ICRU Recommendations

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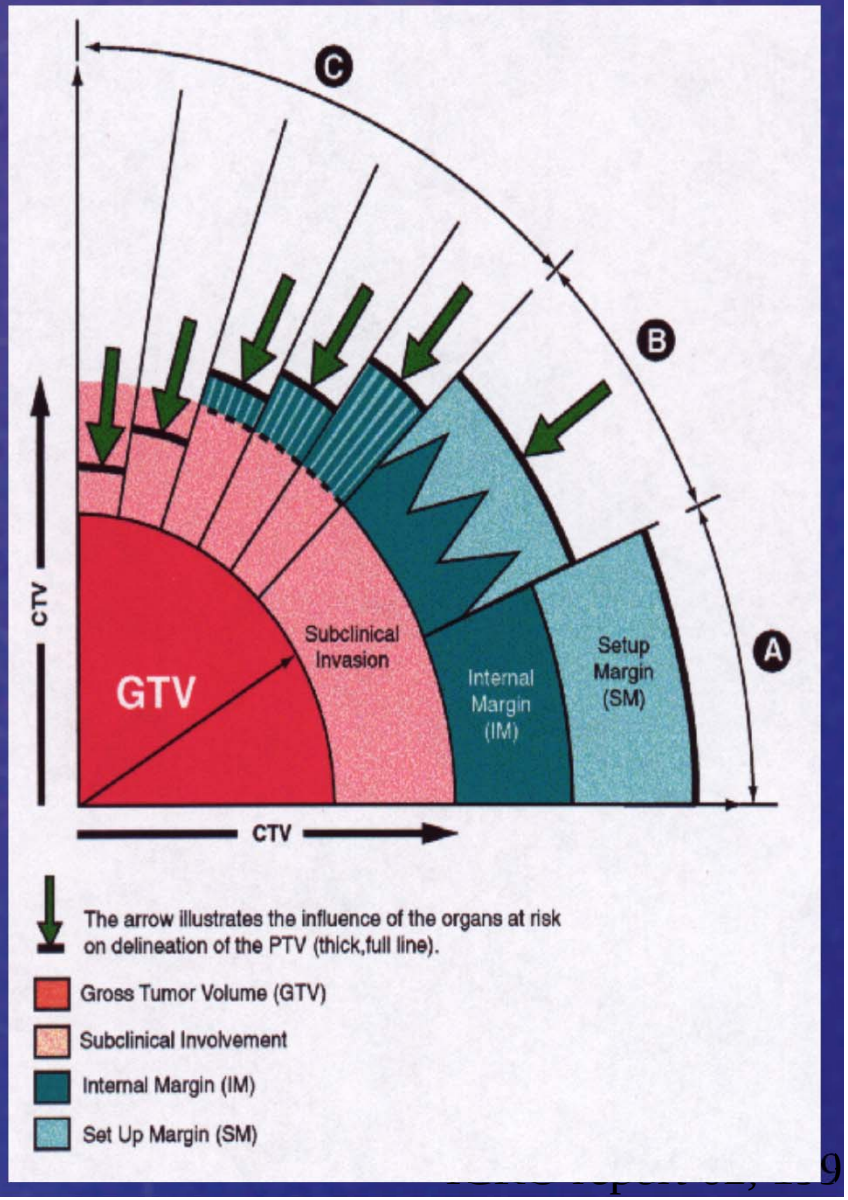
Target Volumes in Radiation Oncology: ICRU 50 and 62:

- Gross Tumor Volume: GTV
- Clinical Target Volume: CTV
- Internal Target Volume: ITV
- Planning Target Volume: PTV
- Organ at Risk: OAR
- Planning Organ at Risk Volume: PRV



The Need for an New ICRU Report on IMRT

It was published and/or mentioned …

- **Biological Target Volume (BTV): C. Ling, IJROBP 2000,**
- **Hypoxic TV (HTV), Proliferation TV (PTV), …: ESTRO physics meeting, 2003,**
- **working PTV (wPTV): Ciernik IF, IJROBP, 2005,**
- **AAPM 2005: "… with the use of IMRT, ICRU recommendations will not be needed anymore…".**

Issues for 3D-CRT and IMRT

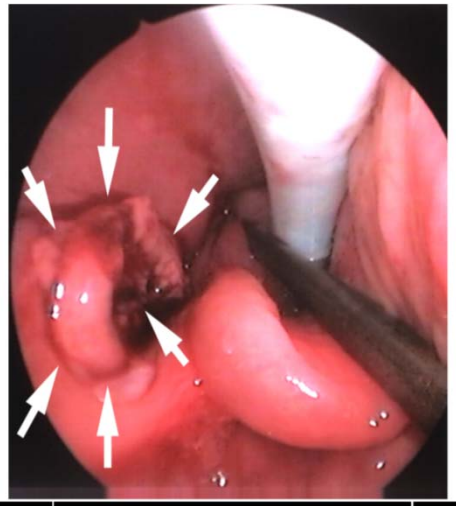
- Multiple GTV, e.g. anatomic vs functional imaging; before and during treatment, …,
- GTV to CTV margins: clinical probability,
- CTV to PTV margins: geometric probability; overlapping volumes,
- ITV ???
- OAR: open vs closed volume? Remaining normal tissues?
- PRV: planning organ at risk volume - serial vs parallel OAR.

Right piriform sinus

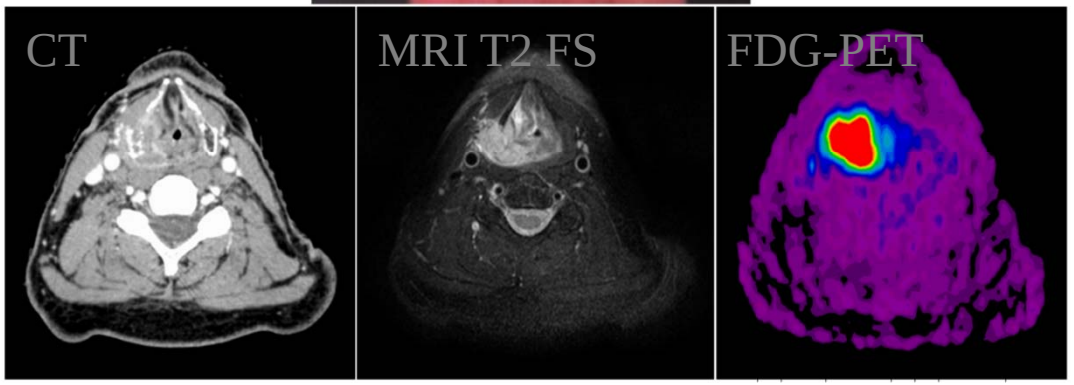
(ICDO-10: C12.9)

SCC grade 2

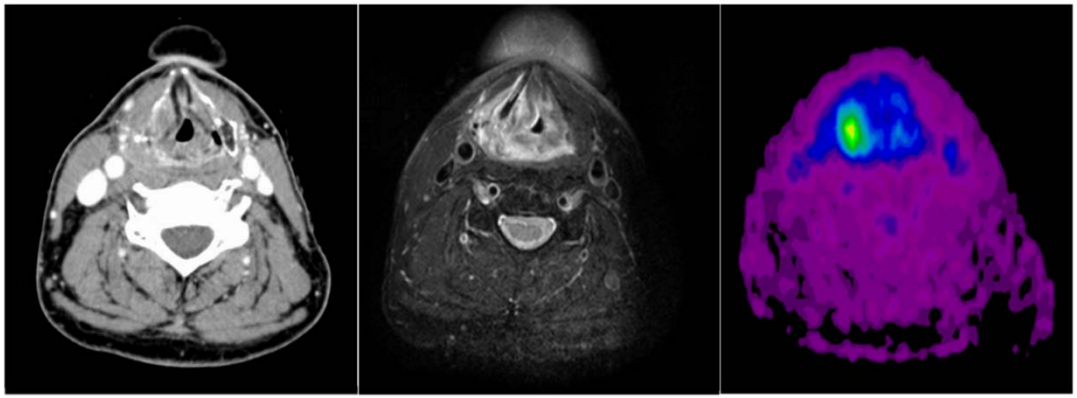
TNM 6th ed: T4N0M0



Fiberoptic examination

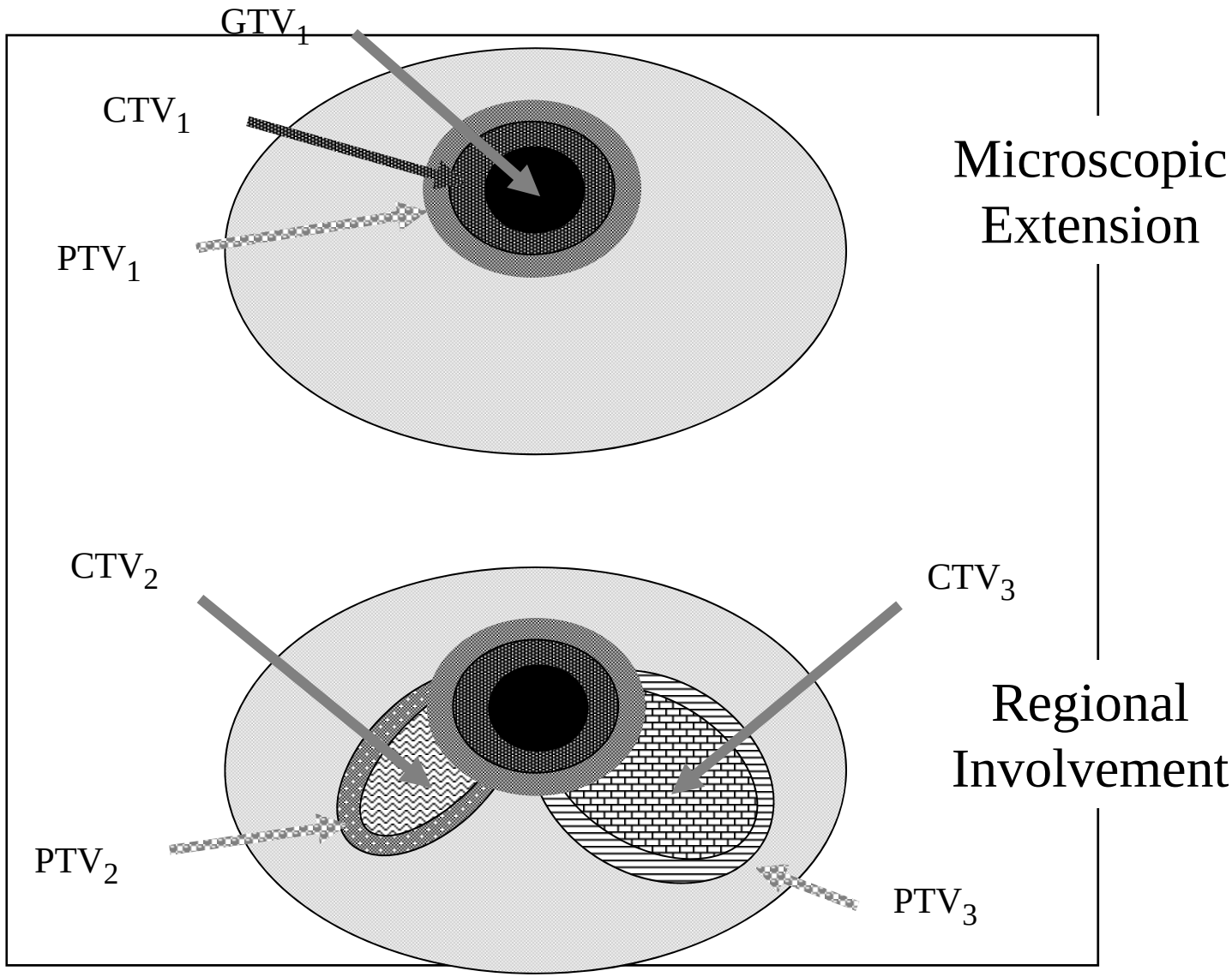


Before Rx-CH

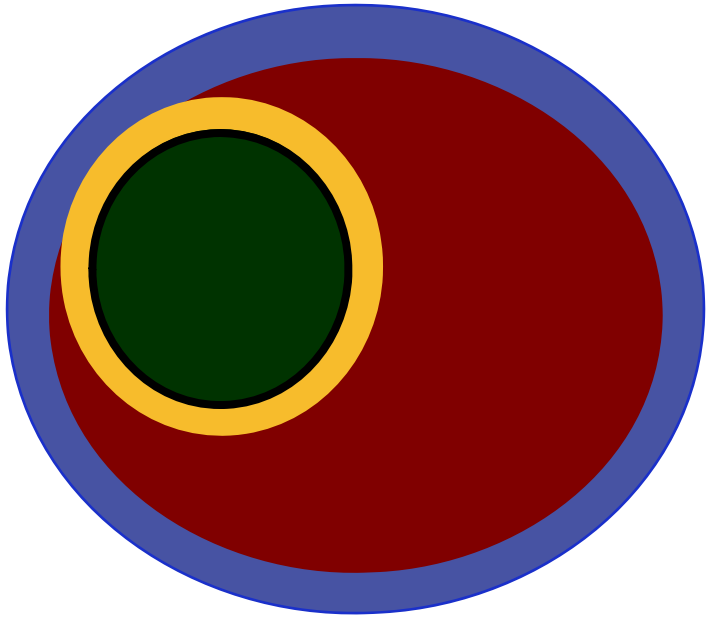


46 Gy (Rx-CH)

Two Types of Margins



Example 1



GTV_1 (pre-RxTh CT+ iv contrast)

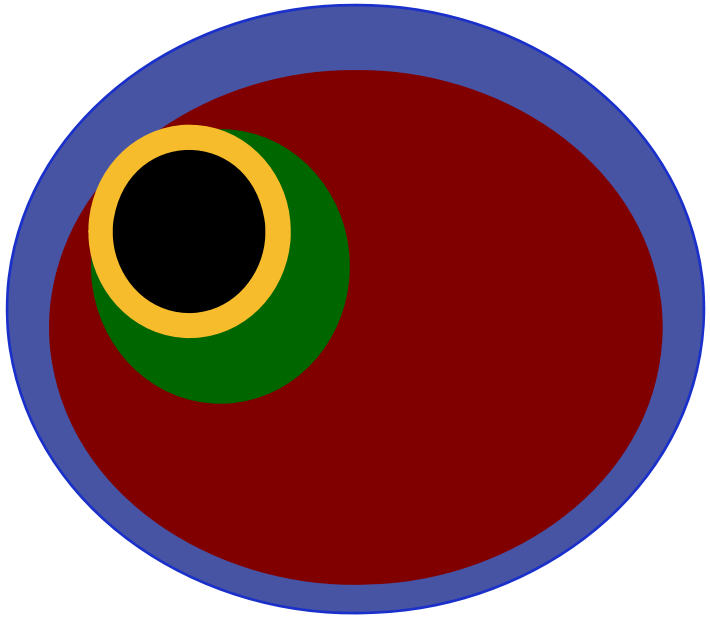
CTV_1

PTV_1: $dose_1$

$CTV_2 = GTV_1$

PTV_2: $dose_2$

Example 2



GTV_1 (pre-RxTh CT+ iv contrast)

CTV_1

PTV_1: $dose_1$

GTV_2 (FDG-PET @ 46 Gy)

$CTV_2 = GTV_2$

PTV_2: $dose_2$

Clinical Target Volume (CTV)

- The Clinical Target Volume (CTV) is a volume of tissue that contains a demonstrable GTV and/or subclinical malignant disease at a certain probability considered relevant for therapy…,
- The CTV is thus an *anatomical-clinical* concept.

Clinical Target Volume (CTV)

- Sometimes the largest component of the margin between the GTV and CTV will be the delineation error in drawing the GTV,
- Consideration should be made for this in the clinical margin.

Clinical Target Volume (CTV)

ELSEVIER

RADIOTHERAPY & ONCOLOGY
JOURNAL OF THE EUROPEAN SOCIETY FOR THERAPEUTIC RADIOLOGY AND ONCOLOGY

Radiotherapy and Oncology 56 (2000) 135–150

www.elsevier.com/locate/radonline

Review article

Selection and delineation of lymph node target volumes in head and neck conformal radiotherapy. Proposal for standardizing terminology and procedure based on the surgical experience

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[b]*Department of Radiology, Université Catholique de Louvain, St-Luc University Hospital, Brussels, Belgium*
[c]*Department of Otolaryngology Head and Neck Surgery, Université Catholique de Louvain, St-Luc University Hospital, Brussels, Belgium*
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Received 20 September 1999; received in revised form 28 March 2000; accepted 13 April 2000

Planning Target Volume (PTV)

The Planning Target Volume is a geometrical concept, introduced for treatment planning and evaluation. It is the recommended *tool* to shape dose distributions that ensure with a clinically acceptable *probability* that an adequate dose will actually be delivered to all parts of the CTV…

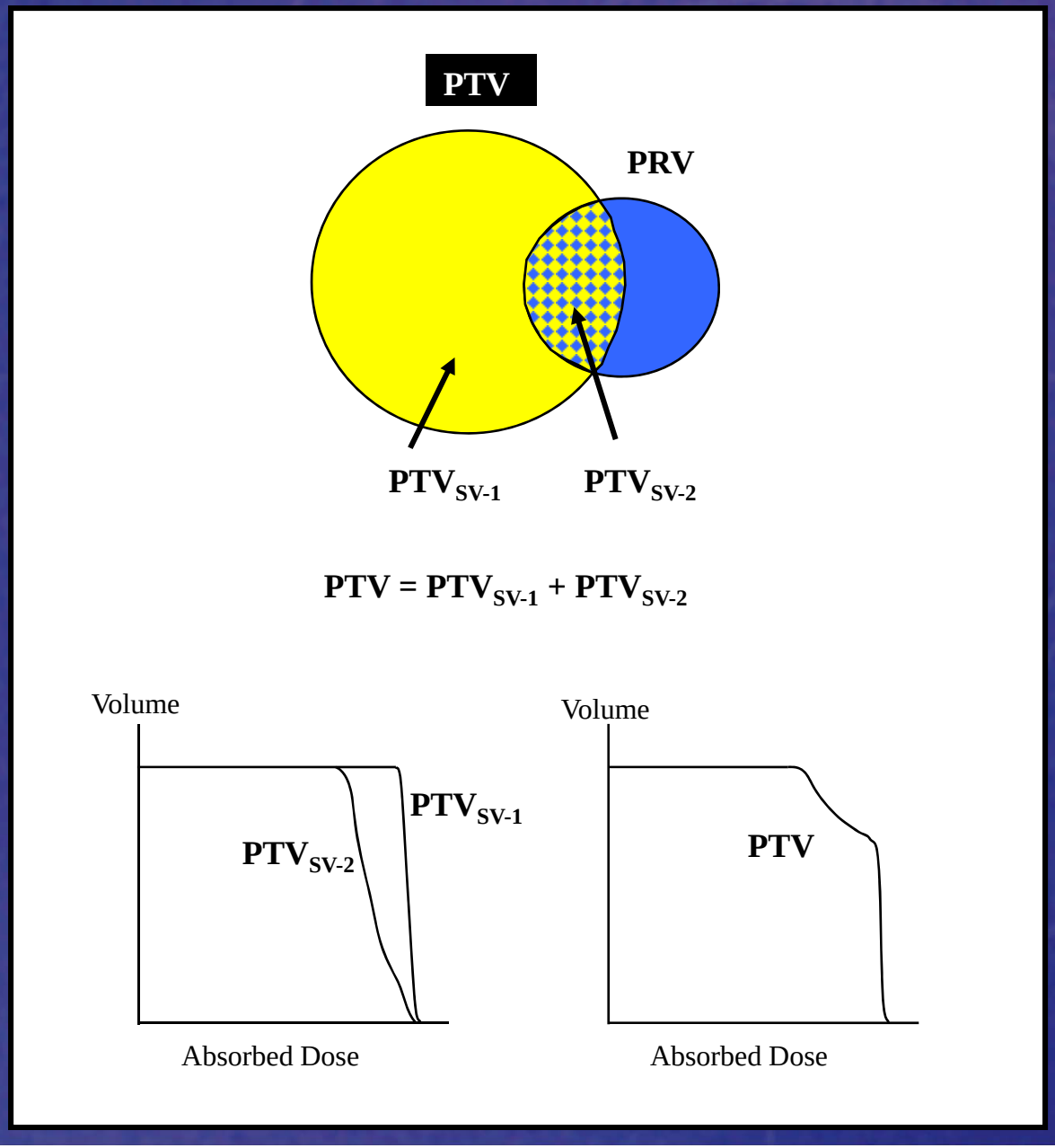
Planning Target Volume (PTV)

- Include both “internal” and “external” variations of the CTV,
- Separate delineation of the ITV is not necessary but motion should be included in the PTV,
- Expansion of the CTV using “rolling ball” algorithms,
- CTV to PTV margin recipe based on random and systematic errors, and beam penumbra,
- Priority rules when overlapping PTVs or PTV-PRV,
- Dose is prescribed and reported on the PTV.
- IMRT can result in hot and cold spots within the PTV.

