Clinical Implementation of SRS/SBRT

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AAPM Ohio River Valley Chapter
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Disclosures

Speaker:

BrainLAB

Standard Imaging

Research collaboration:

RaySearch

Learning Objectives

- Physics Considerations
- SRS Program
- SBRT Program

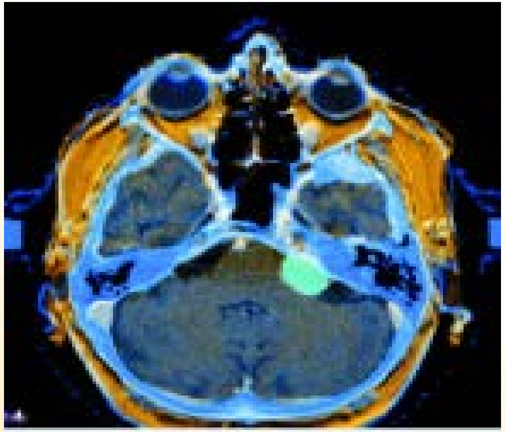
Physics Considerations

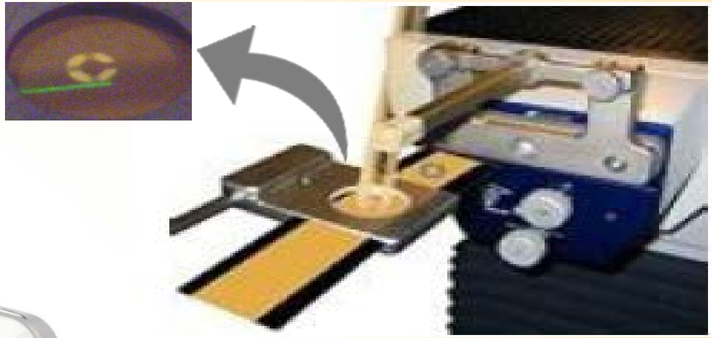
LOYOLA UNIVERSITY HEALTH SYSTEM

- Equipment Selection
- System QA (Image, Plan and Treat)
- Beam Data Measurement
- Data Validation
- End-to-End Test (Process QA)
- Tips and Tricks

System QA

- Winston-Lutz Test
- Process QA
- Image-Fusion Test

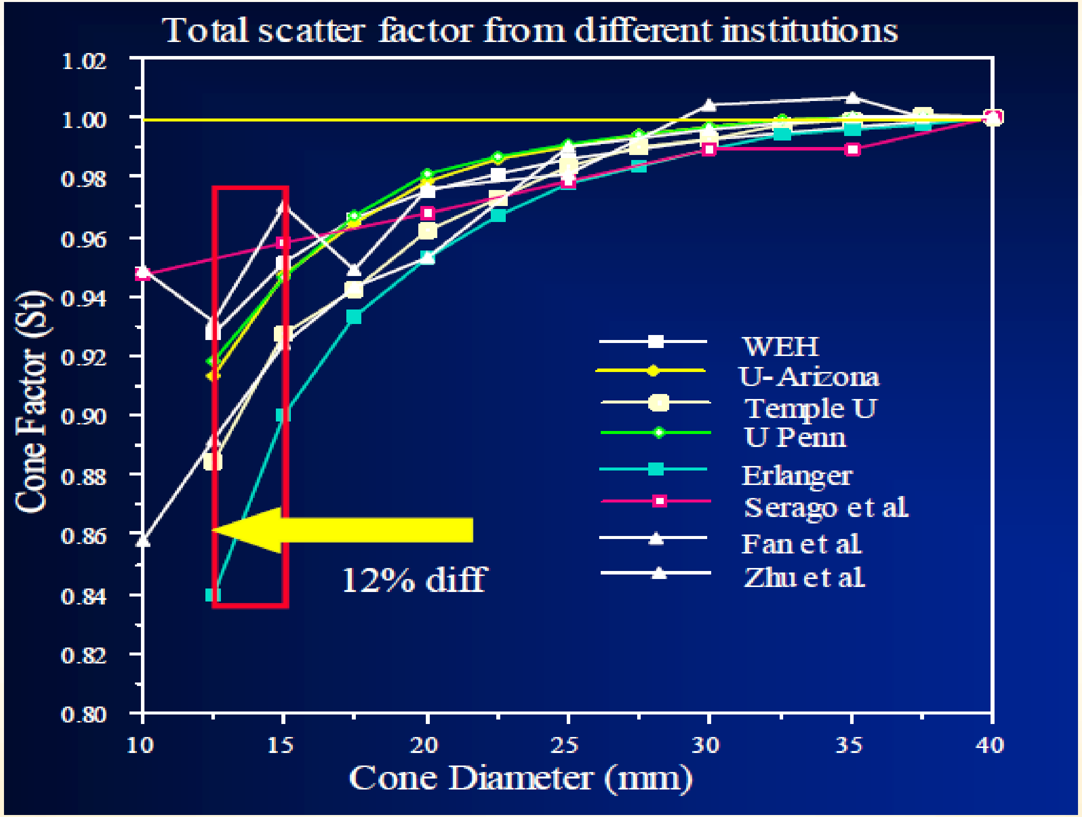




Output/PDD/Profiles

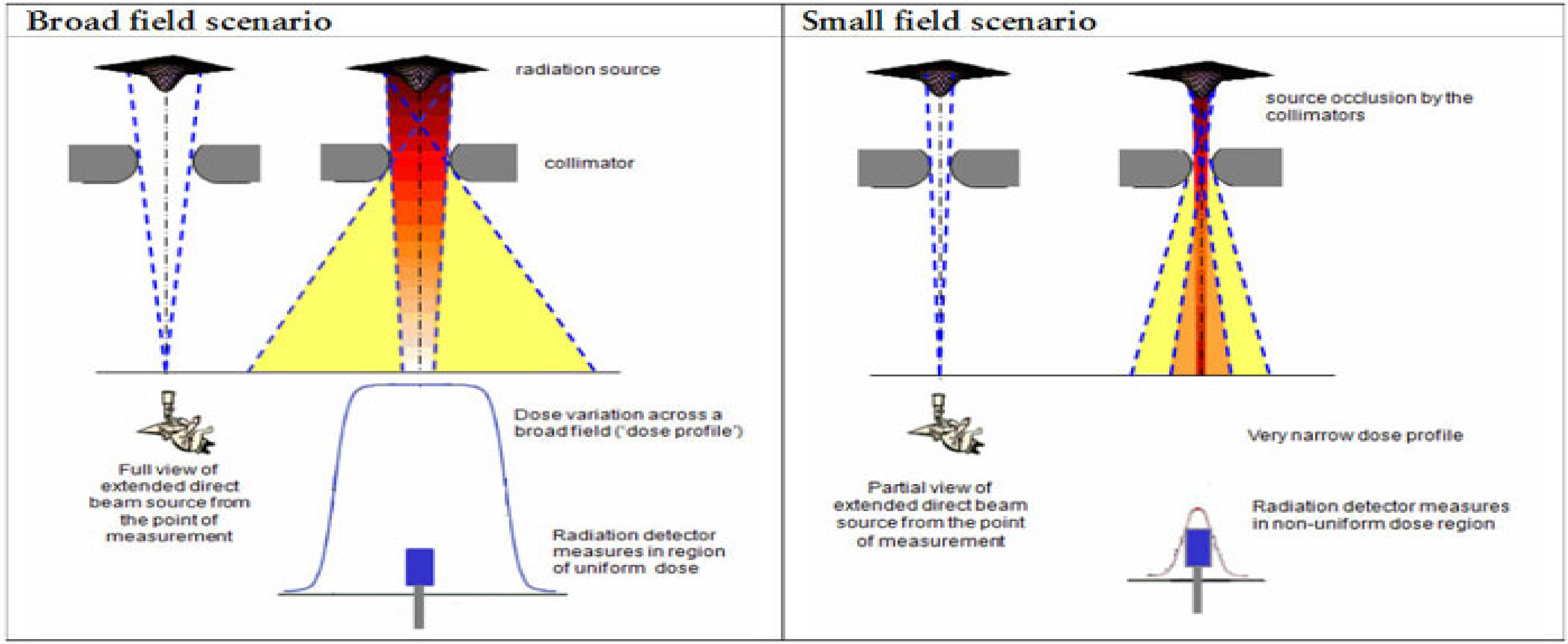
- Beam Output Check: TG-51
- Send for IROC TLDs
- Beam Scans (PDD/Profiles) for MLC & cones
- Scatter(output) factors

Small Field Challenge: Output Factors

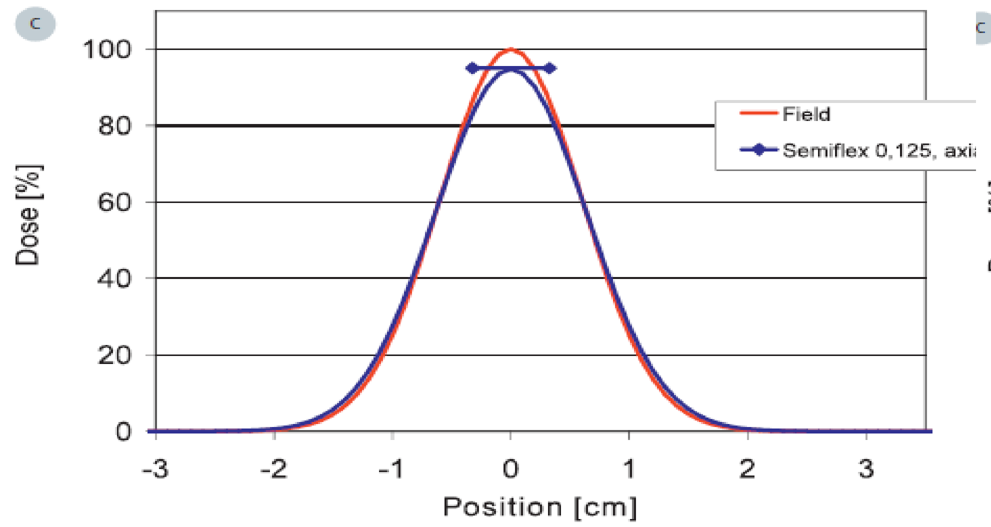


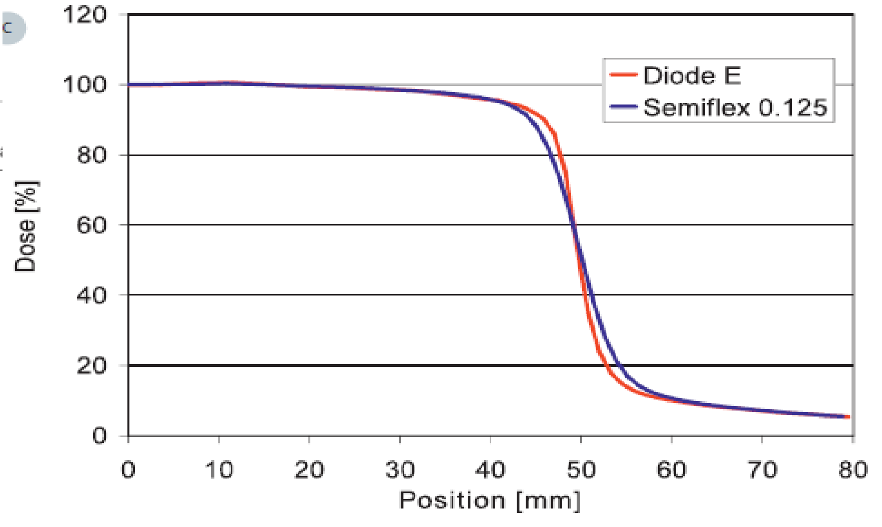
Das *et al.*

Large *vs.* Small Fields



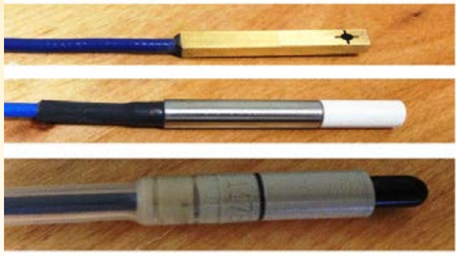
If Wrong Detector….





- **Dose → Under-estimated**
- **Penumbra → Broadened**
- **FWHM → Unaffected**

Which Detector to Use?



- Ensure detector size < (¼ * Field Size)
- Small ion chamber (<0.1cc): stem effect/leakage.
- Medium ion chamber (0.1 – 1.0 cc): volume averaging
  - CA is under-dosed, penumbra broadened
- Recommend:
  - Unshielded diode for small fields and
  - Ion chamber for large fields

SRS Detectors

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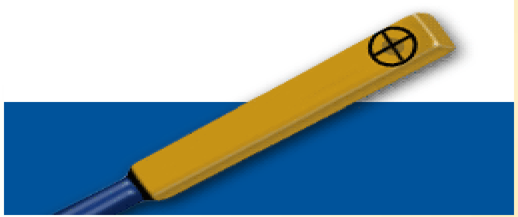
- CC13 (0.13cc active volume)
- A16
- Exradin D1H and D1V
- IBA SFD
- Edge detector
- PTW White diode (60018)



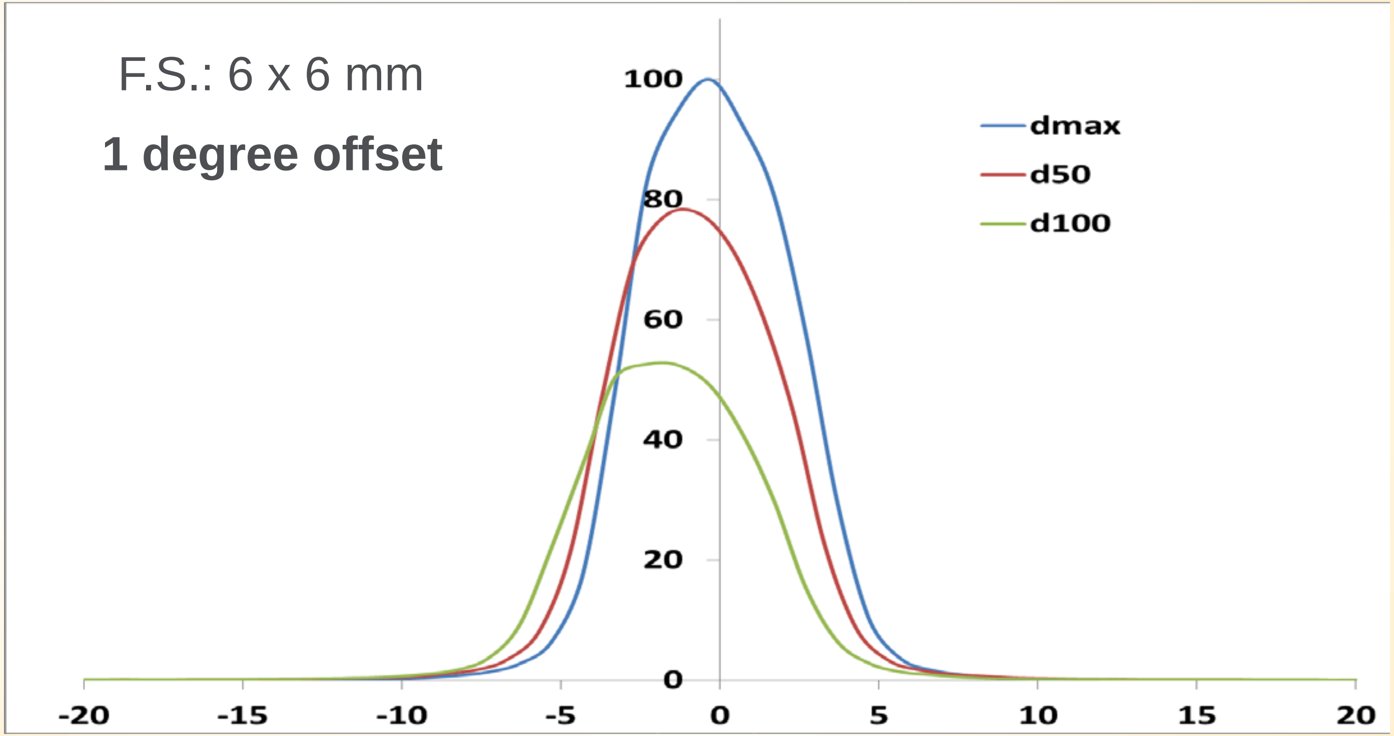



Beam Data Measurement:

Avoid Pitfalls

Beam Misalignment



Off-axis distance (mm)

Beam Misalignment

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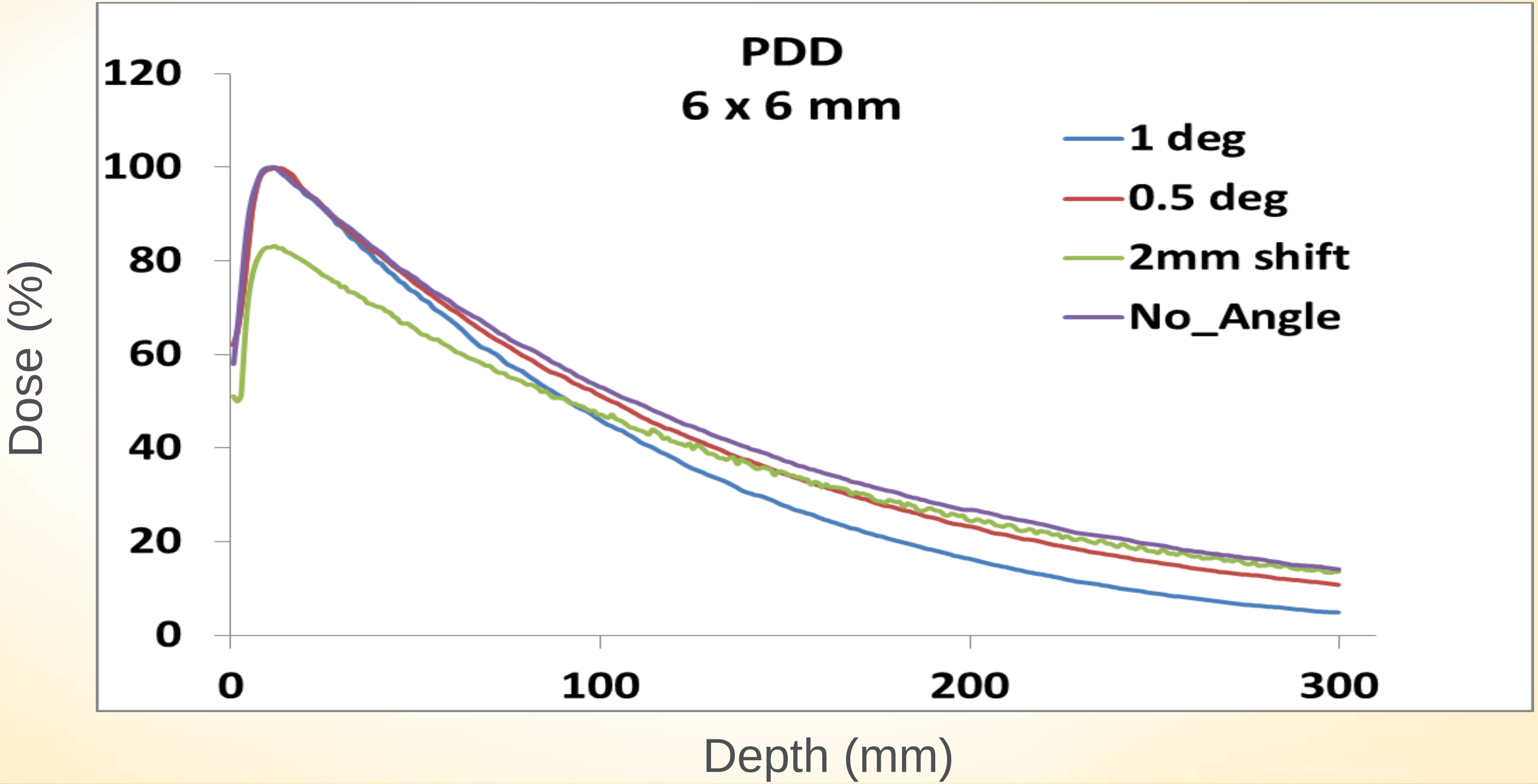

SAM_Q1

In the measurement of very small fields (< 1x1 cm), variation in output factors caused by wrong detector and/or incorrect setup can be no more than

A. <2%
B. 2 - 5%
C. 5 – 10%
D. 10% +
E. There is no problem if you will use the smallest detector available.

SAM_Q1

LOYOLA UNIVERSITY HEALTH SYSTEM

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Reference: Das et al, Task Group 106, Med Phys 35, 4186 (2008). Francescon et al MP (2011).

Beam Data Measurement Tips

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- Check water surface (use d_{max} as reference)
- Correct for Effective point of measurement
- Align scanning system/ detectors with beam axis. Drive Up!
- Scan small field profile (< 2 cm) to verify detector centering & depth correction if needed
- Repeat with MLC and cones

Measurement Tips

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- Verify 10x10 cm PDD/profiles
- Output factors with at-least two diode detectors + small volume ion chamber
- Apply corrrection factors (*Francescon et al, MP 2011*)
- Perform cross calibration before each measurement
- Daisy chain at ~4x4 cm: Perform measurements with large chamber for known MU and then deliver same MU to the small detector. Use charge ratio of output for large detector to adjust output with small detector.

More Tips

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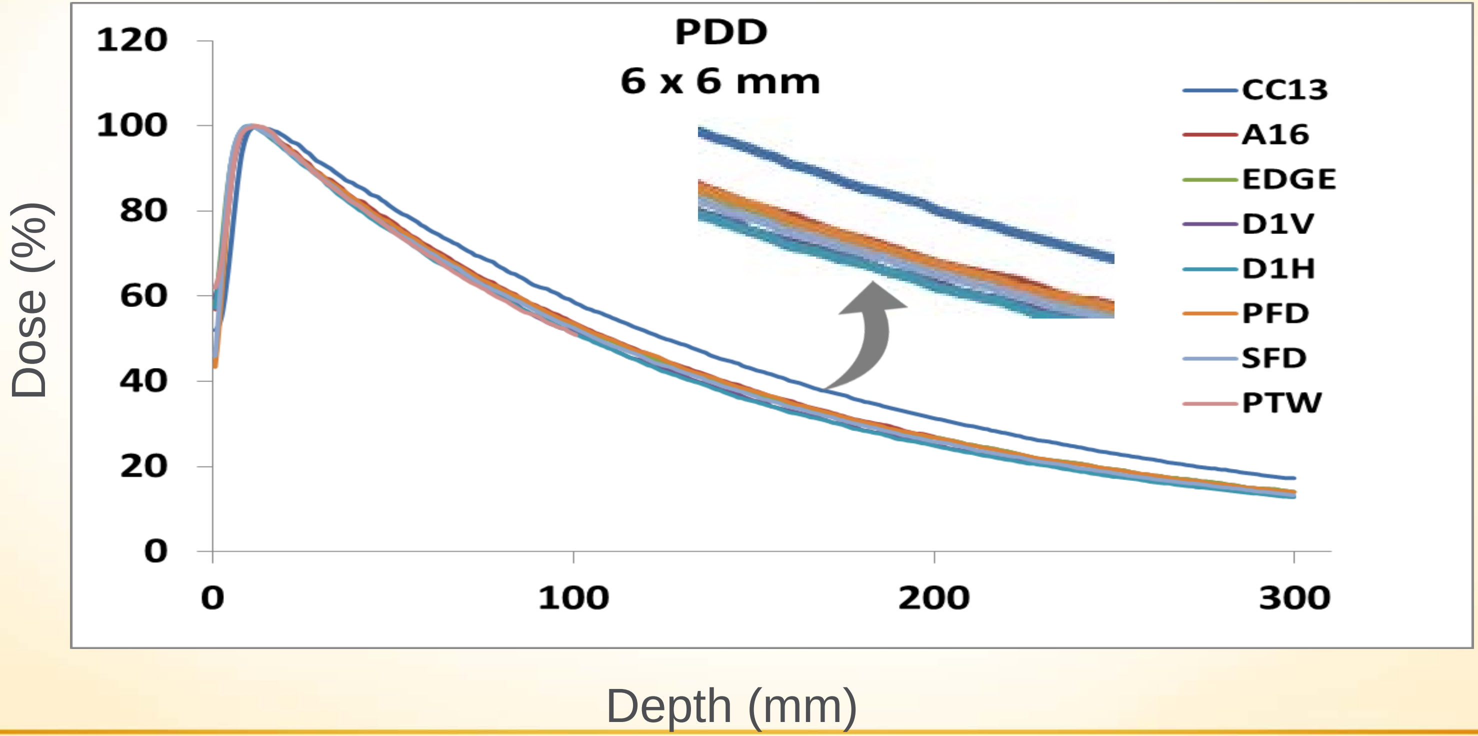
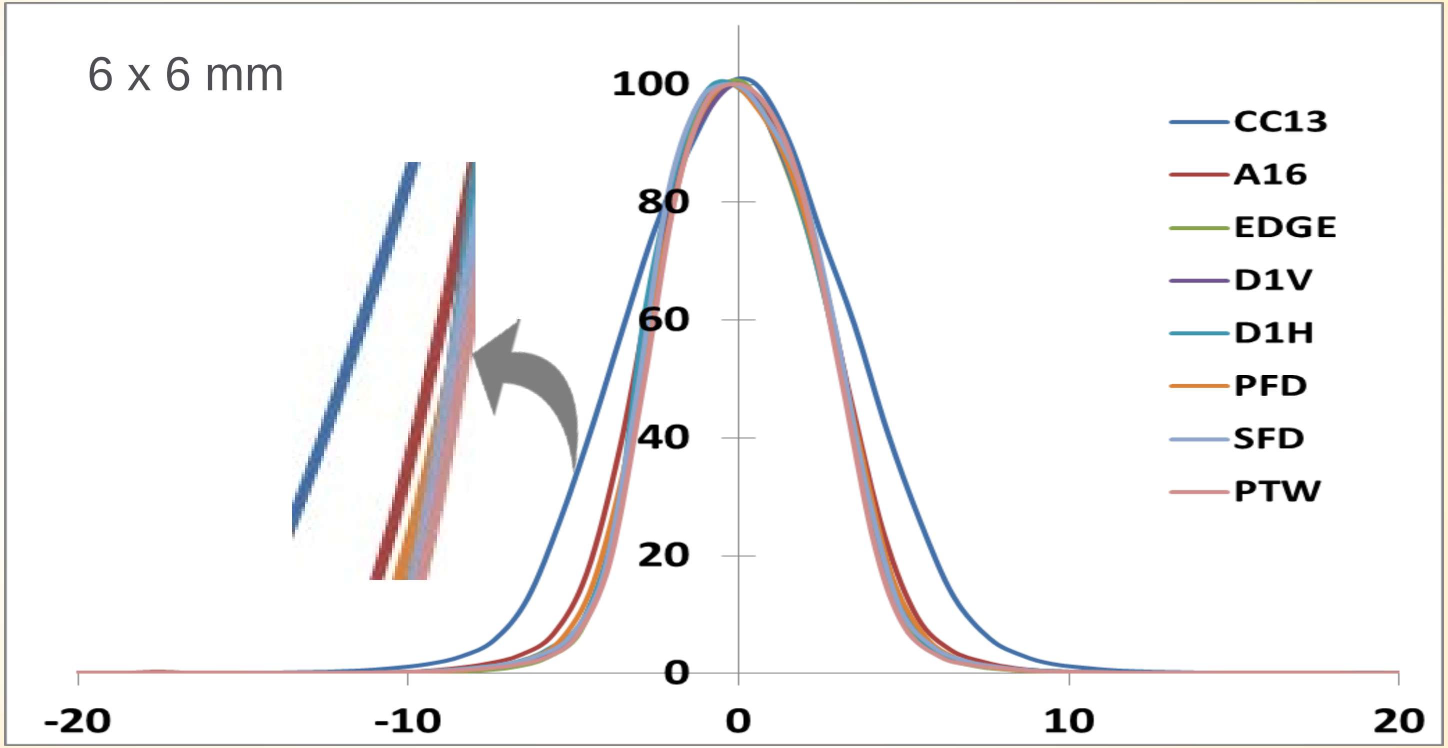
- For small fields, No ref detector
- Slow scan speed, 20+ points/meas.
- Watch for Penumbra asymmetry
- Check leakage and
- Subtract from Output if necessary

