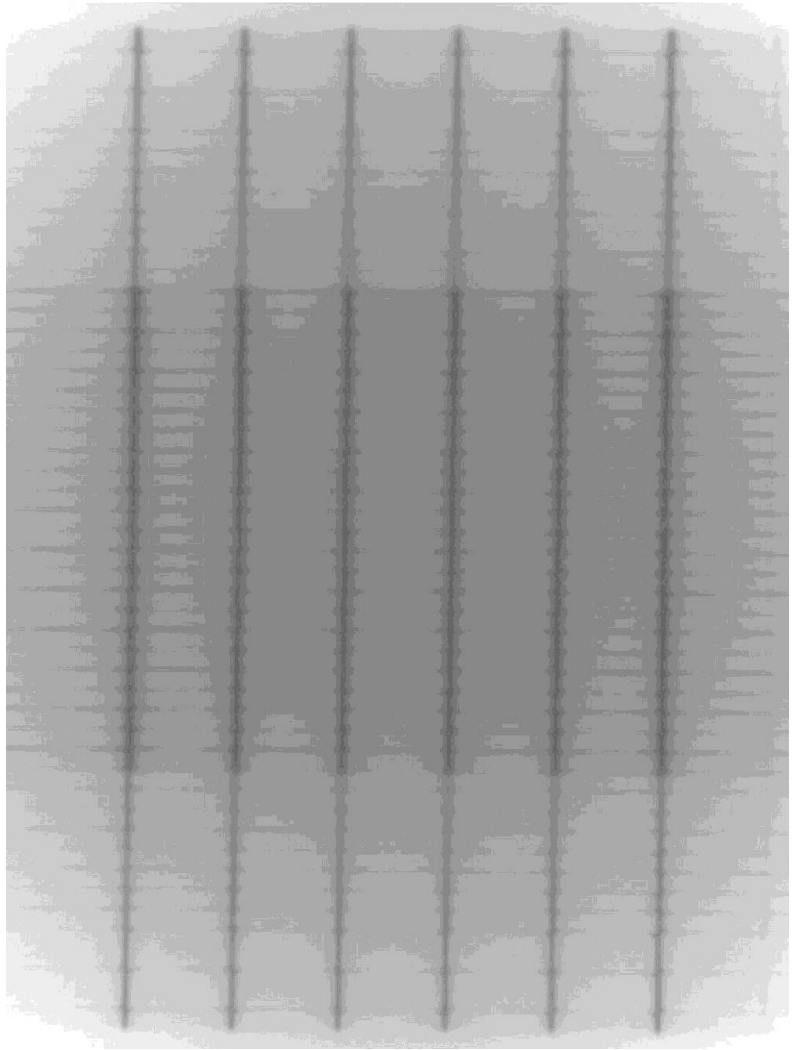
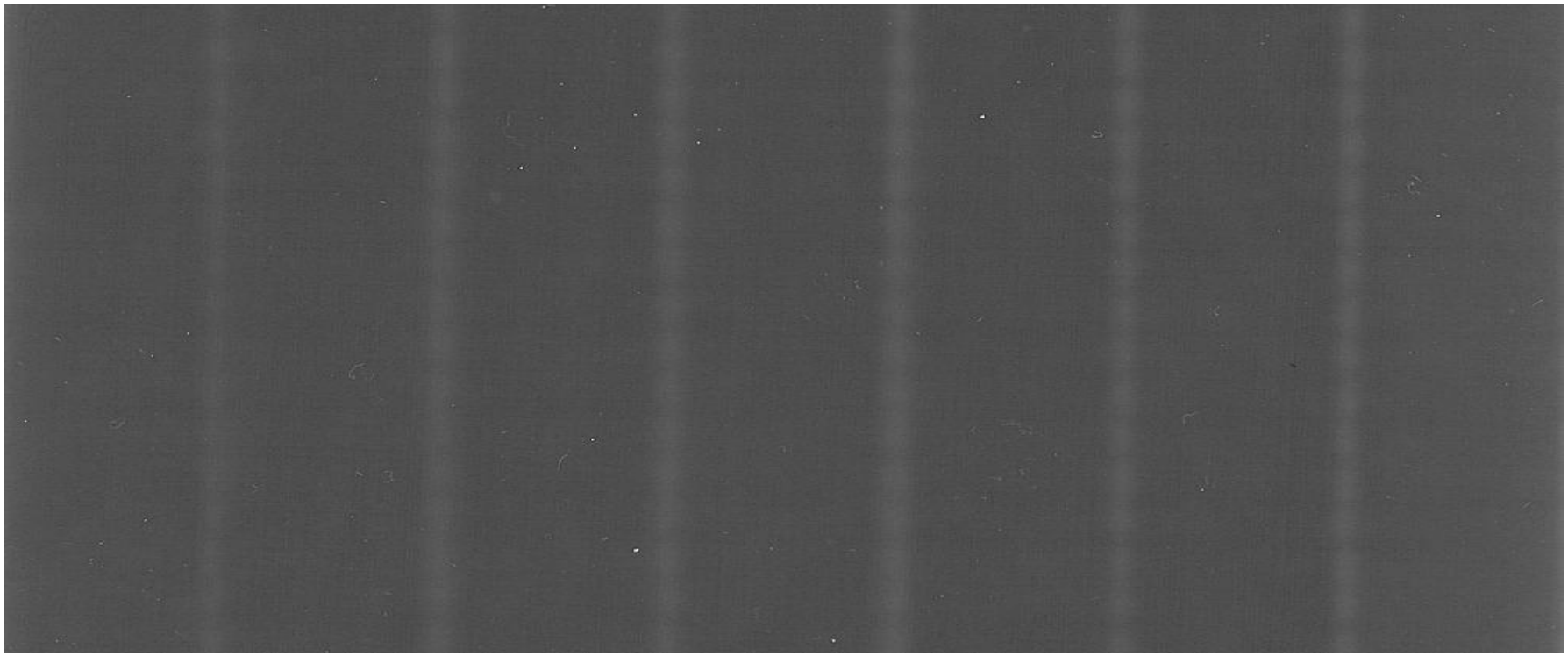
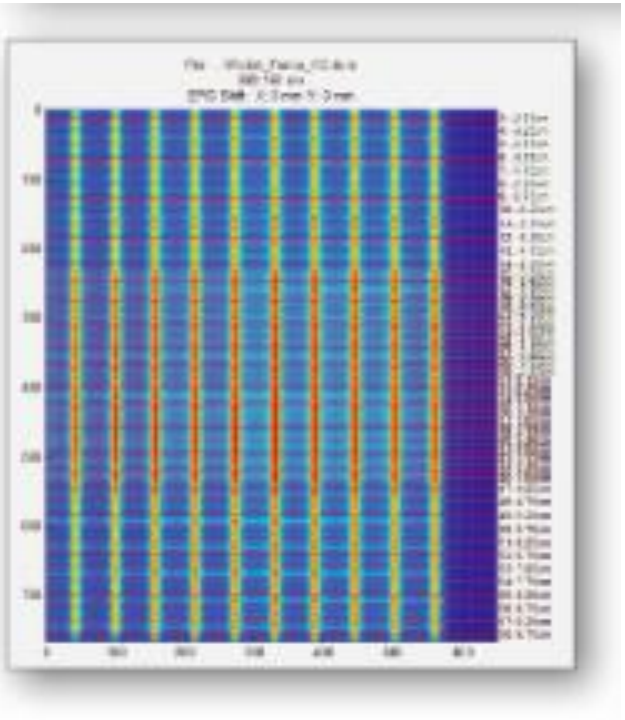