‘Cheating on the PTV Margins’

- The practice of shrinking the CTV to PTV margin to accommodate an OAR is discouraged as it results in a deceptively better PTV homogeneity,
- In IMRT the trade-off can be accomplished by changing the planning aims in the optimizer,
- In 3-D CRT, the trade-off can be accomplished with a separate target delineation used to draw the beam boundary.

Can Use Sub-Volumes to Guide Optimization



CTV to PTV Margin Recipe

Author	Application	Recipe	Assumptions
Bel et al 1996b	Target	0.7 s	Random errors only (linear approximation) Š Monte Carlo
Antolak and Rosen 1999	Target	1.65 s	Random errors only, block margin?
Stroom et al 1999	Target	2 S + 0.7 s	95% dose to on average 99% of CTV tested in realistic plans
Van Herk et al 2000	Target	2.5 S + 0.7 s or (more correct): 2.5 S + 1.64 $(s - s_p)$	Minimum dose to CTV is 95% for 90% of patients. Analytical solution for perfect conformation
McKenzie et al 2000a	Target	2.5 S + b $(s - s_p)$	Extension of van Herk et al for fringe dose to due to limited number of beams
Parker et al 2002	Target	$S + \sqrt{(s^2 + S^2)}$	95% minimum dose and 100% dose for 95% of volume. Probability levels not specified
Van Herk et al 2002	Target	2.5 S + 0.7 s - 3 mm or (more correct): $\sqrt{2.7^2\Sigma^2 + 1.6^2\sigma^2} - 2.8mm$	

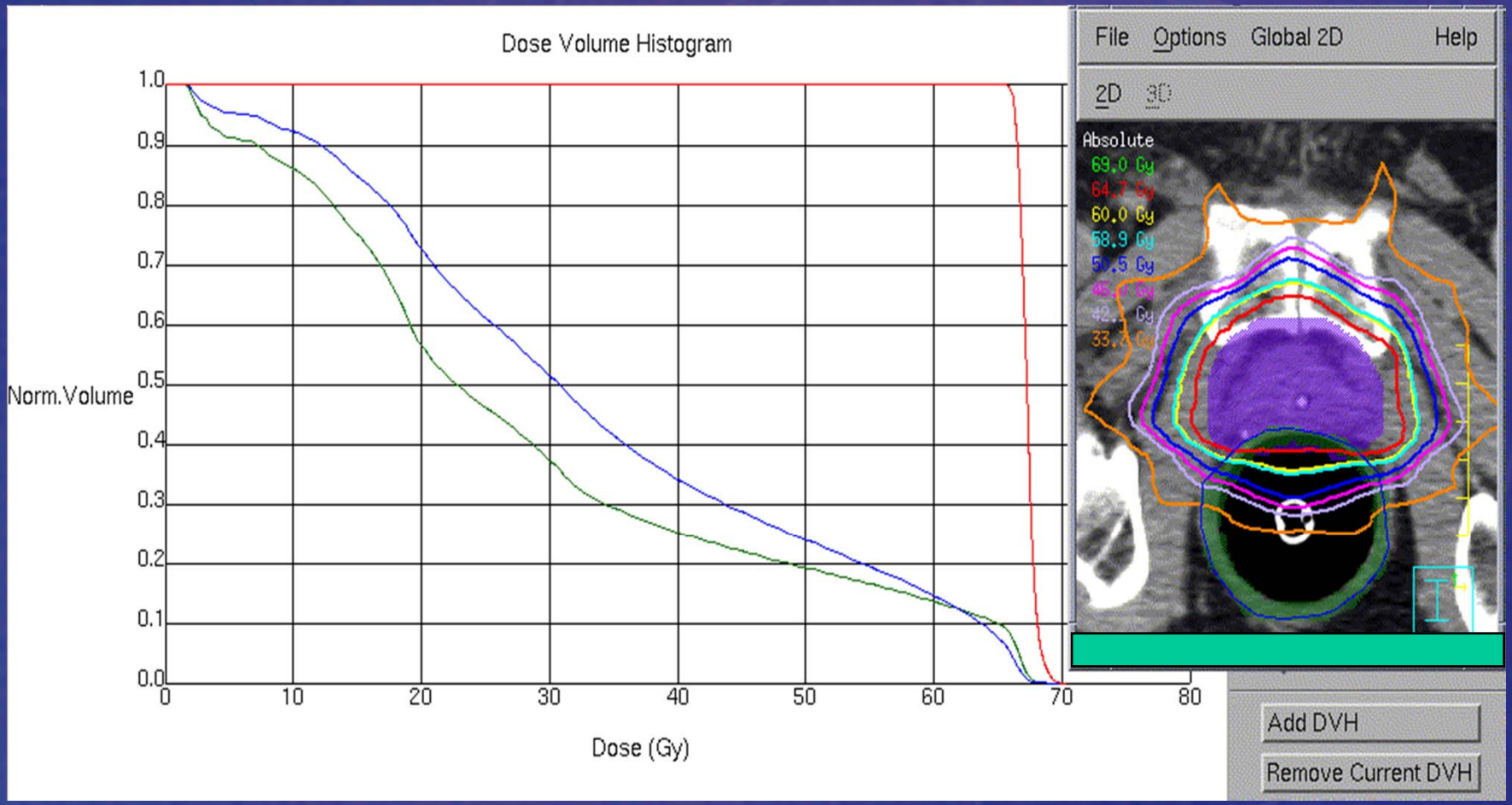
Symbols: S = SD of systematic errors; s = SD of random errors; s_p = describes width of beam penumbra fitted to a Gauss function; A = Peak-peak amplitude of respiration.

Van Herk, 2003

Organ At Risk (OAR) and Remaining Volume at Risk (RVR)

- Distinction between “serial-like” (e.g. spinal cord) and “parallel-like organs” (e.g. parotid gland),
- For “tubed” organs (e.g. rectum) wall delineation,
- Remaining Volume at Risk (RVR): aids optimization and may assist in evaluating very late effects (e.g. carcinogenesis).

Organ At Risk (OAR)



Prostate
Rectum With Contents
Rectal Wall

Contents of tubed organs should not be included

Planning Organ at Risk Volume (PRV)

- PRV is a geometrical concept *(tool)* introduced to ensure that adequate sparing of OAR will actually be achieved with a reasonable *probability*,
- A positive OAR to PRV margin for serial organ.
- Dose-volume constraints on OAR are with respect to the PRV,
- Priority rules when overlapping PTVs or PTV-PRV(OAR),
- Dose metrics are reported to the PRV.

Absorbed Dose in Radiation Oncology: ICRU 50 and 62:

Dose prescription:

- Responsibility of the treating physician.

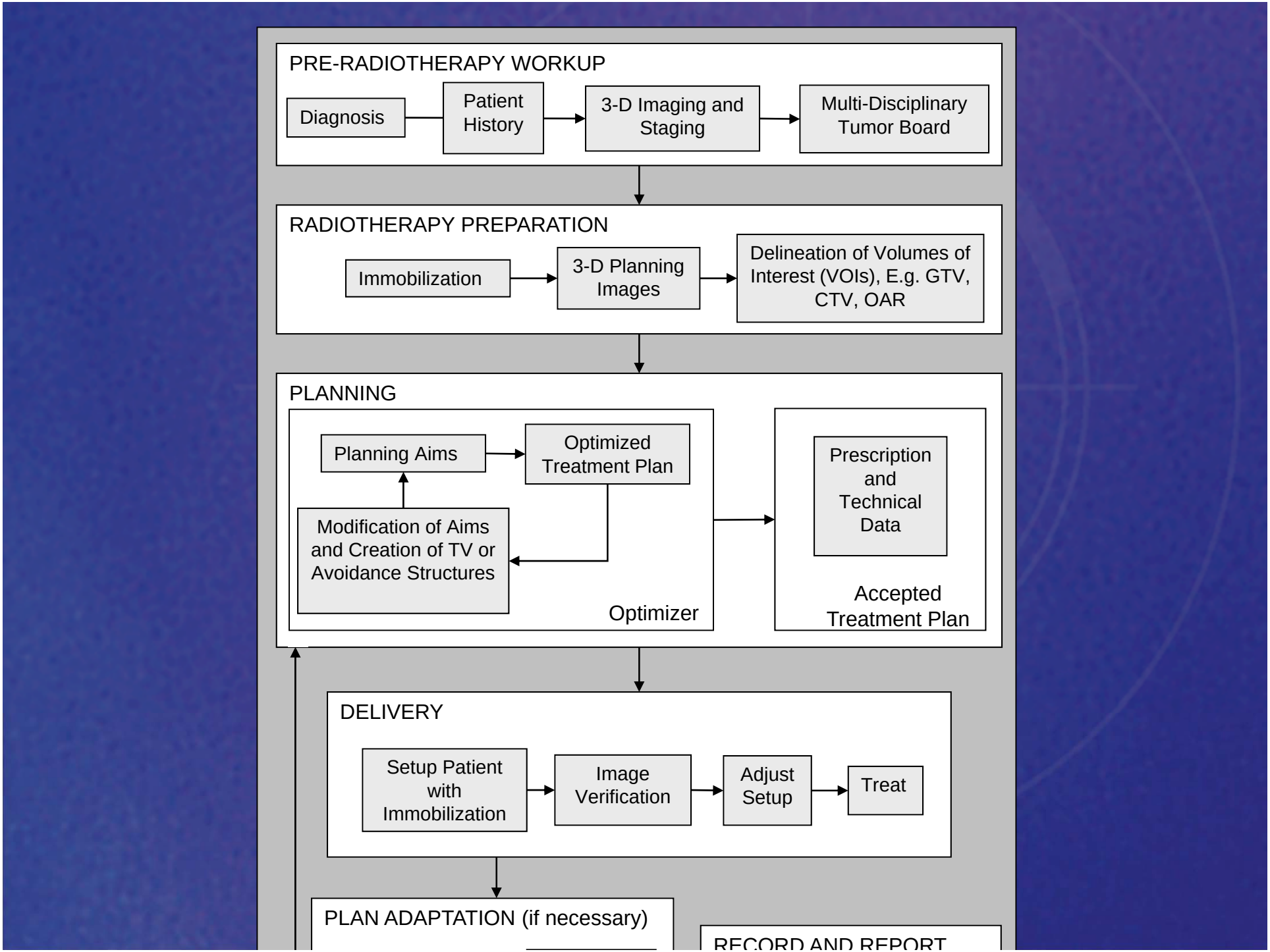
Dose reporting:

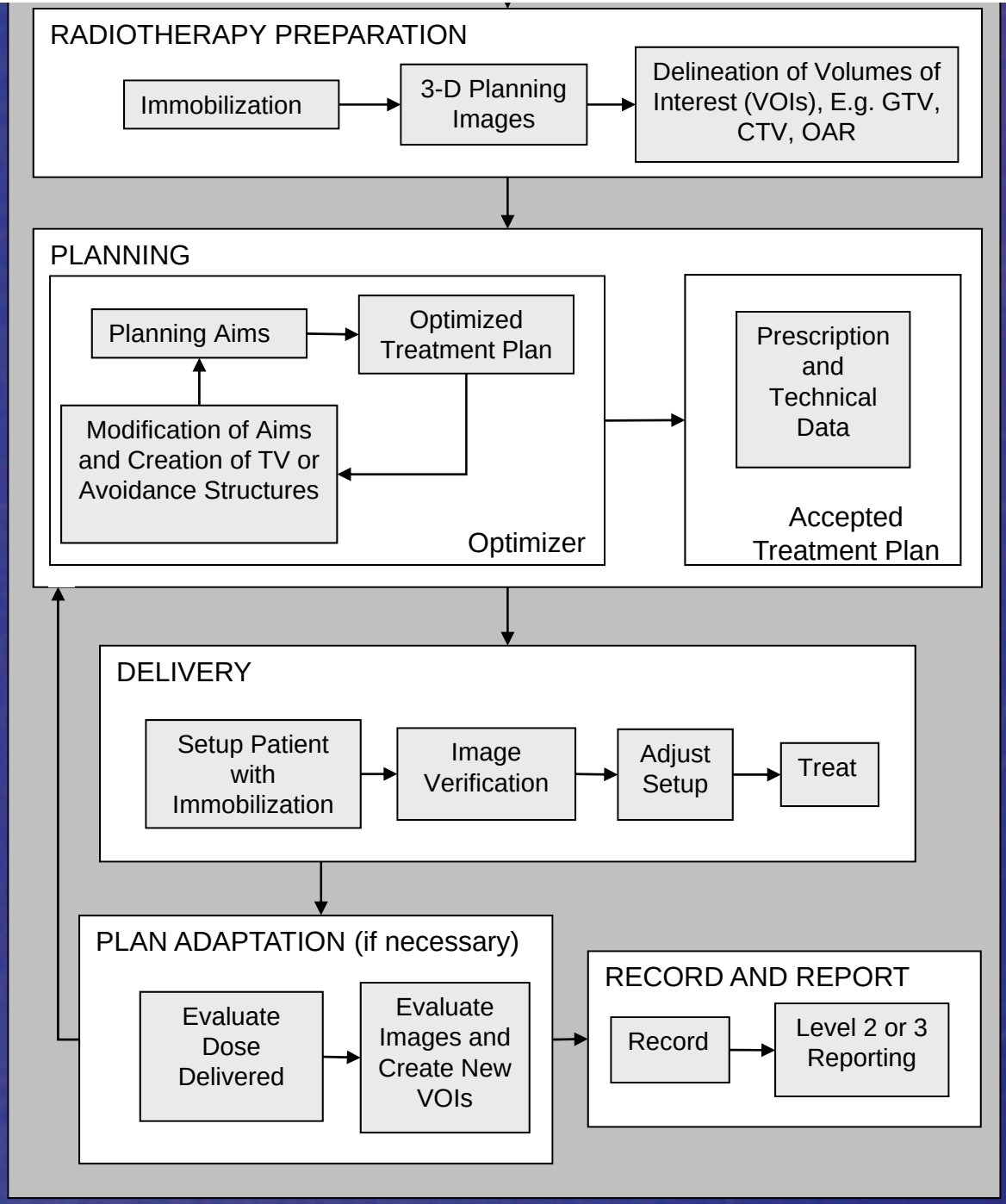
- ICRU reference point,
- Three-levels of dose reporting,
- Point-doses: $D_{ICRU\ point}$, D_{min}, D_{max}, …

Dose recording.

Issues for IMRT

- Discrepancy between dose-volume constraint prescription and dose delivery,
- Single point dose prescription,
- Single point dose reporting,
- Biological metrics (e.g. EUD, TCP, NTCP, …),
- Uncertainties in dose prescription and reporting,
- More quality assurance required.


PRE-RADIOTHERAPY WORKUP
Diagnosis
Patient History
3-D Imaging and Staging
Multi-Disciplinary Tumor Board
RADIOTHERAPY PREPARATION
Immobilization
3-D Planning Images
Delineation of Volumes of Interest (VOIs), E.g. GTV, CTV, OAR
PLANNING
Planning Aims
Optimized Treatment Plan
Modification of Aims and Creation of TV or Avoidance Structures
Optimizer
Prescription and Technical Data
Accepted Treatment Plan
DELIVERY
Setup Patient with Immobilization
Image Verification
Adjust Setup
Treat
PLAN ADAPTATION (if necessary)
RECORD AND REPORT


RADIOTHERAPY PREPARATION
Immobilization
3-D Planning Images
Delineation of Volumes of Interest (VOIs), E.g. GTV, CTV, OAR
PLANNING
Planning Aims
Optimized Treatment Plan
Modification of Aims and Creation of TV or Avoidance Structures
Optimizer
Prescription and Technical Data
Accepted Treatment Plan
DELIVERY
Setup Patient with Immobilization
Image Verification
Adjust Setup
Treat
PLAN ADAPTATION (if necessary)
Evaluate Dose Delivered
Evaluate Images and Create New VOIs
RECORD AND REPORT
Record
Level 2 or 3 Reporting

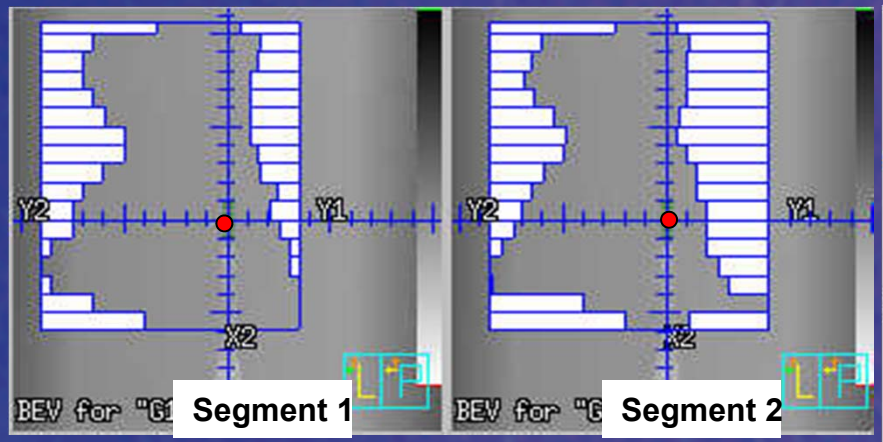
Dose Prescription in IMRT

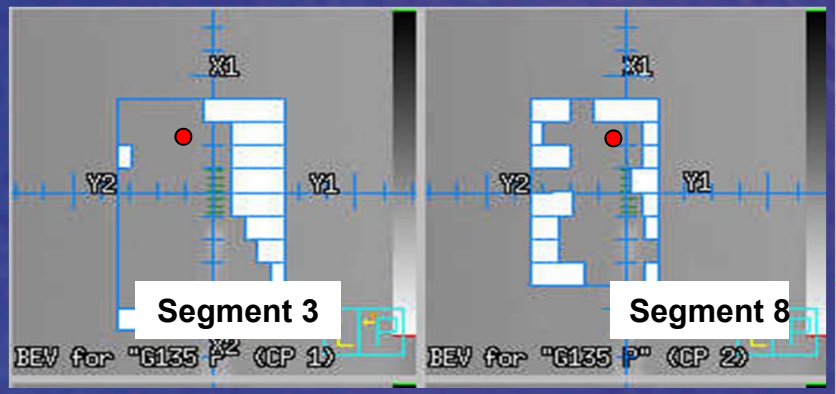
- Planning aims:
  - PTV_1: $dose_x$, D-V constraints, …,
  - Spinal cord: D_{max} = x Gy, …,
  - …
- Prescription:
  - Physician's responsibility,
  - Acceptance of doses, fraction #, OTT, D-V constraints, beam number, beam orientation, …
- Technical data for treatment delivery:
  - Instruction file sent to the linac and/or RVS.

