Advanced Techniques in RT: MR-Linac

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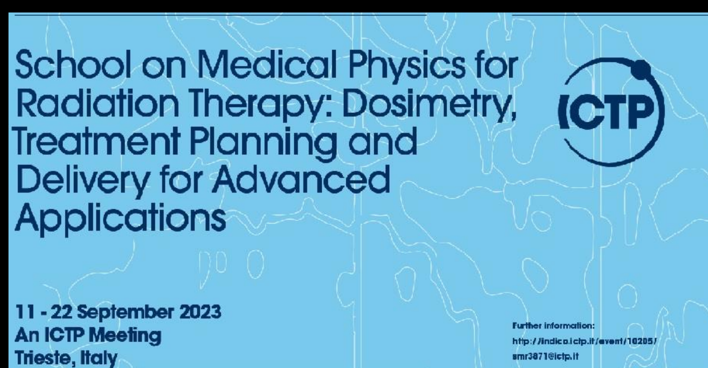

September 2019

POINT/COUNTERPOINT

Suggestions for topics suitable for these Point/Counterpoint debates should be addressed to Habib Zaidi, Geneva University Hospital, Geneva, Switzerland: habib.zaidi@hcuge.ch; Jing Cai, The Hong Kong Polytechnic University, Hong Kong: jing.cai@polyu.edu.hk; and/or Gerald White, Colorado Associates in Medical Physics: gerald.white@mindspring.com. Persons participating in Point/Counterpoint discussions are selected for their knowledge and communicative skill. Their positions for or against a proposition may or may not reflect their personal opinions or the positions of their employers.

MRI-linac systems will replace conventional IGRT systems within 15 years

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IG Technologies - Generation I

Ultrasound

kV Radiographic

Portal Imaging

Markers (Active and Passive)