Image of a film that was exposed twice to the 1-mm-wide picket fence pattern, once at stationary gantry angle and a second time in RapidArc mode.



Film exposed to a RapidArc QA plan, combining different dose-rates, gantry ranges, and gantry speeds, to give the same monitor unit (MU) to the different parts of the field.

MLC Tests for VMAT



RapidArc® MLC

- **Test 0.1:** dMLC Dosimetry
- **Test 0.2:** Picket Fence Test vs. Gantry Angle
- **Test 1.1:** Picket Fence Test during RapidArc®
- **Test 1.2:** Picket Fence Test during RapidArc® with Intentional Errors
- **Test 2:** Accurate Control of Dose Rate and Gantry Speed during RapidArc® Delivery
- **Test 3:** Accurate Control of Leaf Speed during RapidArc® Delivery

https://radimage.com/solutions/mlc-qa/

IMRT/VMAT Commissioning - TPS

- AAPM MPPG 5a recommends the following tests
- VMAT, Segmental IMRT, and Dynamic IMRT need to be validated separately

	Test	
1	Verify small field PDD	<2x2cm2, MLC shaped
2	Output for small MLC defined field	Small MLC defined segments
3	AAPM TG-119 tests	Plan, measure and compare benchmark cases
4	Clinical tests	Plan, measure and compare representative clinical cases
5	External Review	Sim, plan, and treat anthropomorphic phantom

From AAPM MPPG 5a. Journal of Applied Clinical Medical Physics, Vol. 16, No. 5, 2015

Other IMRT/VMAT Commissioning

- Ezzel GA, Galvin JM, Low D et al. Guidance document on delivery, treatment planning, and clinical implementation of IMRT: report of the IMRT subcommittee of the AAPM radiation therapy committee. Med Phys. 2003; 30:2089-2115.
- Ling et al. Commissioning and quality assurance of rapidarc delivery system. IJROBP.2008 Oct 1;72(2):575-81 (Varian)
- Beford et al. Commissioning of Voumetric Modulated Arc Therapy (VMAT). IJROBP. 2009;73:537-545. (Elekta)
- ESTRO Booklet 9
- Read the manual!