ICRU Levels of Reporting

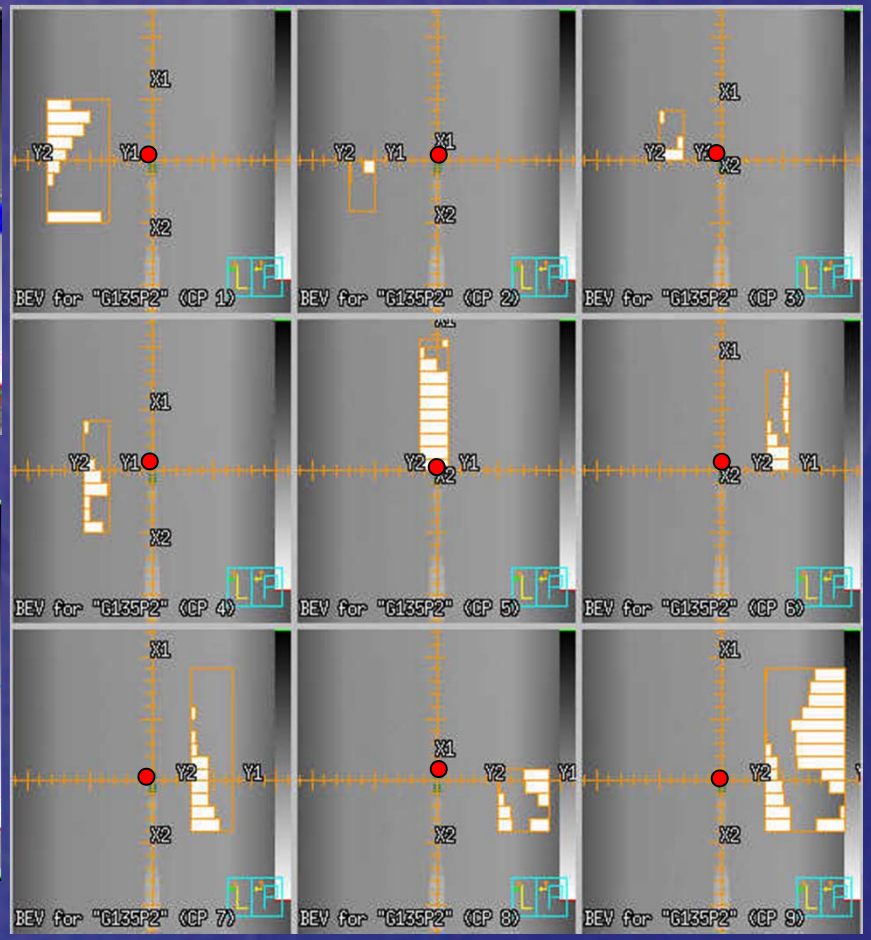
- Level 1: ~~not adequate for IMRT,~~
- Level 2: standard level for dose reporting,
- Level 3: homogeneity, conformity and biological metrics (TCP, NTCP, EUD, …) and confidence intervals.

ICRU Reference Point Not A "Typical Point" for IMRT





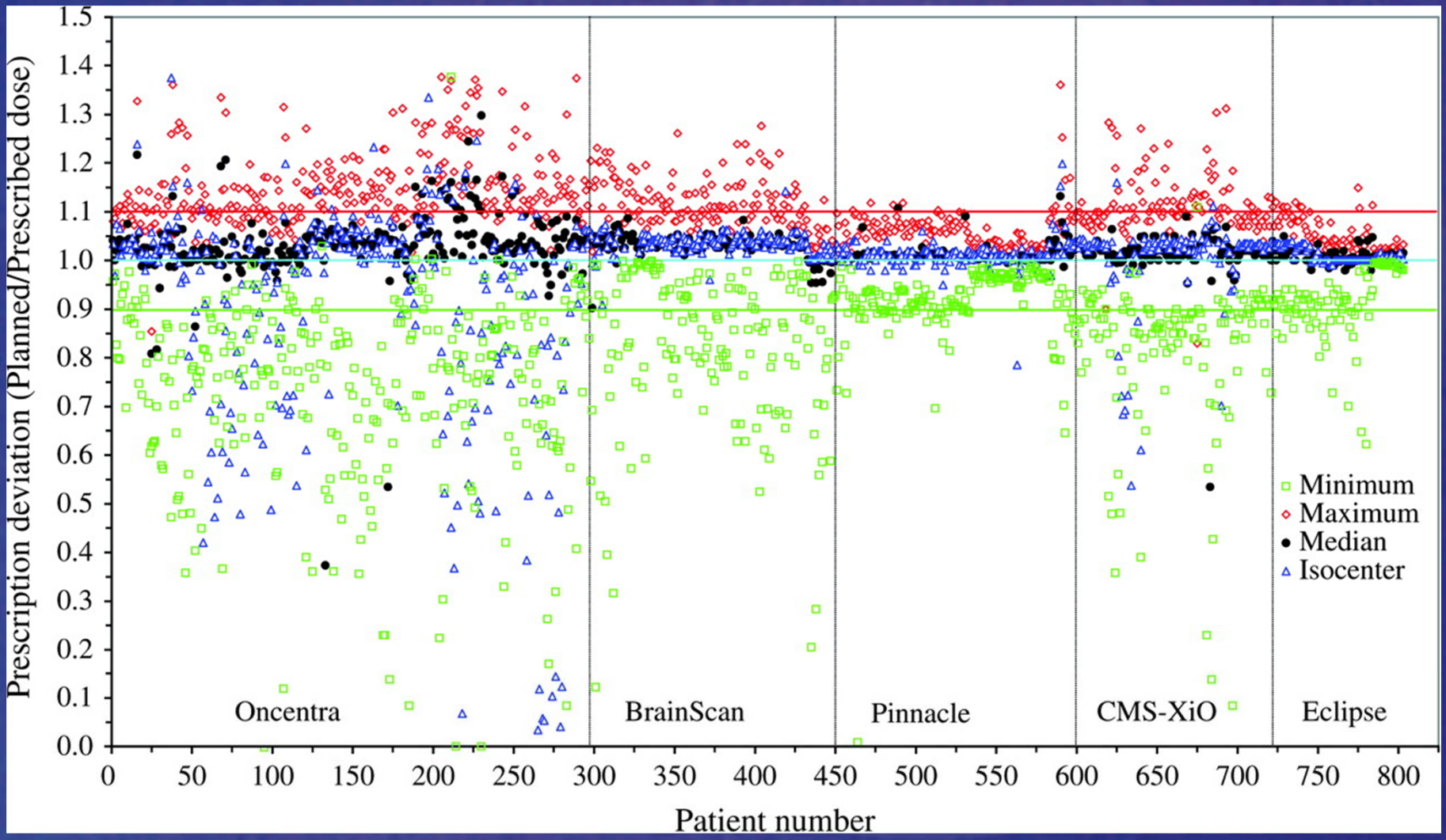
13 segment IM Field



Segments 4-7, 9-13

From Jatinder Palta, University of Florida

Reliability of Planning Metrics



Median dose is most reliable

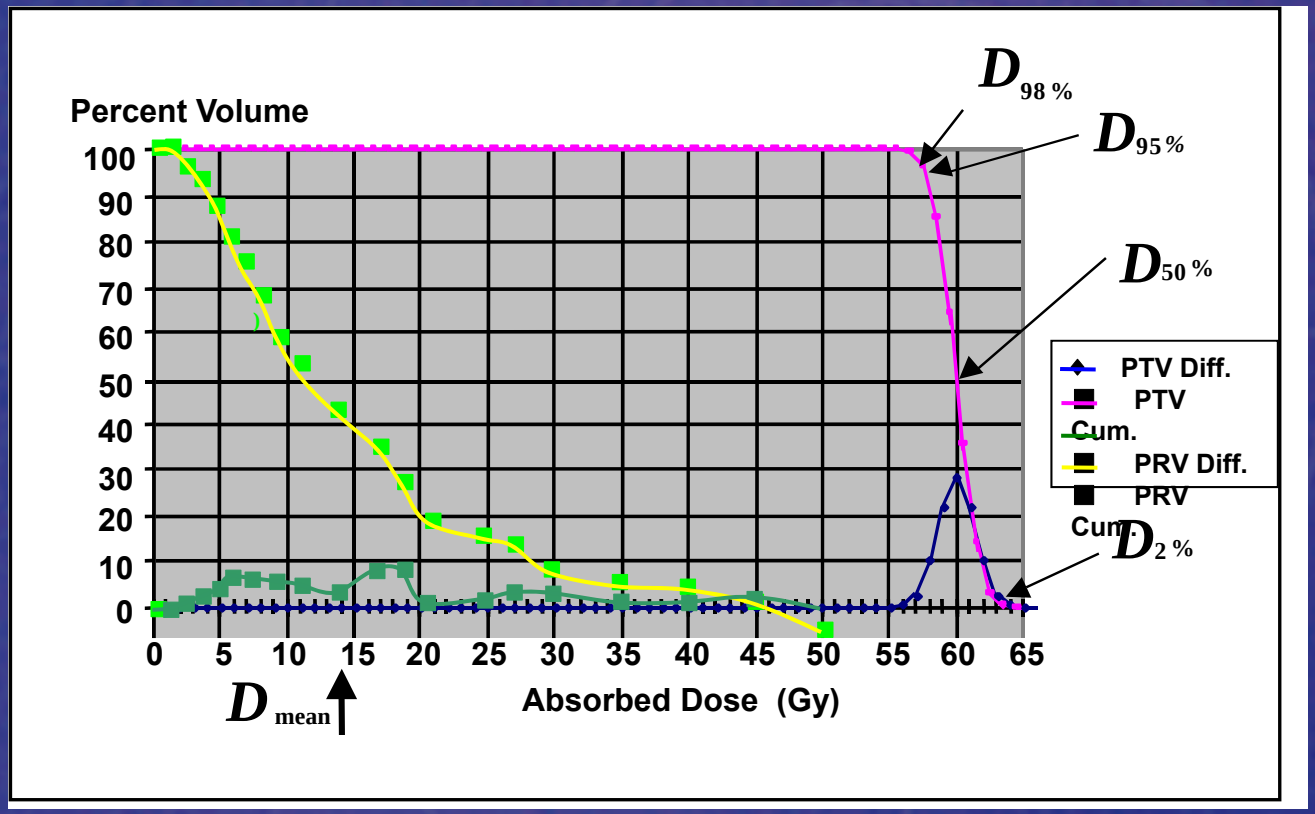
From Indra Das

Absorbed dose in Radiation Oncology:

Metrics for Level 2 Reporting of PTV

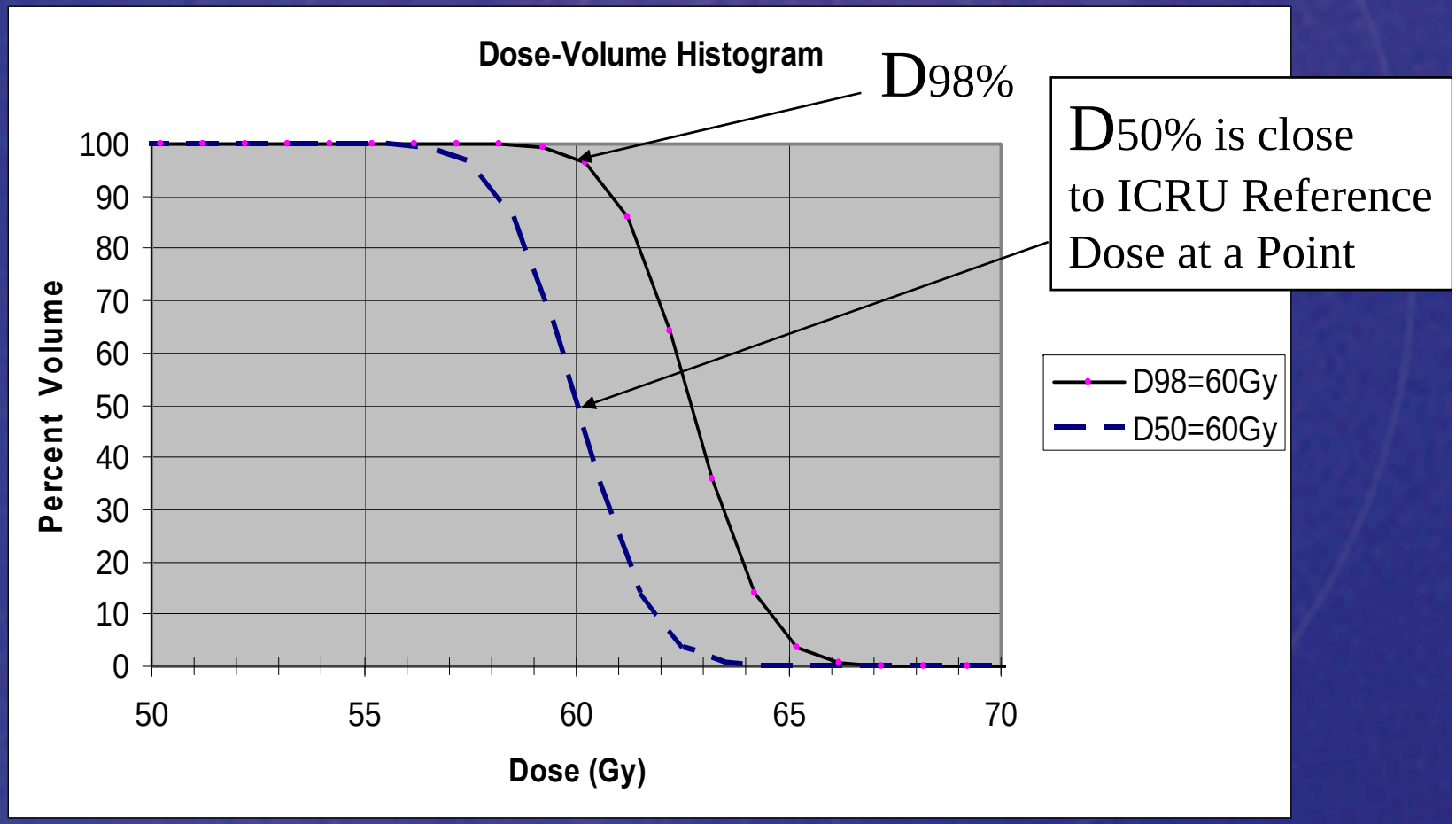
- Dose-volume reporting (ie., D_V)
  - $D_{50\%}$ (D_{median}), prescription value, e.g., $D_{95\%}$
  - D_{mean}
  - Near Minimum dose: $D_{98\%}$
  - Near Maximum dose: $D_{2\%}$
- State the make, model and version number of the treatment planning and delivery software used to produce the plans and deliver the treatment.

Dose-Volume Reporting



- Doses at a point are not as reliable as DVH near-min and near-max
- PTV median dose is the “typical dose” to the PTV
- PTV mean dose and PTV median dose are nearly identical
- PRV mean dose and PRV median dose are not necessarily similar

Dose-Volume Reporting

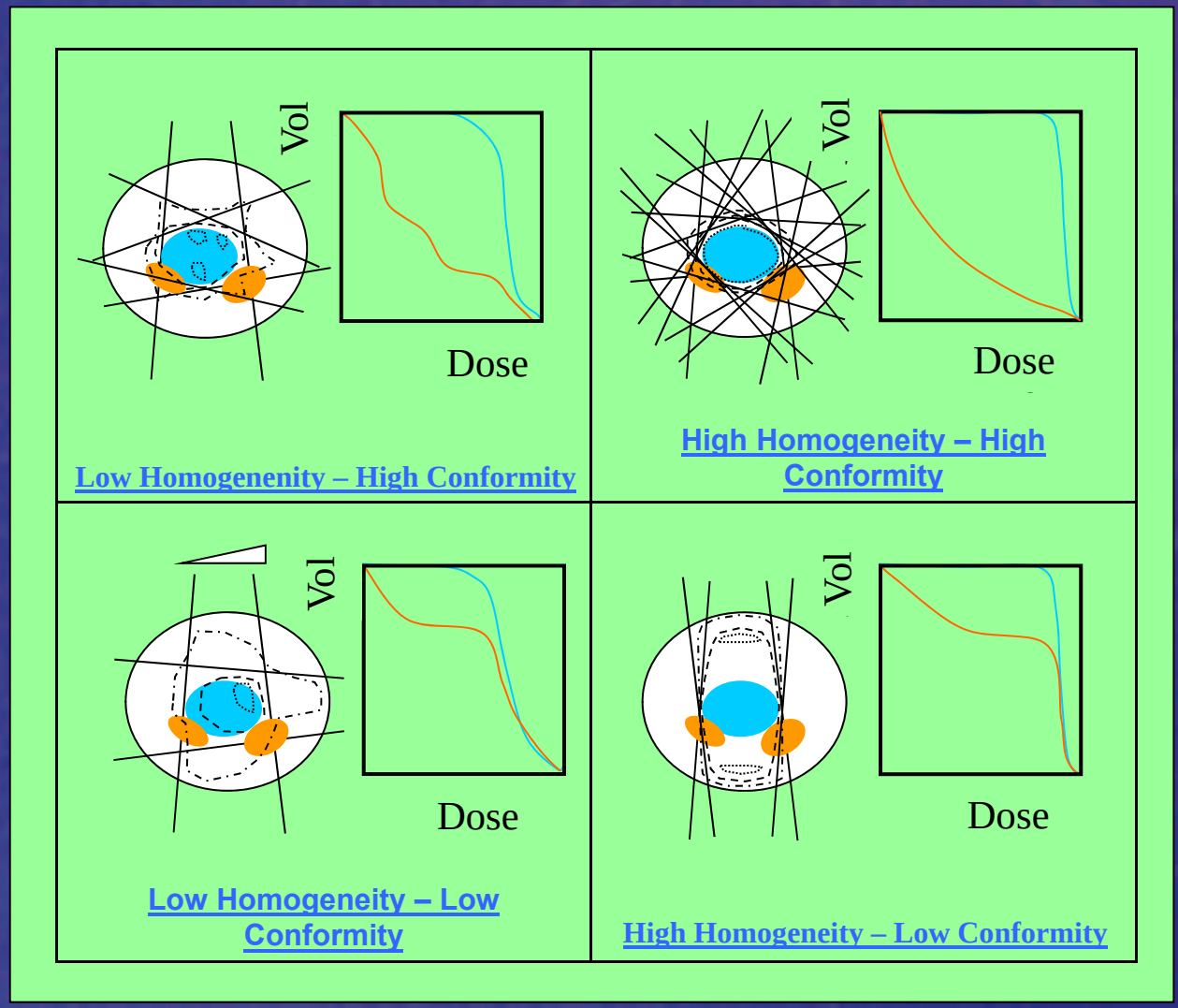


Dv with v≠50 may require a change in prescription value

Metrics for Level 2 Reporting of PRV

- "Serial-like" organs:
  - $D_{near\text{-}max} = D_{98}$.
- "Parallel-like" organs:
  - D_{mean} (e.g. parotid) ,
  - V_d where d refers to dose in Gy (e.g. $V_{20\ Gy}$ for lung).

