Measurement Considerations in an MR-guided Radiation Therapy Environment

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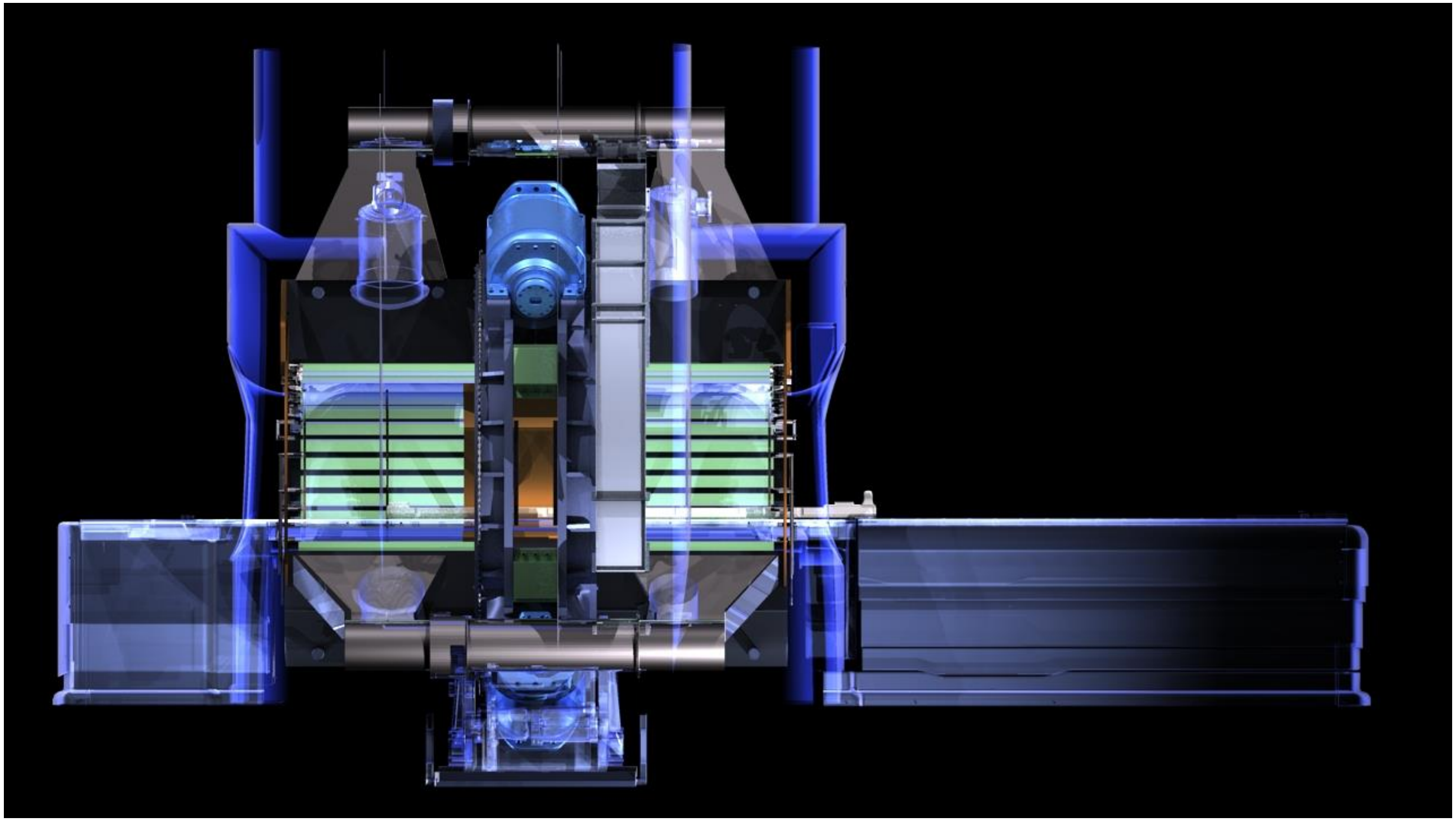
University of Wisconsin - Madison

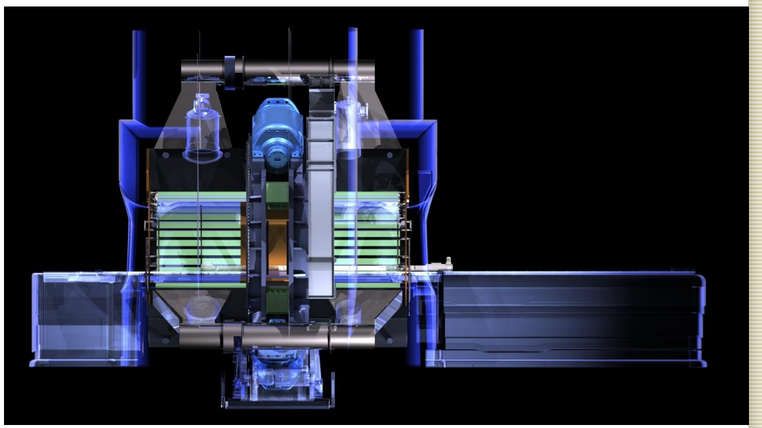
Disclosures

- Member of ViewRay Scientific Advisory Board



System Specifications - Imaging

- Superconducting split-bore magnet
- 28 cm central gap - **0.35 T**
- Geometric Accuracy: 1 mm < 20 cm / 2 mm < 35 cm diameter sphere
- 3D volumetric acquisitions (35x35x35 cm) with an SNR > 30 (23 sec)
- Cine planar acquisitions every 250

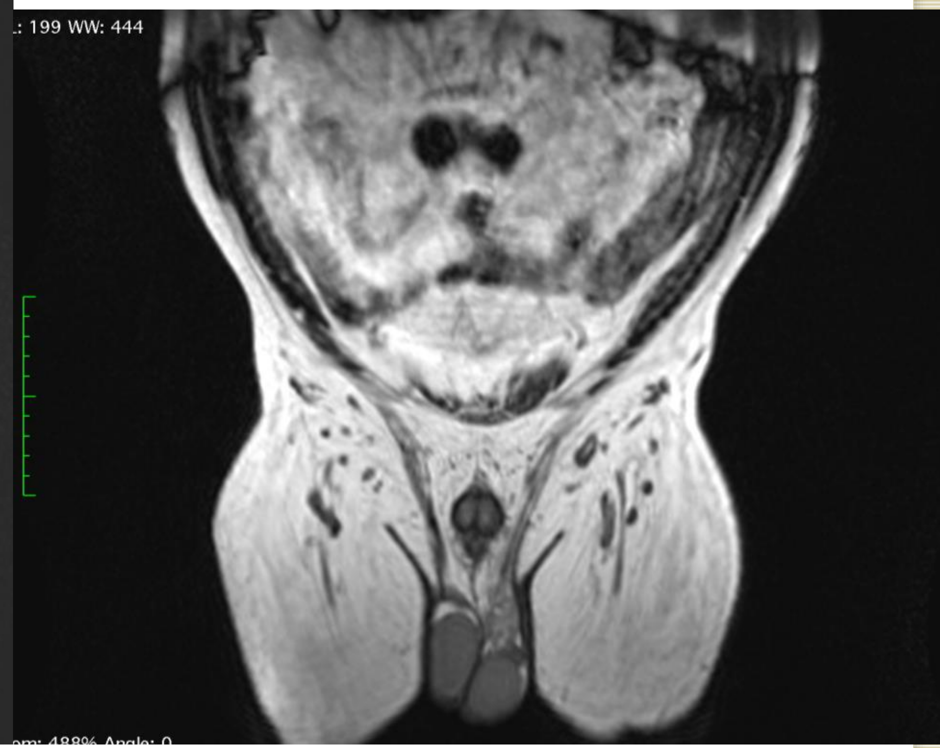


Can we really see anything at 0.35T?

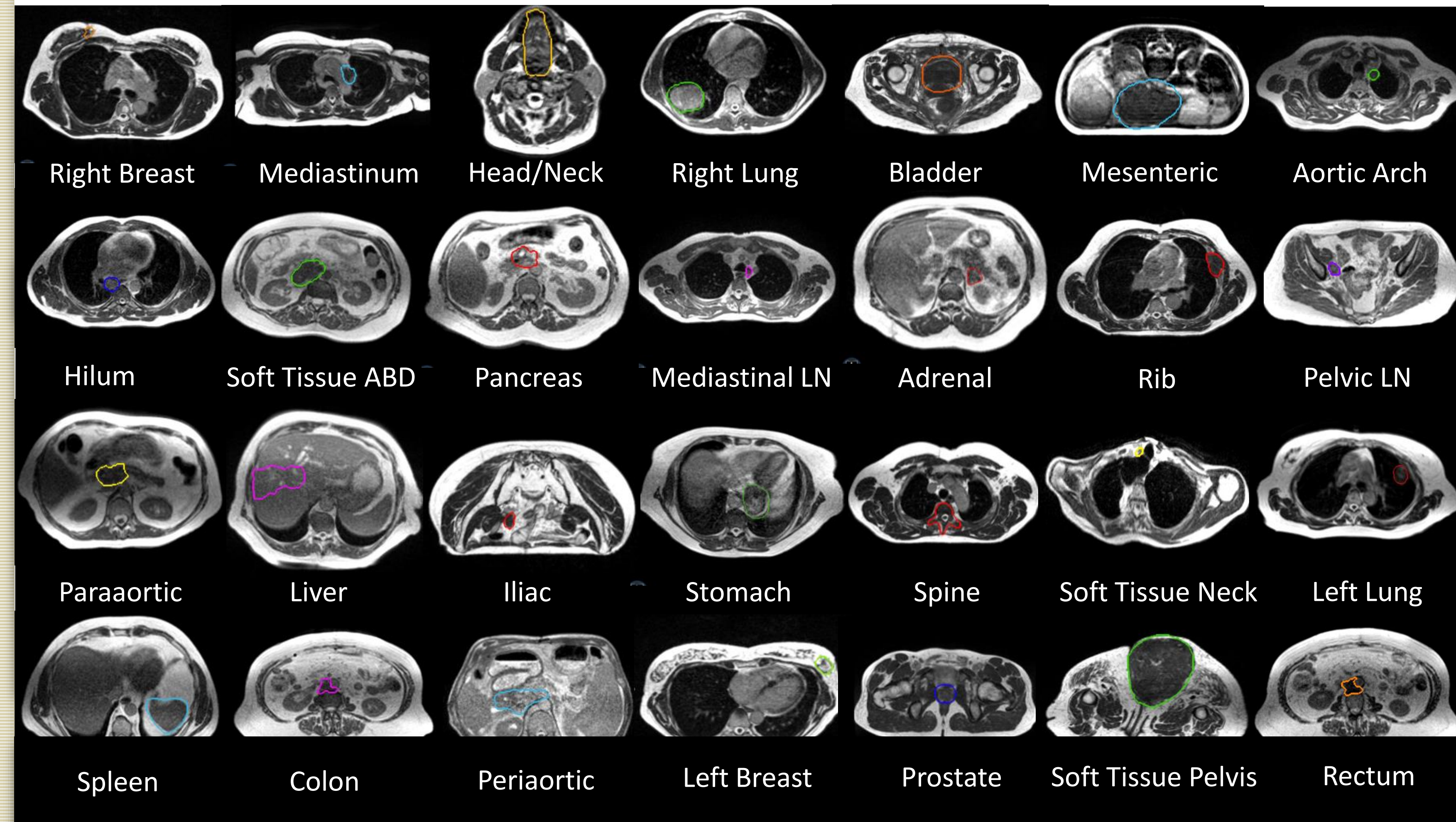
iPhone. Jobs, et al.

Image Quality

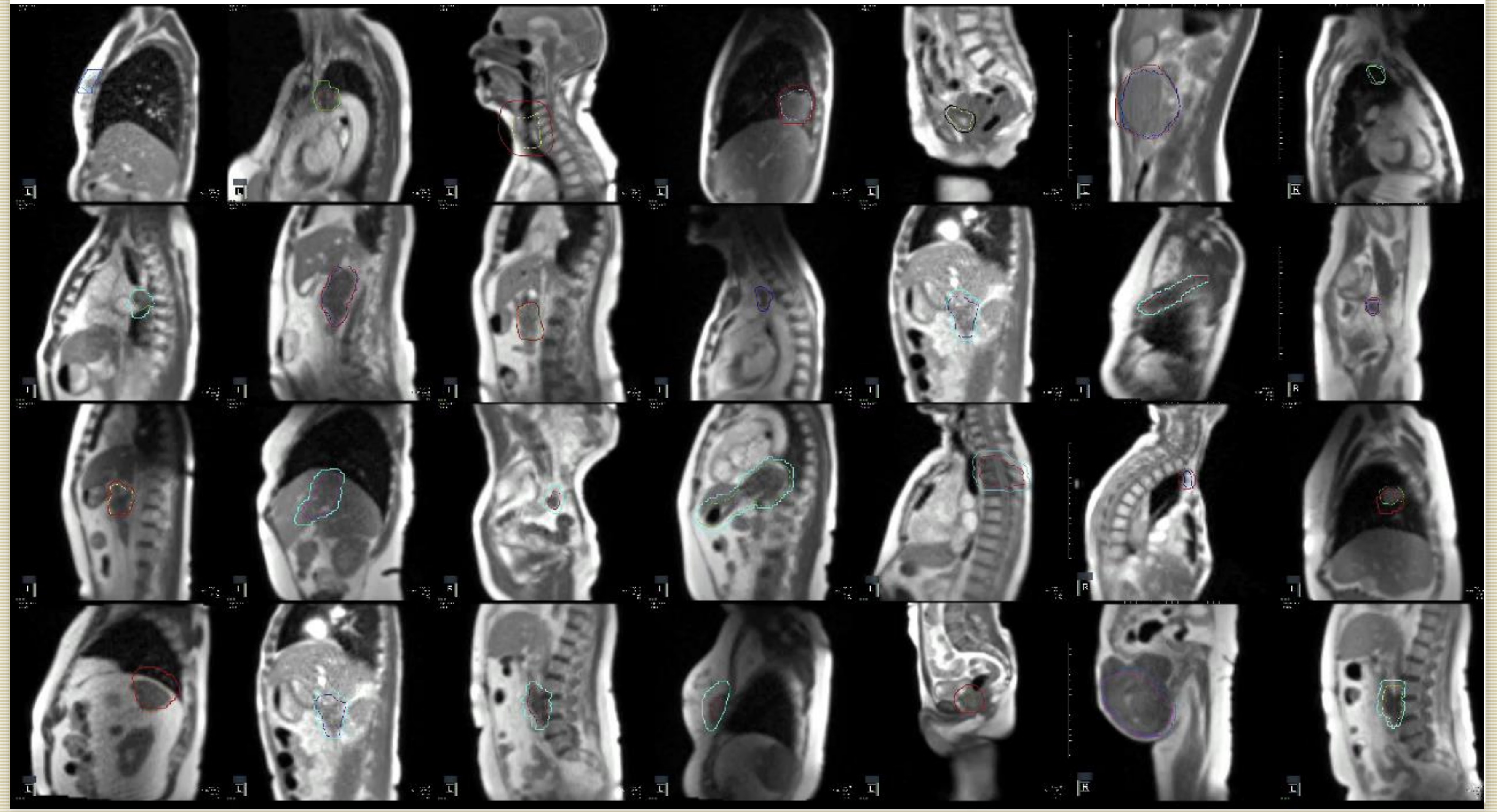
3D Volumetric images of patient: bladder cancer