Courtesy: Dr David Jaffray

IG Technologies - Generation II

Siemens
PRIMATOM™

kV CT
Approach

TomoTherapy
Hi-Art™

MV CT
Approach

Elekta Synergy™

Siemens MVision™

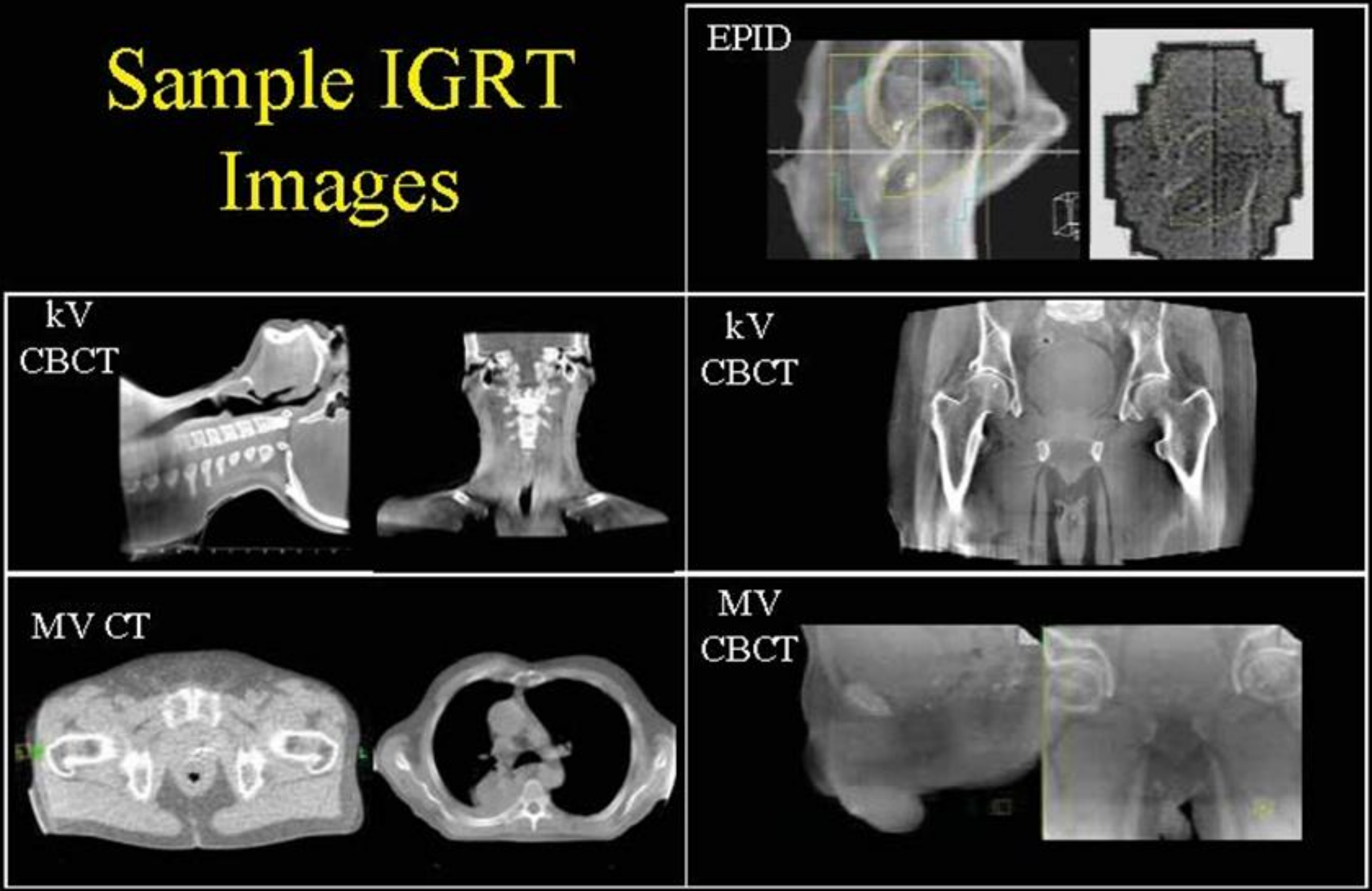
Varian OBI™

Siemens Artiste™

kV and MV Cone-beam CT
Approach

Courtesy: Dr David Jaffray

Sample IGRT Images



Courtesy: Dr David Jaffray

Adaptive RT (ART)

Phys. Med. Biol. **42** (1997) 123–132. Printed in the UK

PII: S0031-9155(97)67292-9

Adaptive radiation therapy

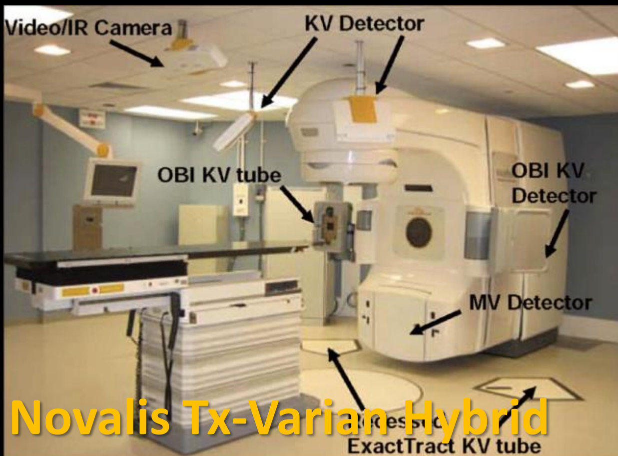
Di Yan†, Frank Vicini, John Wong and Alvaro Martinez

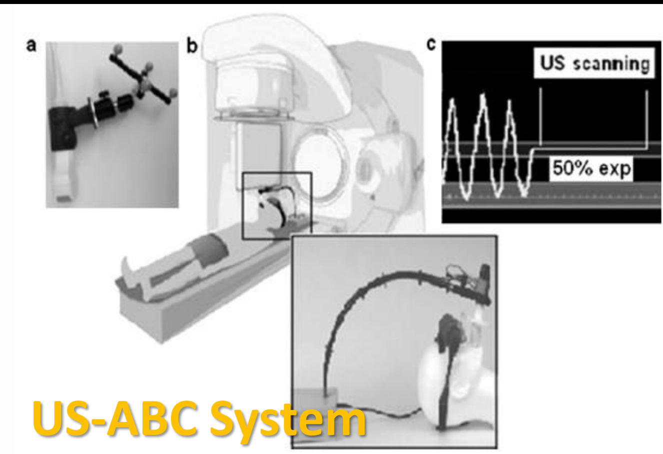
Department of Radiation Oncology, William Beaumont Hospital, Royal Oak, MI 48073, USA