Homogeneity and Conformity



Examples of Metrics for Level 3 Reporting of PTV

- **Homogeneity:**
  - **Standard deviation in dose to the PTV.**
- **Conformity:**
  - **Conformity Index: CI = TVpresc/PTV,**
  - **Dice Similarity Coefficient (DSC):**

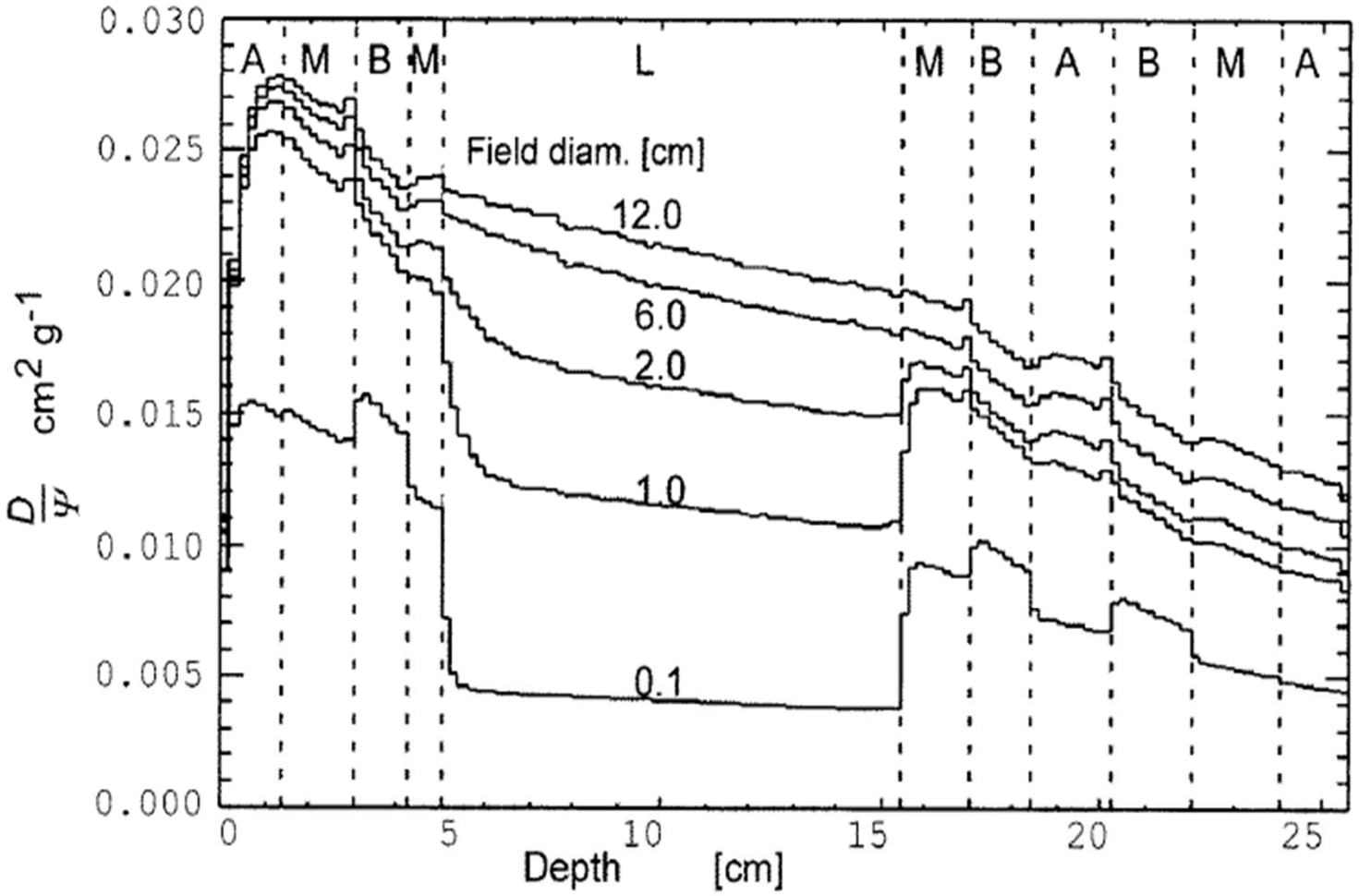
$$DSC = 2(TVpresc \cap PTV)/(TVpresc + PTV)$$

Recording in IMRT

- Electronic archiving for at least the life of patient or 5 years – whatever is longer,
- Complete reconstruction of the treatment technical data, plan and delivery record,
- For clinical trials, longer archiving if scientifically justified.

Use Doses Corrected for Tissue Heterogeneities

A=Adipose, M=Muscle, B=Bone, L=Lung 4 MV, Parallel Beam



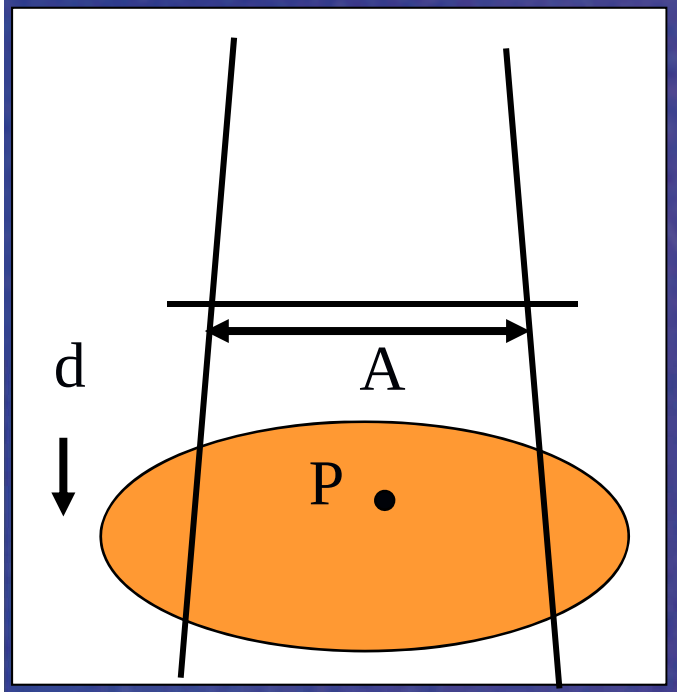
Ahnesjo and Asparadakis, 1999 Phys Med Biol 44:R99-R155

Absorbed dose in Radiation Oncology: Report Dose to Water

- While the dose is corrected for tissue heterogeneities, the dose to a small mass of water in tissue is reported.
- Consistent with the older methods as well as convolution/superposition methods.
- Monte Carlo dose computation will have to be corrected to dose to a small mass of water in tissue

Monitor Units Calculations for Model-Based Dose Calculation

$$\frac{D}{MU}(A,r) = \frac{\Psi_0}{MU}(A,r)\,\frac{D}{\Psi_0}(A,r)\,(1+b(A))^{-1}$$



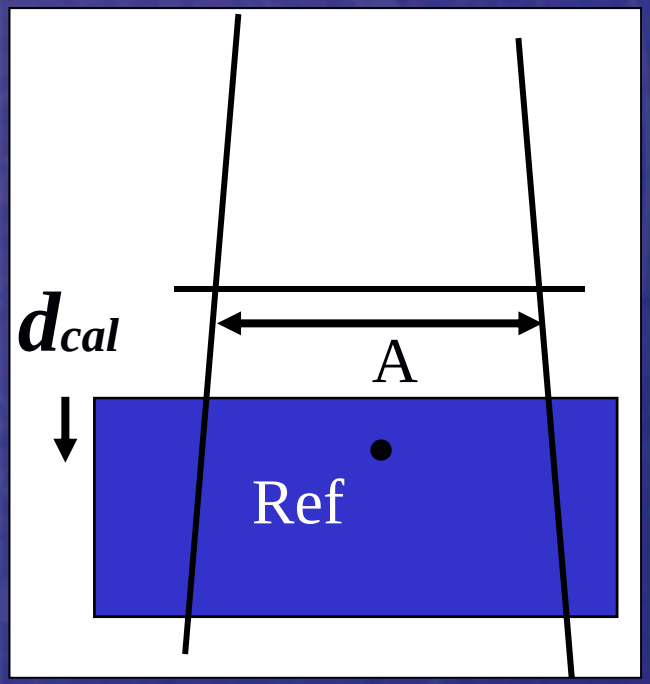
Beam Output

Computed Directly

Correction to Account for Backscatter Into Monitor Chamber

Monitor Units Calculations for Model-Based Dose Calculation

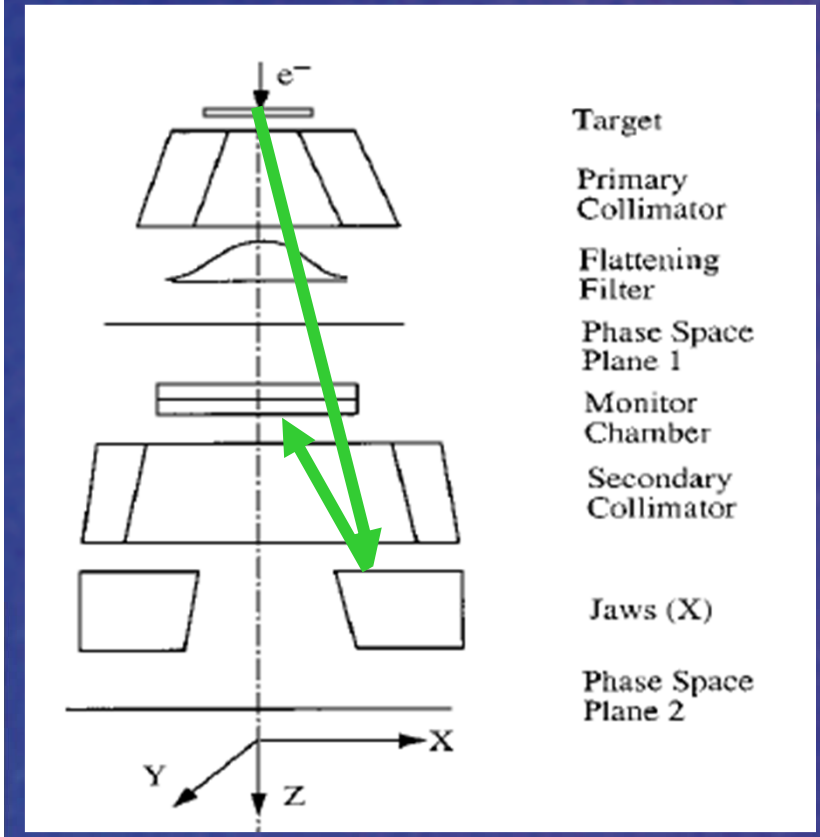
$$\frac{\Psi_0}{MU} = \frac{\left[\frac{D}{M}(A_{cal}, d_{cal})\right]_{Measured}}{\left[\frac{D}{\Psi_0}(A_{cal}, d_{cal})\right]_{Calculated}}(1 + b(A_{cal}))$$



Not including the effect of backscatter into the monitor chamber will result in about a 2% error at worst.

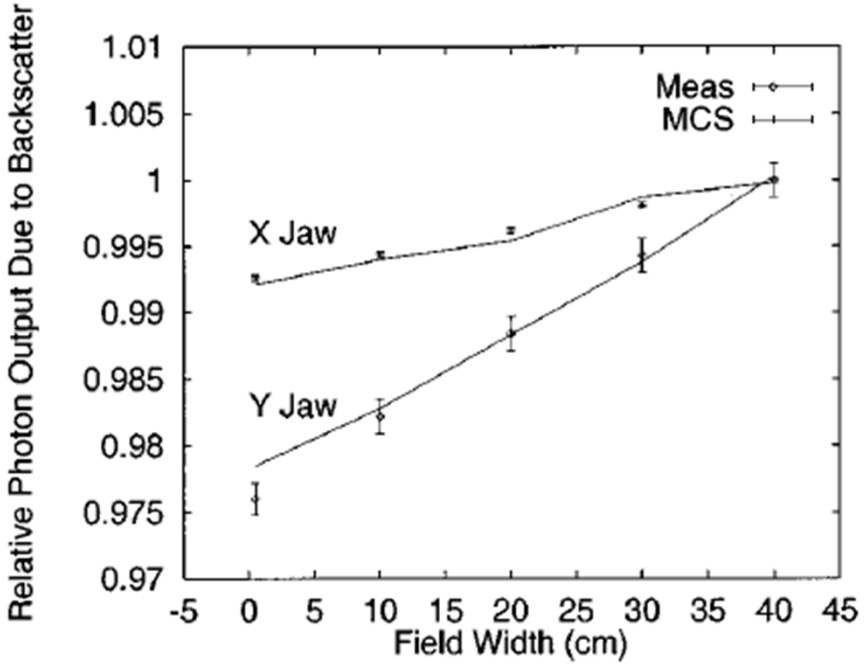
Backscatter into Monitor Chamber

The effect is due to backscattered photons entering the monitor and resulting in feedback to the linac to lower its output