MR Guidance for Treatment of Soft Tissue Disease



MR Guidance for Treatment of Soft Tissue Motion

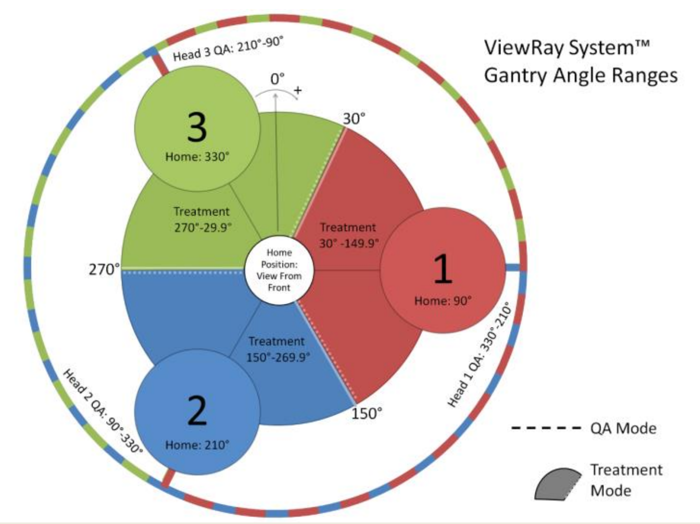


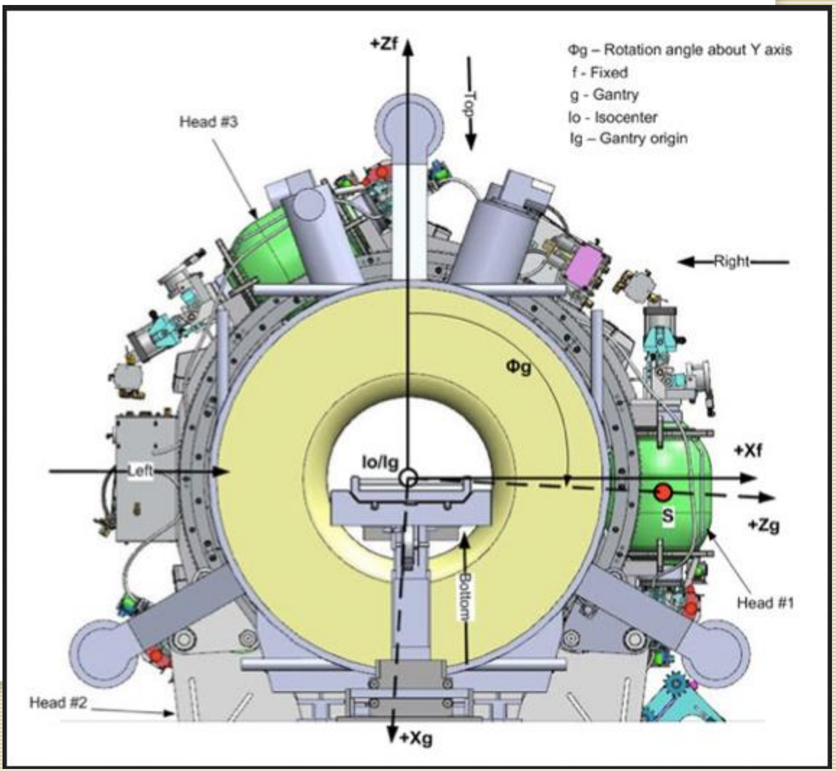
Specifications – Mechanical

3 Gantry Heads: 120 degrees of separation

Gantry Rotation: ± 60 degrees from its zero position for treatment mode, ± 120 degrees for physics mode.

Gantry Bore: 70 cm





System Specifications - MLC

MLC Geometry

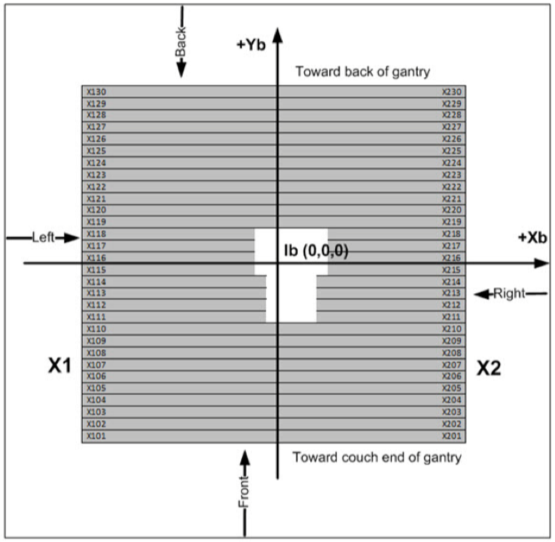
60 leaves, two opposing banks of 30 leaves

27.3 cm x 27.3 cm field sizes

1.05 cm leaf resolution at the nominal isocenter distance of 105 cm

doubly divergent design

leakage: < 0.375%



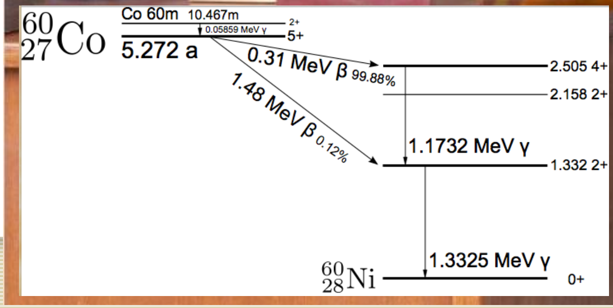
Welcome Back Co-60

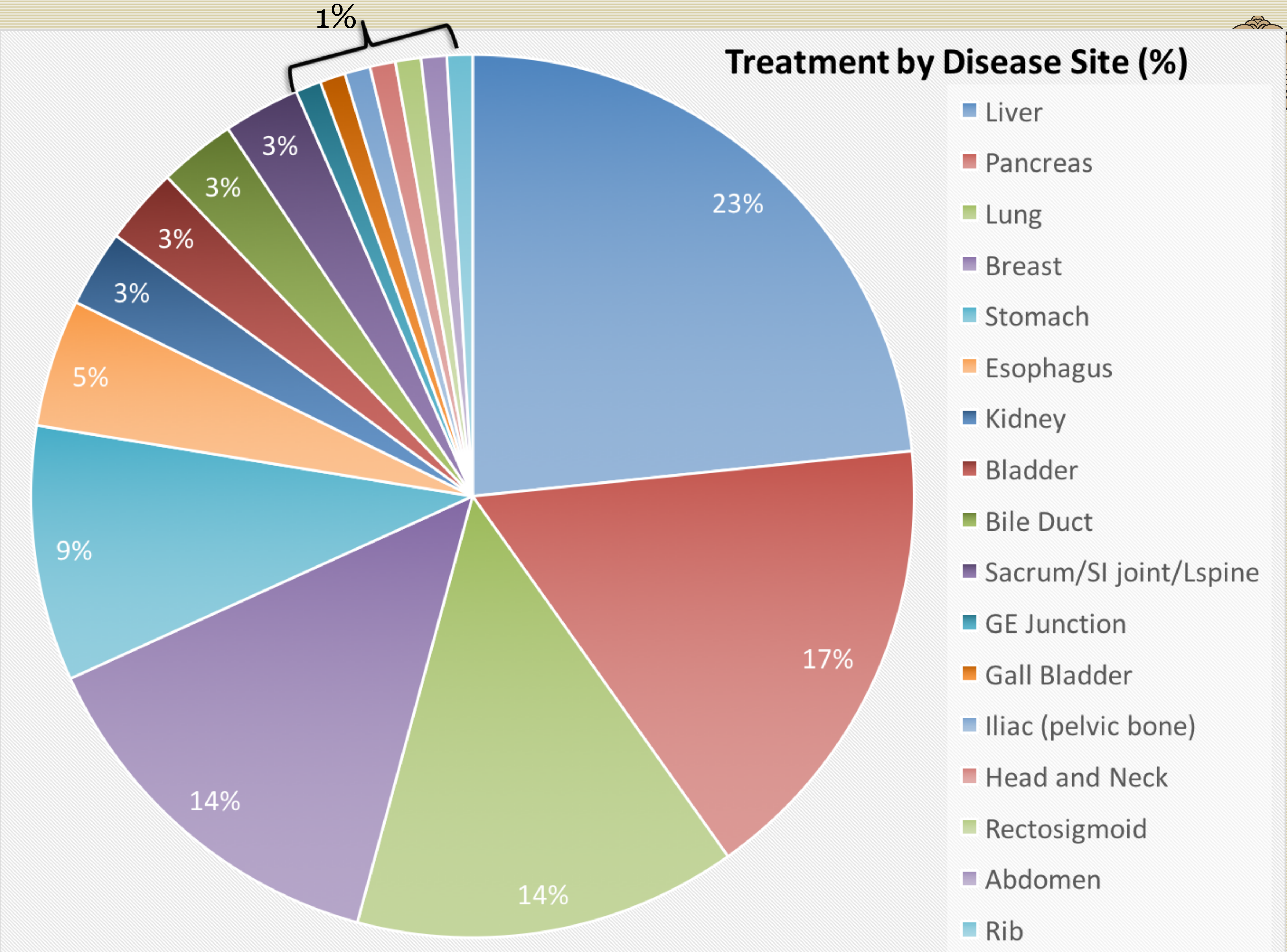
Dose Rate

600 cGy / minute, ~ 200 cGy/min/15,000 Ci source at 105 cm

Penumbra

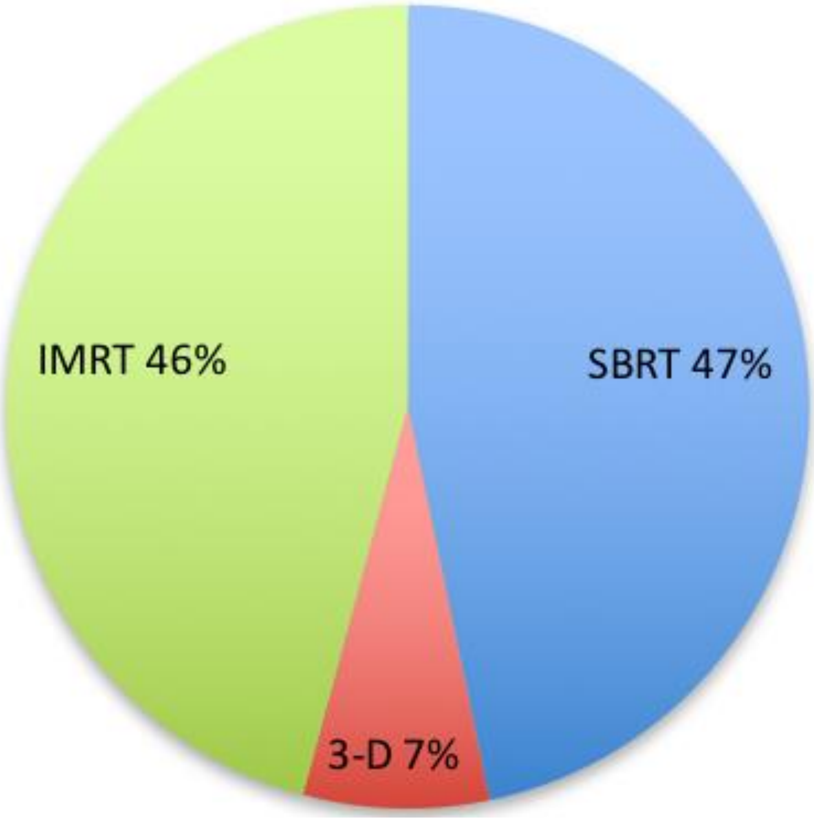
9 mm - distance between the 20% and 80% isodose lines for a 10 cm x 10 cm field measured at a depth of 10 cm with a 105 cm TSD





Treatment by Disease Site (%)
1%
23%
17%
14%
14%
9%
5%
3%
3%
3%
3%
Liver
Pancreas
Lung
Breast
Stomach
Esophagus
Kidney
Bladder
Bile Duct
Sacrum/SI joint/Lspine
GE Junction
Gall Bladder
Iliac (pelvic bone)
Head and Neck
Rectosigmoid
Abdomen
Rib

MRI Guidance Delivery Techniques



Over 500 patients treated across first 4 customers

- WUSTL
- UW-Madison
- UCLA
- Seoul National

RT challenges in presence of magnetic field

MRI image formation assumes linear field gradients

- nonlinearities can distort images
- Field strength independent
- QA is needed to check this during clinical use.

The patient's tissues can locally change the magnetic field leading to "magnetic susceptibility artifacts"

- Tissues have paramagnetic or diamagnetic nature
- Increases with magnetic field strength

The chemical environment can change the precession frequency leading to "chemical shift artifacts"

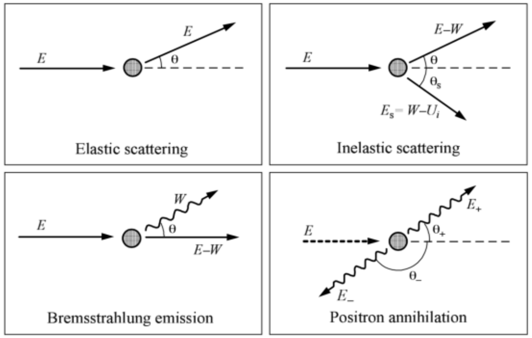
- C-H and O-H Hydrogen has different chemical environment and different precession rates
- Increases with magnetic field strength

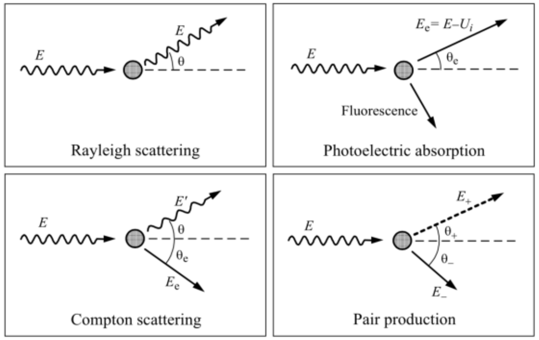
How is Dose Influenced by Magnetic Fields?