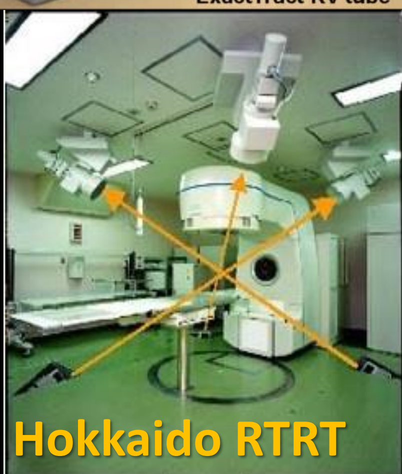
Received 11 August 1995, in final form 29 August 1996

Abstract. Adaptive radiation therapy is a closed-loop radiation treatment process where the treatment plan can be modified using a systematic feedback of measurements. Adaptive radiation therapy intends to improve radiation treatment by systematically monitoring treatment variations and incorporating them to re-optimize the treatment plan early on during the course of treatment. In this process, field margin and treatment dose can be routinely customized to each individual patient to achieve a safe dose escalation.

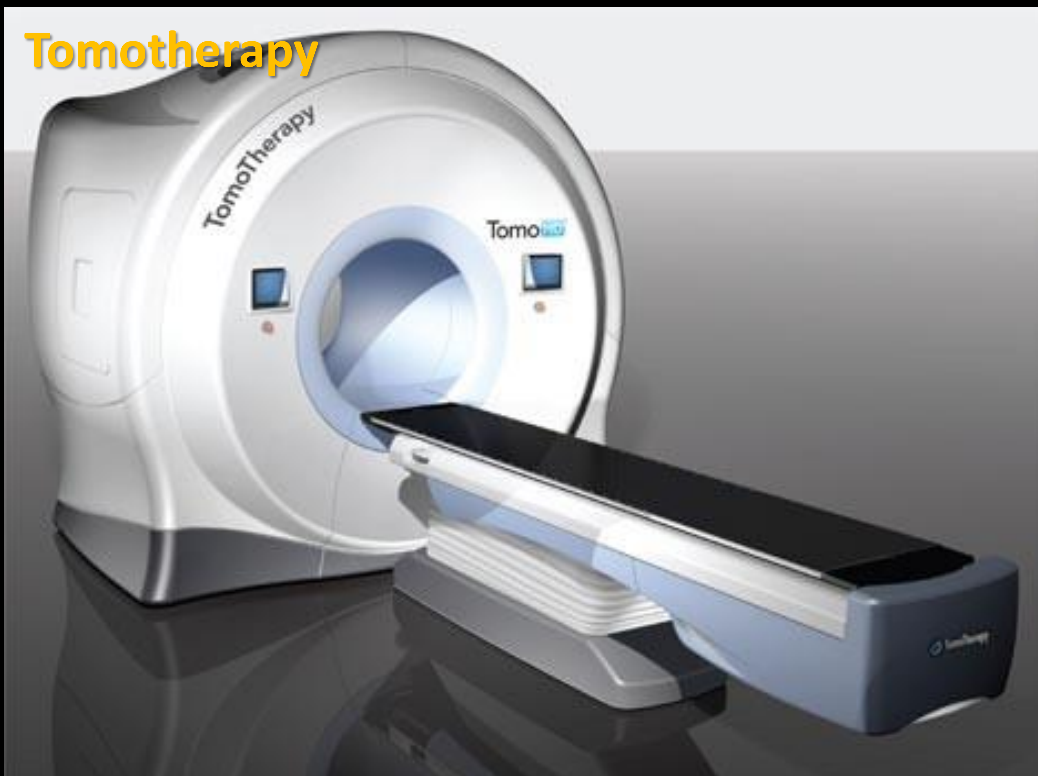