Detector Compare



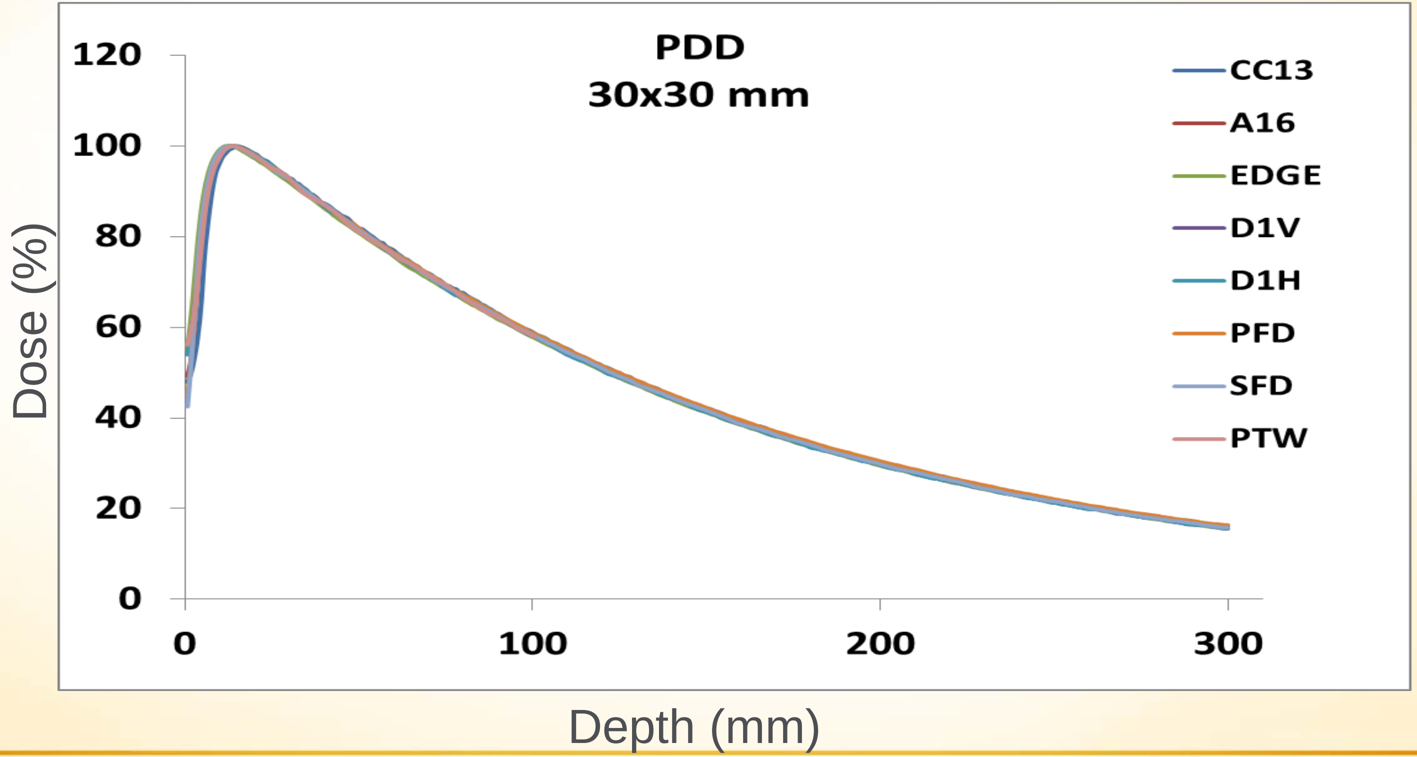
Detector Compare



Off-axis distance (mm)

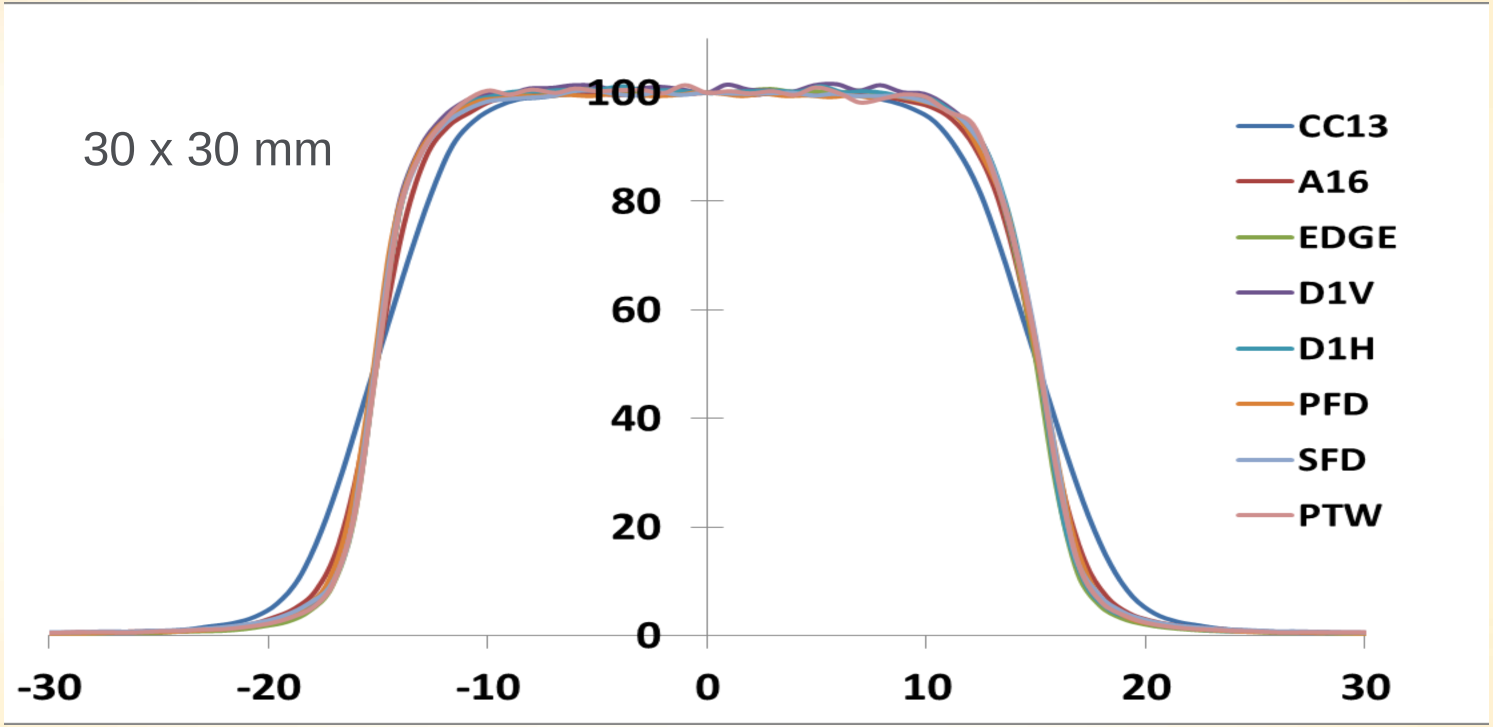
Detector Compare

30 x 30 mm PDD



Detector Compare

LOYOLA UNIVERSITY HEALTH SYSTEM



Off-axis distance (mm)

Detector Compare

Penumbra Measurements

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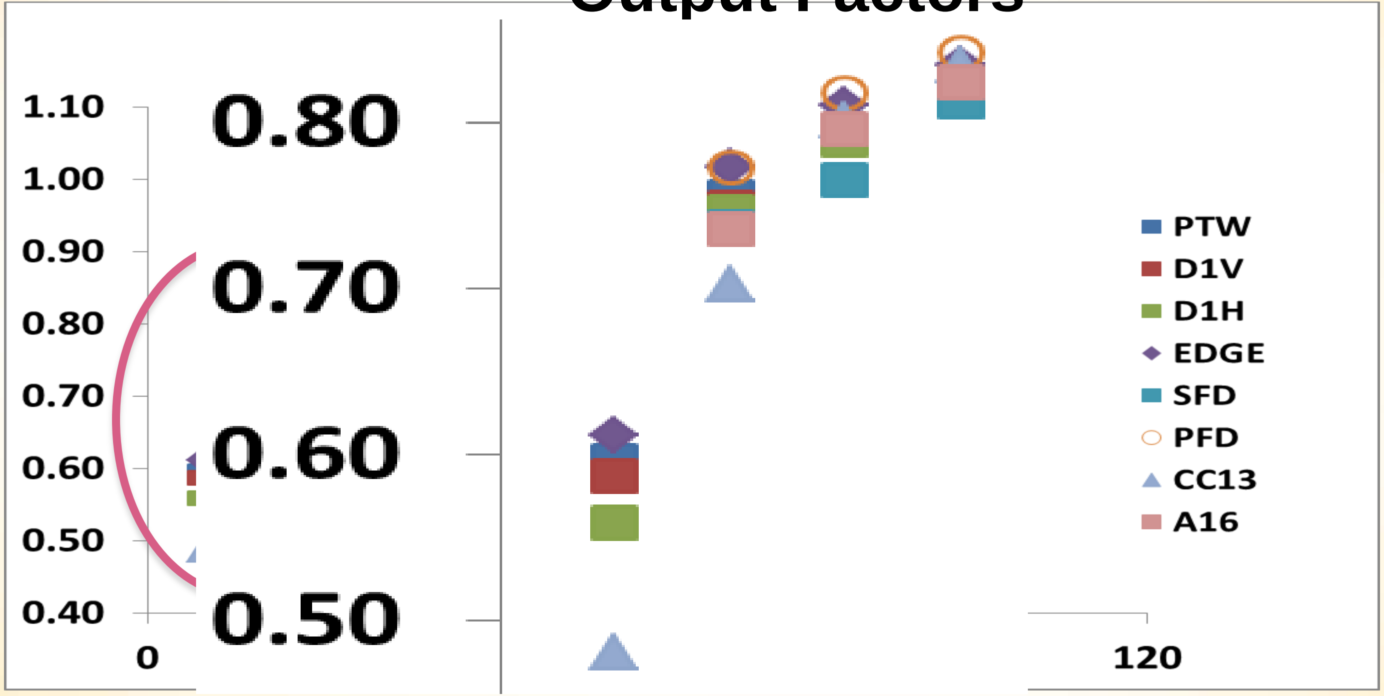
F.S. (mm)	→	100 x 100	30 x30	12x 12	6x6
Detector	*Vendor*				
CC13	IBA	5.2	4.9	4.7	3.8
A16	Std Imaging	3.8	3.3	3.1	2.4
Edge	Sun Nuclear	3.2	2.6	2.2	2.1
D1V	Std Imaging	3.0	2.3	2.2	2.1
D1H	Std Imaging	3.0	2.3	2.3	1.9
PFD	IBA	3.5	2.5	2.5	2.3
SFD	IBA	3.1	2.4	2.3	2.0
TN 60018	PTW	3	2.2	2.3	2.1

Detector Compare

Output Factors



Field size (mm)

SAM_Q2

Detector size impacts all of the following SRS measurements **except**:

A. Output factors
B. PDD
C. Beam Profile
D. MU calculations
E. FWHM

SAM_Q2

Detector size impacts all of the following SRS measurements **except**:

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C. Beam Profile
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Reference: Das et al, Task Group 106, Med Phys 35, 4186 (2008).

TPS Validation

- Independent MU to Dose Calc.
- TG-119 (Planar Array/ ion-chamber/film)
- MU *vs.* Measurement for MLC and Cone plans
- Heterogeneity Correction *vs.* Field size
- Verify Dose/MU for select fields
- RPC/RTOG credentialing

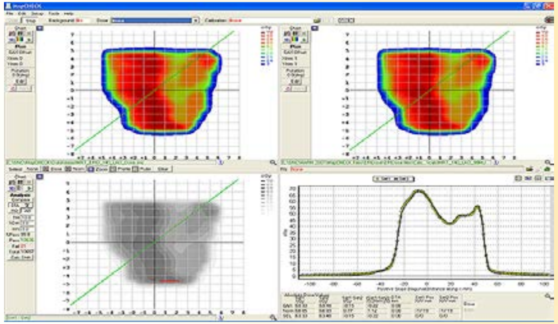
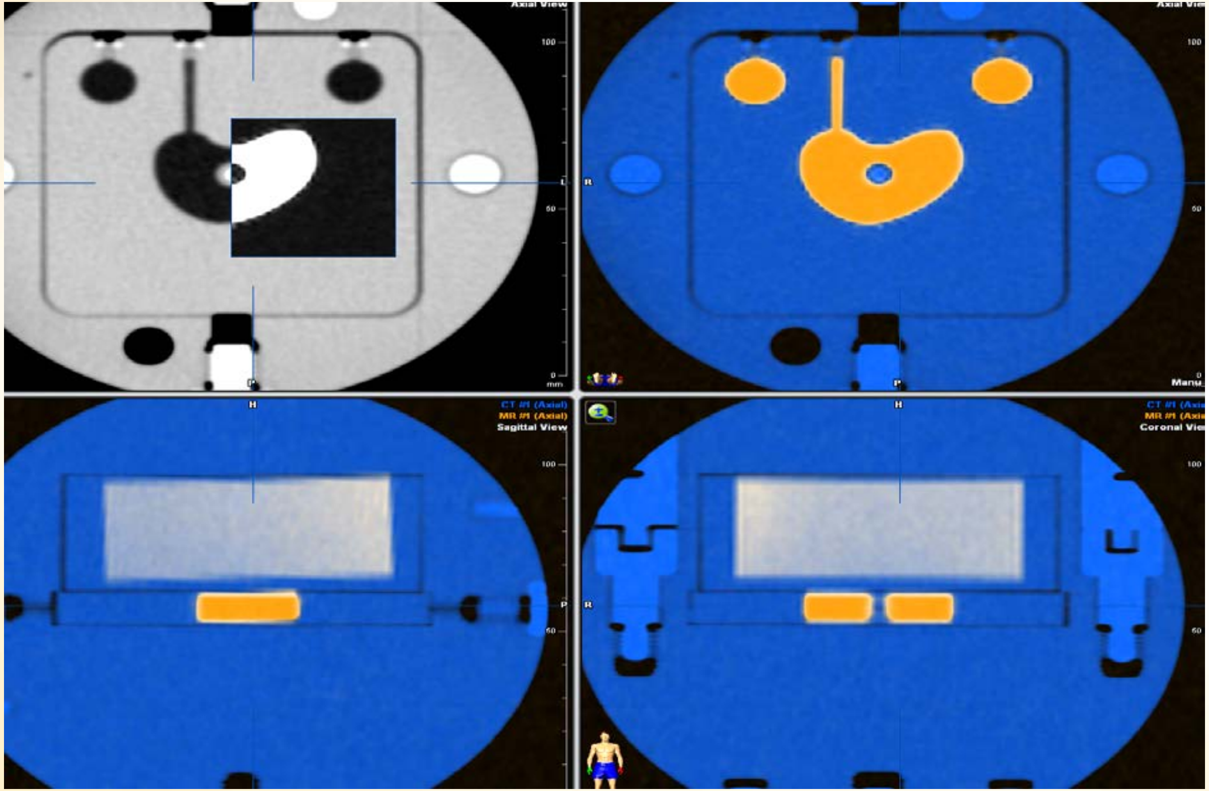


Image Fusion QA: CT/MR



Results:

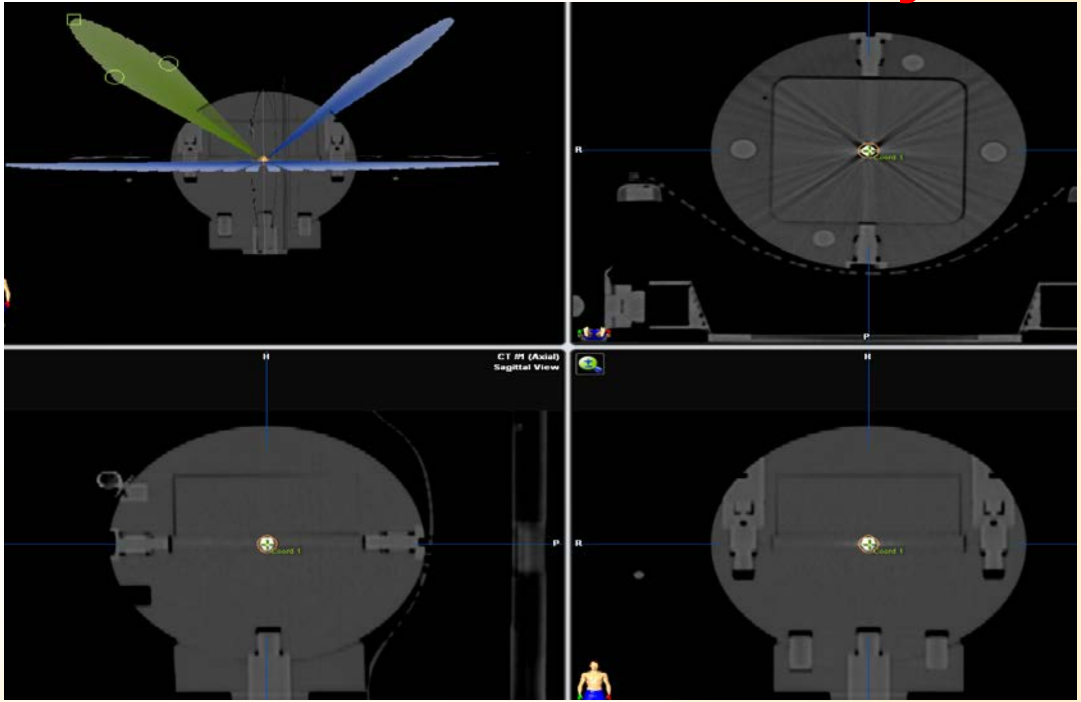
CT/CT :
0.48 ± 0.07 mm

CT/MR :
1.09 ± 0.65 mm

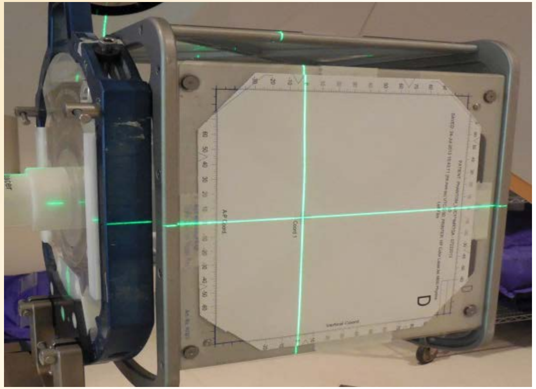
Process QA: Hidden Target Test

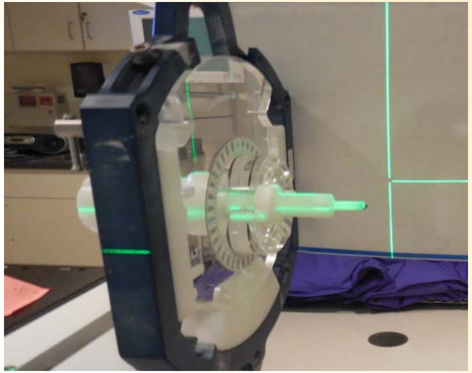
LOYOLA UNIVERSITY HEALTH SYSTEM

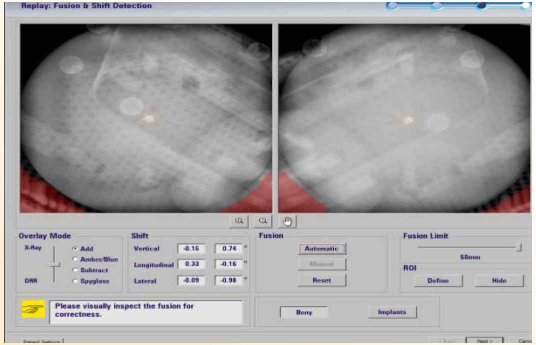
Scan, Plan, Treat, and Verify!

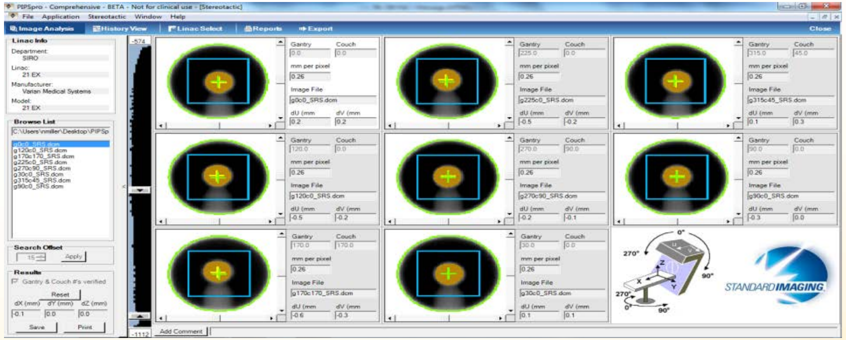


HTT for SRS/SBRT









Results

Position: 1.14 mm

Dose: < 2%

SAM_Q3

Good practice recommendation to ensure accuracy of small field output factors measured in your clinic is to use

A. One Ion Chamber
B. Any one ion chamber + one diode
C. Two ion chambers + one diode
D. One ion chamber + two diodes
E. Trust your instincts!

SAM_Q3

Good practice recommendation to ensure accuracy of small field output factors measured in your clinic is to use

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Reference: Das et al, Task Group 106, Med Phys 35, 4186 (2008).

LOYOLA UNIVERSITY HEALTH SYSTEM

Output/PDD/Profile
WL test

Linac

TPS
Modeling

IGRT
QA

TPS

Image

Dose algorithm, calculations

Image quality

Image
Fusion

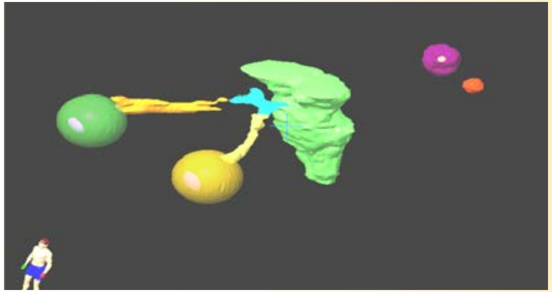
Summary

- Select appropriate set of detectors for small fields
- Ensure positioning and alignment with respect to central axis
- Redundancy of measurements
- Cross check with standard data
- RTP commissioning/verification: for typical treatment fields
- System QA: Imaging/TPS/Linac

SRS Treatment Planning

SRS Rx Dose

- Target Volume, Type, and Location
- SRS Rx dose (RTOG 95-08) max tolerable *vs.* GTV diameter:
  - < 2cm: 24 Gy
  - 2.1 - 3cm: 18 Gy
  - 3.1 - 4cm: 15Gy
- Mets/AVM typically treated with SRS
- Malignant lesions with SRT



SRS Treatment Planning

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- Follow RTOG guidelines (www.rtog.org)
- Use DVHs to get
  - target Rx Dose or D_{min}
- Volume of healthy tissue irradiated
  - Conformality index
- Target dose homogeneity (max/min target dose)
  - homogeneity index
- *SRS dose homogeneity is relaxed in favor of dose Conformality*

SRS Treatment Planning

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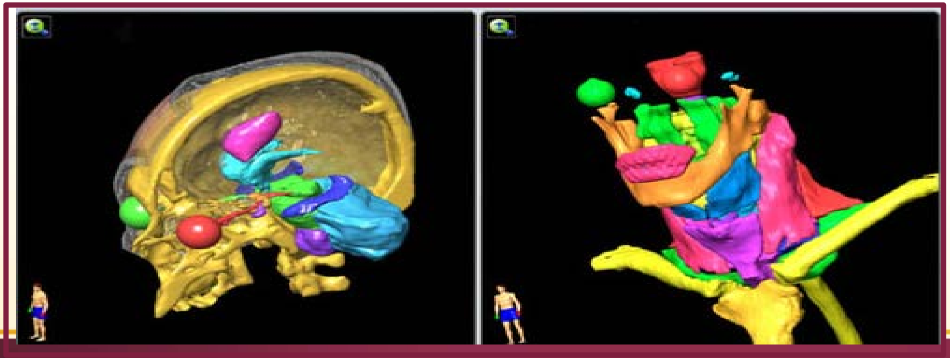
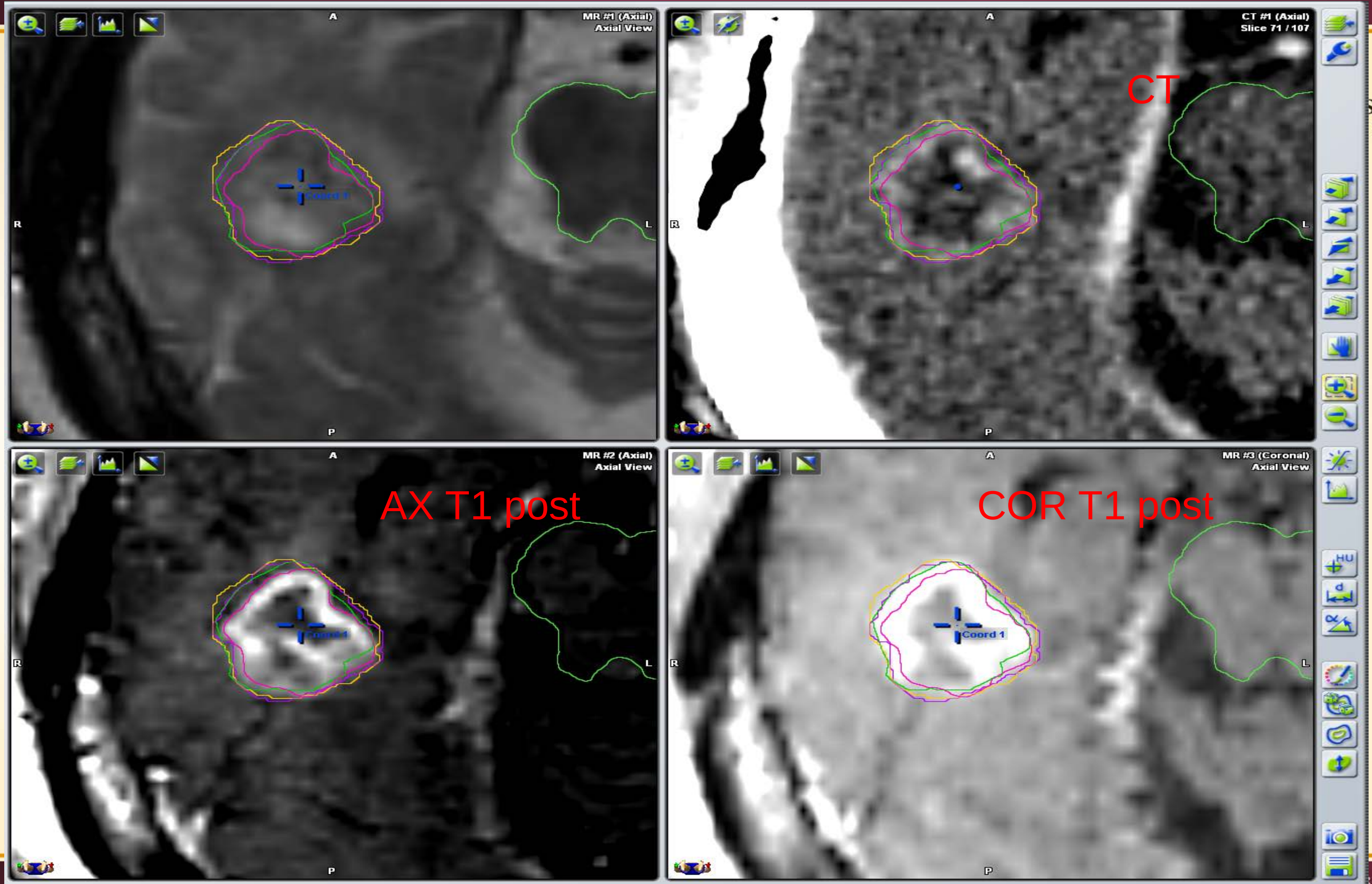
- Draw separate GTVs on CT & MR
  - PTV = GTV (SRS)
  - PTV = GTV + 2mm (SRT)
- Use composite GTV (CT + MR) for planning
- OARs (auto segmentation but verify)





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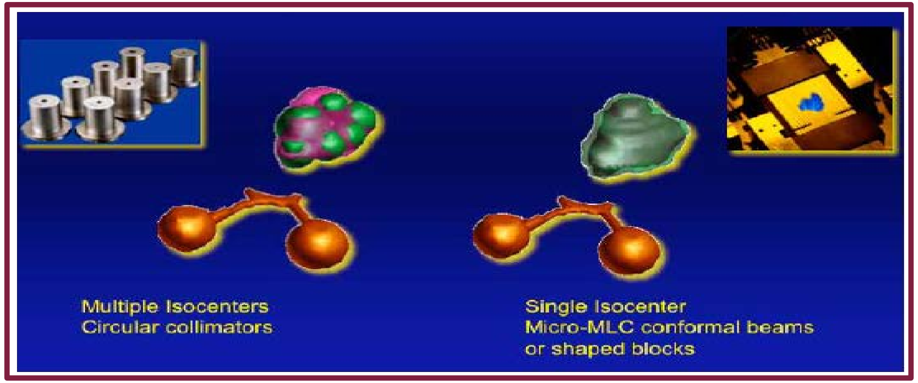
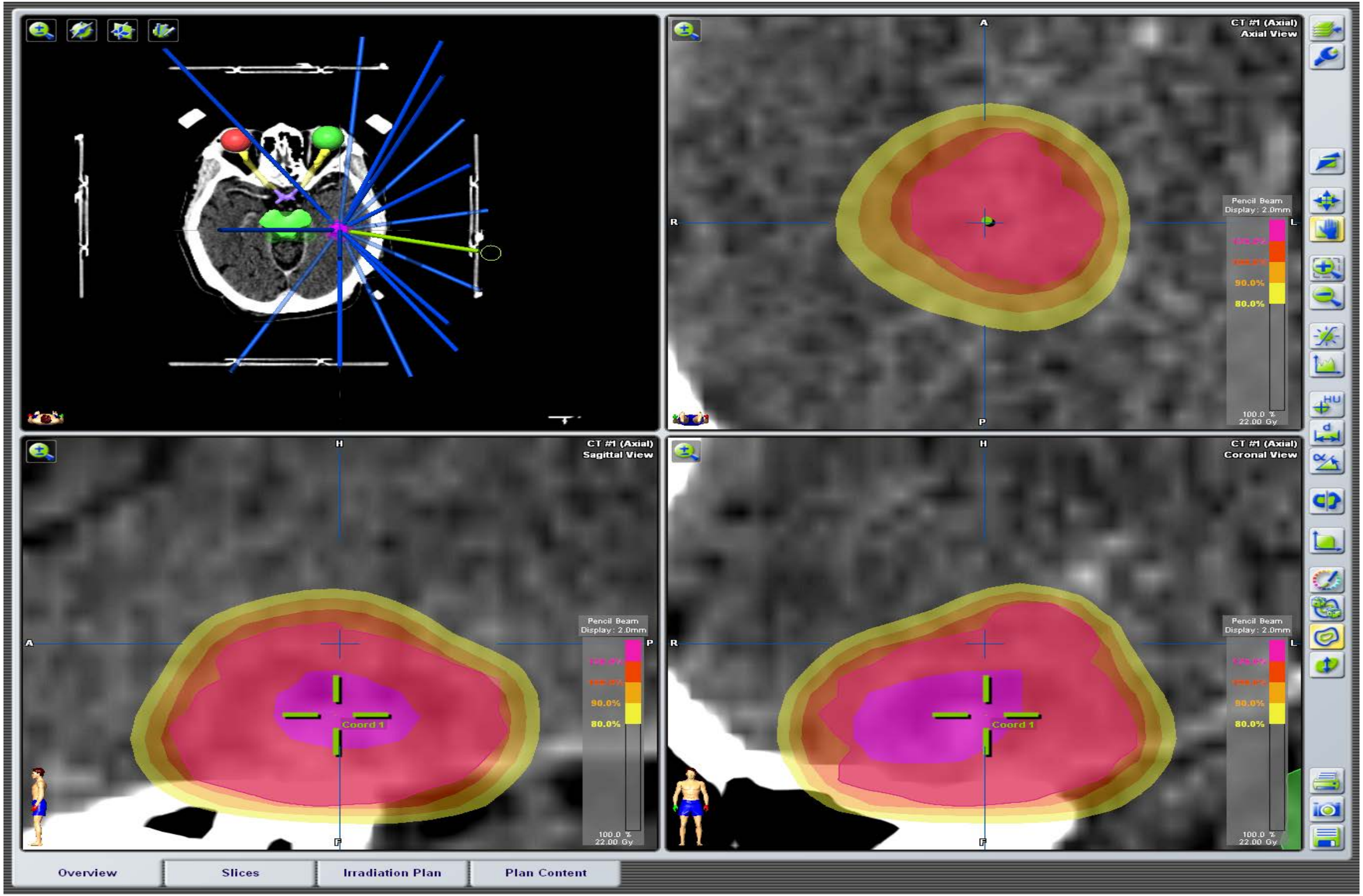
SRS Treatment Planning