Photon transport is unperturbed by magnetic field

- polarization of spins could influence interaction cross sections (Zeeman effect)
- polarization is in competition with thermal excitations
- the energy difference between the spin states due to the Zeeman effect is very small in comparison with the average thermal energy of about 0.04 eV at 300K temperature
- Radiation source is much hotter by 100's of K
- At 1 Tesla, the fraction of nuclei polarized are ~ 4 ppm
- Practically, the atomic level physics is unperturbed by external

Electron transport experiences drift due to magnetic field (Lorentz force)





Distortion of Radiation Dose from the Lorentz force

Raaysmaker et al. Phys. Med. Biol. **49** (2004) 4109–4118

Raaijmakers et al. Phys. Med. Biol. **50** (2005) 1363–1376

The radius of gyration for 1 MeV electron

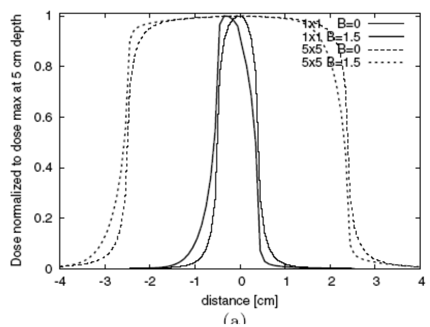
- 1.5 T 0.2 cm
- 0.35 T 1.0 cm

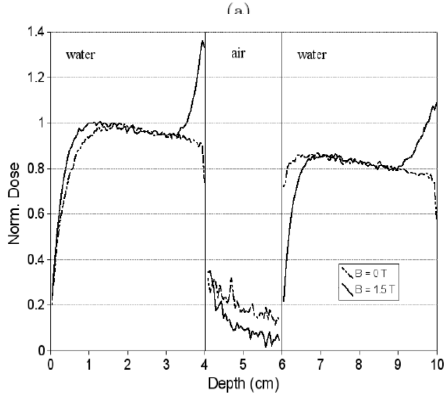
1. Radial confinement

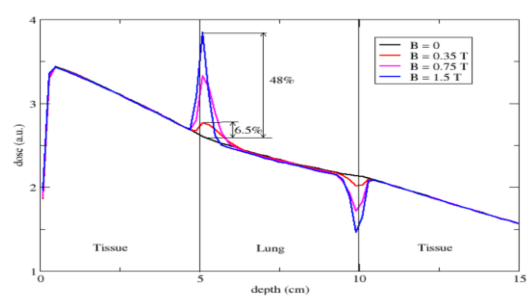
While in vacuum in the presence of uniform magnetic fields, electrons are known to spiral about magnetic field lines in a helical orbit with a gyration radius, r_g, given by

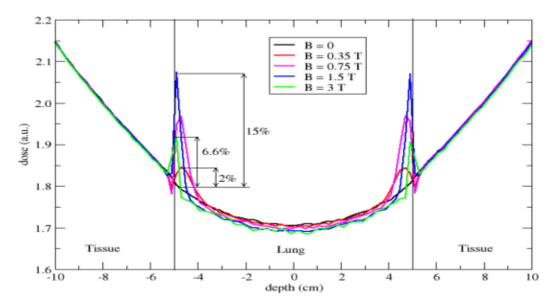
$$r_g = \frac{p_\perp}{3.00B}, \quad (1)$$

where r_g is measured in cm, $p_\perp$, the momentum of the electron perpendicular to the direction of the magnetic field, measured in MeV/c, c is the speed of light, and B is the magnetic field strength measured in Tesla (T).[17]



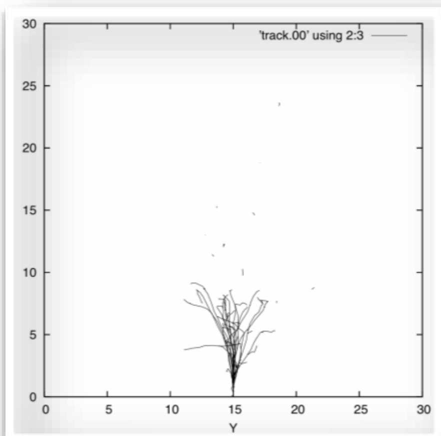




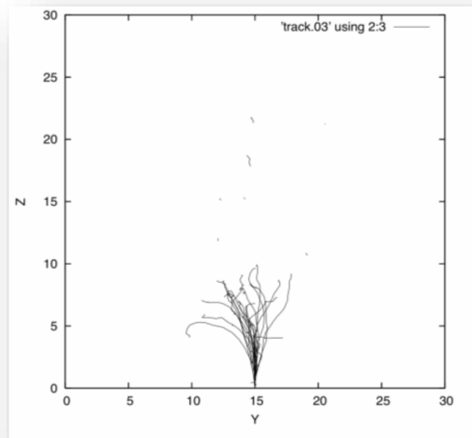


Competition: large angle scattering MFP vs. radius of gyration

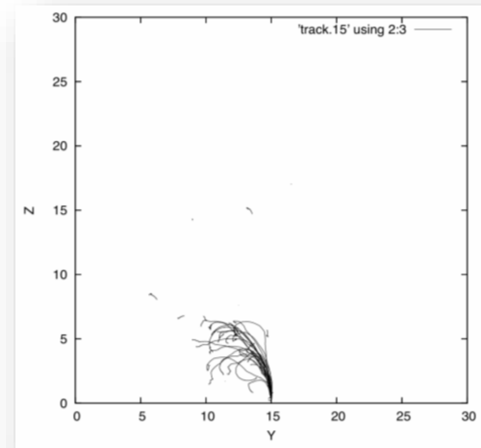
0.0 T



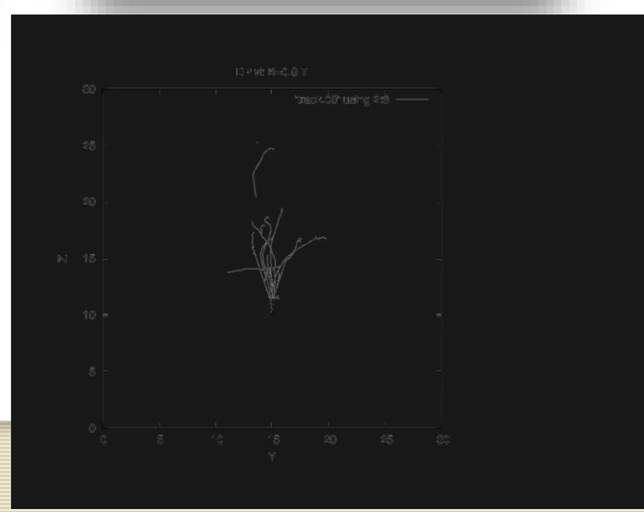
0.35 T



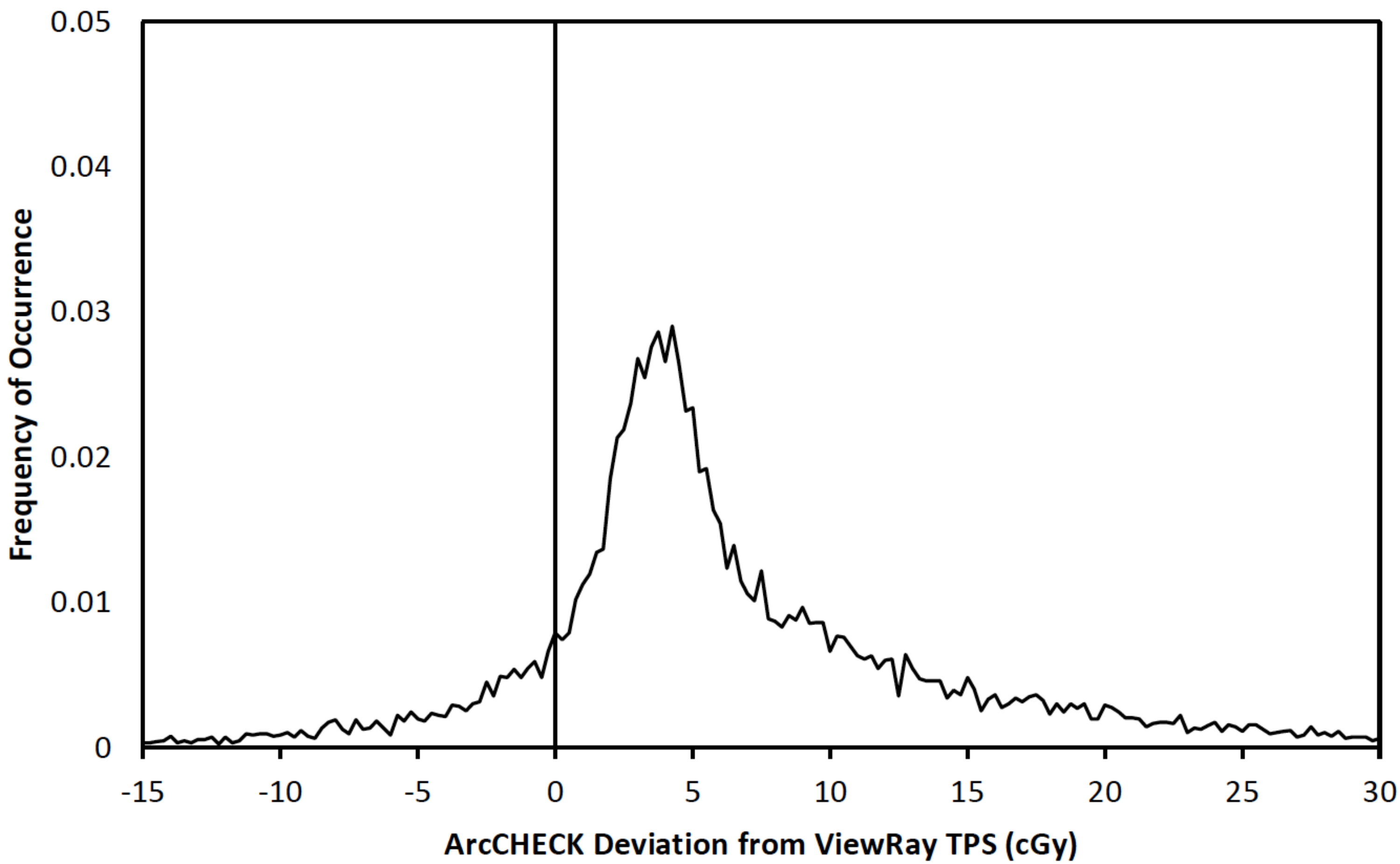
1.5 T



Scrolling from 0.0 T to 7.0 T



Diode Measurements of Radiation Dose in Magnetic Field



Diode Measurements of Radiation Dose in Magnetic Field

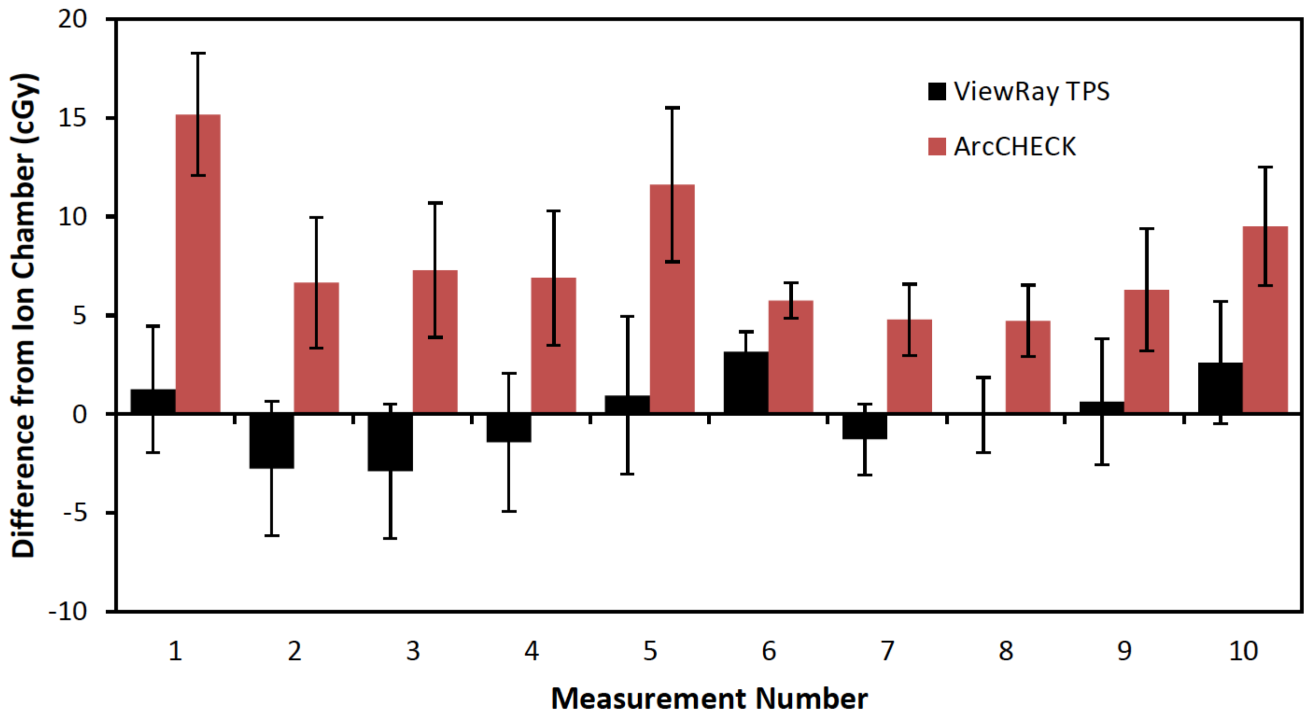
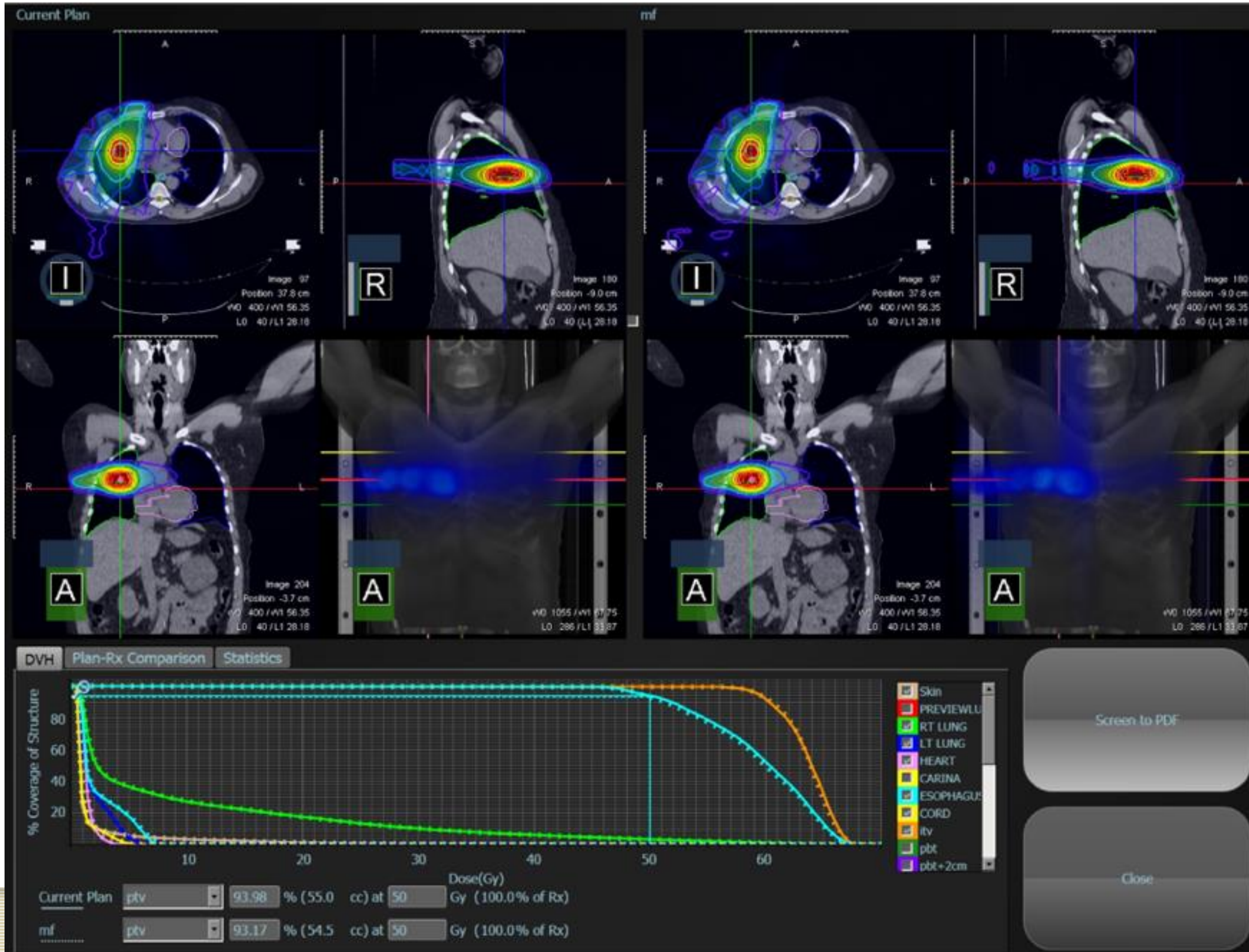


Figure 3.8 Bar graph depicting differences between ion chamber measurement and ViewRay TPS calculation (black) and ArcCHECK measurement (red). Error bars are representative of total k=1 measurement uncertainty, derived using the uncertainty budget in Appendix B.