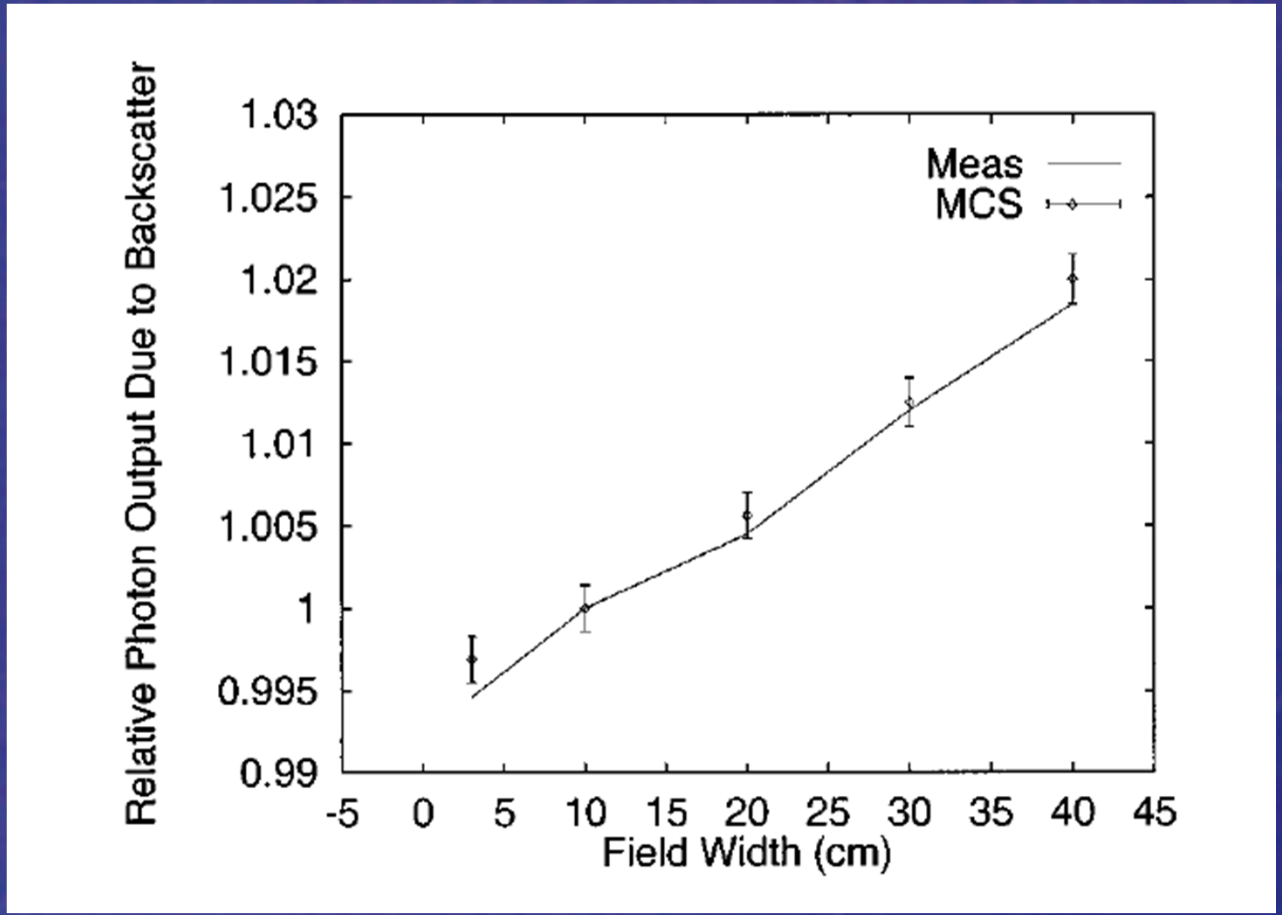
Liu et al.,
Med. Phys 2000;27:737-744

Varian 2100 – 10 MV. Results with other jaw completely open



Monitor Backscatter for Square On-Axis Fields

Varian 2100 – 10 MV



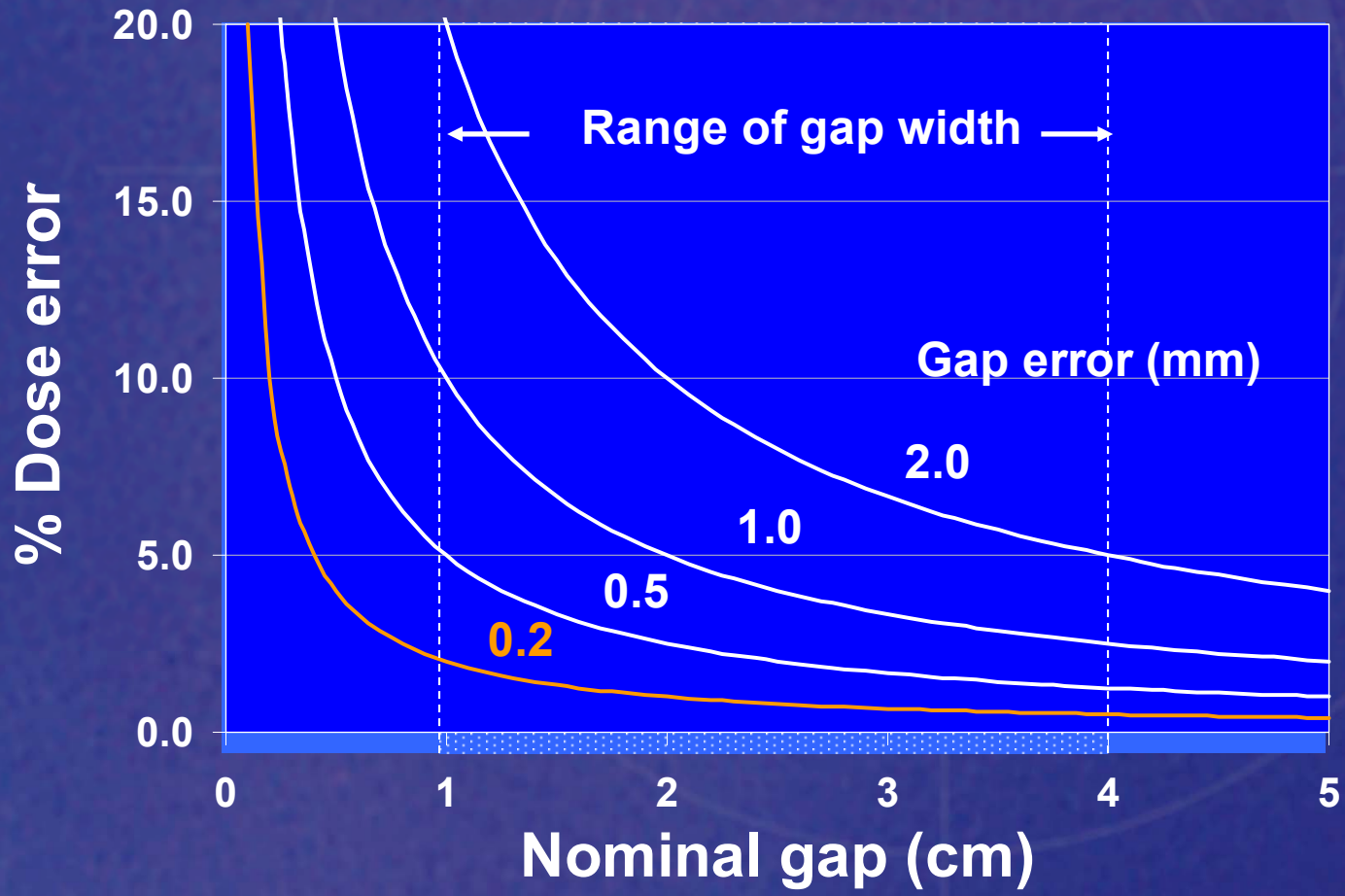
Liu et al., Med. Phys 2000;27:737-744

QA for IMRT

- Appropriate QA of TPS and delivery equipment
- Patient-specific QA:
  - Delivery of individual fields into a dosimeter
  - Delivery of all of the fields into a phantom
  - Independent dose calculation algorithms with similar of better dose calculation accuracy
  - In-vivo dosimetry not limited to a single point.

Gap Error is Fundamental fo Conventional MLCs

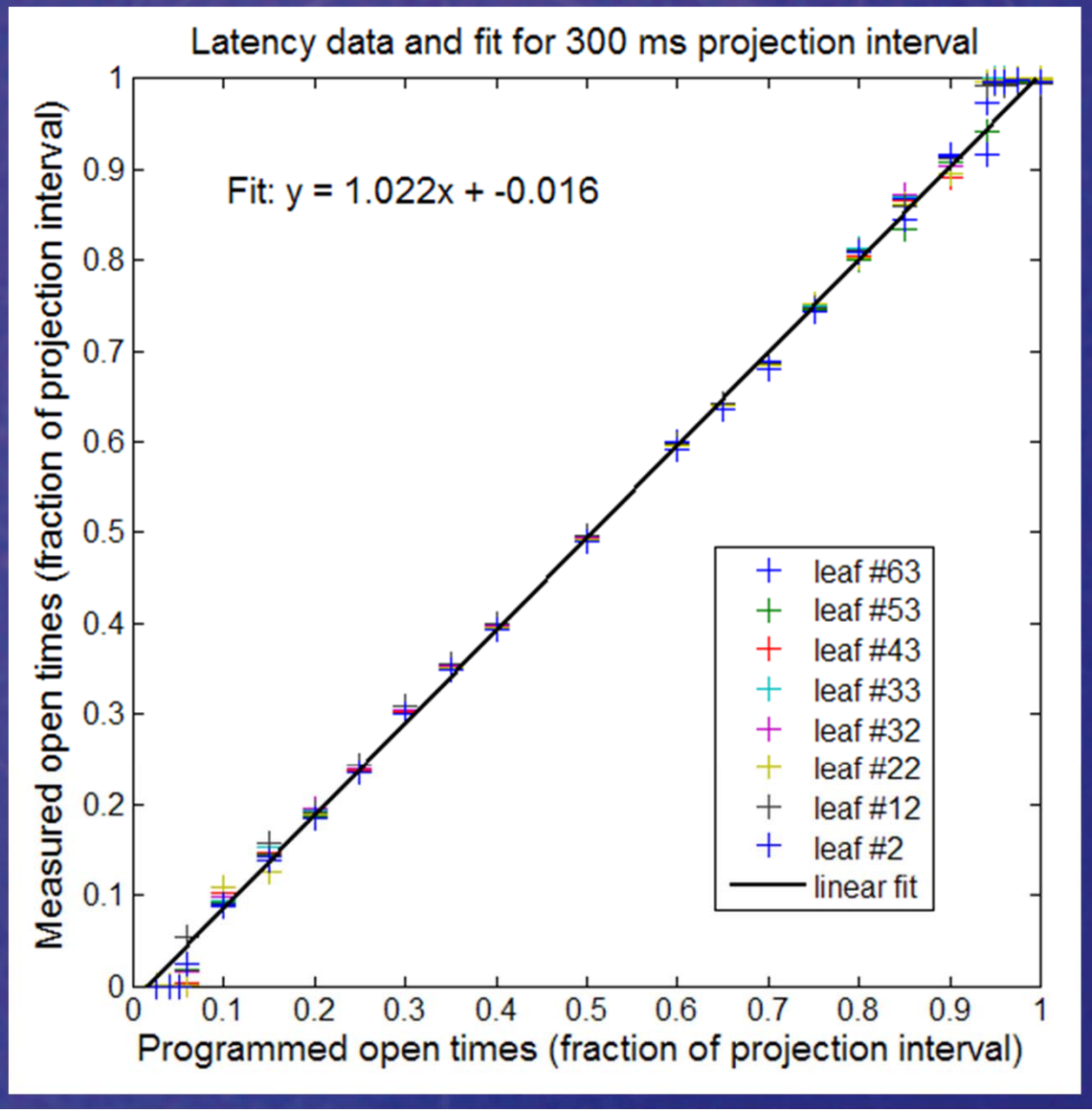
Gap error ⟶ Dose error



From Tom Losasso, Memorial Sloan Kettering

Leaf Latency is Fundamental fo Binary MLCs

- TomoTherapy uses linear fit of measured data to model leaf latency
- Plans with small opening times lead to uncertainty in delivery – also leads to delivery inefficiencies



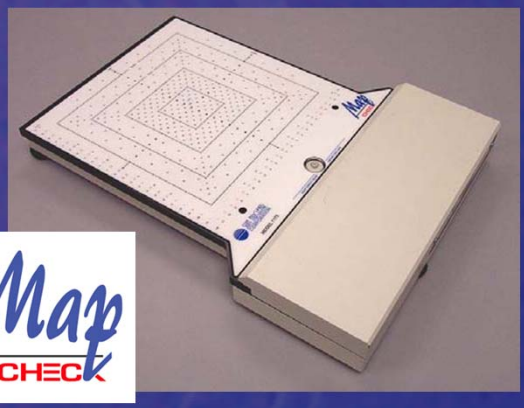
QA of Individual Fields

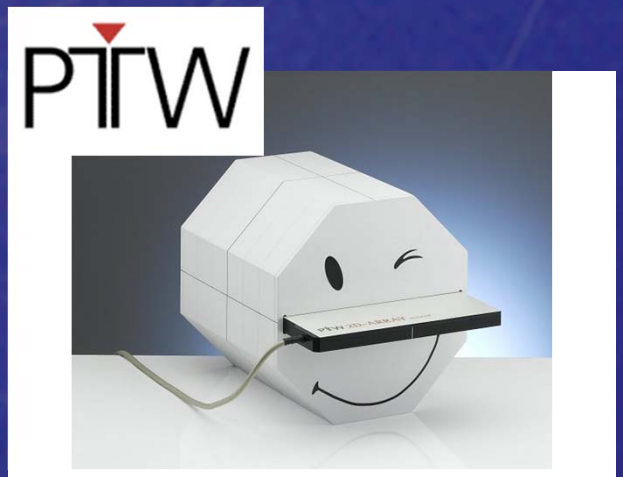
External diode/ion-chamber arrays

- MapCheck
- PTW Octavius phantom
- IBA Matrix

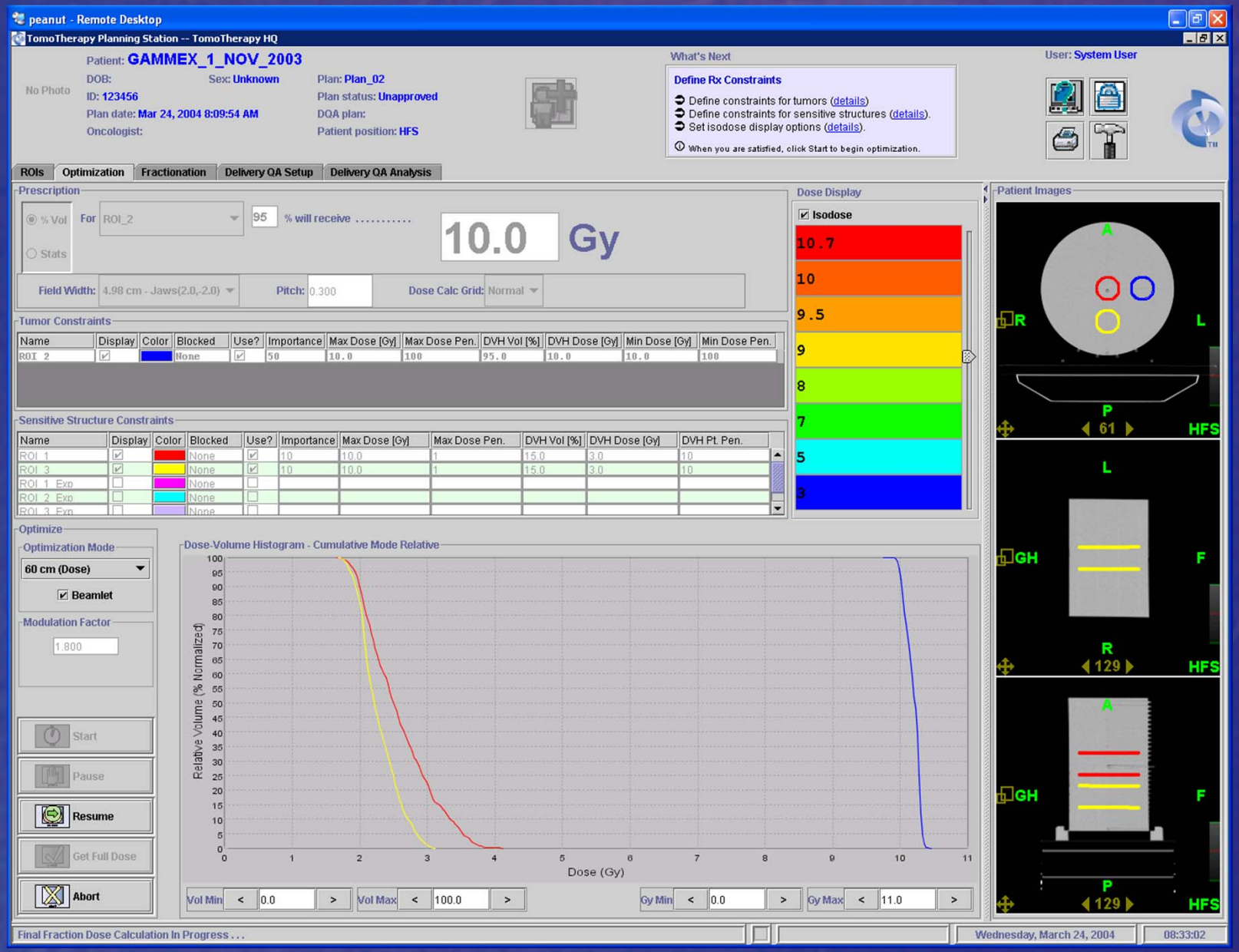
Integrated detector systems

- EPID portal dosimetry



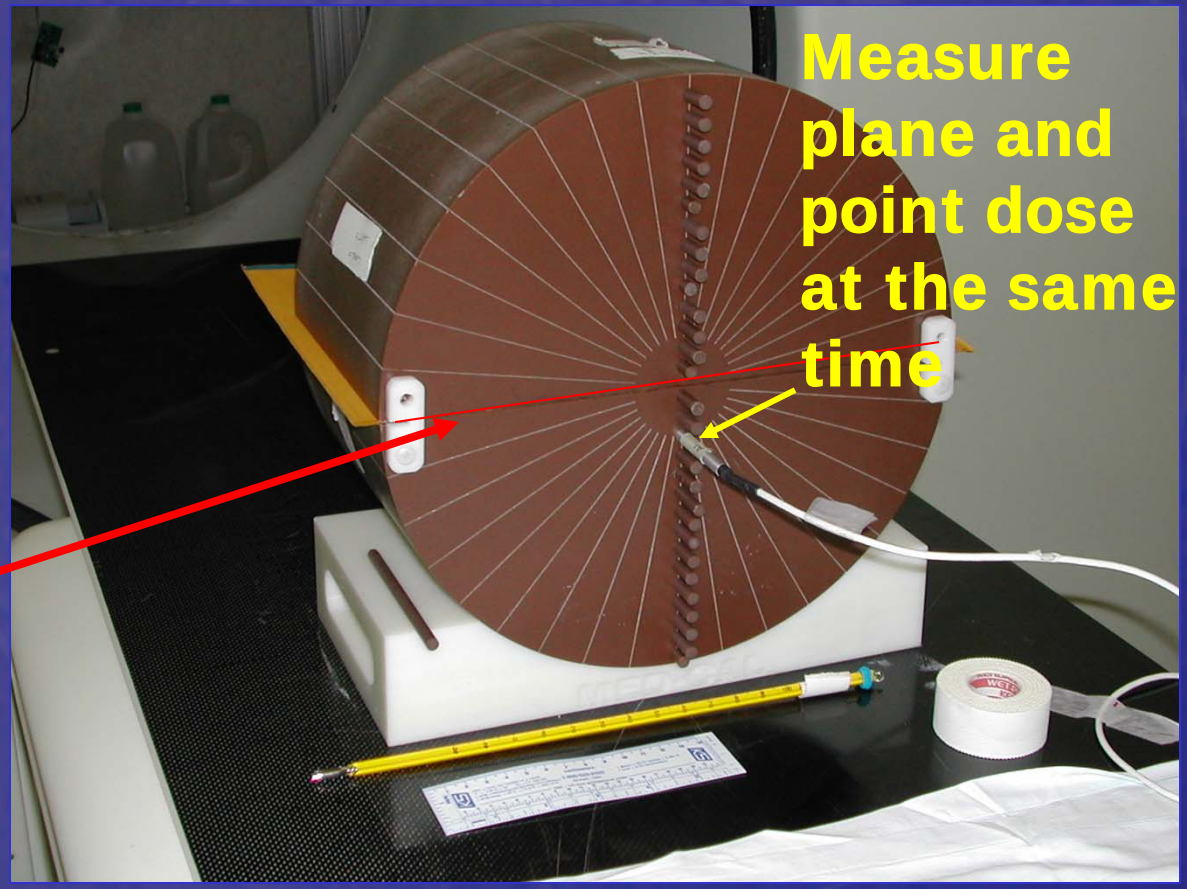


End-to-End QA


peanut - Remote Desktop
TomoTherapy Planning Station -- TomoTherapy HQ
No Photo
Patient: GAMMEX_1_NOV_2003
DOB:
Sex: Unknown
ID: 123456
Plan date: Mar 24, 2004 8:09:54 AM
Oncologist:
Plan: Plan_02
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 ROI_2
95
% will receive .....
10.0 Gy
Field Width: 4.98 cm - Jaws(2.0,-2.0)
Pitch: 0.300
Dose Calc Grid: Normal
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.
ROI_2 None 50 10.0 100 95.0 10.0 10.0 100
Sensitive Structure Constraints
Name Display Color Blocked Use? Importance Max Dose [Gy] Max Dose Pen. DVH Vol [%] DVH Dose [Gy] DVH Pt. Pen.
ROI_1 None 10 10.0 1 15.0 3.0 10
ROI_3 None 10 10.0 1 15.0 3.0 10
ROI_1_Exp None
ROI_2_Exp None
ROI_3_Exp None
Dose Display
Isodose
10.7
10
9.5
9
8
7
5
3
Patient Images
A
R
L
P
61
HFS
L
GH
F
R
129
HFS
A
GH
F
P
129
HFS
Optimize
Optimization Mode
60 cm (Dose)
Beamlet
Modulation Factor
1.800
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 11.0
Final Fraction Dose Calculation In Progress . . .
Wednesday, March 24, 2004
08:33:02