- Target size,
- location,
- proximity to OARs
- dose fractionation.
- 3-4 VMAT Arcs
- Can also use conformal fixed fields or circular arcs




CT #1 (Axial)
Axial View
Pencil Beam
Display: 2.0mm
90.0%
80.0%
100.0 %
22.00 Gy
CT #1 (Axial)
Sagittal View
Coord 1
CT #1 (Axial)
Coronal View
Overview
Slices
Irradiation Plan
Plan Content

Dose constraints

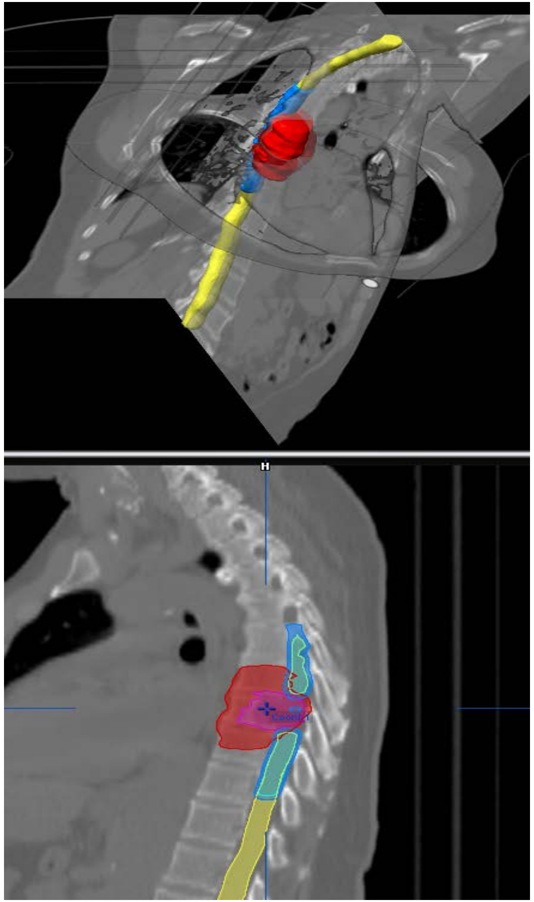
Structure	Dose (Gy)	Endpoint
Optic chiasm	10	Neuritis
Cochlea	12	Hearing loss
Brainstem	15	Cranial neuropathy
Cord	14	Myelitis

Optic, auditory< trigeminal <motor CN

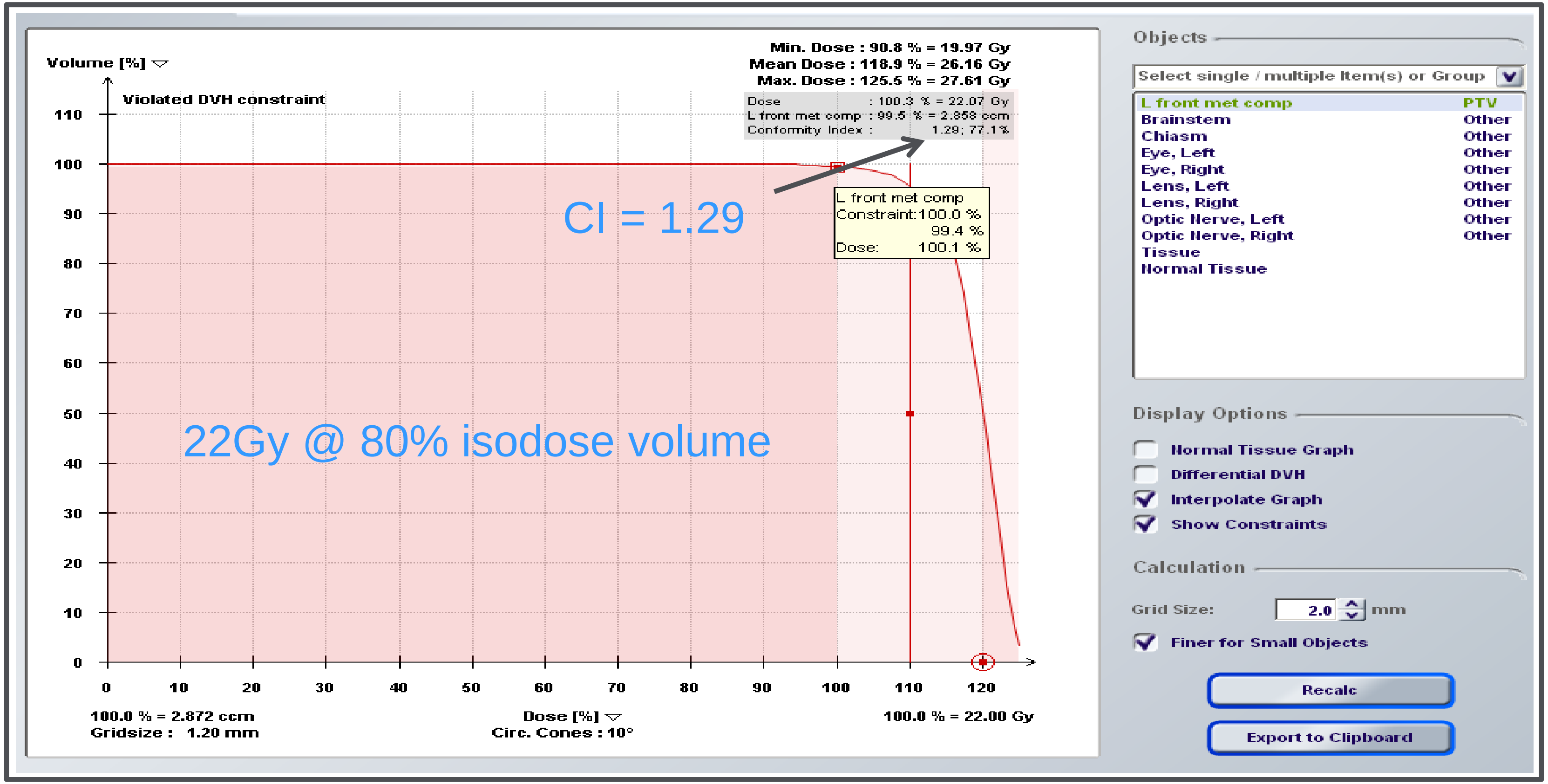
Ref.: QUANTEC (Red J. 2010); Mayo, (Red J. 2009);
SBRT TG101(Med Phys 2010)

SRS Plan Evaluation

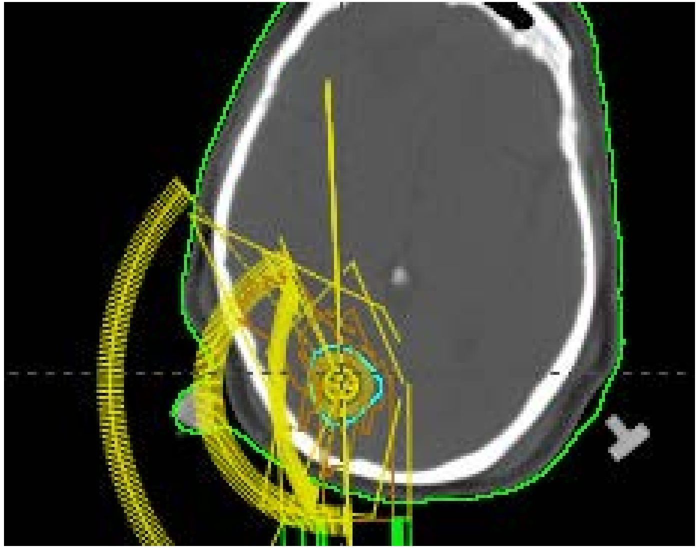
- Draw “Irradiated_OARs” for long structures such as cord, brain stem for accuracy.
- Examine DVHs, Rx Isodose coverage, and OAR sparing
- Conformality index (V100/PTV)
- Homogeneity index (D5/D95)

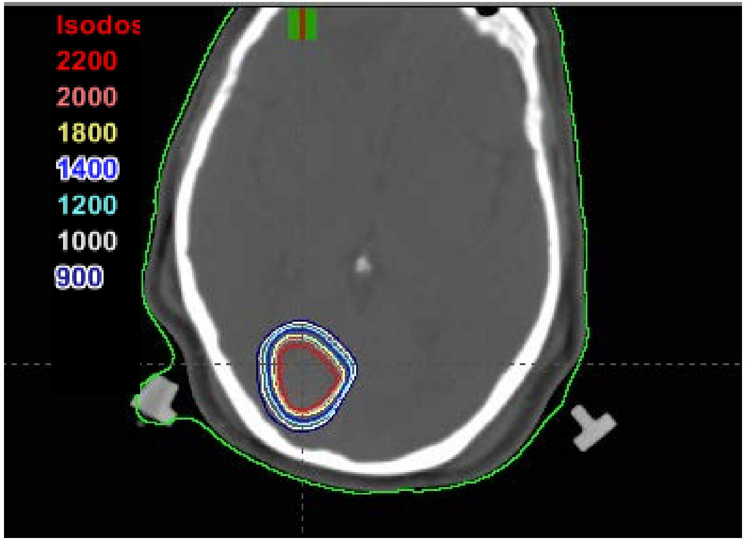


Case 1: Brain Met DVH



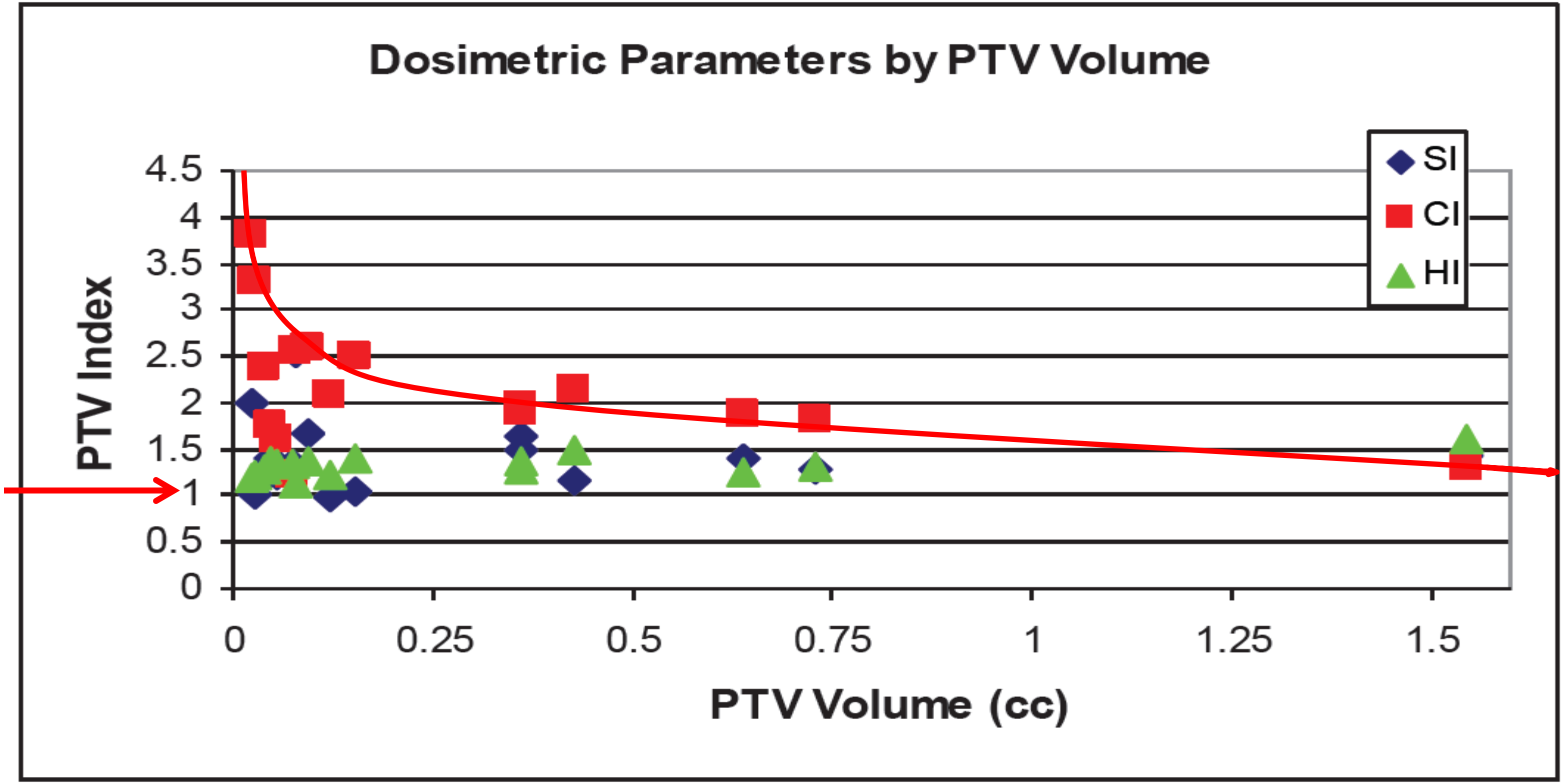
Case 2: Rt Occipital Met





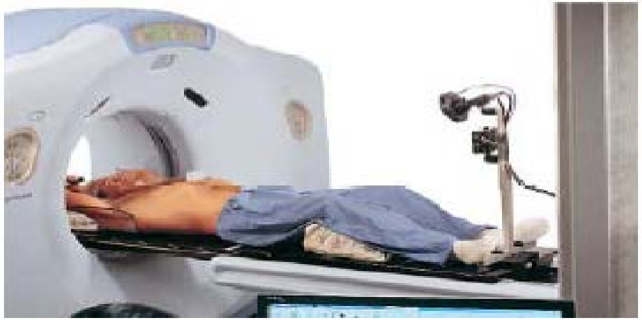
4 VMAT arcs, 4 table angles, 18Gy, single fraction