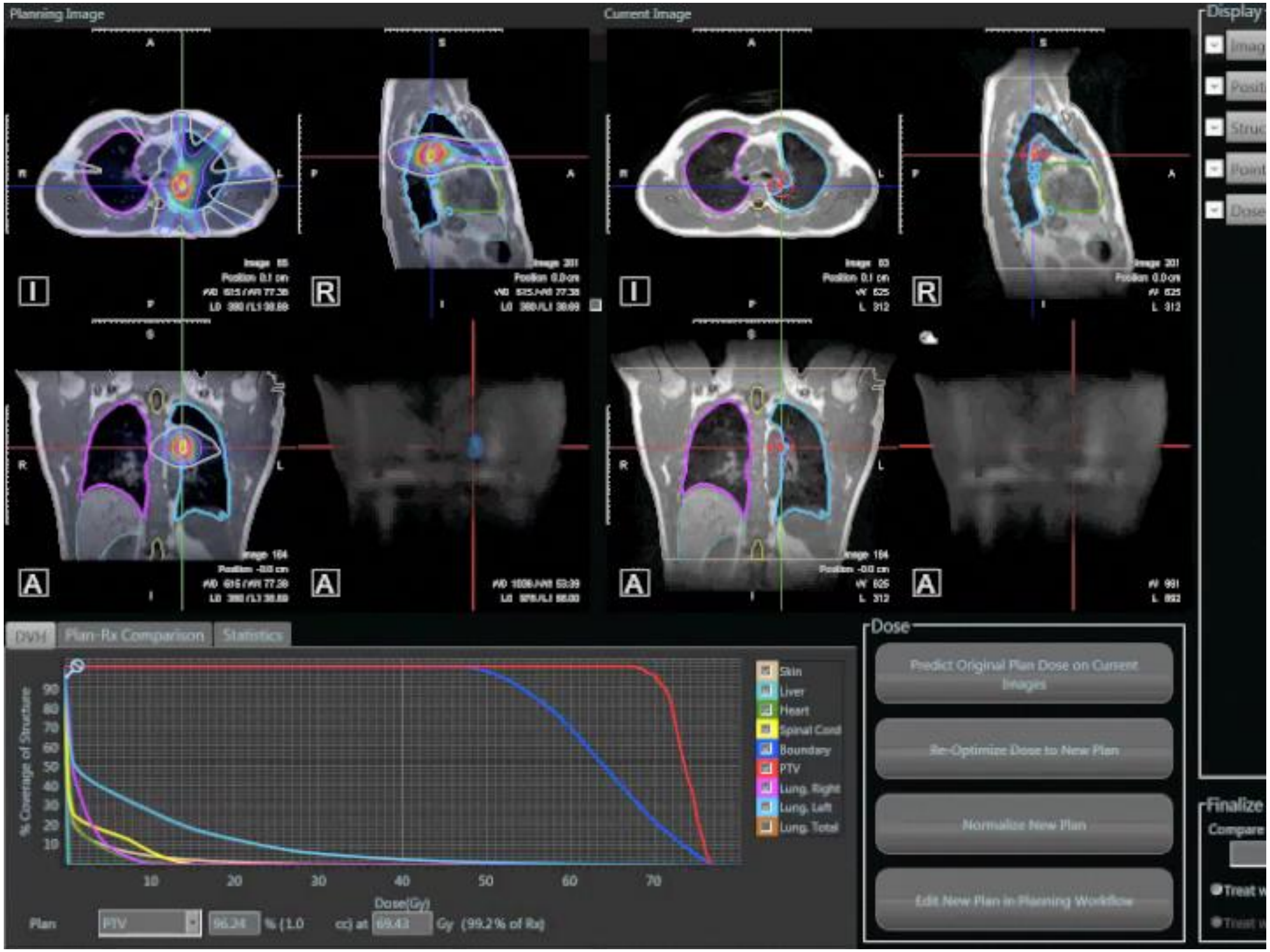
@ 0.35 T Dose Perturbations are negligible but accounted for by Monte Carlo



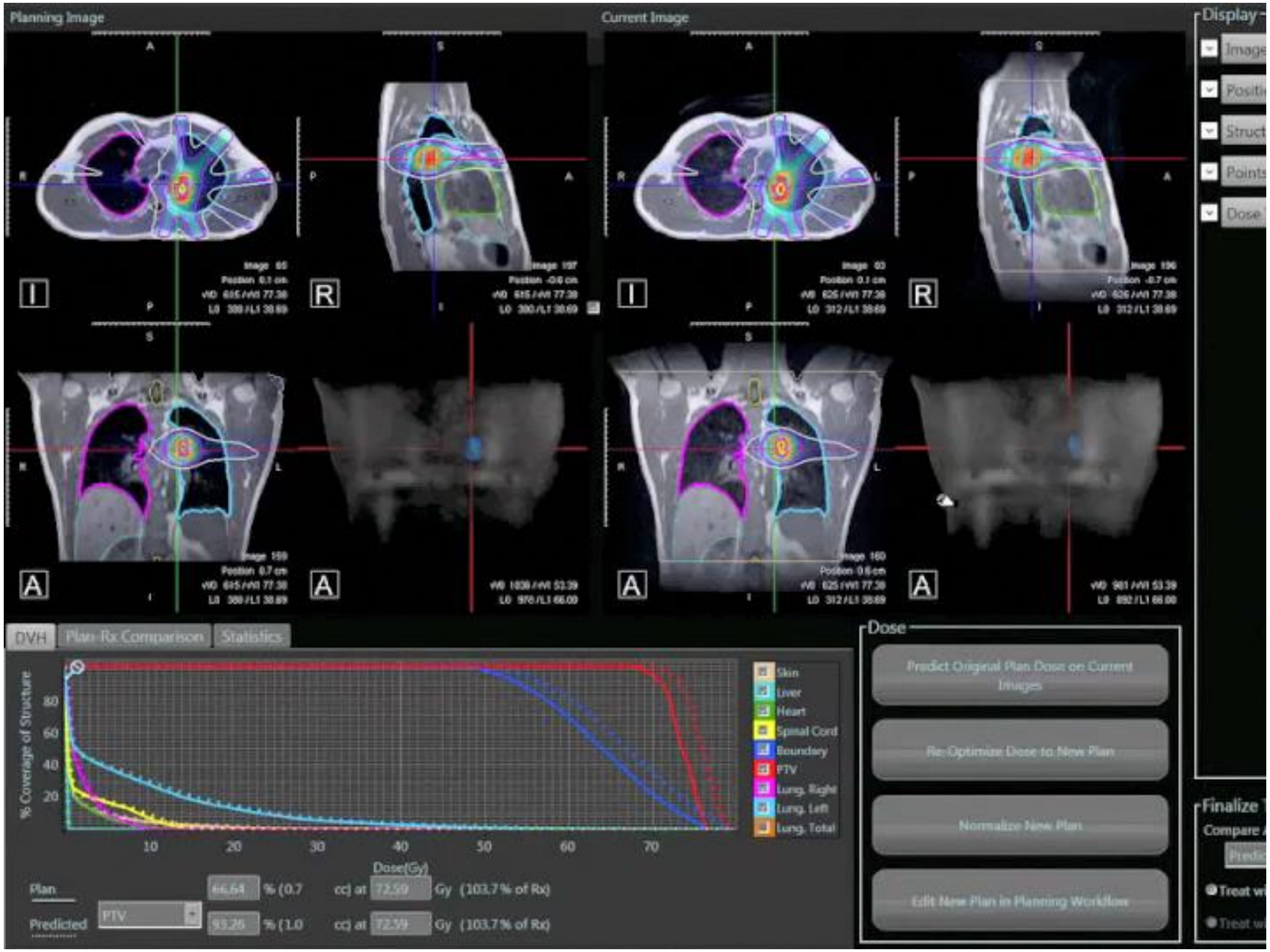
Clinical Workflow: Automatically Identify & Locate Tissue

Slide provided by ViewRay

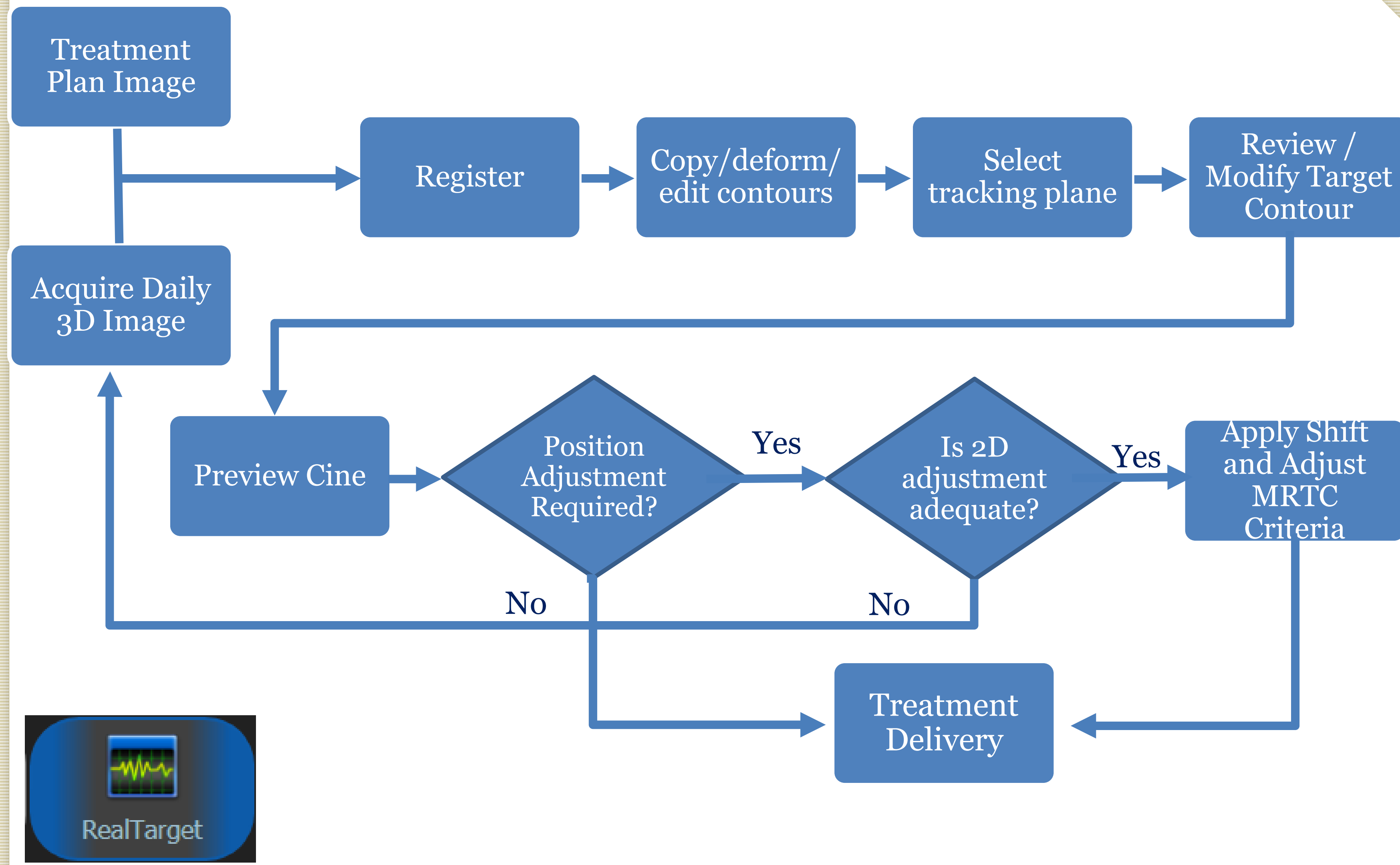
Predict Dose



Optimize New Plan

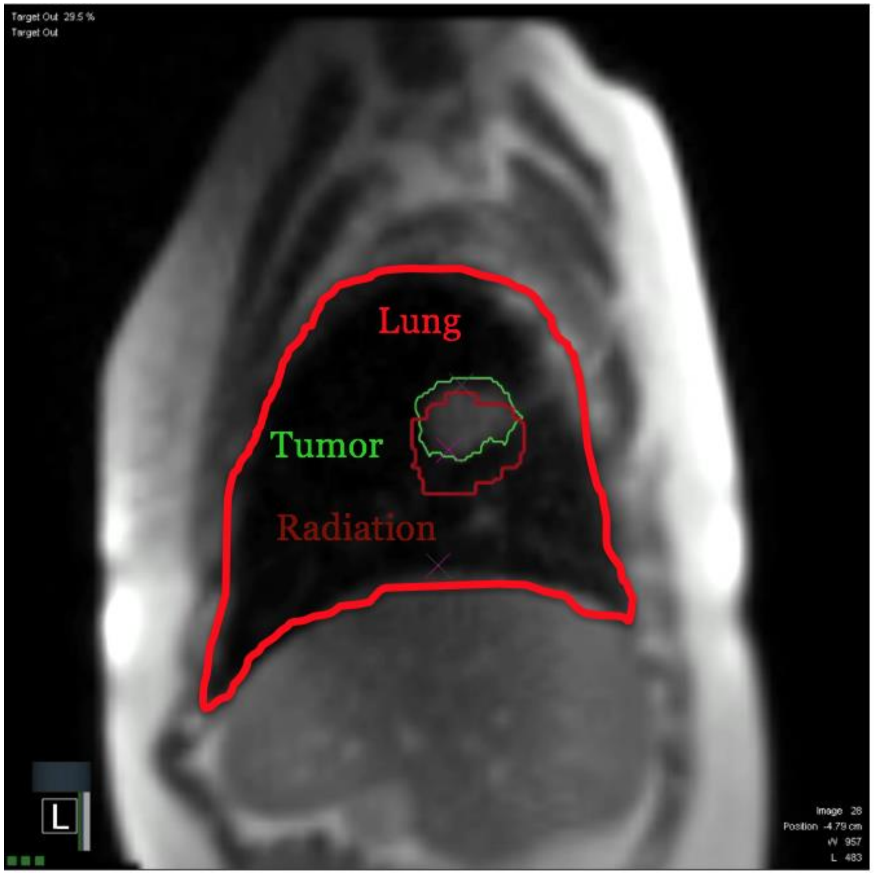


MRTC Workflow



Lung Cancer Motion and Targeting with MRI Guidance

- MRI allows us to continuously ensure treated area is within the treatment area
- Radiation is only on when the target is within the radiation field
- Deep breath expands lung so less normal lung treated