QA Measurements

"Cheese" Phantom used for QA measurements

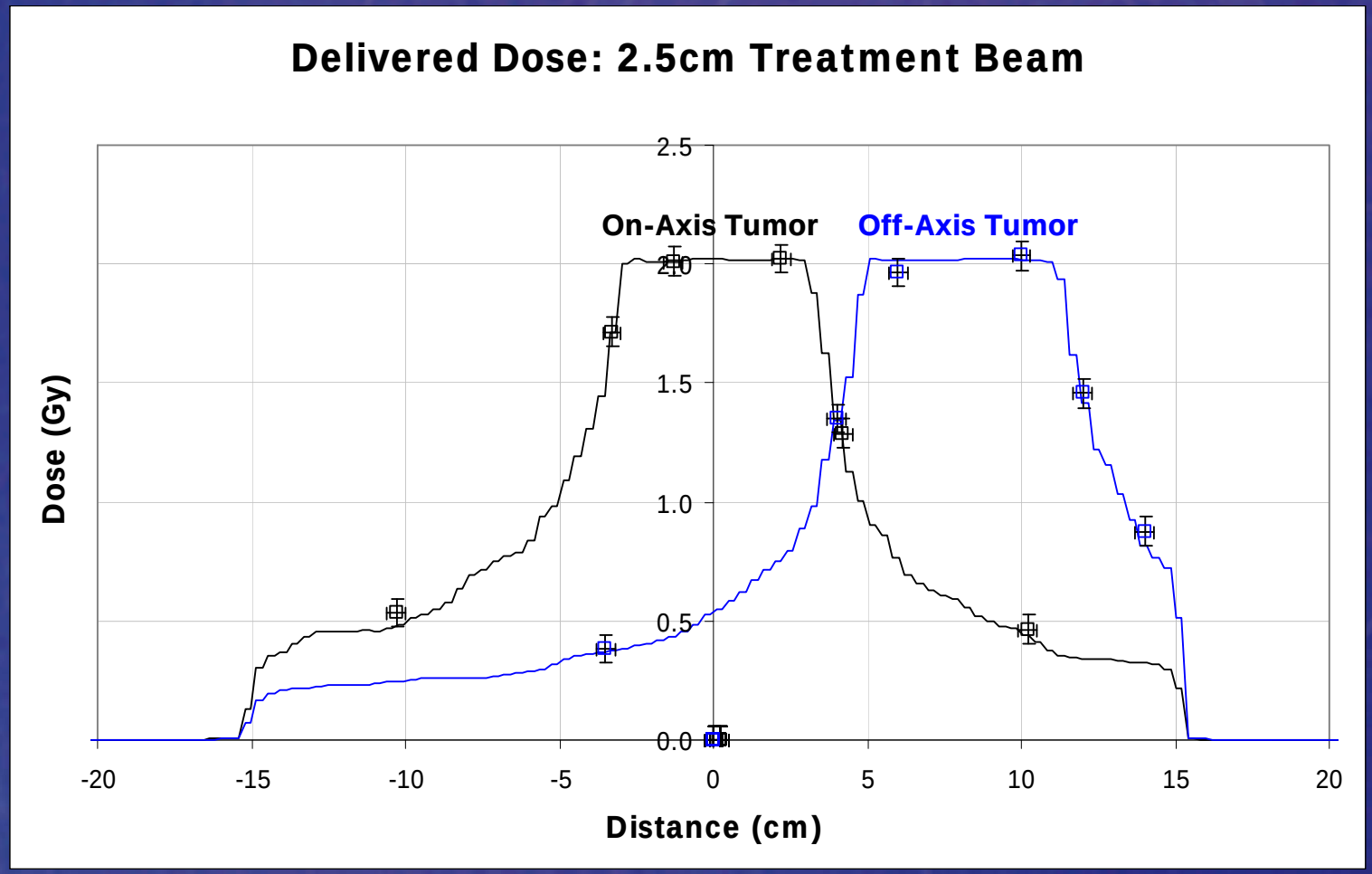


Film Plane

Phantom can be rotated or turned to acquire any orthogonal plane

On and Off-Axis Results

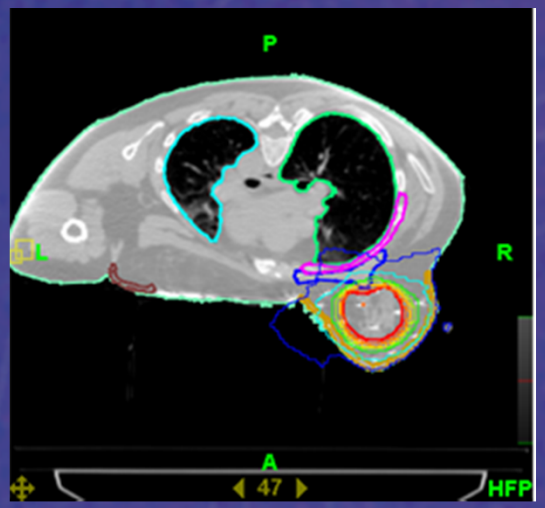
Film and Ion Chamber Absolute Dose

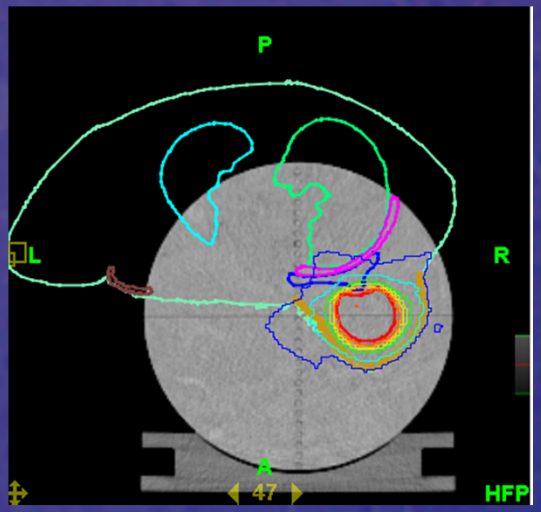


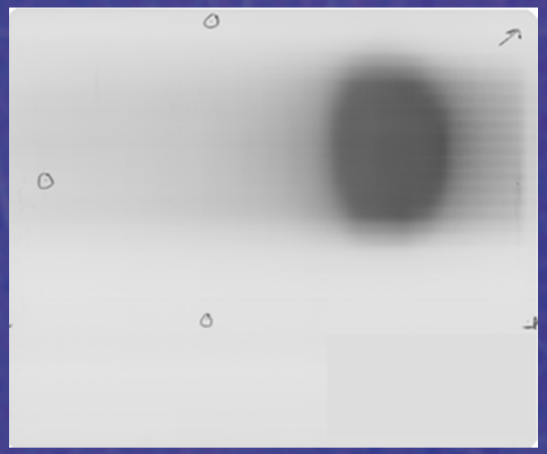
Tomotherapy Example

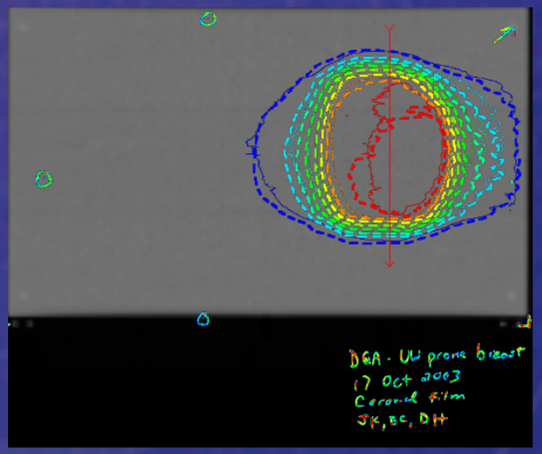
QA for All of the Fields

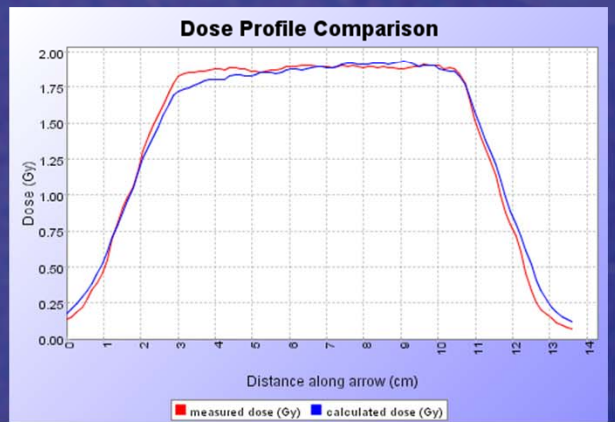
Tomotherapy Example

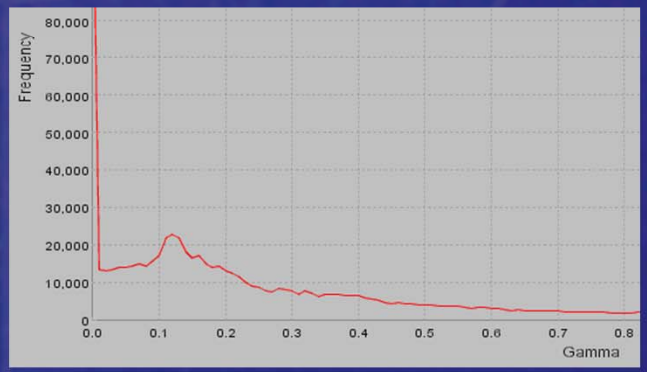


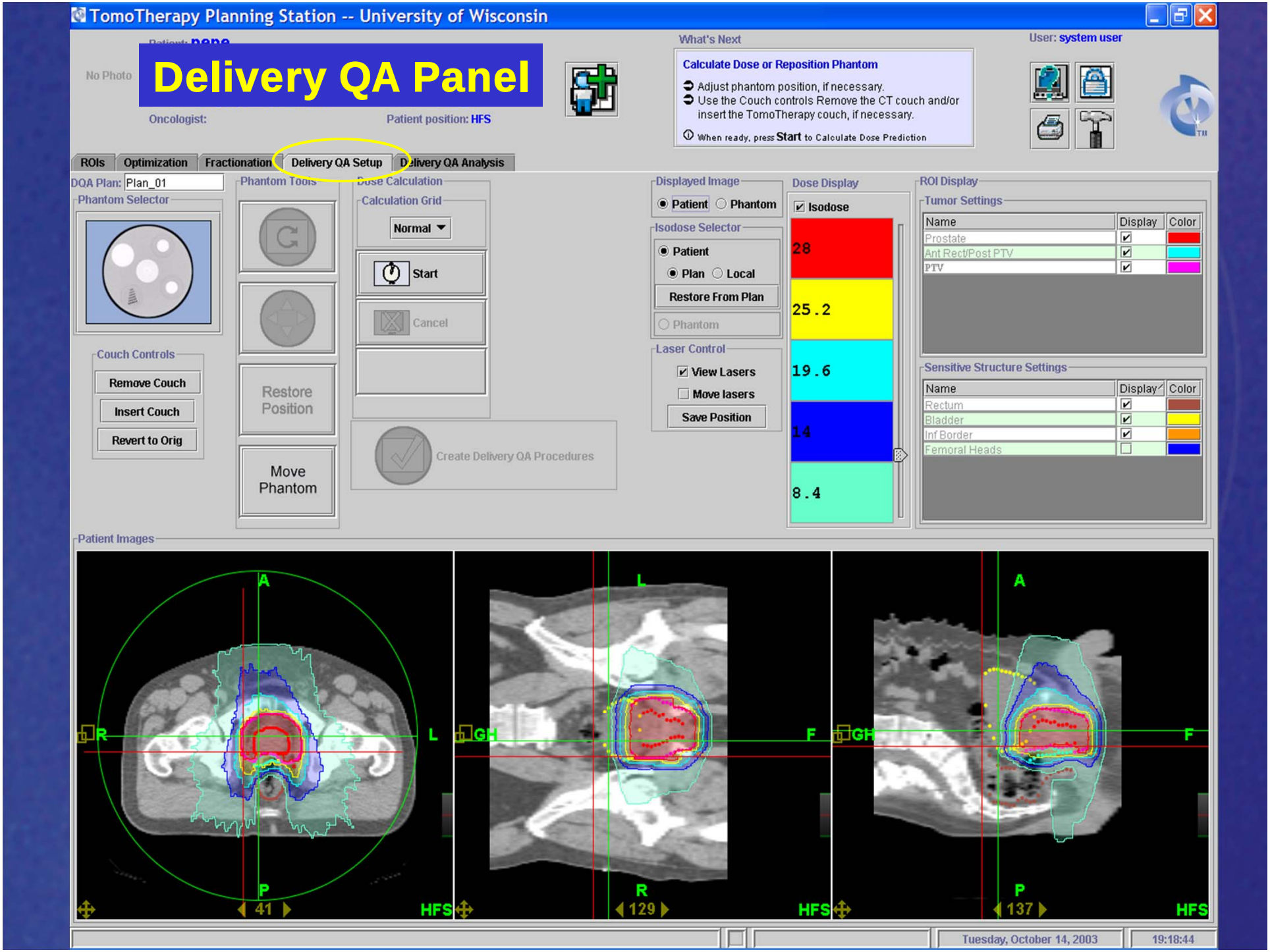


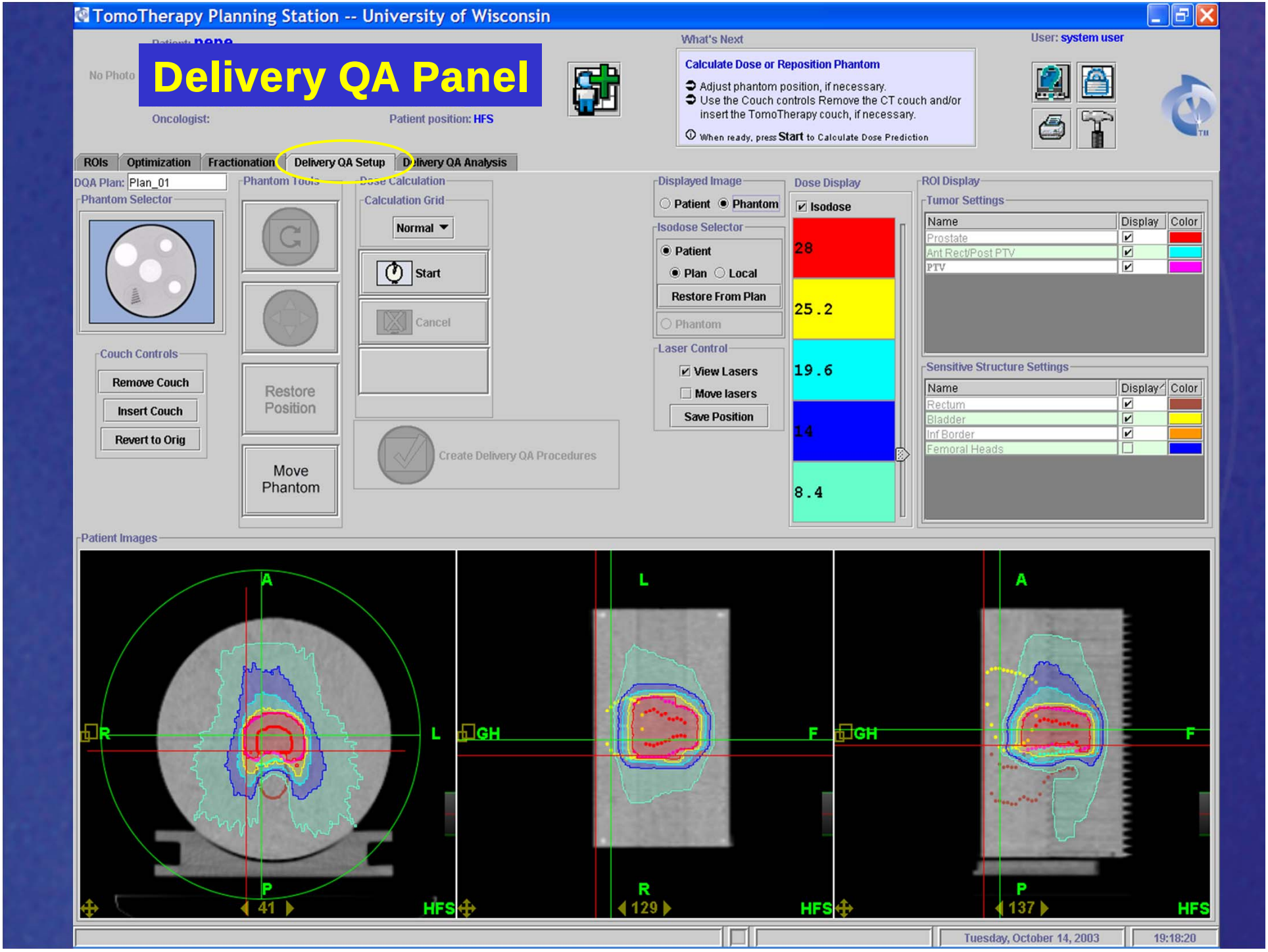









TomoTherapy Planning Station -- University of Wisconsin
Delivery QA Panel
No Photo
Oncologist:
Patient position: HFS
What's Next
Calculate Dose or Reposition Phantom
Adjust phantom position, if necessary.
Use the Couch controls Remove the CT couch and/or insert the TomoTherapy couch, if necessary.
When ready, press Start to Calculate Dose Prediction
User: system user
ROIs
Optimization
Fractionation
Delivery QA Setup
Delivery QA Analysis
DQA Plan: Plan_01
Phantom Selector
Couch Controls
Remove Couch
Insert Couch
Revert to Orig
Phantom Tools
Restore Position
Move Phantom
Dose Calculation
Calculation Grid
Normal
Start
Cancel
Create Delivery QA Procedures
Displayed Image
Patient
Phantom
Isodose Selector
Patient
Plan
Local
Restore From Plan
Phantom
Laser Control
View Lasers
Move lasers
Save Position
Dose Display
Isodose
28
25.2
19.6
14
8.4
ROI Display
Tumor Settings
Name
Display
Color
Prostate
Ant Rect/Post PTV
PTV
Sensitive Structure Settings
Name
Display
Color
Rectum
Bladder
Inf Border
Femoral Heads
Patient Images
A
R
L
P
41
HFS
L
GH
F
R
129
HFS
A
GH
F
P
137
HFS