Tips: Conformity Index *vs.* Target size



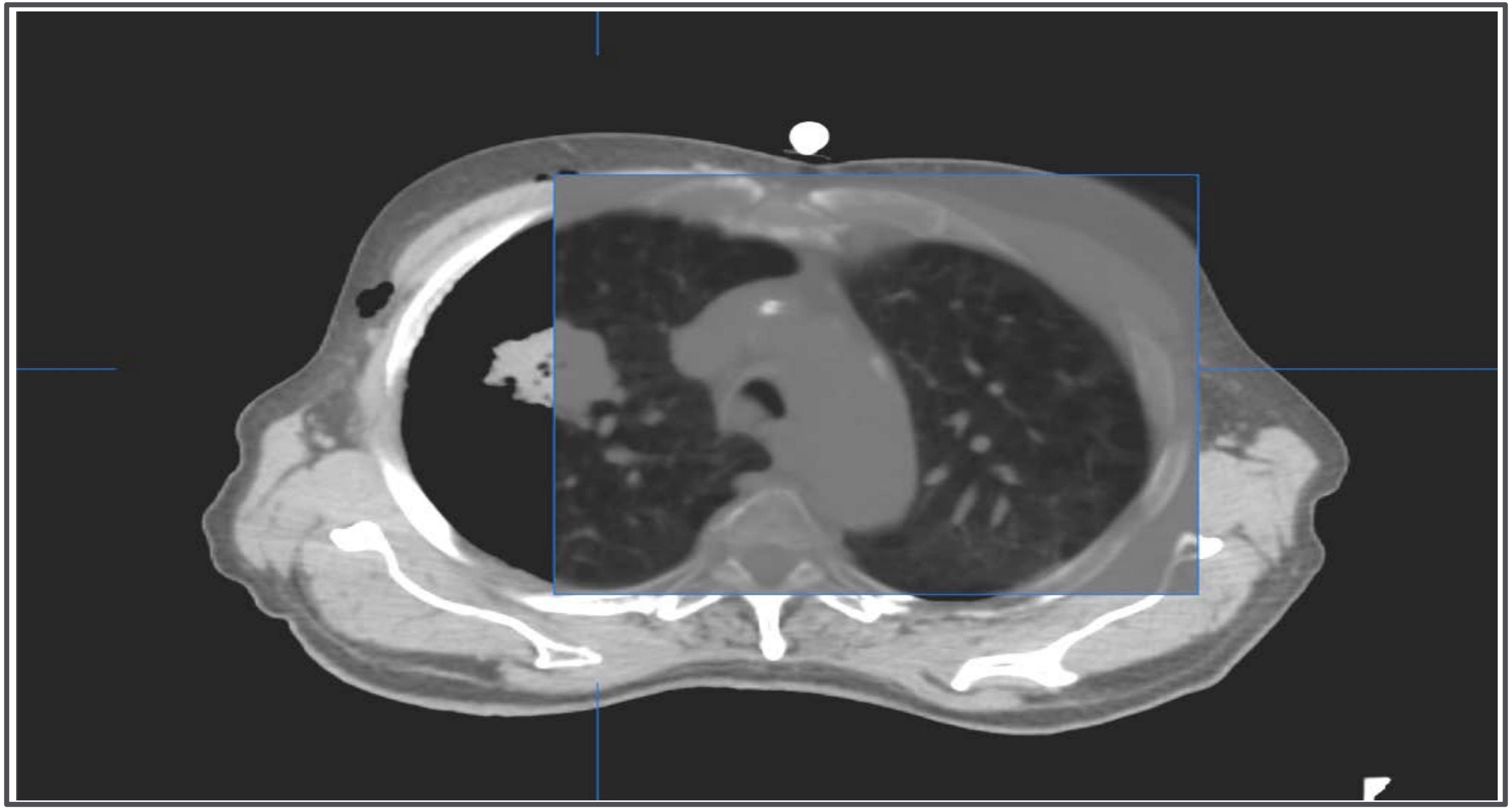
SBRT Planning

4DCT Scanning

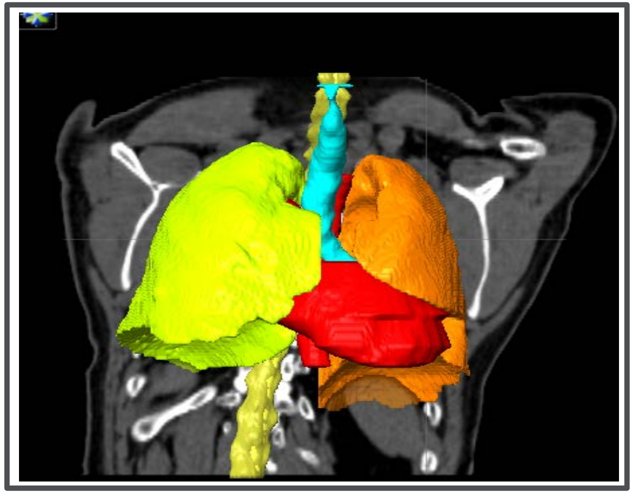


- Free breathing (FB) scan
  - 3x3mm slices
- 4D scan with Varian's RPM
  - ROI: (±5 cm around PTV)
  - 2-3 mm slice width.
- Create MIP (maximum intensity projection) data set.
- Transfer FB images & 4D sets (0%, 50%, MIP & Ave. Int. projection) to TPS

Image Fusion

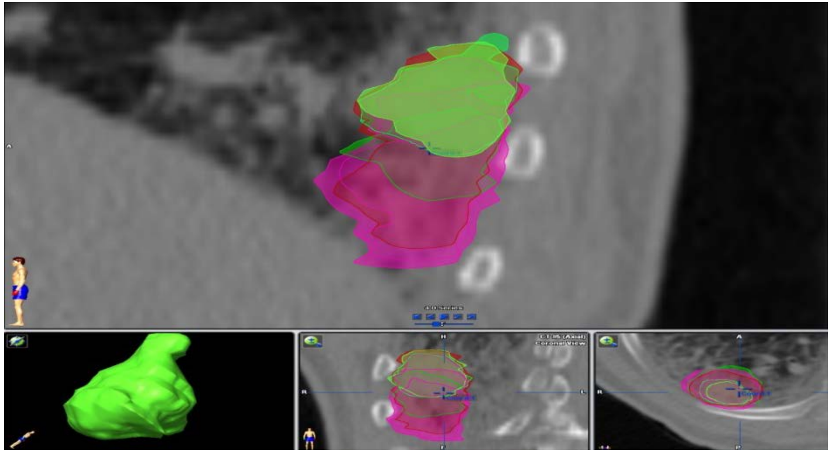


SBRT OARs



- Rt + Lt lung (pulmonary window)
- Heart, Trachea, Carina
- Esophagus_irrad. (± 3cm sup/inf around PTV)
- Spinal cord_irrad. (± 3cm sup/inf around PTV)
- Liver, kidneys, Small bowel, Pancreas
- **Do not include GTV/PTV in lung definition*

SBRT Targets



- GTV on FB, 0%, 50% CT sets; ITV on MIP
- PTV = ITV + 3 - 5mm
- Create D2cm = PTV + 2cm (high dose spillage)

SBRT Dose Rx.

Loyola:

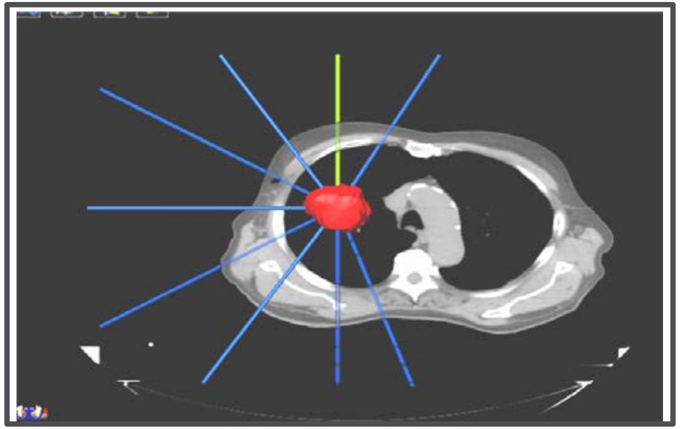
- For lung patients:

  10 - 12Gy/fx x 5 fractions = 50-60Gy

  BED ~ 100-150 Gy

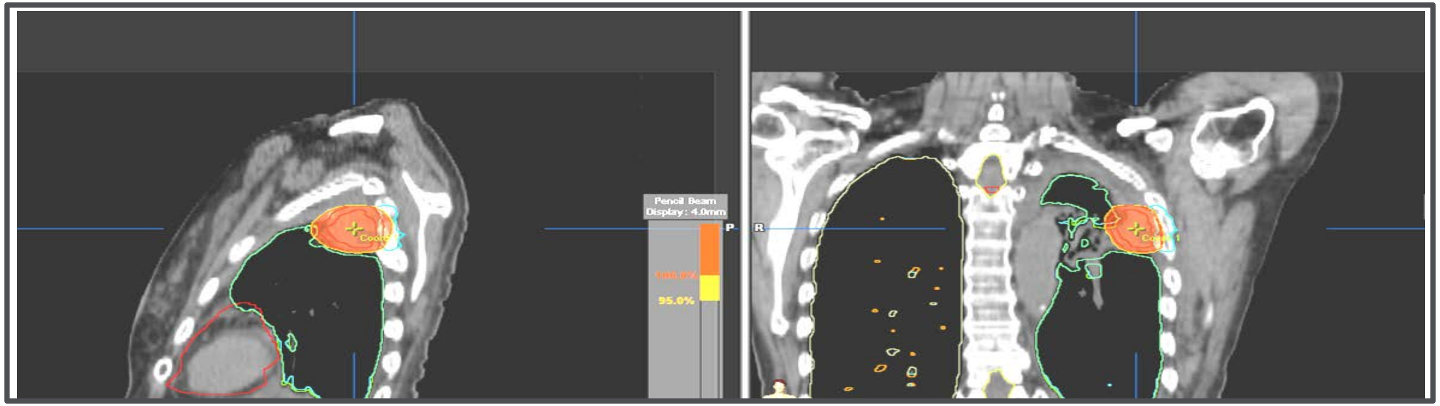
  M-W-F treatments

SBRT Treatment Planning



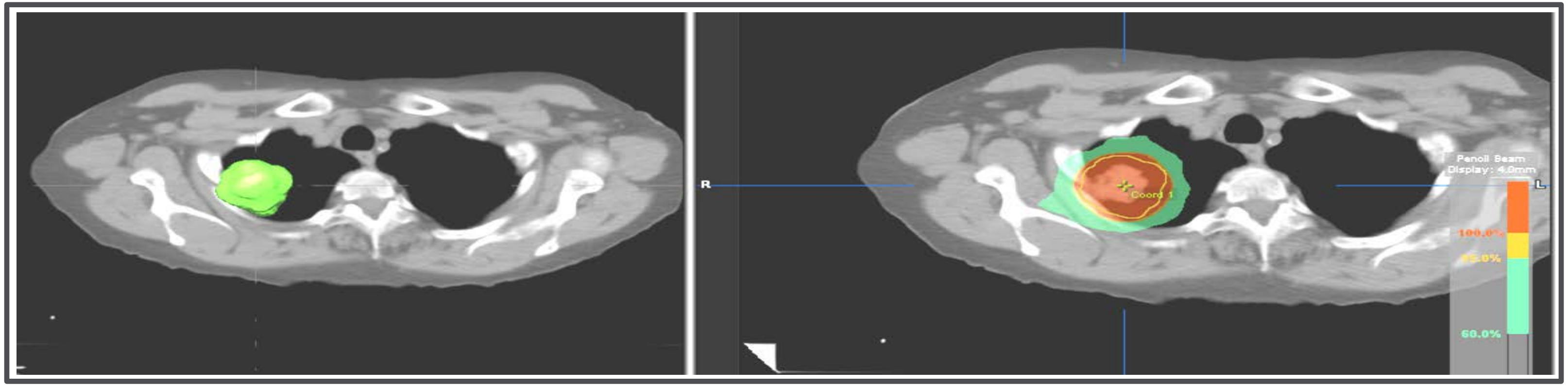
- 6 – 10 MV X-rays,
- VMAT: 3 – 4 VMAT non-coplanar arcs or
- 3DCRT: 8 – 12 non-coplanar, non-opposing fields.

SBRT Plan Evaluation



- Target Coverage: 95% of PTV and 100% of GTV
- Hot spot must be less than ~10-15% & within PTV.
- Target Dose Homogeneity : < 15-20%
- Dose spillage: V50/PTV (see RTOG table)

SBRT Plan Evaluation



- Dose Conformality: V100/PTV = 1.2 - 1.5 (higher values for smaller targets)
- Tighten up PTV - MLC margin or adjust beam parameters to achieve better Conformality index (CI).
- Ensure small calc. grid (1mm) for small structures.