Lung Cancer Motion and Targeting with MRI Guidance

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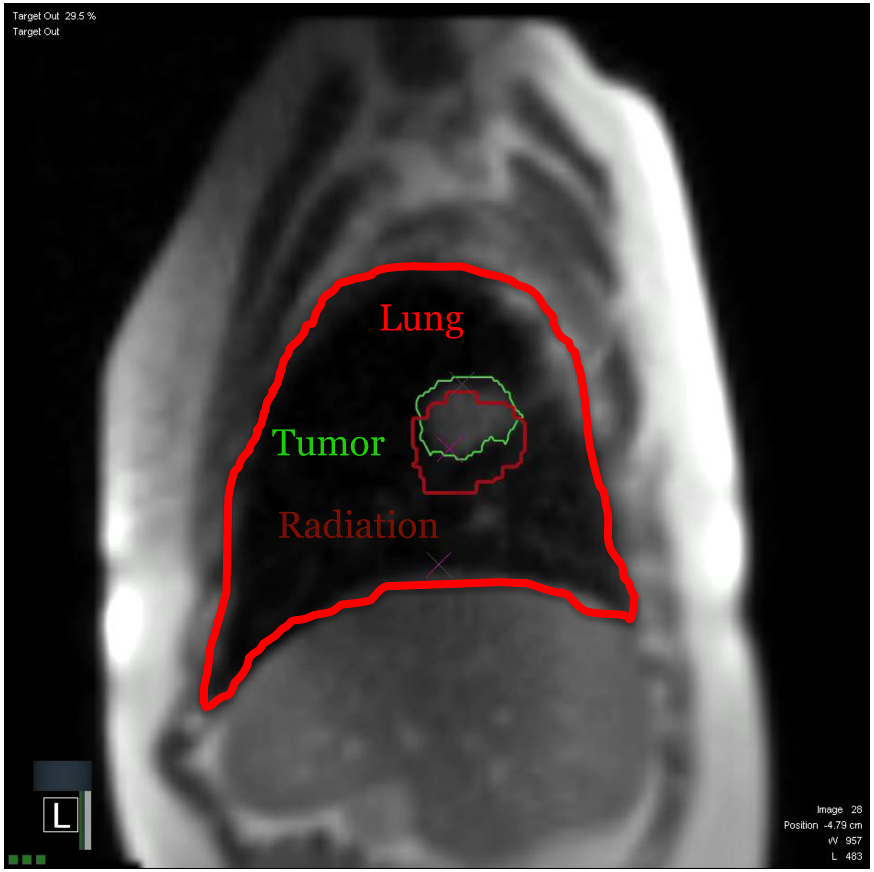
Superior



Anterior

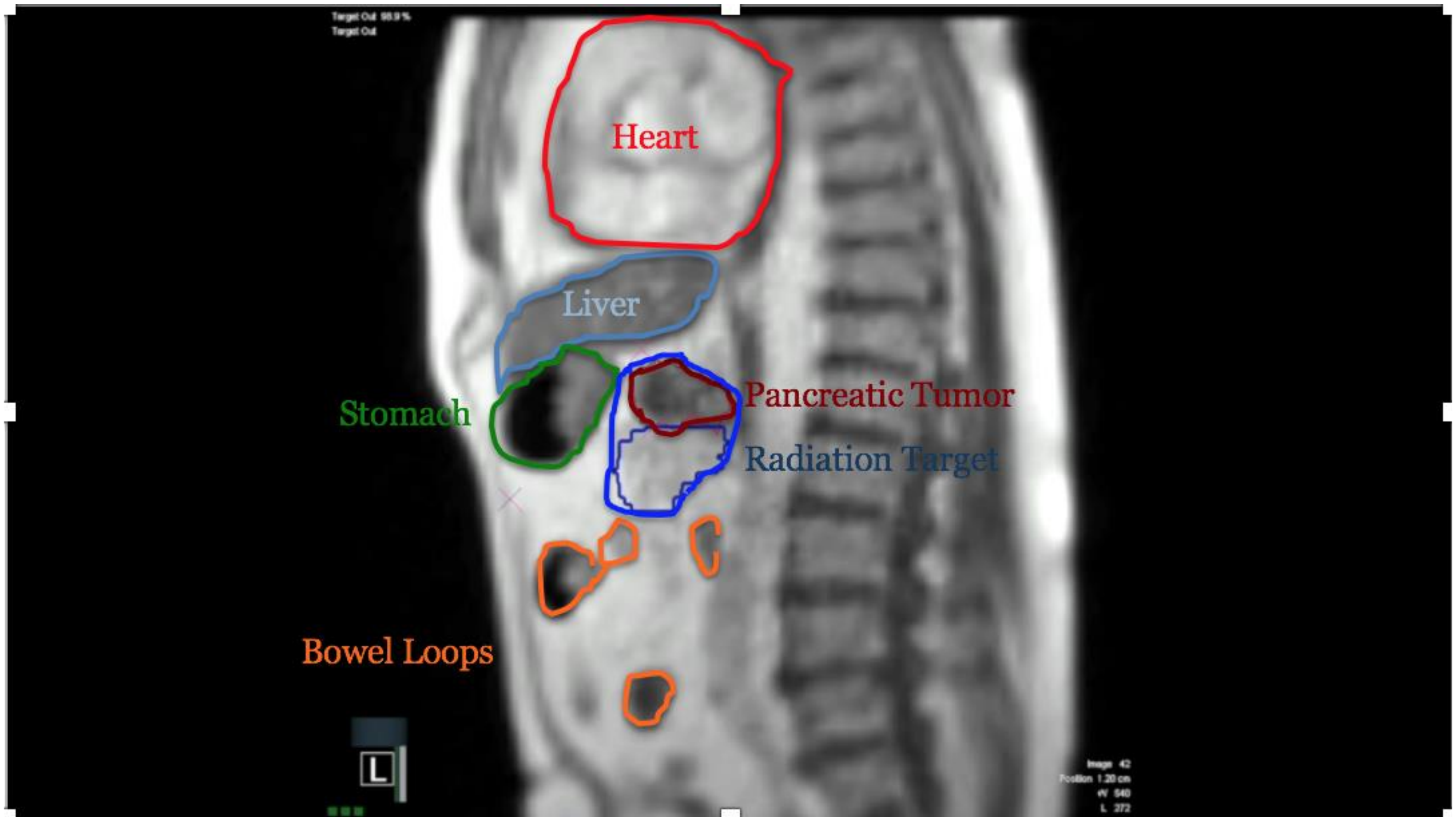
posterior

Inferior

Pancreas IMRT with breath hold gating

Superior

Anterior



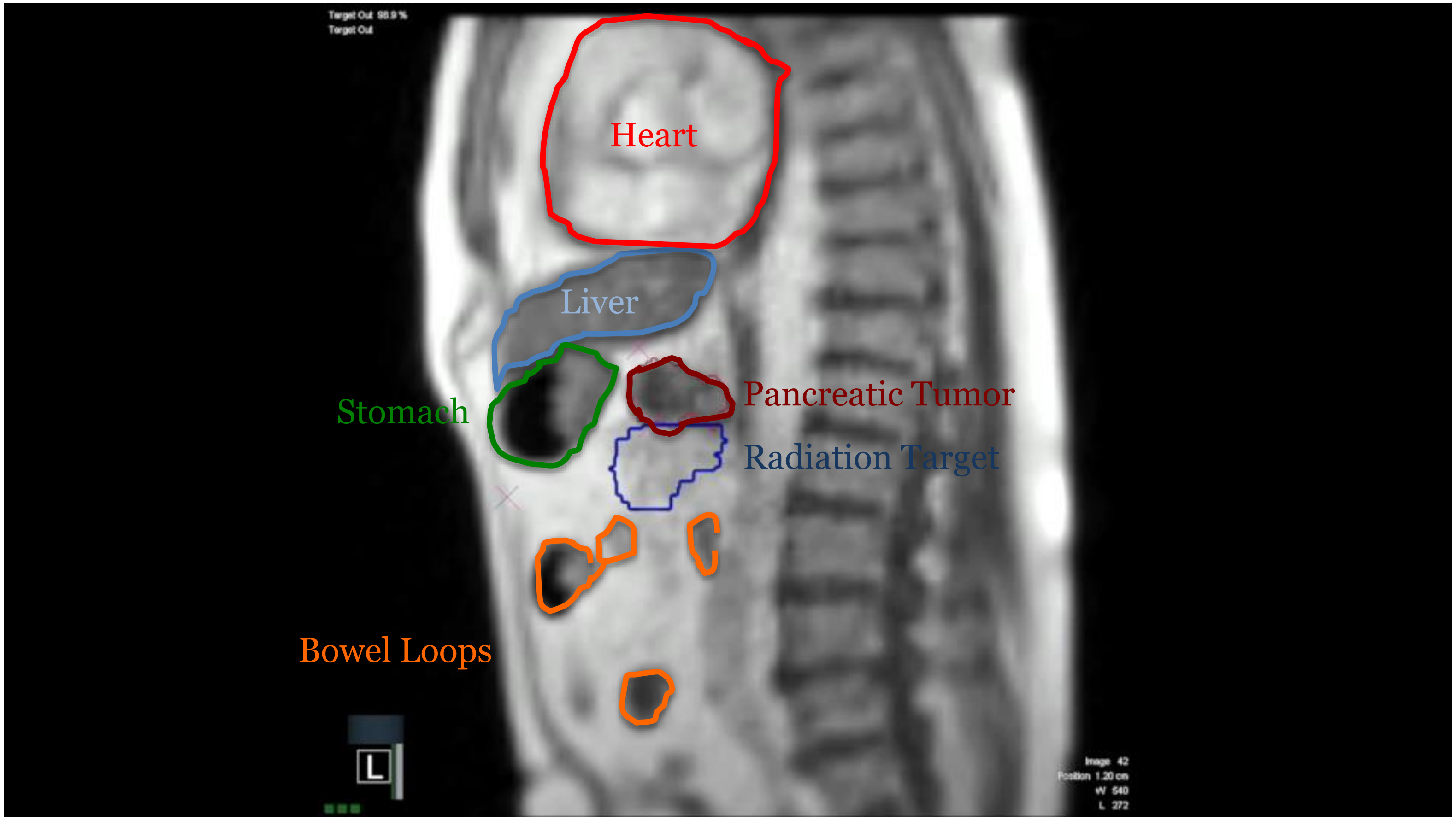
posterior

Inferior

Pancreas IMRT with breath hold gating

Superior

Anterior



posterior

Inferior

Pancreas IMRT with breath hold gating

Superior

Anterior

posterior

Inferior

Stereotactic Ablative Liver Metastasis Radiation

50Gy in 5 Fx

Patient driven repeated breath-hold technique with a high duty cycle

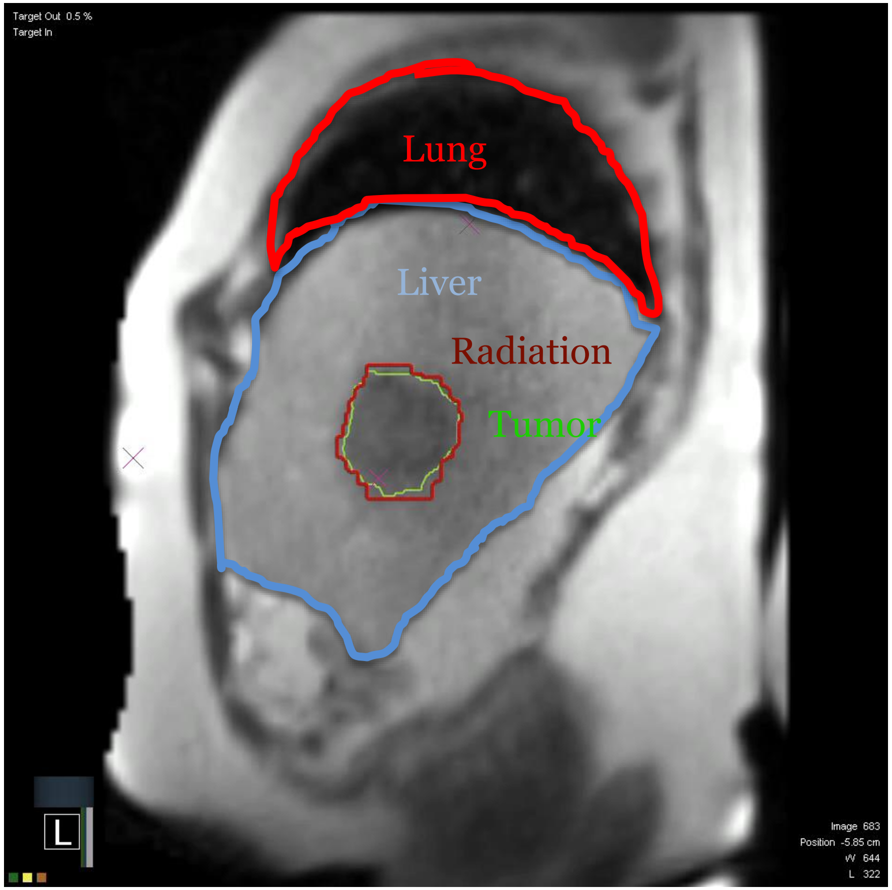
Radiation beam is only on when tumor is in proper position