Tuesday, October 14, 2003
19:18:44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Phantom
Isodose Selector
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Plan
Local
Restore From Plan
Phantom
Laser Control
View Lasers
Move lasers
Save Position
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28
25.2
19.6
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ROI Display
Tumor Settings
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Display
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PTV
Sensitive Structure Settings
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Color
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A
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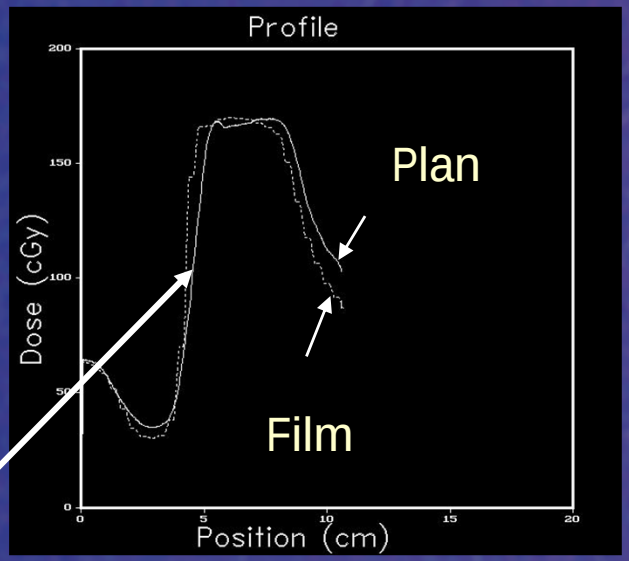
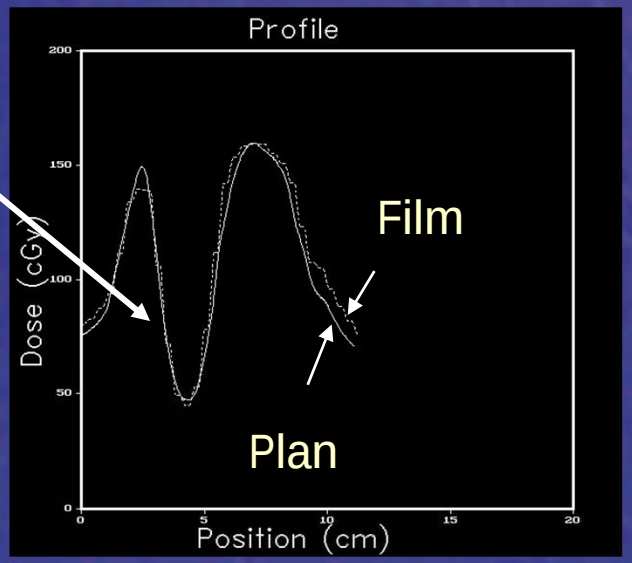
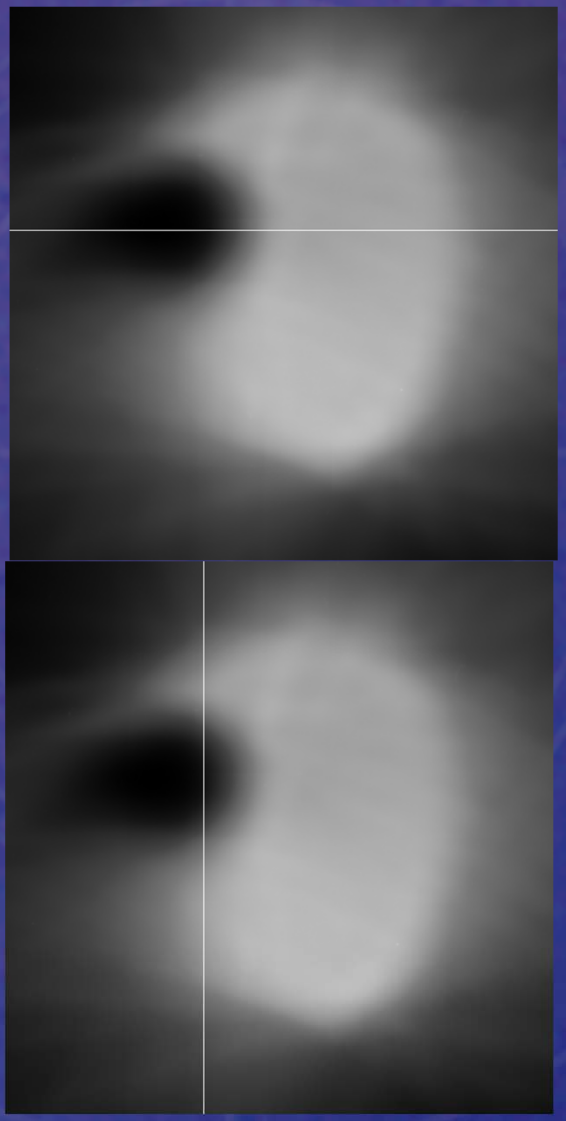
41
HFS
L
GH
F
R
129
HFS
A
GH
F
P
137
HFS
Tuesday, October 14, 2003
19:18:20

Comparison of Phantom Plan and Verification Film



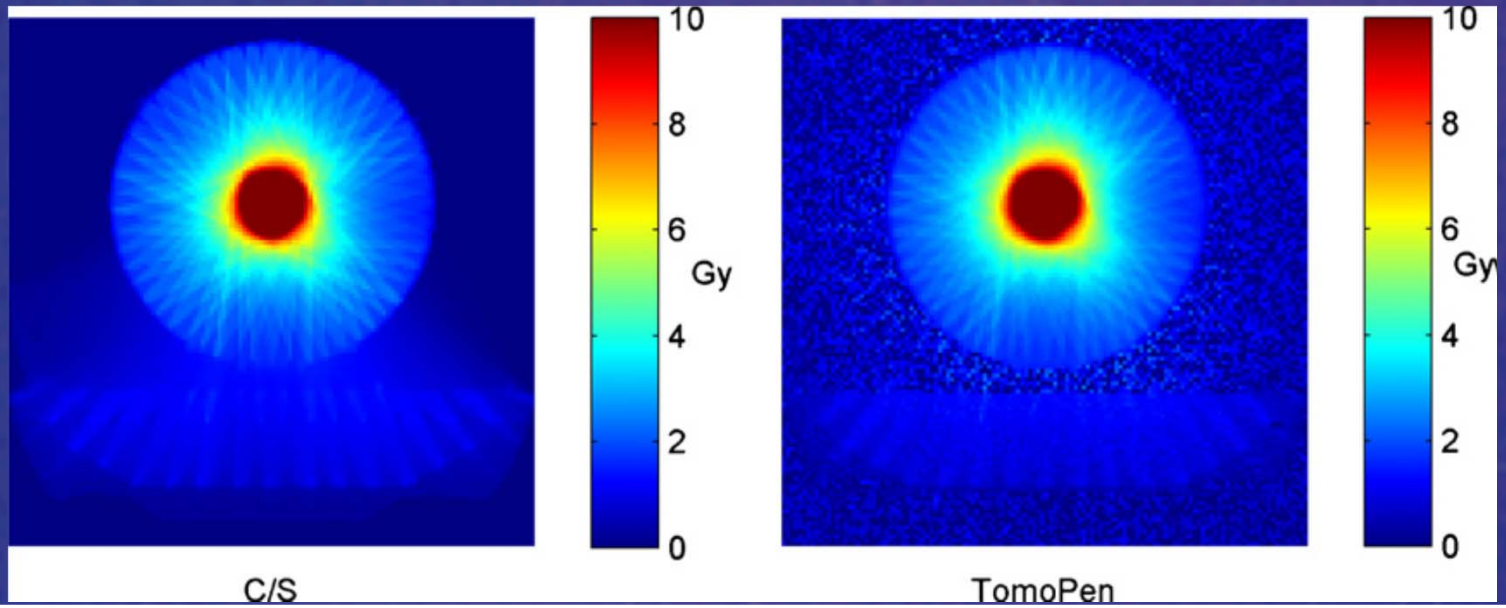
Note the High Gradients

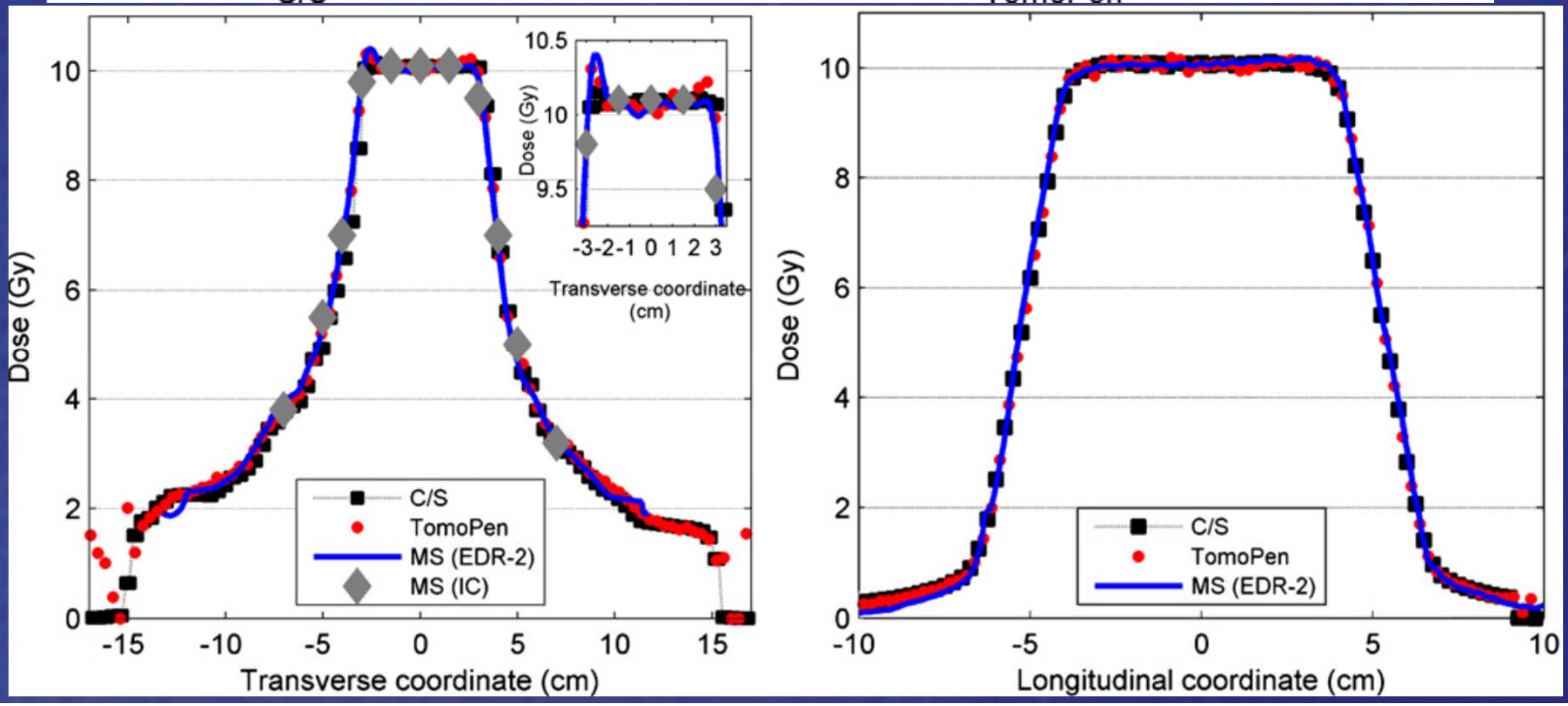




From Chet Ramsey, Thompson Cancer Survival Center

Independent Calculation



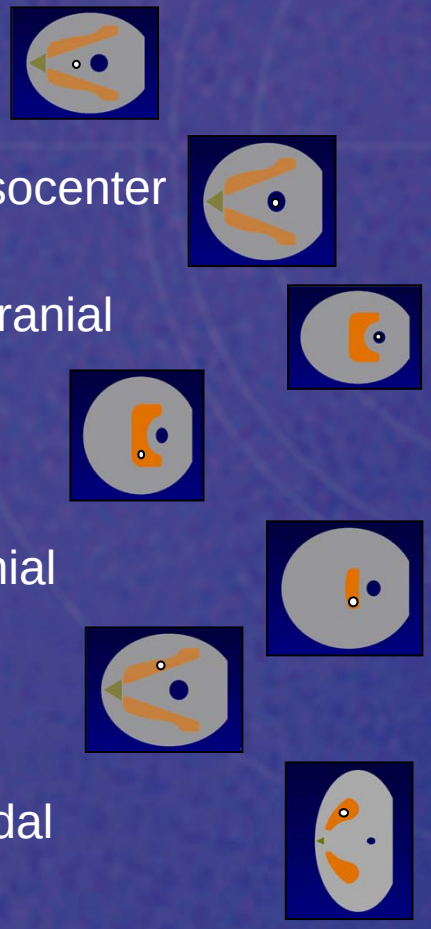


GORTEC
Groupe Oncologie Radiothérapie
Tête Et Cou
Radiotherapy oncology group for head & neck

Gortec IMRT Test Phantom

TLDs are placed at seven locations.

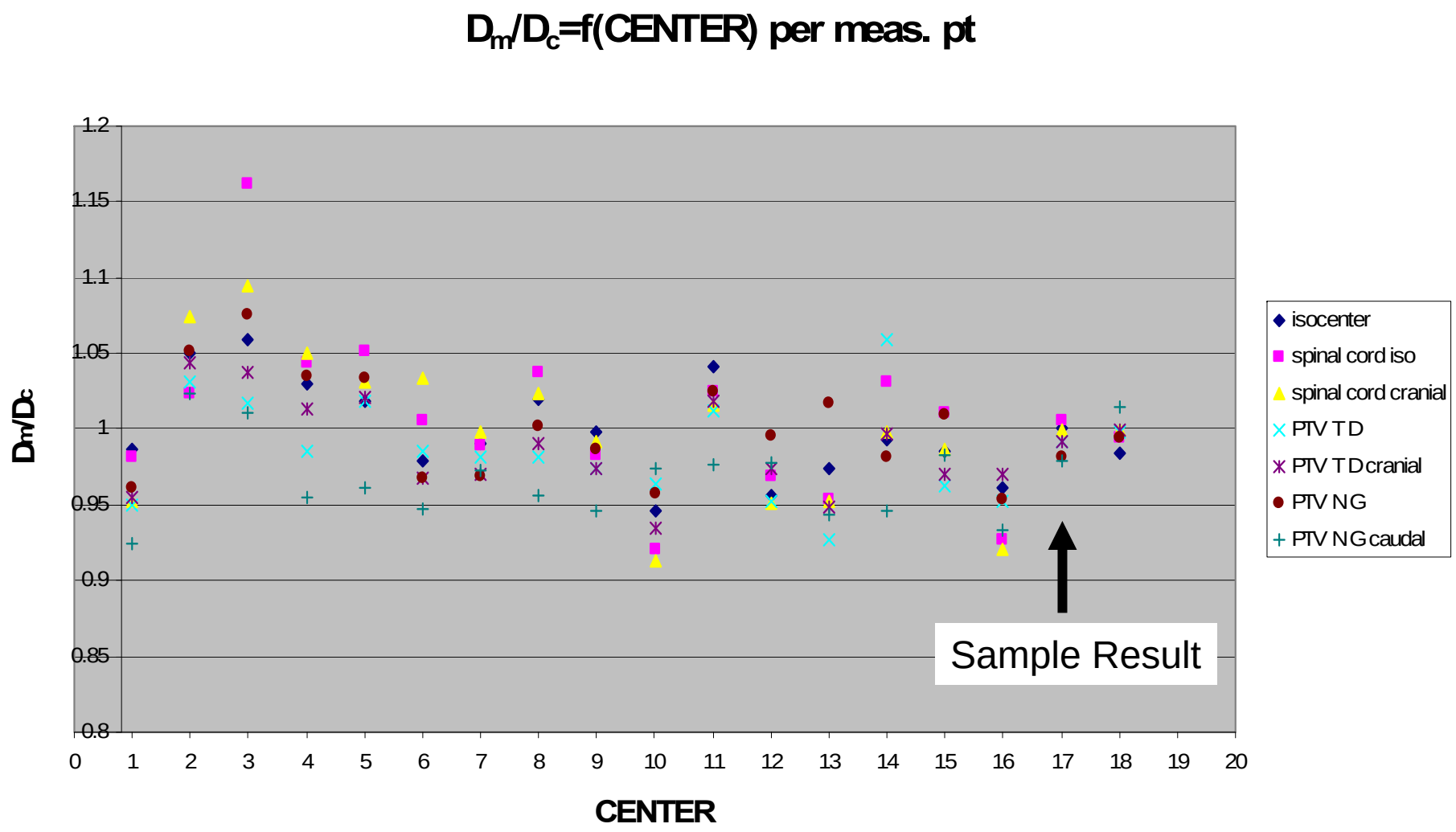
- Point 1: Isocenter
- Point 2: Spinal cord isocenter
- Point 3: Spinal cord cranial
- Point 4: PTV T R
- Point 5: PTV T R cranial
- Point 6: PTV N L
- Point 7: PTV N L caudal



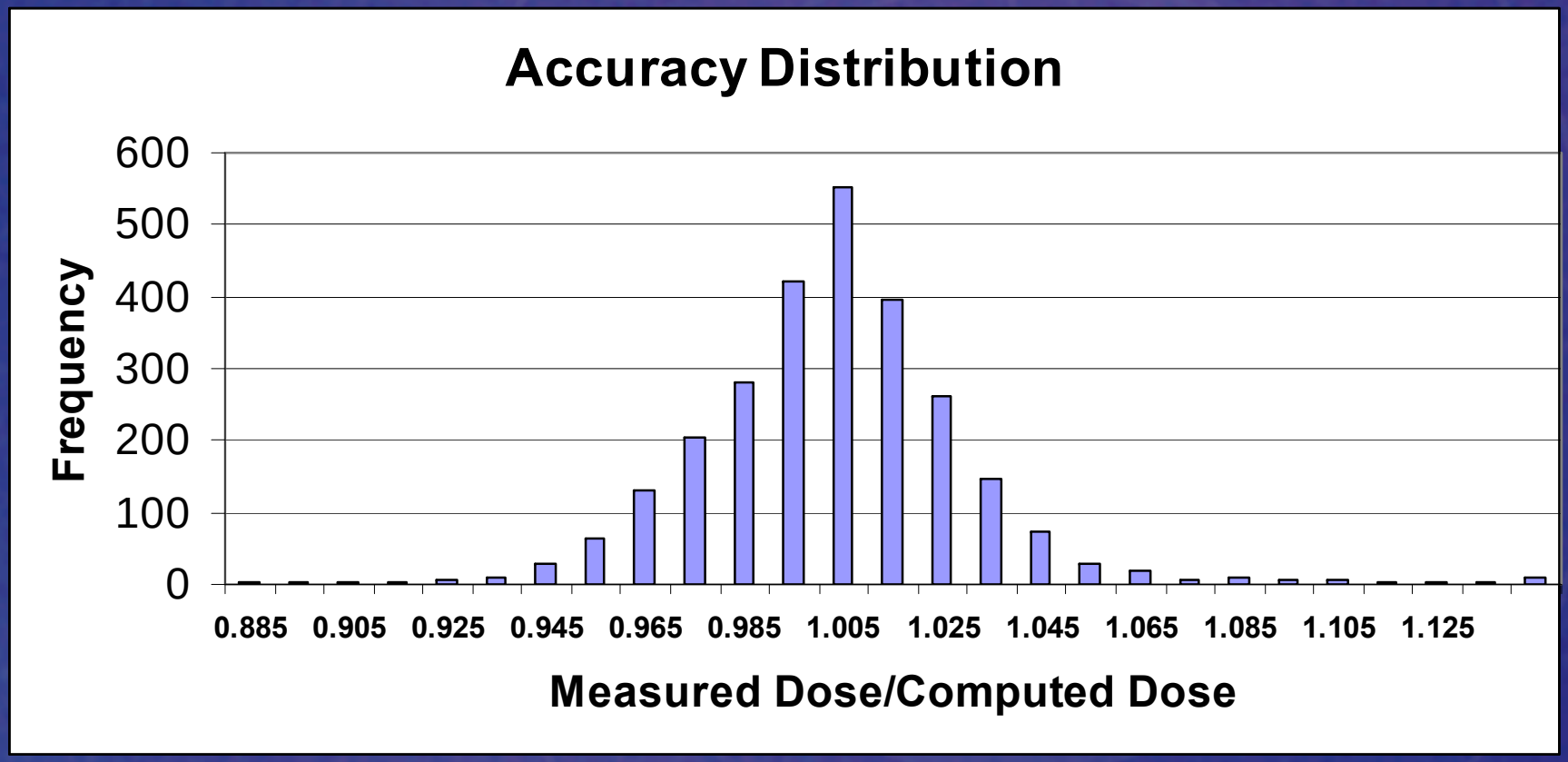
Courtesy M. Tomsej, Brussels

GORTEC
Groupe Oncologie Radiothérapie
Tête Et Cou
Radiotherapy oncology group for head & neck