SBRT Plan Evaluation

Table 1: Conformality of Prescribed Dose for Calculations Based on Deposition of Photon Beam Energy in Heterogeneous Tissue

PTV Volume (cc)	Ratio of Prescription Isodose Volume to the PTV Volume		Ratio of 50% Prescription Isodose Volume to the PTV Volume, $R_{50\%}$		Maximum Dose (in % of dose prescribed) @ 2 cm from PTV in Any Direction, D_{2cm} (Gy)		Percent of Lung Receiving 20 Gy Total or More, V_{20} (%)	
	Deviation		Deviation		Deviation		Deviation	
	None	Minor	None	Minor	None	Minor	None	Minor
1.8	<1.2	<1.5	<5.9	<7.5	<50.0	<57.0	<10	<15
3.8	<1.2	.<1.5	<5.5	<6.5	<50.0	<57.0	<10	<15
7.4	<1.2	<1.5	<5.1	<6.0	<50.0	<58.0	<10	<15
13.2	<1.2	<1.5	<4.7	<5.8	<50.0	<58.0	<10	<15
22.0	<1.2	<1.5	<4.5	<5.5	<54.0	<63.0	<10	<15
34.0	<1.2	<1.5	<4.3	<5.3	<58.0	<68.0	<10	<15
50.0	<1.2	<1.5	<4.0	<5.0	<62.0	<77.0	<10	<15
70.0	<1.2	<1.5	<3.5	<4.8	<66.0	<86.0	<10	<15
95.0	<1.2	<1.5	<3.3	<4.4	<70.0	<89.0	<10	<15
126.0	<1.2	<1.5	<3.1	<4.0	<73.0	>91.0	<10	<15
163.0	<1.2	<1.5	<2.9	<3.7	<77.0	>94.0	<10	<15

From: RTOG 0813 / 0915 / 0236

OAR Dose Constraints

Serial Tissue	Volume (mL)	Volume Max (Gy)	Max Point Dose (Gy)	Endpoint (≥Grade 3)
FIVE-FRACTION TREATMENT				
Optic pathway	<0.2	20 (4 Gy/fx)	25 (5 Gy/fx)	Neuritis
Cochlea			27.5 (5.5 Gy/fx)	Hearing loss
Brainstem	<1	26 (5.2 Gy/fx)	31 (6.2 Gy/fx)	Cranial neuropathy
Spinal cord	<0.25	22.5 (4.5 Gy/fx)	30 (6 Gy/fx)	Myelitis
	<1.2	13.5 (2.7 Gy/fx)		
Cauda equina	<5	30 (6 Gy/fx)	34 (6.4 Gy/fx)	Neuritis
Sacral plexus	<3	30 (6 Gy/fx)	32 (6.4 Gy/fx)	Neuropathy
Esophagus*	<5	27.5 (5.5 Gy/fx)	35 (7 Gy/fx)	Stenosis/fistula
Ipsilateral brachial plexus	<3	30 (6 Gy/fx)	32 (6.4 Gy/fx)	Neuropathy
Heart/pericardium	<15	32 (6.4 Gy/fx)	38 (7.6 Gy/fx)	Pericarditis
Great vessels	<10	47 (9.4 Gy/fx)	53 (10.6 Gy/fx)	Aneurysm
Trachea and ipsilateral bronchus*	<4	18 (3.6 Gy/fx)	38 (7.6 Gy/fx)	Stenosis/fistula
Skin	<10	30 (6 Gy/fx)	32 (6.4 Gy/fx)	Ulceration
Stomach	<10	28 (5.6 Gy/fx)	32 (6.4 Gy/fx)	Ulceration/fistula
Duodenum*	<5	18 (3.6 Gy/fx)	32 (6.4 Gy/fx)	Ulceration
Jejunum/ileum*	<5	19.5 (3.9 Gy/fx)	35 (7 Gy/fx)	enteritis/obstruction
Colon*	<20	25 (5 Gy/fx)	38 (7.6 Gy/fx)	colitis/fistula
Rectum*	<20	25 (5 Gy/fx)	38 (7.6 Gy/fx)	proctitis/fistula
Bladder wall	<15	18.3 (3.65 Gy/fx)	38 (7.6 Gy/fx)	cystitis/fistula
Penile bulb	<3	30 (6 Gy/fx)	50 (10 Gy/fx)	Impotence
Femoral heads (right and left)	<10	30 (6 Gy/fx)		Necrosis
Renal hilum/vascular trunk	<2/3 volume	23 (4.6 Gy/fx)		Malignant hypertension

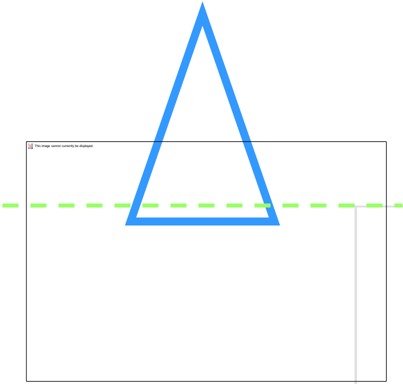
Parallel Tissue	Critical Volume (mL)	Critical Volume Dose Max (Gy)	Endpoint (≥Grade 3)
Lung (right and left)	1,500	12.5 (2.5 Gy/fx)	Basic lung function
Lung (right and left)	1000	13.5 (2.7 Gy/fx)	Pneumonitis
Liver	700	21 (4.2 Gy/fx)	Basic liver function
Renal cortex (right and left)	200	17.5 (3.5 Gy/fx)	Basic renal function

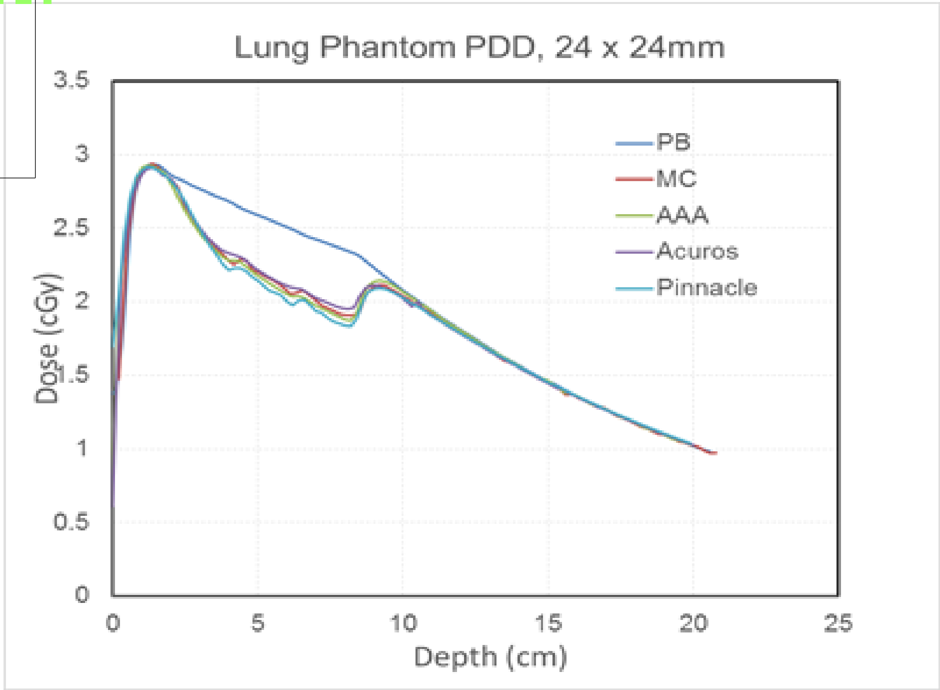
*Avoid circumferential irradiation.

Ref: QUANTEC; RTOG

Dose Calculation Algorithms :
Impact on Txt. Planning and Validation

Depth dose, 6 MV





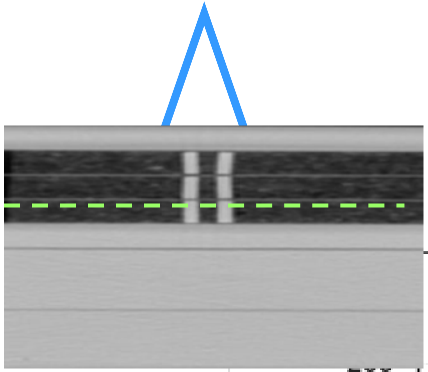
Problems with algorithms that do not model electron transport.

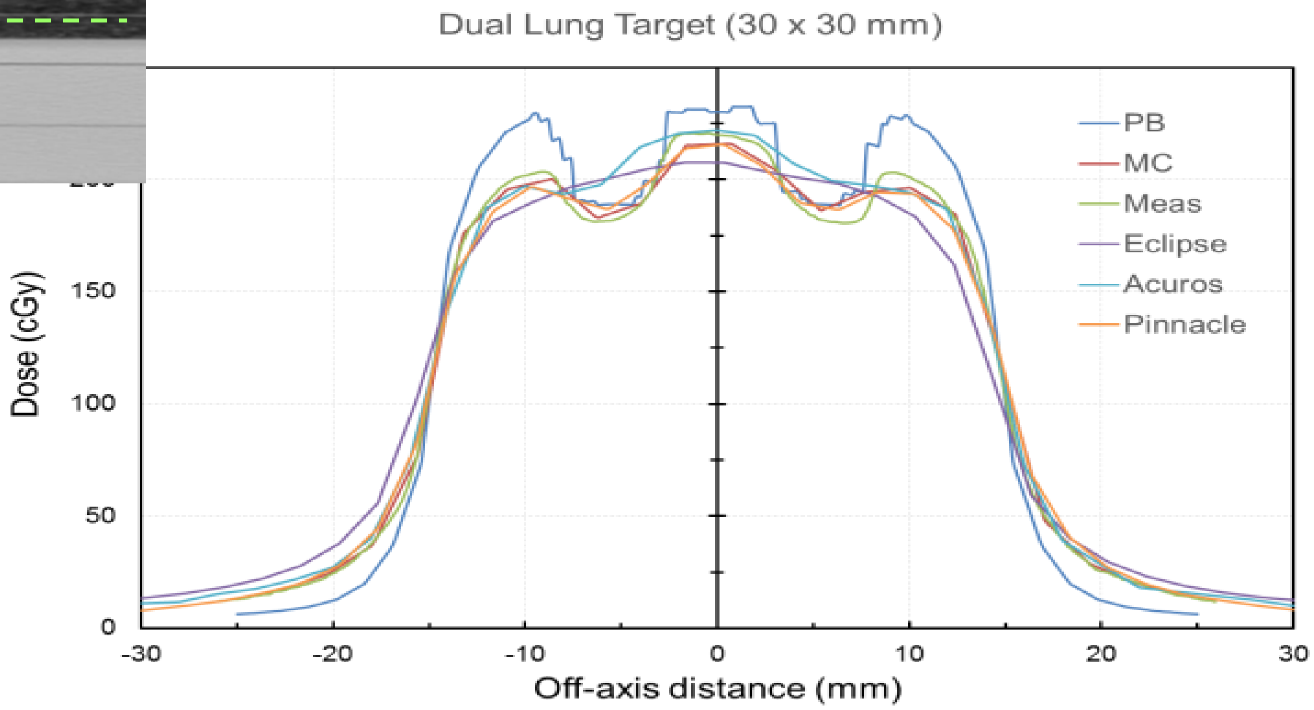
Electronic equilibrium? No problem.

Better agreement between Pinnacle CC and Monte Carlo than between Eclipse AAA and Monte Carlo.

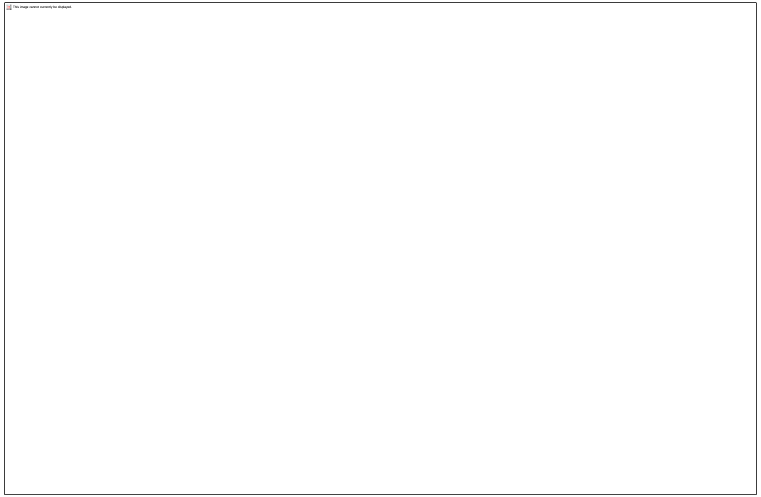
Chopra et al.

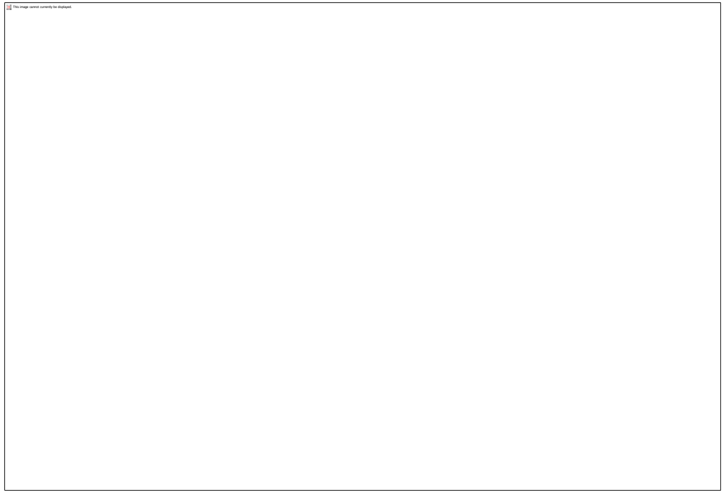
Dual Lung Phantom





Challenging Cases - 1

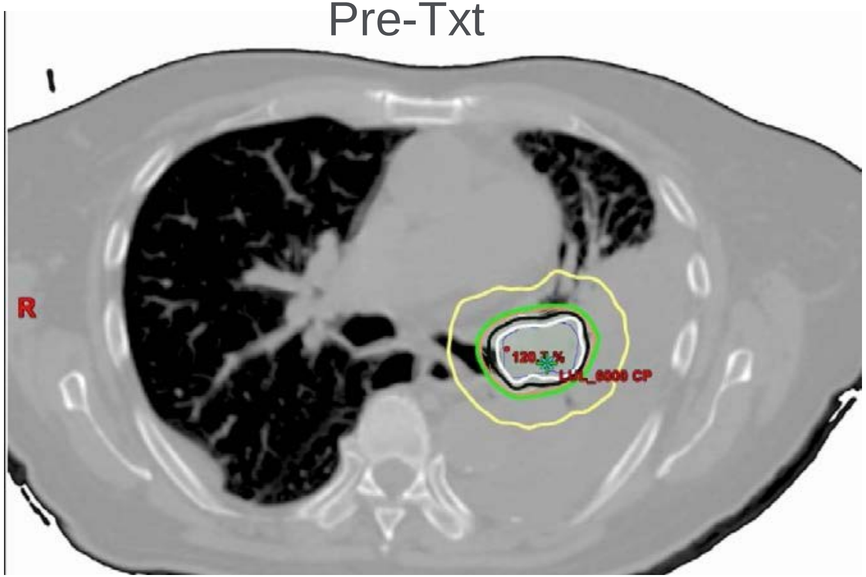




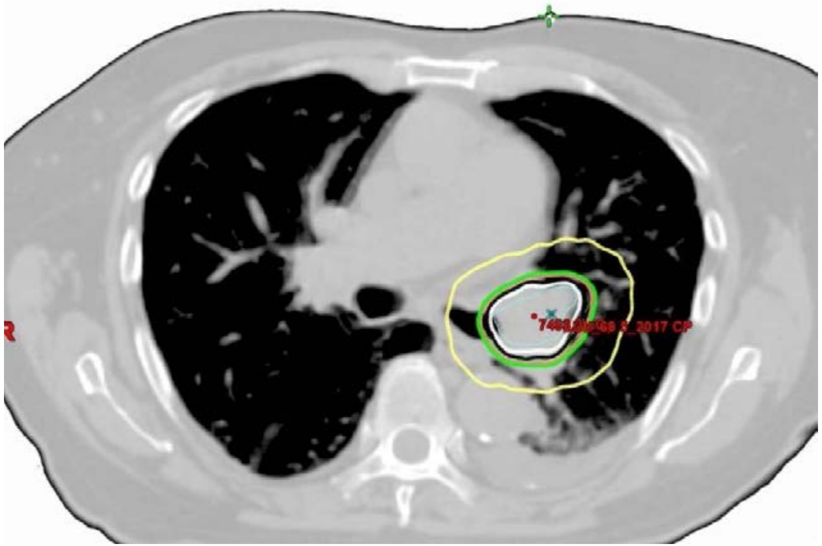
Patient had 3D treatment for lung target 2 years ago and recurred.
Prev Cord dose = 49 Gy, deliver minimum dose to cord
Beam arranged to not enter thru cord, exit only
Cord as OAR in optimization