Contrast used to highlight the tumor and allow daily tracking

Unique to be able to see and track actual tumor (not a surrogate) in realtime

MRI Tracking During Treatment

Superior

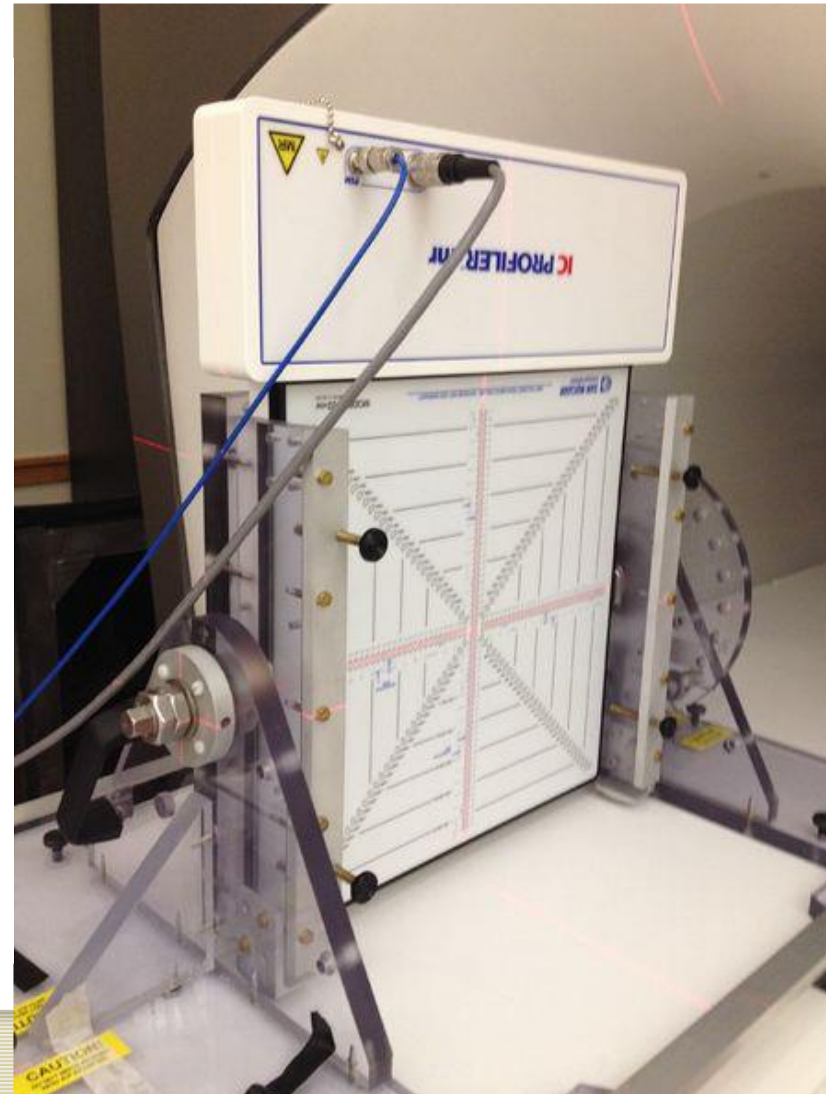


Anterior

posterior

Inferior

Quality Assurance



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Report of IMRT Head and Neck Phantom Irradiation

Date of Report:	September 26, 2014
Institution:	University of Wisconsin
Physicist:	Mark Geurts
Radiation Machine:	ViewRay, ViewRay (101) – 6 MV
Intensity Modulation Device:	Multileaf Collimator
IMRT Technique:	Segmental (step and shoot) MLC
Treatment Planning System:	ViewRay MRidian (IMRT) – Monte Carlo
Date of Irradiation:	September 4, 2014

Description of Procedure

An anthropomorphic head phantom incorporating a rectangular dosimetry insert was imaged and irradiated to approximately 6.6 Gy using an IMRT technique. The dosimetry insert consisted of one primary PTV containing four TLD capsules, a secondary PTV and an organ at risk (OAR), each containing two TLD capsules. The TLD capsules provided point dose information. Three sheets of GAFChromic™ Dosimetry Media provided dose profiles through the center of primary PTV.

The dosimetric precision of the TLD is 3%, and the spatial precision of the film and densitometer system is 1 mm.

Summary of TLD and film results:

Location	IROC-H vs. Inst.	Criteria	Acceptable
Primary PTV sup. ant.	0.95	0.93 – 1.07	Yes
Primary PTV inf. ant.	0.96	0.93 – 1.07	Yes
Primary PTV sup. post.	0.96	0.93 – 1.07	Yes
Primary PTV inf. post.	0.95	0.93 – 1.07	Yes
Secondary PTV sup.	0.98	0.93 – 1.07	Yes
Secondary PTV inf.	0.98	0.93 – 1.07	Yes

Film Plane	Gamma Index*	Criteria	Acceptable
Axial	100%	≥85%	Yes
Sagittal	99%	≥85%	Yes

*Percentage of points meeting gamma-index criteria of 7% and 4 mm.

The phantom irradiation results listed in the table above **do meet** the criteria established by IROC Houston in collaboration with the cooperative study groups. Therefore, your institution **has satisfied** the phantom irradiation component of the credentialing process to enter patients into certain protocols that allow the use of IMRT.

TLD and Film Analysis by: Nadia Hernandez and Andrea Molineu, M.S.

Report Checked by:

David S. Followill, Ph.D.
Director, IROC Houston QA Center

ACR AMERICAN COLLEGE OF RADIOLOGY Grants Administration

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CK OF PHOTON BEAM OUTPUT
v 8.0.2

University of Wisconsin, Madison, WI
2622
Mark Geurts
ViewRay Serial 101
Co-60 gamma rays (Head 2)
105.0 cm

n reported dose at rence depth:*	Ratio of absorbed dose determined by IROC Houston to that stated by institution: OSLD/INST
0 cGy to water	1.00

THIS INFORMATION SHOULD BE USED ONLY AS A CHECK OF MACHINE OPERATION AND NOT AS A MACHINE CALIBRATION, nor as an alternative to frequent calibration by a qualified physicist.

The OSLD dose was evaluated using the AAPM TG-51 Dosimetry Calibration Protocol.

OSLD read on:	12-Sep-2014
OSLD read by:	Travell Hollingsworth
Checked by:	Stephen Kry, Ph.D.

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s.

ne

David S. Followill
Director

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he National Cancer Institute

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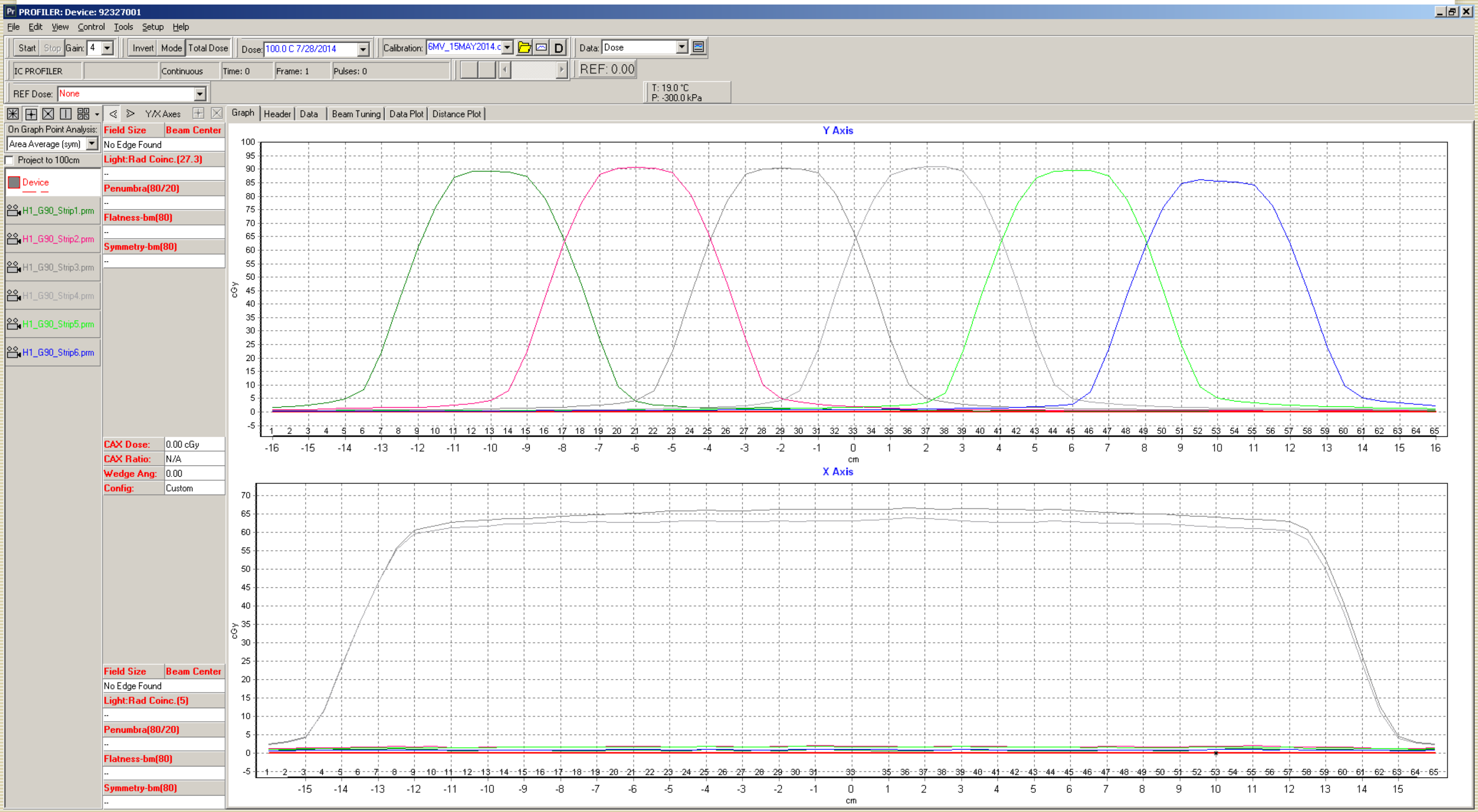
Quality Assurance - MLC



Quality Assurance - MLC

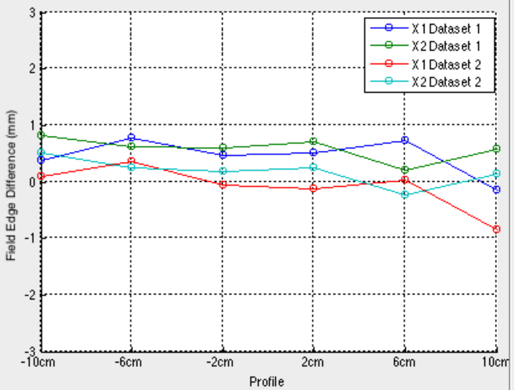
AnalyzeMLCProfiles

ViewRay MLC Position Check

Head 1

Angle 1: 0 — nal Hybrid Calibration/Profiler2Export_H1_G0.txt — Browse
Angle 2: 90 — al Hybrid Calibration/Profiler2Export_H1_G90.txt — Browse
Angle 3: — Browse
Angle 4: — Browse

Display: Field Edge Offsets



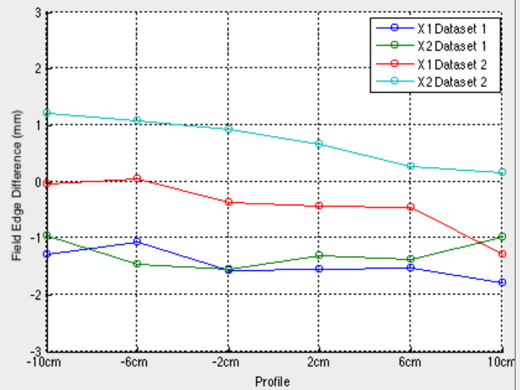
Statistic	X1	X2	Both
Min Field Edge Offset (mm)	-0.85	-0.23	-0.85
Max Field Edge Offset (mm)	0.77	0.82	0.82
Avg Field Edge Offset (mm)	0.16	0.39	0.27
Offets less than 1 mm	100.0%	100.0%	100.0%

Clear All Data

Head 2

Angle 1: 90 — al Hybrid Calibration/Profiler2Export_H2_G90.txt — Browse
Angle 2: 180 — l Hybrid Calibration/Profiler2Export_H2_G180.txt — Browse
Angle 3: — Browse
Angle 4: — Browse

Display: Field Edge Offsets



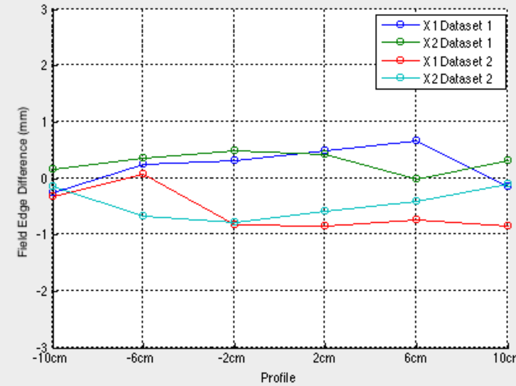
Statistic	X1	X2	Both
Min Field Edge Offset (mm)	-1.58	-1.55	-1.58
Max Field Edge Offset (mm)	0.06	1.21	1.21
Avg Field Edge Offset (mm)	-0.80	-0.09	-0.45
Offets less than 1 mm	100.0%	80.0%	90.0%

Clear All Data

Head 3

Angle 1: 0 — nal Hybrid Calibration/Profiler2Export_H3_G0.txt — Browse
Angle 2: 270 — ion Change/Profiler2Export_H3_G270_2113.txt — Browse
Angle 3: — Browse
Angle 4: — Browse

Display: Field Edge Offsets



Statistic	X1	X2	Both
Min Field Edge Offset (mm)	-0.85	-0.78	-0.85
Max Field Edge Offset (mm)	0.49	0.49	0.49
Avg Field Edge Offset (mm)	-0.27	-0.12	-0.20
Offets less than 1 mm	100.0%	100.0%	100.0%

Clear All Data

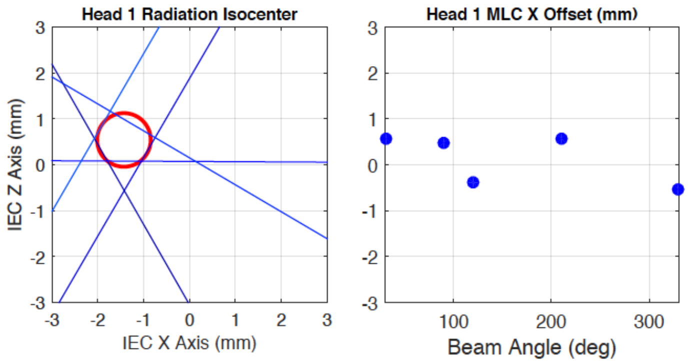
Quality Assurance

Radiation Isocenter(s)

ViewRay ArcCheck Radiation Isocenter

Report Date:	01-Apr-2015 00:22:32	**SNC Software:**	6.4.1.26817
Physicist:	viewray-physics\physics	**Collector:**	ArcCHECK 1220
Version:	1.1.0 (11-Feb-2015 15:37:11)	**Serial Number:**	86089001

Input File: W:\ViewRay\physics\Quality_Assurance_Data\Monthly_QA\201503\Head1_20150331.acm