Linac-X-ray Hybrids – Generation III

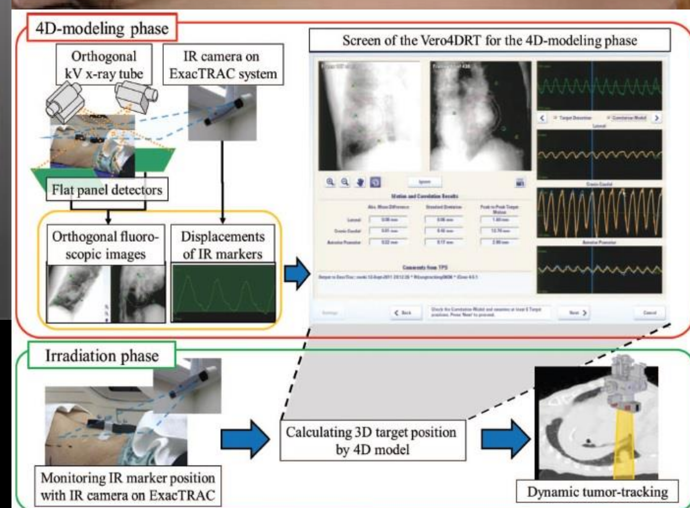






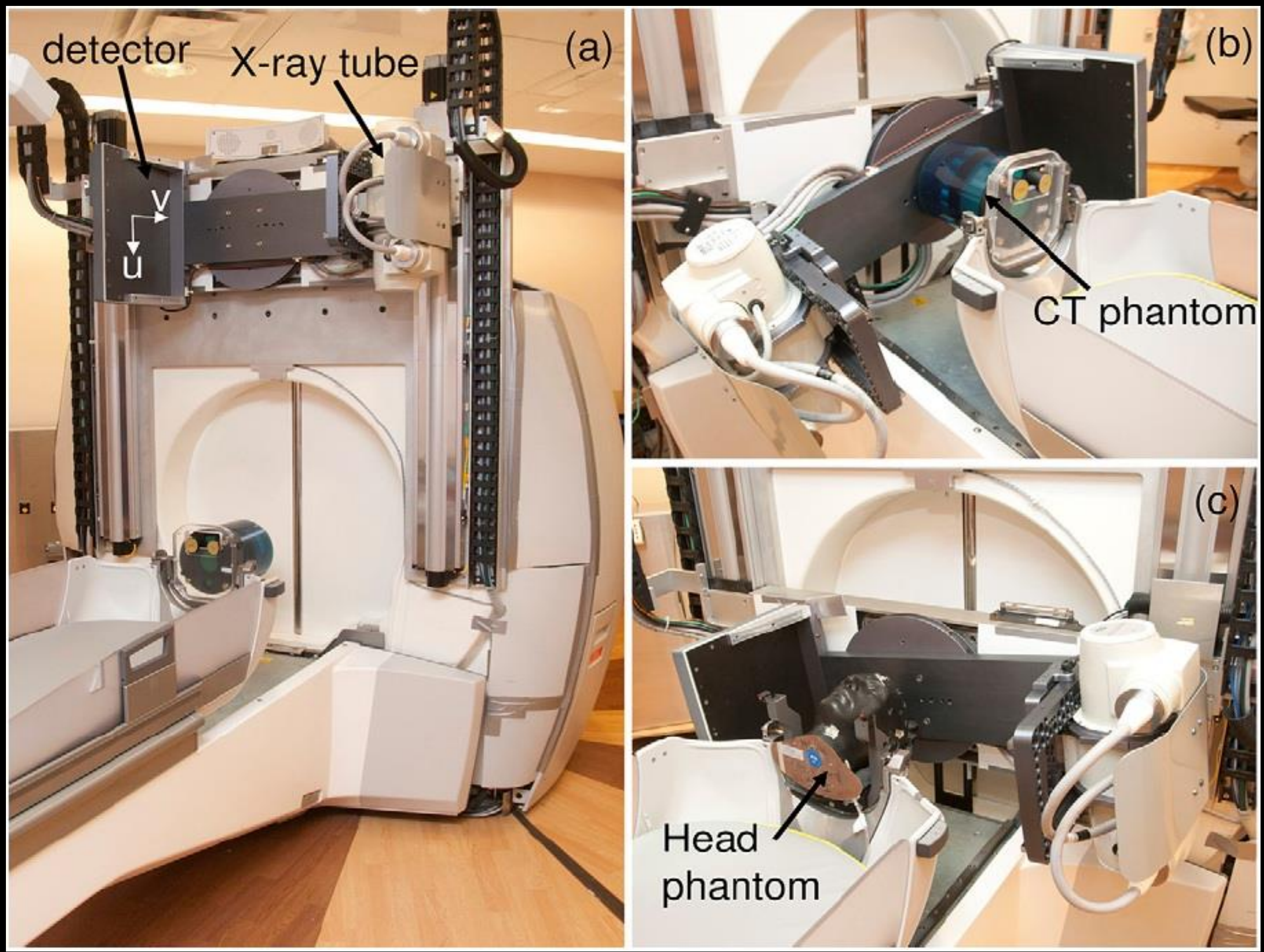
Ring Gantry – Generation IV





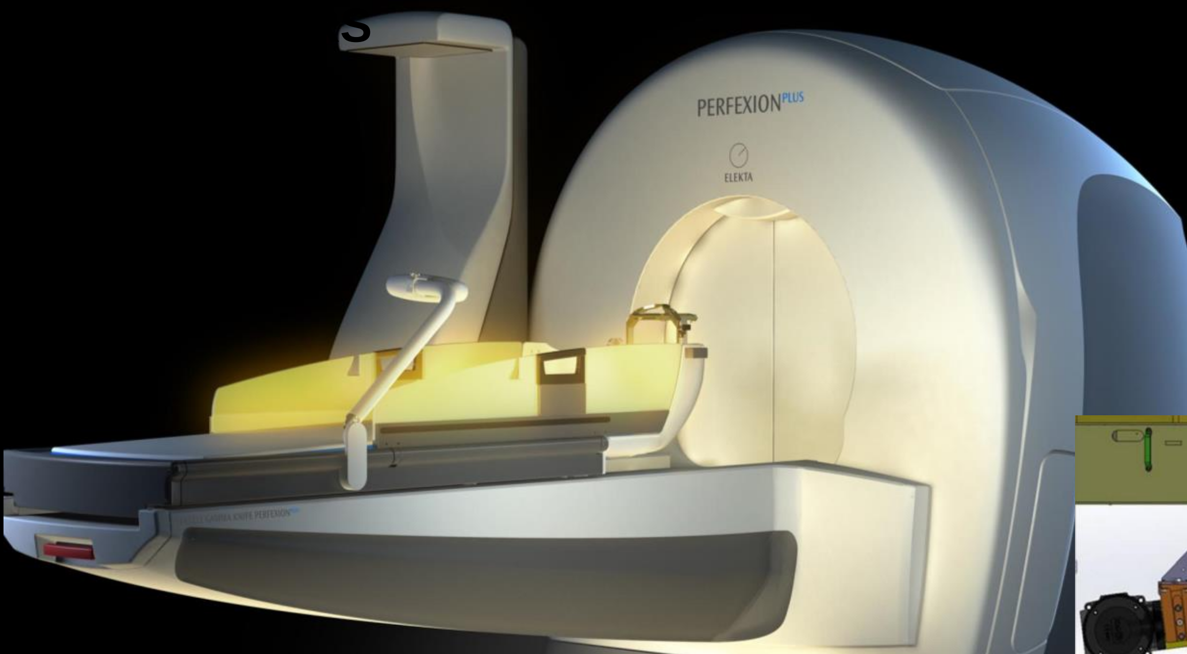
Mukumoto *et al.*, Med Phys 2013;40(4):041706

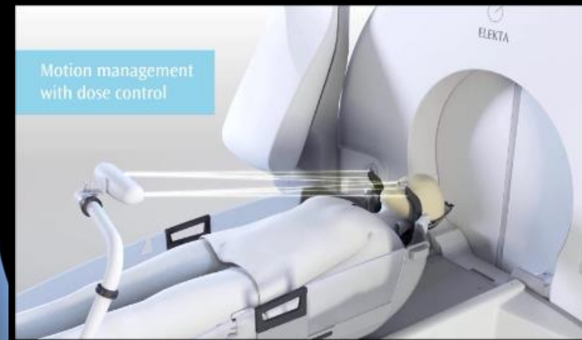
GammaKnife-CBCT (Frameless)