Challenging Case - 2

Pre-Txt

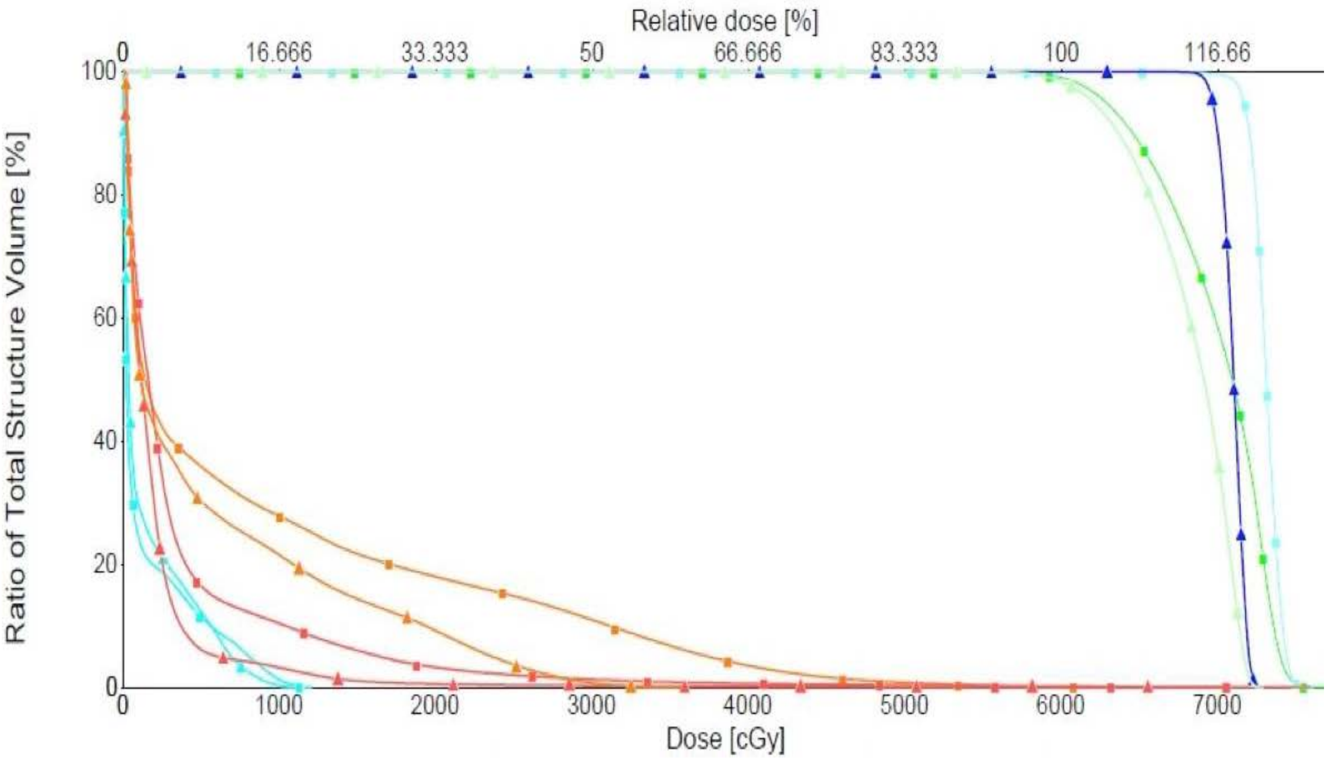


After 3-fxs

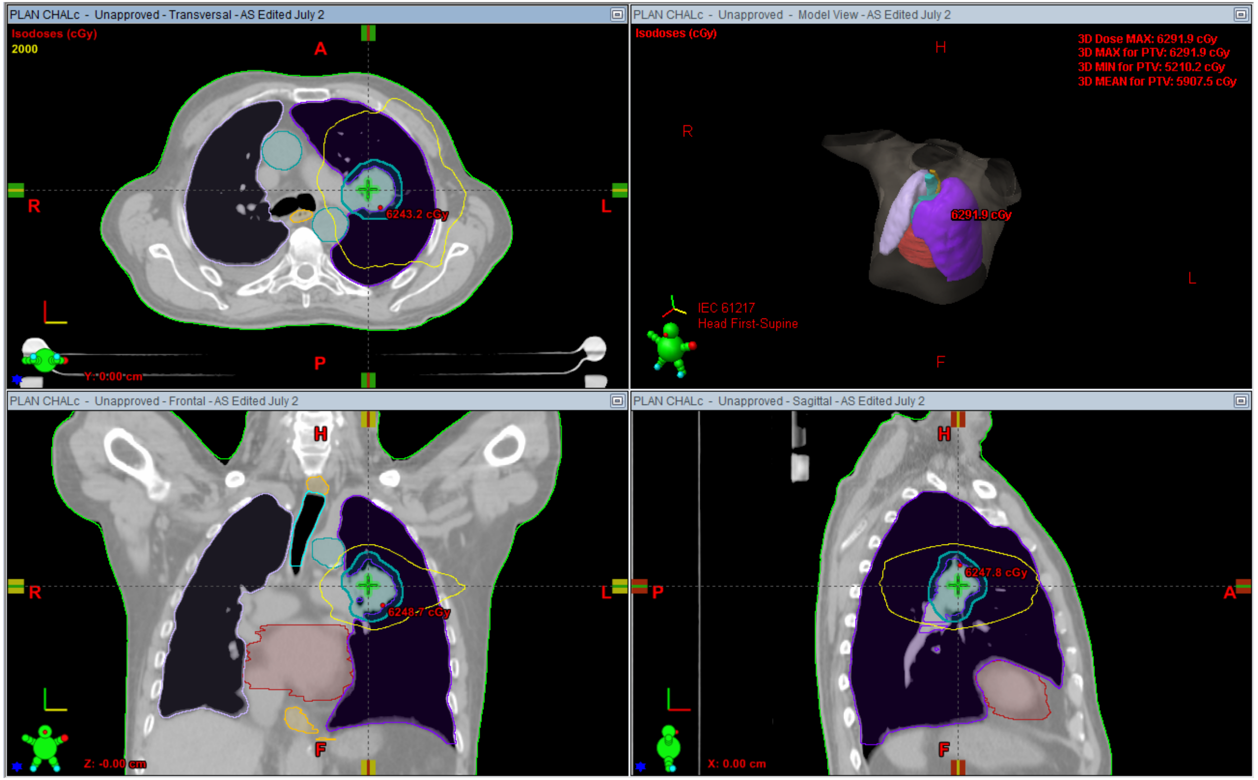


- Patient with LUL lesion. Significant left lung obstruction.
- Opened up after three fx. Re-planning required. Significant (~10%) change in PTV dose.
- Will impact MU validation as well as 2nd check are insensitive to density corrections.

Challenging Case - 2



Future Directions



PTV Rx:

55Gy in 5 fx

ProKnow

Scoring powered by PlanIQ™
Sun Nuclear Corporation

METRIC	RESULT	MIN REQ			IDEAL	POINTS	WEIGHT
Dose (Gy) covering 98 (%) of the PTV	54.534	52.25 ✓	0p 52.25	21p 55	55	17.44	21.00
Dose (Gy) covering whole PTV minus 0.03 (cc)	51.591	49.5 ✓	5p 49.5	10p 55	55	6.90	10.00
Conformation Number [52.25 (Gy), PTV]	0.859	0.75 ✓	0p 0.75	12p 0.95	0.95	6.54	12.00
Conformality Index [27.5 (Gy), PTV]	3.929	5 ✓	0p 5	12p 4	4 ✓	12.00	12.00
Homogeneity Index [55 (Gy), PTV]	0.147	---	---		---	---	---
Minimum dose (Gy) to the ITV	56.856	52.25 ✓	0p 52.25	10p 55	55 ✓	10.00	10.00
Structure(s) containing the global max dose point	(3 values)	PTV ✓			ITV ✓	10.00	10.00
Volume (cc) of the HEART covered by 10 (Gy)	0.416	10 ✓	0p 10	5p 0	0	4.79	5.00
Dose (Gy) covering 0.03 (cc) of the PRVSPINALCANAL	9.071	20 ✓	0p 20	5p 7.5	7.5	4.37	5.00
Dose (Gy) covering 0.03 (cc) of the TRACHEA	8.245	40 ✓	0p 40	5p 10	10 ✓	5.00	5.00
Volume (%) of the LUNG_MINUS_ITV covered by 20 (Gy)	11.366	15 ✓	5p 15	10p 5	5	6.82	10.00
Volume (%) of the LUNG_MINUS_ITV covered by 5 (Gy)	23.988	30 ✓	3.5p 30	7p 10	10	4.55	7.00
Mean dose (Gy) to the LUNG_MINUS_ITV	6.288	10 ✓	0p 10	5p 5	5	3.71	5.00
Volume (%) of the RLUNG covered by 5 (Gy)	1.409	30 ✓	0p 30	5p 0	0	4.77	5.00
Volume (cc) of the THORACICWALL covered by 30 (Gy)	0.000	10 ✓	0p 10	5p 0	0 ✓	5.00	5.00
Dose (Gy) covering 4 (cc) of the ESOPHAGUS	8.874	32.5 ✓	0p 32.5	5p 10	10 ✓	5.00	5.00
Dose (Gy) covering 0.03 (cc) of the ESOPHAGUS	12.320	40 ✓	0p 40	5p 10	10	4.61	5.00
Dose (Gy) covering 0.03 (cc) of the VESSELS	51.993	57.75 ✓	0p 57.75	5p 50	50	3.71	5.00
Dose (Gy) covering 4 (cc) of the PBT	26.655	50 ✓	0p 50	5p 20	20	3.89	5.00
Dose (Gy) covering 1.5 (cc) of the PBT	43.208	55 ✓	0p 55	5p 40	40	3.93	5.00
Dose (Gy) covering 0.03 (cc) of the SKIN	16.462	30 ✓	1.5p 30	3p 10	10	2.52	3.00

Stereotactic body radiation therapy: The report of AAPM Task Group 101

Stanley H. Benedict, Chairman[a)]
University of Virginia Health System, Charlottesville, Virginia 22908

Accelerator beam data commissioning equipment and procedures: Report of the TG-106 of the Therapy Physics Committee of the AAPM

Indra J. Das[a)]
Department of Radiation Oncology, University of Pennsylvania, Philadelphia, Pennsylvania 19104

Quality and safety considerations in stereotactic radiosurgery and stereotactic body radiation therapy: Executive summary

Timothy D. Solberg PhD [a,*], James M. Balter PhD [b], Stanley H. Benedict PhD [c], Benedick A. Fraass PhD [d], Brian Kavanagh MD [e], Curtis Miyamoto MD [f], Todd Pawlicki PhD [g], Louis Potters MD [h], Yoshiya Yamada MD [i]

AAPM-RSS Medical Physics Practice Guideline 9.a. for SRS-SBRT

Per H. Halvorsen[1] | Eileen Cirino[1] | Indra J. Das[2] | Jeffrey A. Garrett[3] | Jun Yang[4] | Fang-Fang Yin[5] | Lynne A. Fairobent[6]

REFERENCES:

RTOG 0813

SEAMLESS PHASE I/II STUDY OF STEREOTACTIC LUNG RADIOTHERAPY (SBRT) FOR EARLY STAGE, CENTRALLY LOCATED, NON-SMALL CELL LUNG CANCER (NSCLC) IN MEDICALLY INOPERABLE PATIENTS

RTOG 0915
(NCCTG N0927)

A RANDOMIZED PHASE II STUDY COMPARING 2 STEREOTACTIC BODY RADIATION THERAPY (SBRT) SCHEDULES FOR MEDICALLY INOPERABLE PATIENTS WITH STAGE I PERIPHERAL NON-SMALL CELL LUNG CANCER

RTOG 0236

A Phase II Trial of Stereotactic Body Radiation Therapy (SBRT) in the Treatment of Patients with Medically Inoperable Stage I/II Non-Small Cell Lung Cancer

Summary

- Ensure adequate resources are available for:
  - Imaging,
  - Txt Planning and
  - Delivery
- Acceptance Testing/Commissioning
- Robust System QA (End-to-End Test)
- IMRT/VMAT QA

Summary

- Checklists + Independent MU calc
- Follow RTOG Guidelines
- Establish site specific protocols consistent with departmental resources
- Automate Planning and Evaluation methods for efficient and consistent planning
- Follow AAPM/ASTRO/RTOG guidelines

SAM_Q4

For lung SBRT of small targets, independent checks of TPS calculated monitor units (MUs)

A. Should never be done because they never agree with TPS
B. Will always produce same MUs as TPS because both account for heterogeneity corrections
C. Will produce lower MUs than TPS because independent calculations fail to account for reduced scatter conditions in TPS
D. Will produce higher MUs because scatter is missing in independent calculations
E. Will produce higher MUs because independent calculations are 2D and TPS is 3D.

SAM_Q4

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E. Will produce higher MUs because independent calculations are 2D and TPS is 3D.

Reference: Benedict et al, Task Group 101, Med Phys 37, 4078 (2010)

SAM_Q5

According to RTOG 0813 guidelines, the ratio of 50% isodose volume to planning target volume (PTV) should ______________ with increasing PTV size

A. Increase
B. Decrease
C. Stay the same

SAM_Q5

According to RTOG 0813 guidelines, the ratio of 50% isodose volume to planning target volume (PTV) should ____________ with increasing PTV size

A. Increase
B. Decrease
C. Stay the same

Reference: RTOG- 0813 - Seamless Phase I/II Study of Stereotactic Lung Radiotherapy (SBRT) for Early Stage, Centrally Located, Non-Small Cell Lung Cancer (NSCLC) in Medically Inoperable Patients

Thank you!