Statistic	Result
Minimum Radius	0.58 mm
Isocenter IEC X Offset	-1.43 mm
Isocenter IEC Y Offset	0.14 mm
Isocenter IEC Z Offset	0.54 mm
Mean MLC X Offset	0.13 mm
Max MLC X Offset	0.57 mm
Min MLC X Offset	-0.54 mm

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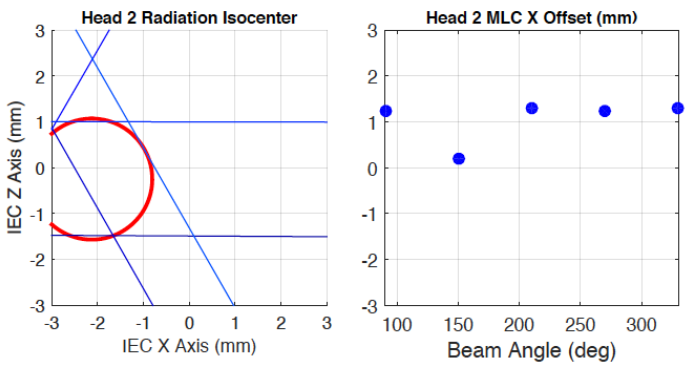
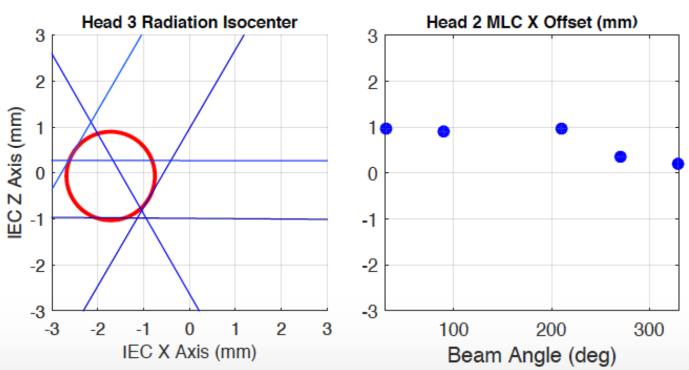


Statistic	Result
Minimum Radius	1.32 mm
Isocenter IEC X Offset	-2.13 mm
Isocenter IEC Y Offset	0.93 mm
Isocenter IEC Z Offset	-0.25 mm
Mean MLC X Offset	1.06 mm
Max MLC X Offset	1.32 mm
Min MLC X Offset	0.20 mm

Input File: W:\ViewRay\physics\Quality_Assurance_Data\Monthly_QA\201503\Head3_20150331.acm

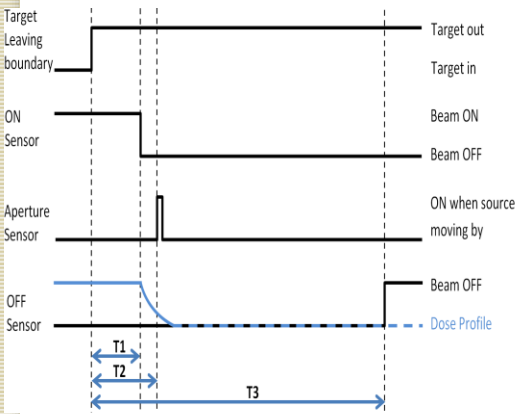


Statistic	Result
Minimum Radius	0.96 mm
Isocenter IEC X Offset	-1.72 mm
Isocenter IEC Y Offset	-0.46 mm
Isocenter IEC Z Offset	-0.07 mm
Mean MLC X Offset	0.68 mm
Max MLC X Offset	0.96 mm
Min MLC X Offset	0.21 mm