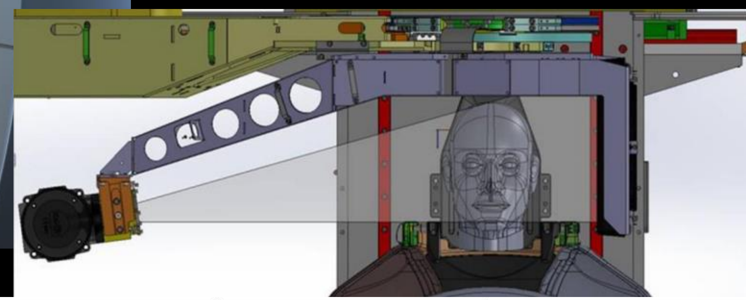
Ruschin *et al.*, IJROBP 2013;85(1):243-250

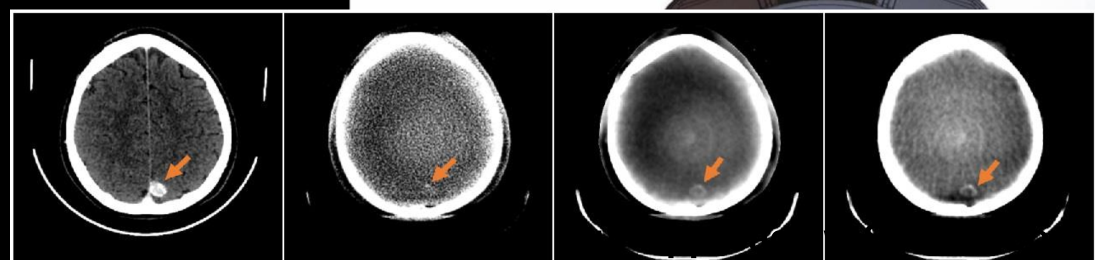
GammaKnife Icon®





Frameless Optical Guidance





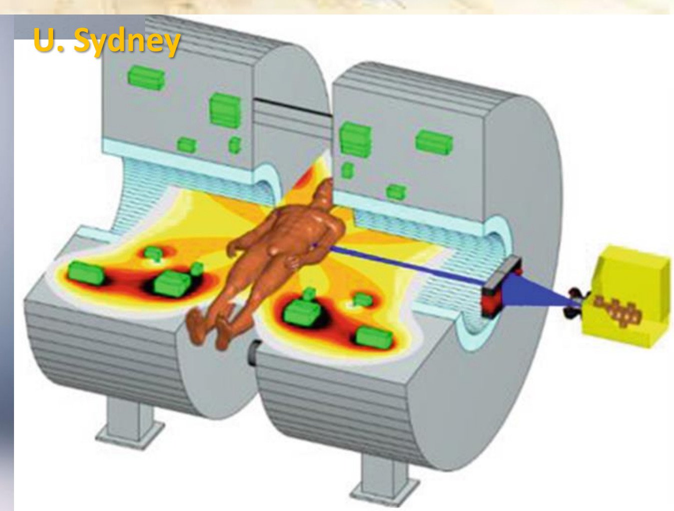
Hashemi *et al*., Med Phys 2017

SRS – Evolution of Immobilization

- Frame-less, bite-block-less, stereotactic radiosurgery
- UCSD has an extensive experience (since 2009)

- Setup time: 5-7 min
- Treats in 15-min slot

MR-Linac – Generation V



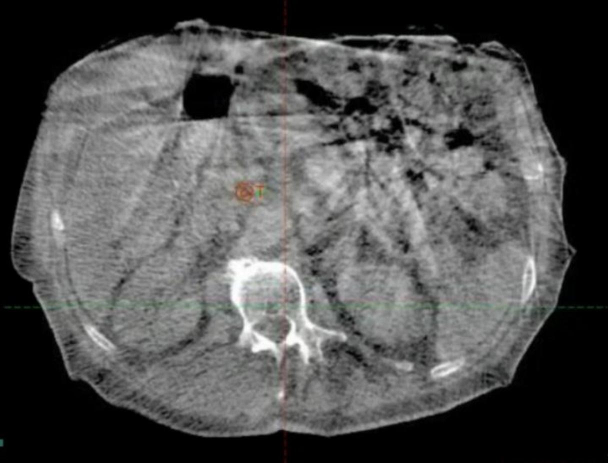
Why MRI?