Audit Results



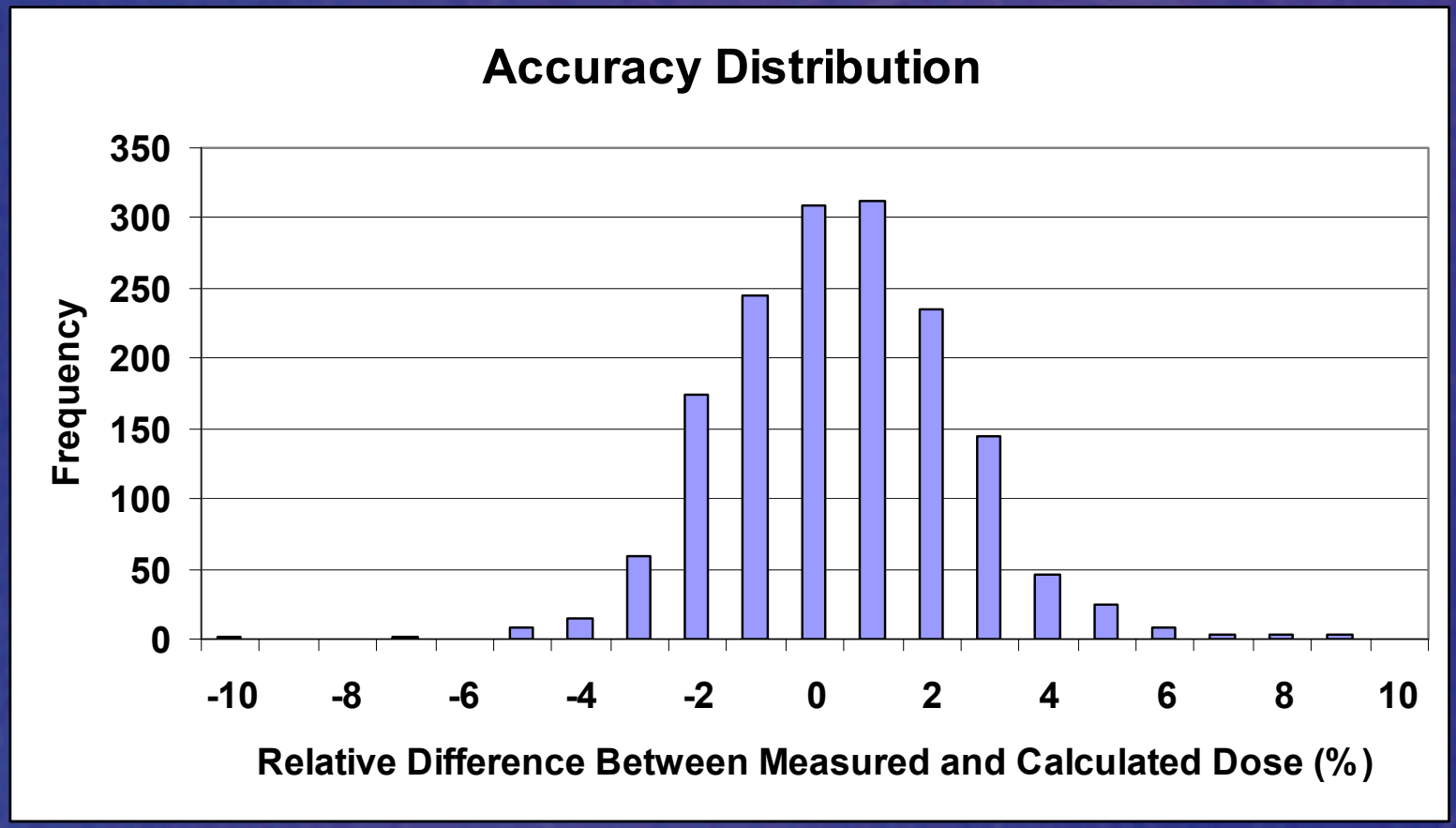
Inter-Institution Dose Accuracy



Number of Measurements = 2679
Mean = 0.995
Standard Deviation = 0.025

(Updated from Zefkili et al 2004)

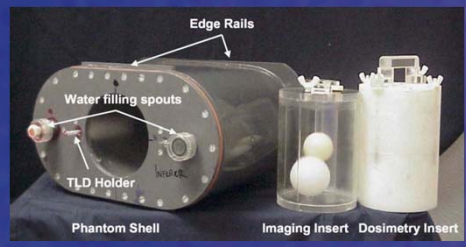
Intra-Institution Dose Accuracy

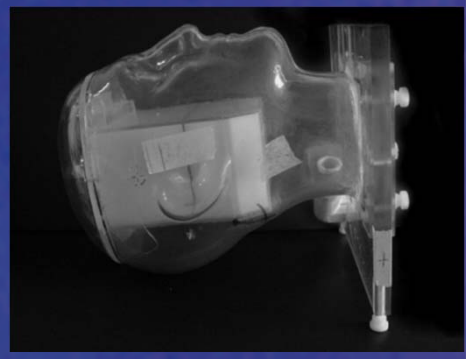


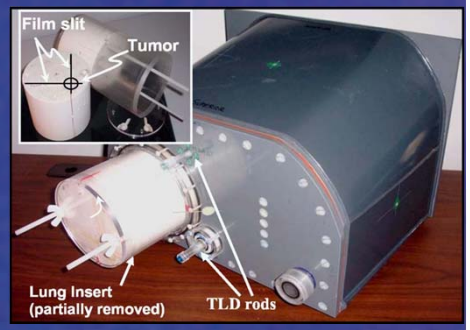
Number of Measurements = 1591
Mean = 0.45%
Standard Deviation = 2.5%

(Updated from Dong et al 2003)

IMRT Evaluation using Anthropomorphic Phantoms







Molineu *et al* IJROBP 2005
Ibott *et al* Tech in Ca RT 2006
Followill *et al* Med Phys 2007

Phantom Results

Comparison between institution's plan and delivered dose.

Criteria for agreement: 7% or 4 mm DTA (5%/5mm for lung)

Site	Institutions	Irradia-tions	Pass	Fail
H&N	472	631	75%	25%
Pelvis	108	130	82%	18%
Lung	67	77	71%	29%
Liver	15	18	50%	50%

For H&N, using a criteria of 5% or 4mm, the passing rate drops from 75% to 58%

Courtesy Ibott, RPC

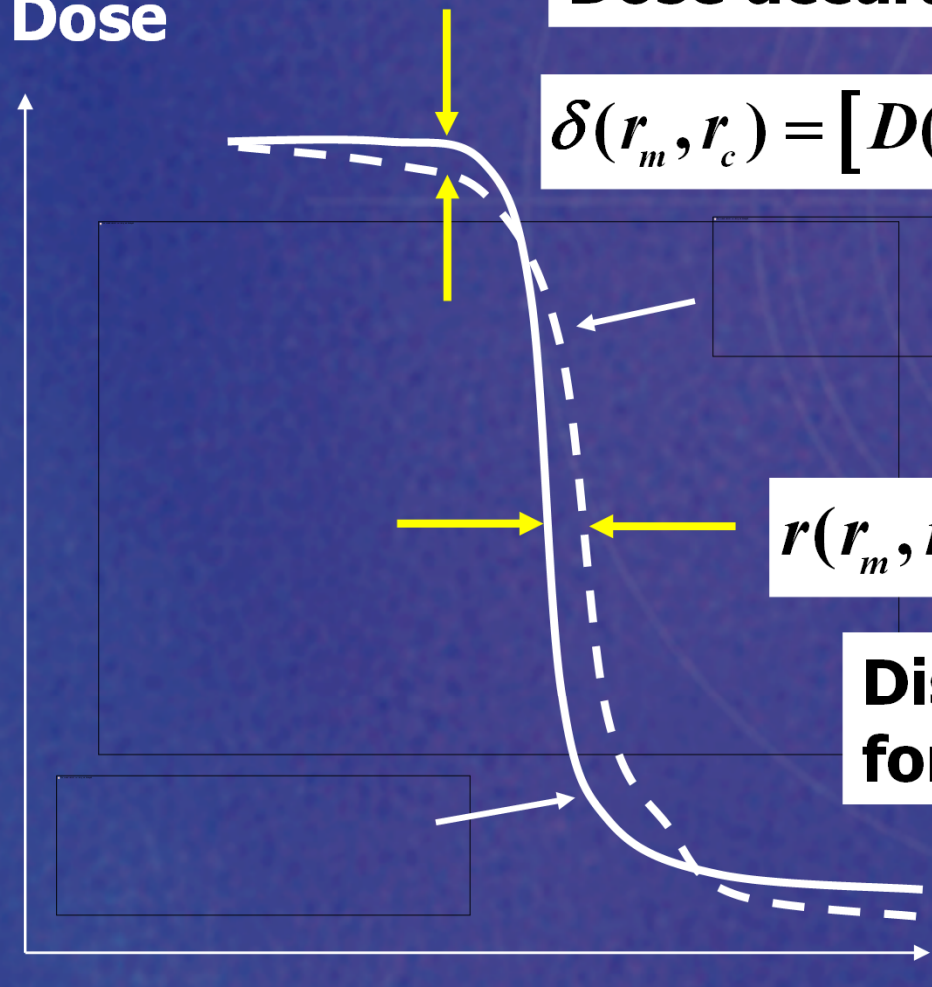
QA Accuracy for IMRT

- Previous ICRU 5% point-dose accuracy specification replaced by a volumetric dose accuracy specification.
- Proposed new ICRU volumetric dose accuracy specification:
  - High gradient (≥ 20%/cm): 85% of points within 5 mm (3.5 mm SD),
  - Low gradient (< 20%/cm): 85% of points within 5% of predicted dose normalized to the prescribed dose (3.5% SD).

Dose Accuracy and Distance to Agreement

Dose accuracy for low gradients

$$\delta(r_m, r_c) = \left[D(r_m) - D(r_c) \right] / D_{50\%}$$



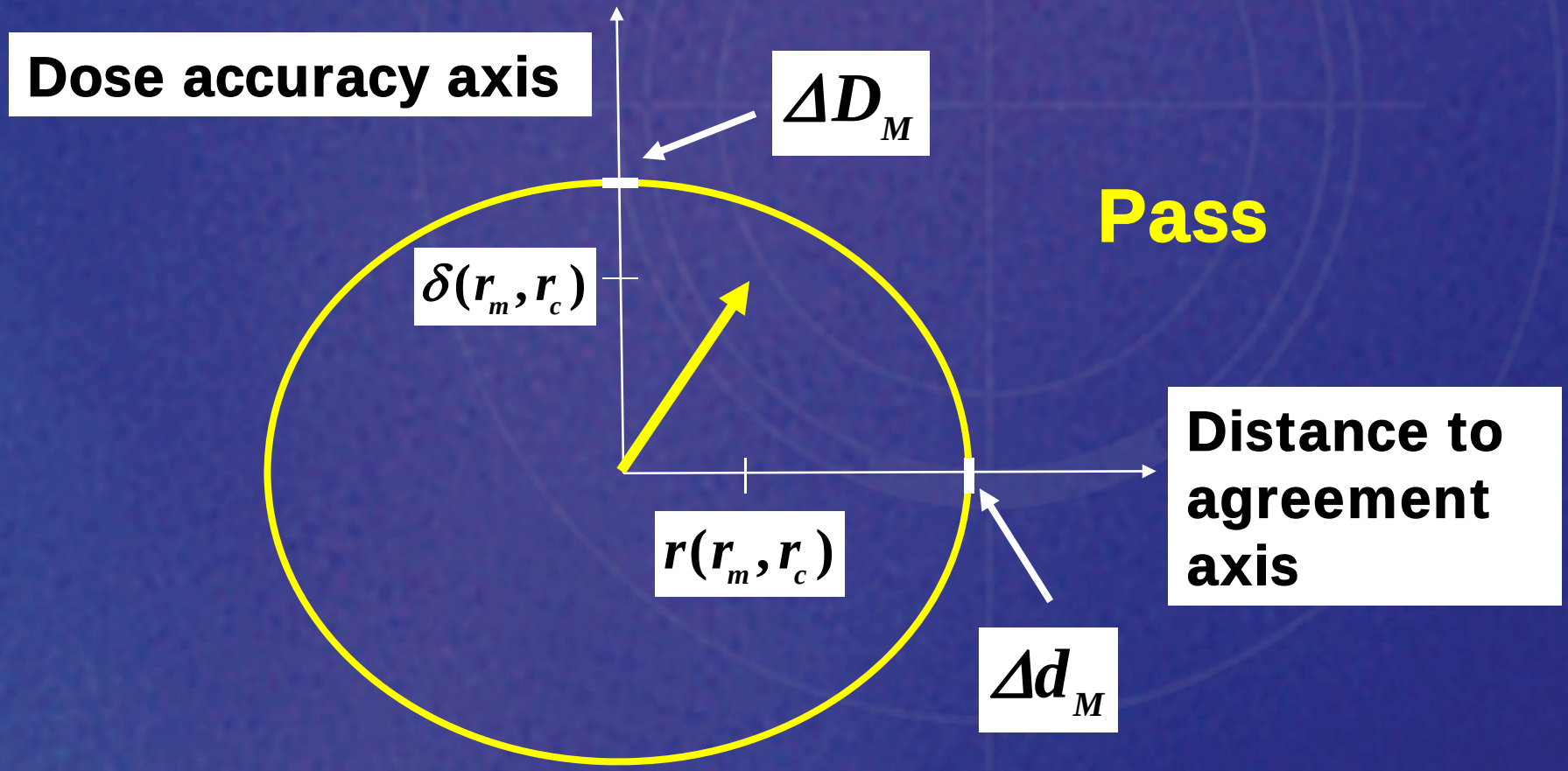
Low gradients < 20%/cm

$$r(r_m, r_c) = \left| r_m - r_c \right|$$

Distance to agreement for high gradients

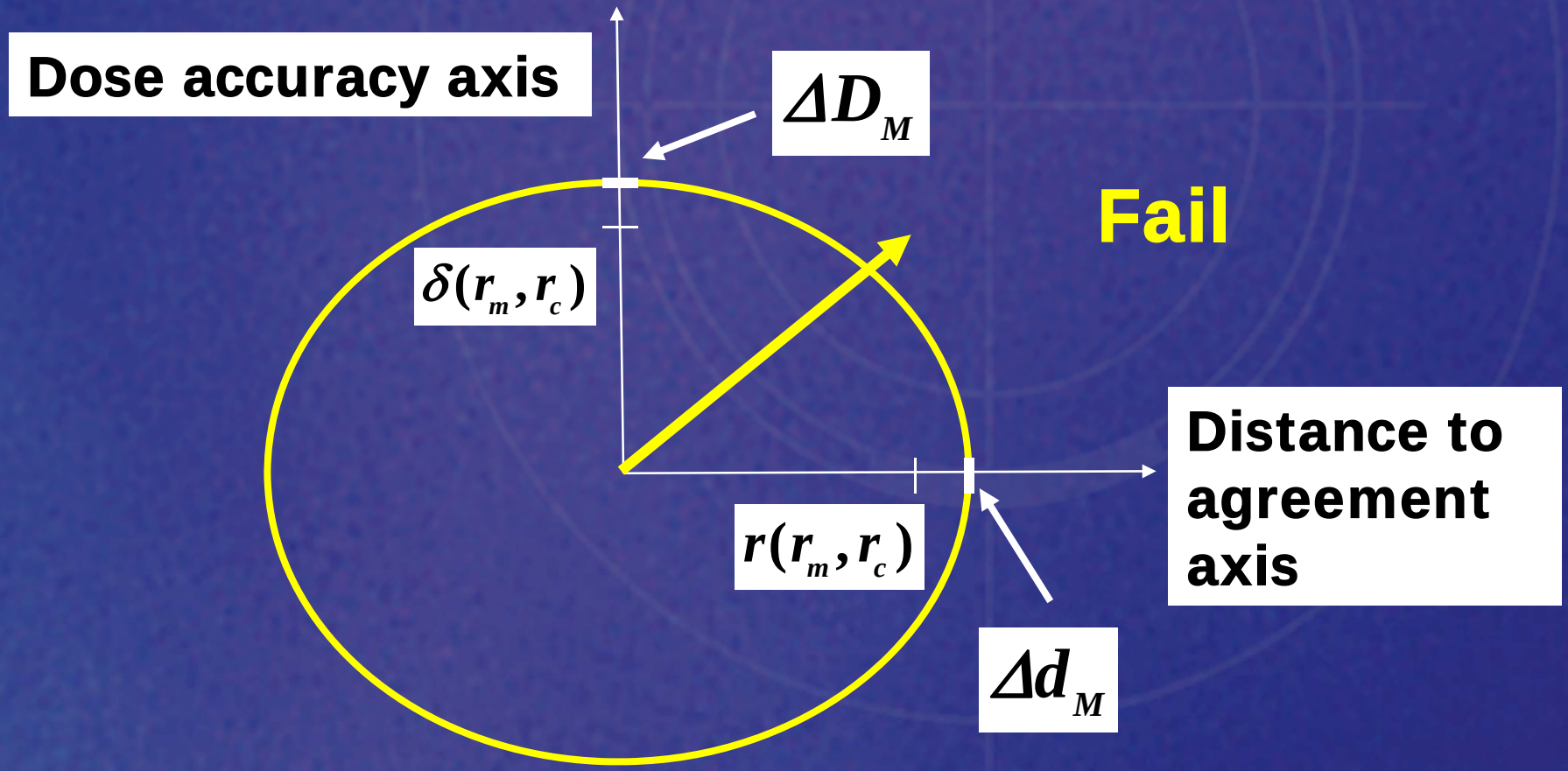
Gamma Function

$$\Gamma(r_m, r_c) = \{[\delta(r_m, r_c) / \Delta D_M]^2 + [r(r_m, r_c) / \Delta d_M]^2\}^{1/2}$$



Gamma Function

$$\Gamma(r_m, r_c) = \{[\delta(r_m, r_c) / \Delta D_M]^2 + [r(r_m, r_c) / \Delta d_M]^2\}^{1/2}$$



Summary of Changes Between ICRU 50 & 62 and IMRT ICRU (83)

- More emphasis on statistics.
- Prescription and reporting with dose-volume specifications.
- No longer use ICRU-Reference Point.
- Want median dose D_{50} reported.
- Use model-based dose calculations.
- Include the effect of tissue heterogeneities.
- Report dose to small mass of water, not dose to tissue.