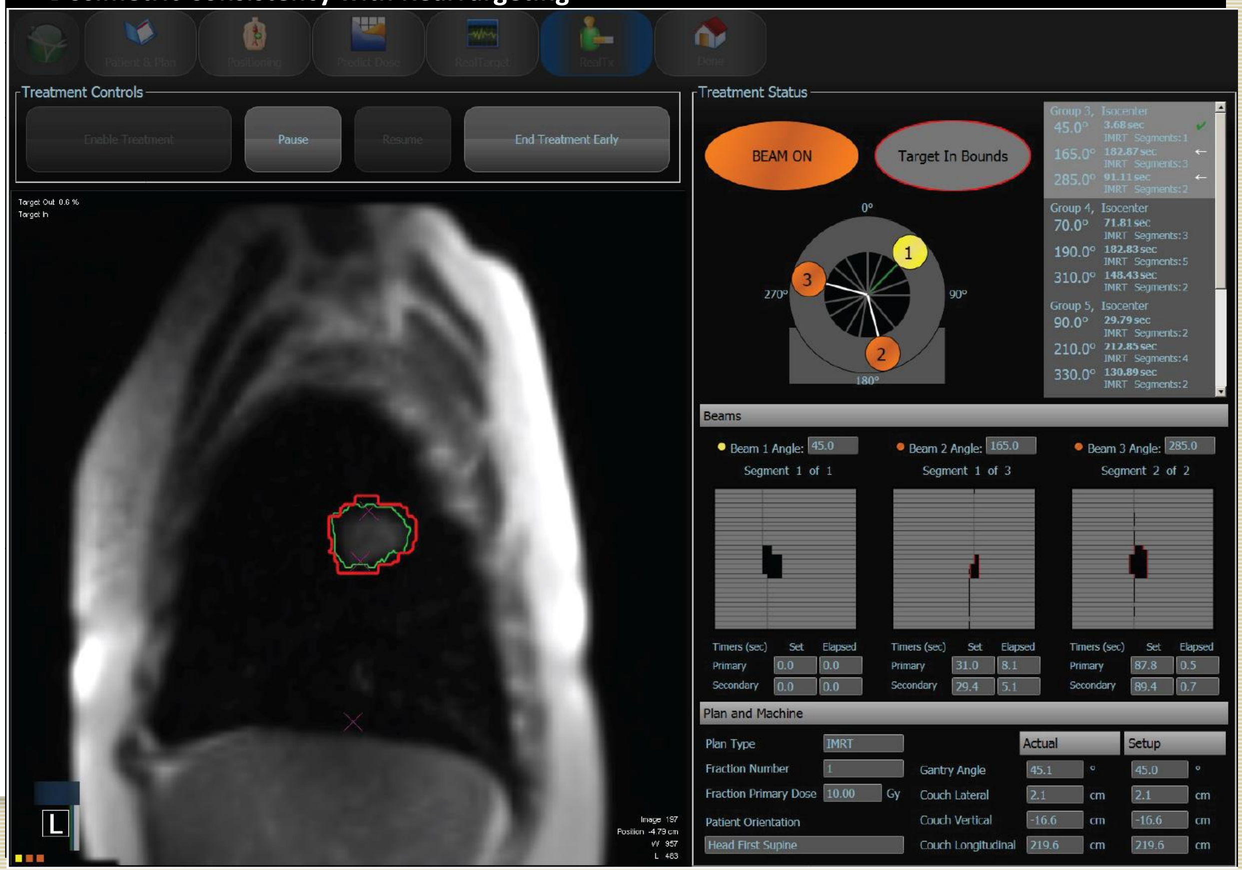
System Latency

Quality Assurance

Trigger beam hold within 500 msec of target moving outside pre-defined boundary

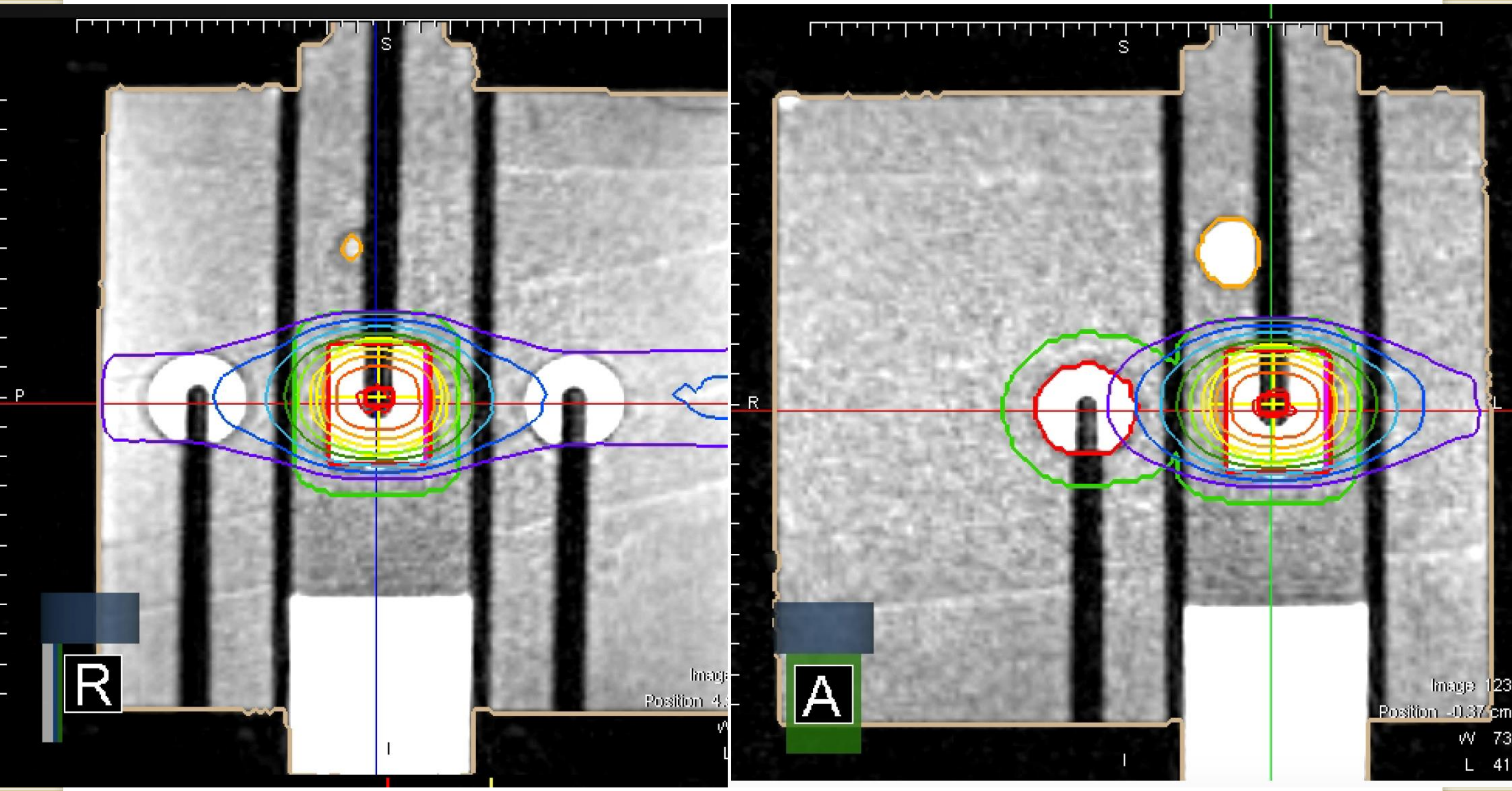


Dosimetric Consistency with RealTargeting –



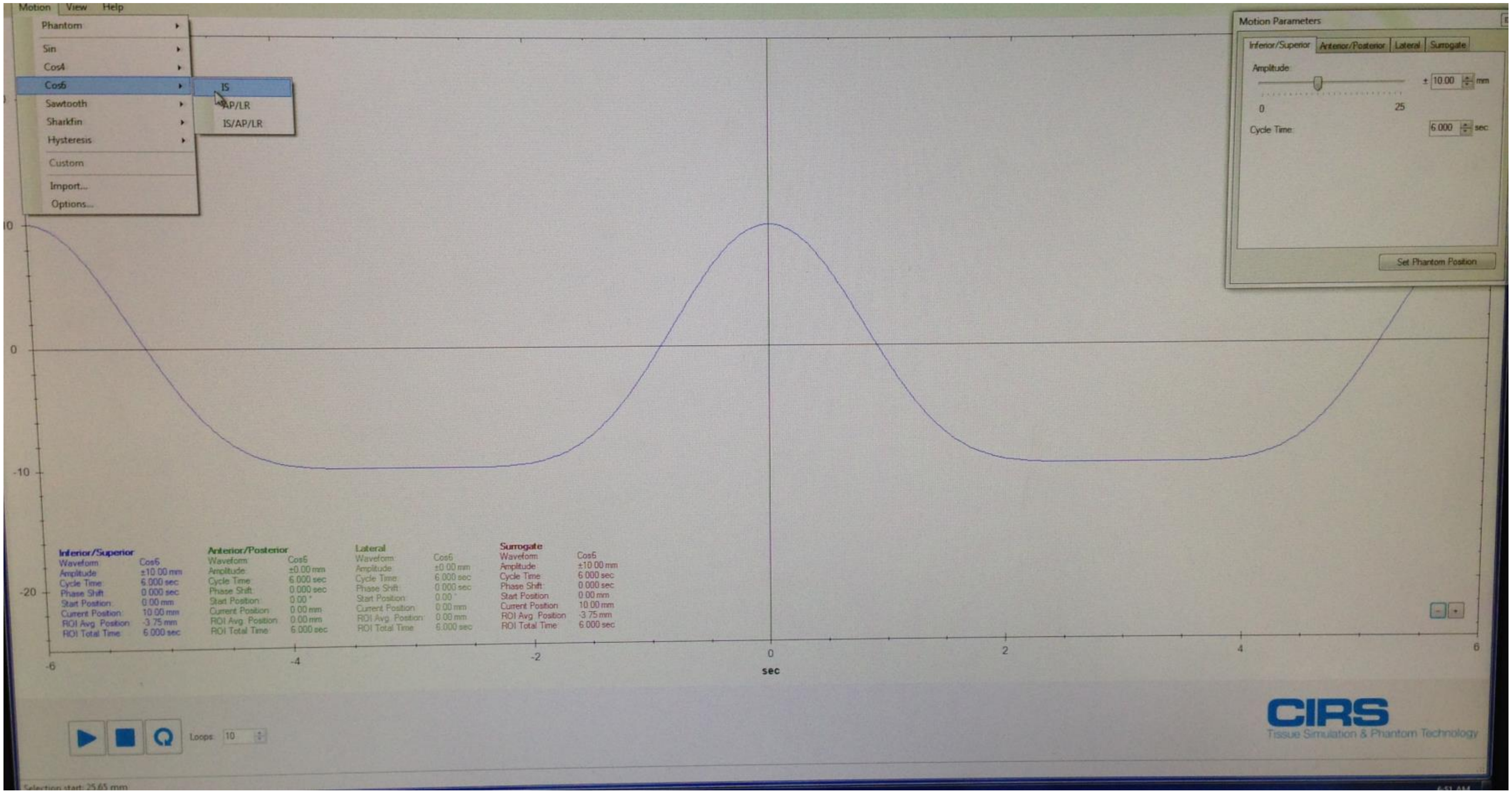
Quality Assurance

Verification of Dose during MRTC



Phantom Motion

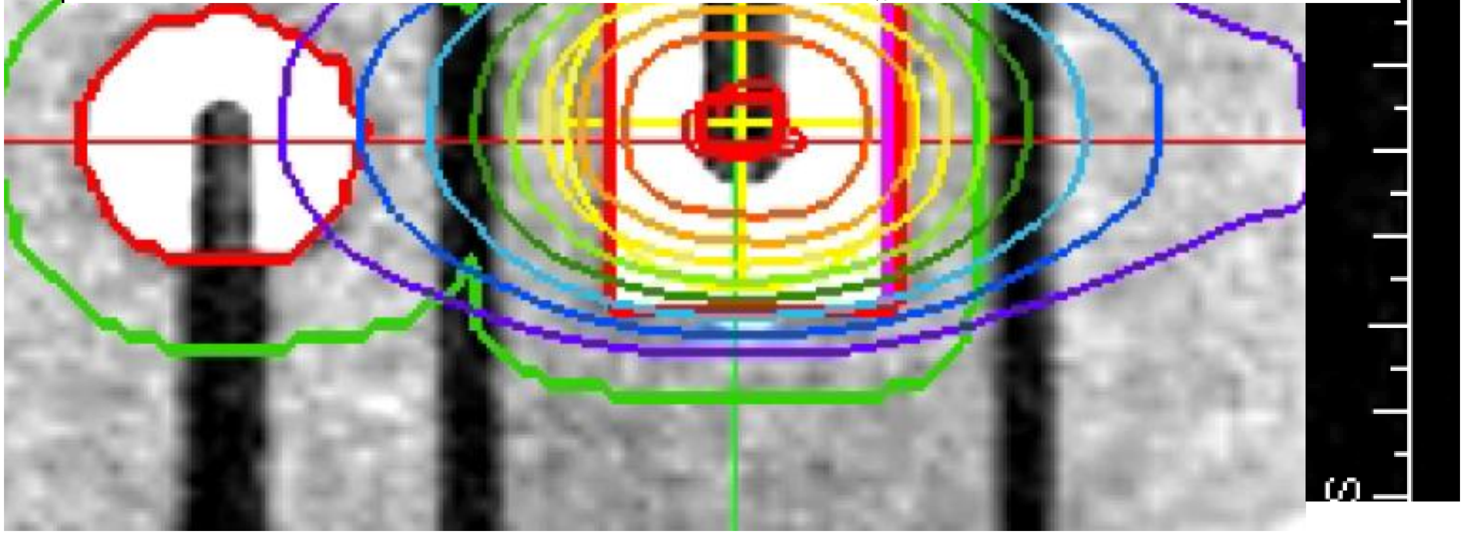
2 cm motion at 6 second periods (10 bpm)
(~ 10 mm/sec speed)



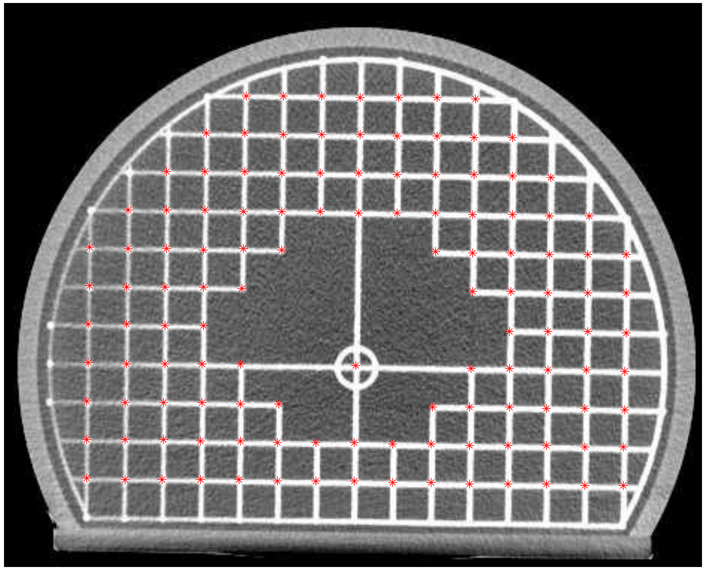
Verification of Dose during MRTC

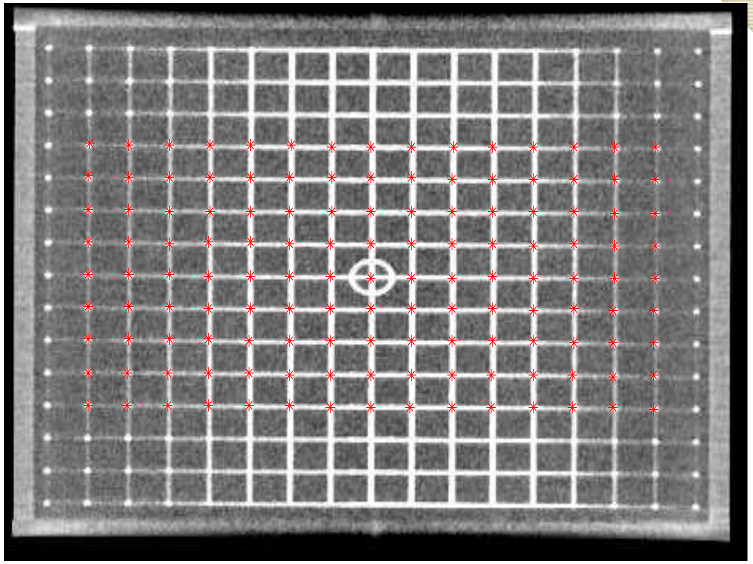
Dosimetric Consistency with RealTargeting – Conformal Plan

Test Item	Measured values	
Measured dose without motion.	Target Chamber (nC)	7.03
Measured dose with motion	Target Chamber (nC)	7.12
	Target Chamber (% diff)	1.3%

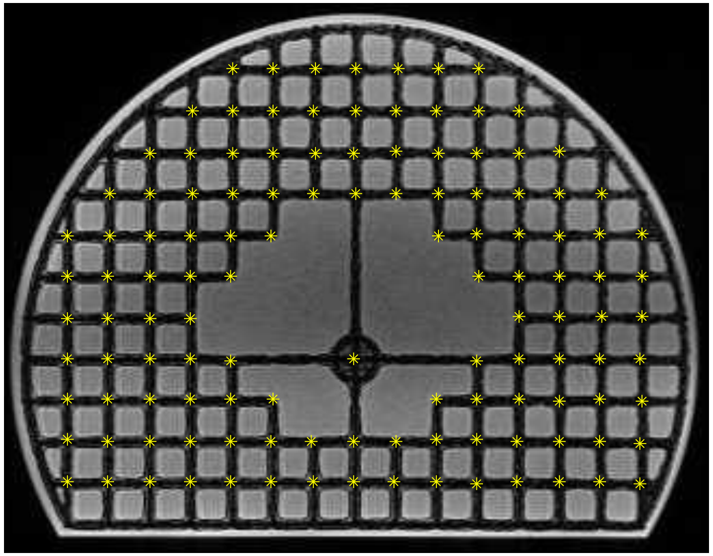


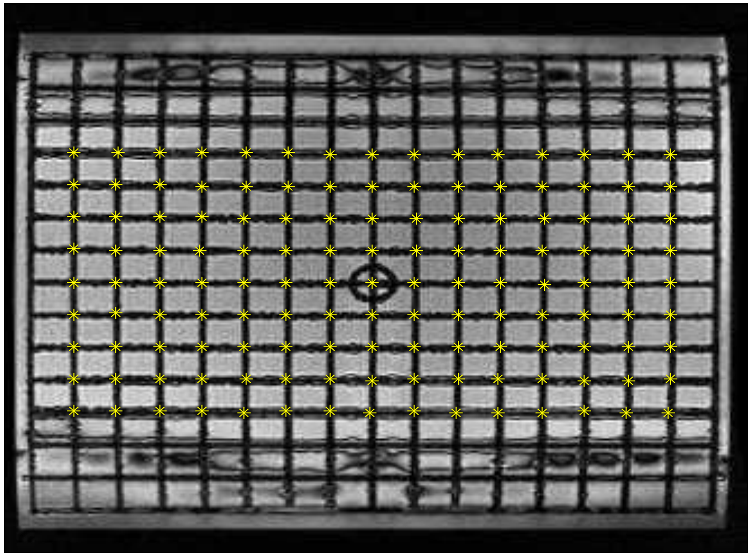
Spatial Distortion





CT

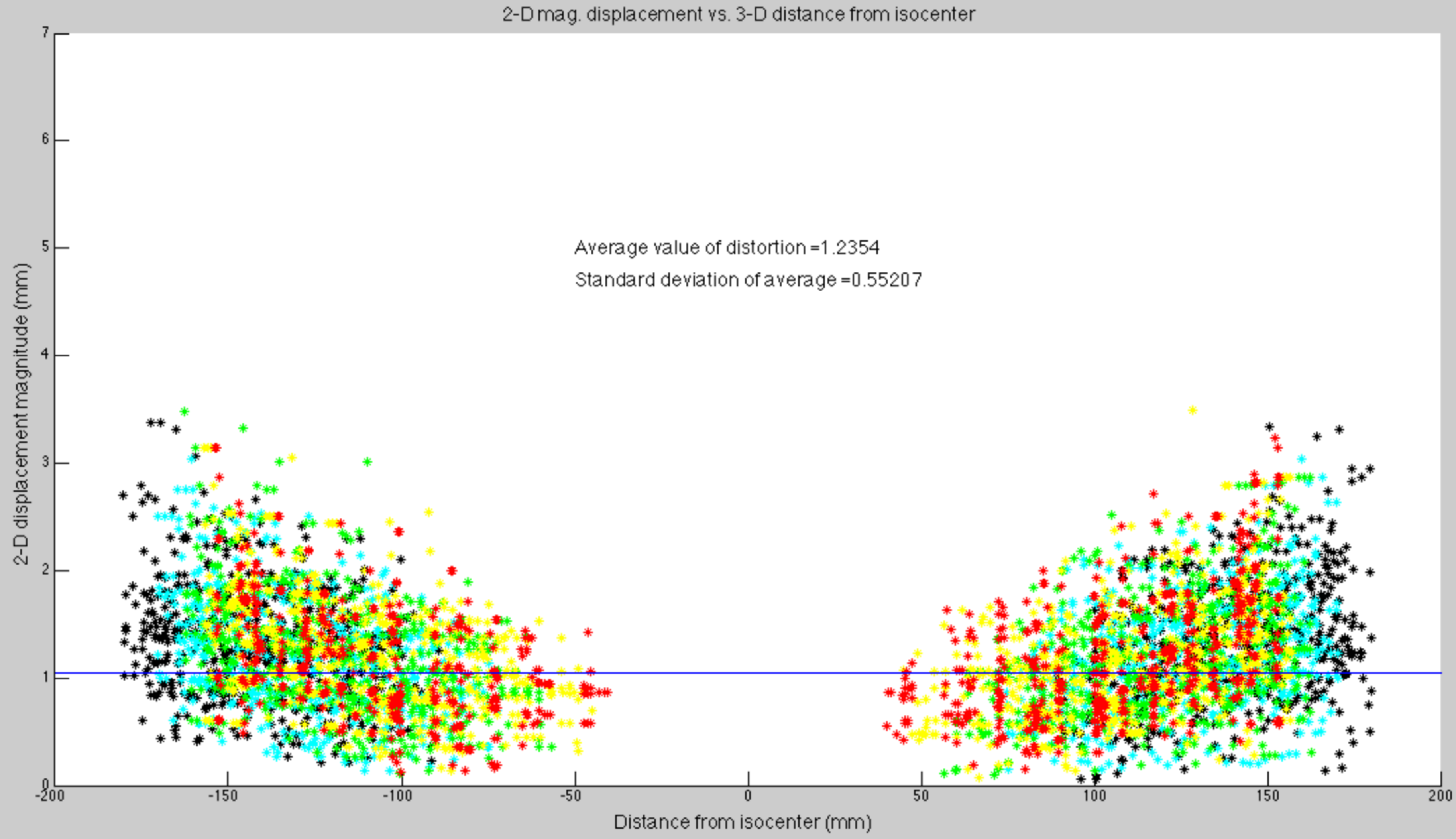




MRI

Calaboration with CIRS

ViewRay 3-D Spatial Distortion



Red = 0–19 mm, Yellow = 19–38 mm, Green = 38–57 mm, Cyan = 57–76 mm, Black = 76–95 mm, 5 mm Axial Resolution, Blue line represents pixel spacing

Calaboration with Antolak & Jackson

Conclusions

- Our clinic finds the ViewRay MRIdian to be highly accurate clinical tool
- MRTC allows visualization of targets and OARs during entire treatment
- Robust QA of MRTC possible

DEPARTMENT OF
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University of Wisconsin
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RTTs

ViewRay & CIRS

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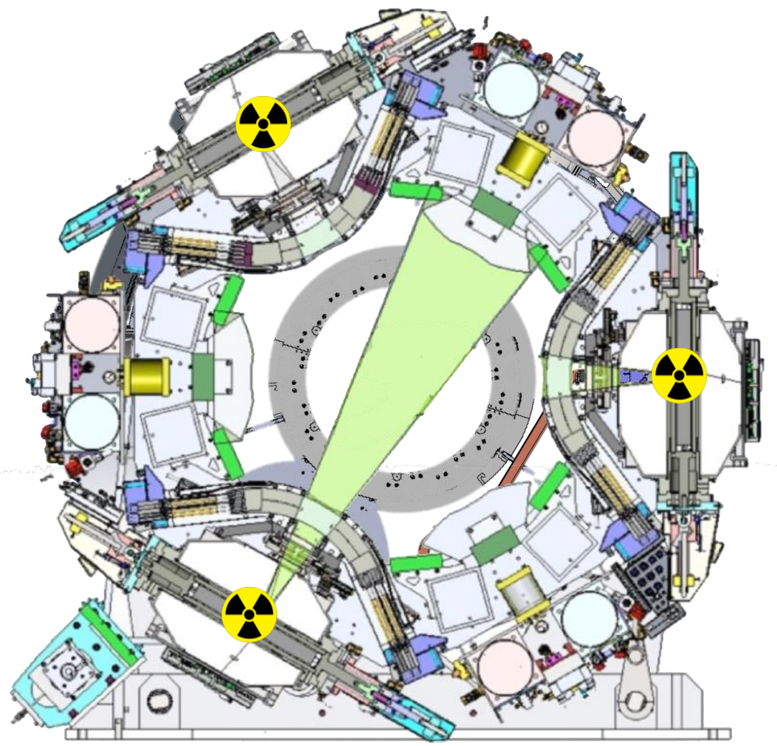
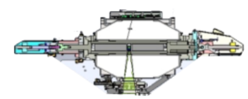
Recently Announced Linac System

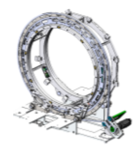


Cobalt ^{60} X 3

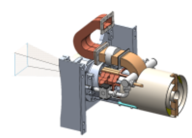


DU Heads X 3

MLC's X 2



Heavy Gantry X 1
Install & Other



Linac Sub-system*

*Technology in development. Descriptions and performance subject to change. Not available for sale or clinical use in the United States or for clinical use elsewhere.

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