Press Esc to exit full screen

Principles behind MRgRT

Daily Treatment Imaging with MRI:
Superior Soft Tissue Resolution

Cone Beam CT



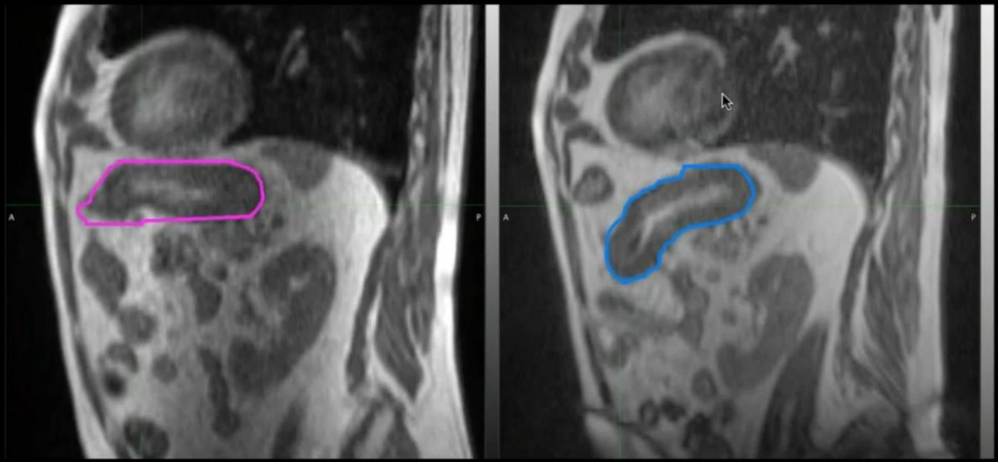
0.35T MRI

BAPTIST HEALTH SOUTH FLORIDA

Why Adapt?

Press Esc to exit full screen

ART to avoid missing target coverage



K. Mittauer, B. Paliwal, P Hill, J. E. Bayouth, M. W. Geurts, A. M. Baschnagel, K. A. Bradley, P. M. Harari, S. Rosenberg, J. V. Brower, A. P. Wojcieszynski, C. Hullett, R A. Bayliss, Z. E. Labby, M. F. Bassetti, "A New Era of Image Guidance with Magnetic Resonance-guided Radiation Therapy for Abdominal and Thoracic Malignancies," Cureus 2018.

MRI-Linac Systems

MRgRT system	Radiation	Magnet field		
		Configuration	Orientation	Strength
ViewRay MRIdian Cobalt	Cobalt-60	split superconducting close bore	Perpendicular	0.35 T
ViewRay MRIdian Linac	6 MV	split superconducting close bore	Perpendicular	0.35 T
MagnetTx Aurora RT	6 MV	superconducting rotating open bore	Parallel	0.5 T
Australian MRI-Linac	6 MV	superconducting open bore	Parallel/ Perpendicular	1.0 T
Elekta Unity	7 MV	superconducting close bore	Perpendicular	1.5 T

Elekta Unity®

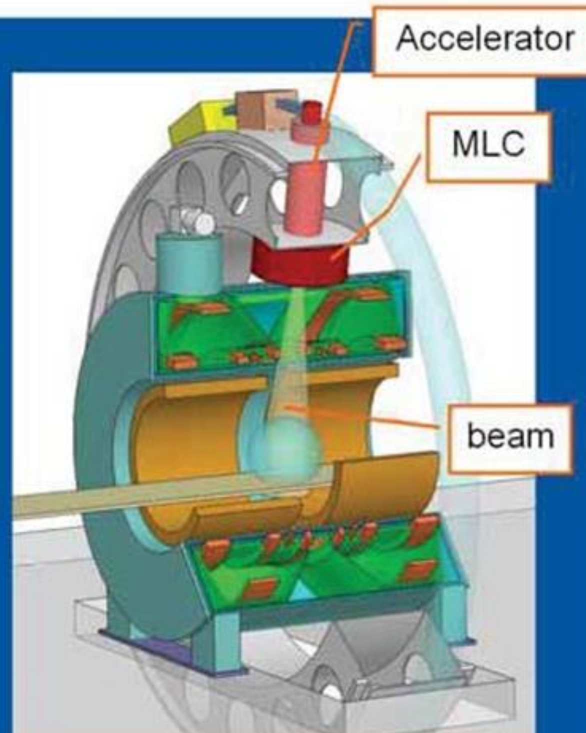
Elekta Unity®

Concept of integrated MR/Linac system

Universitair Medisch Centrum Utrecht

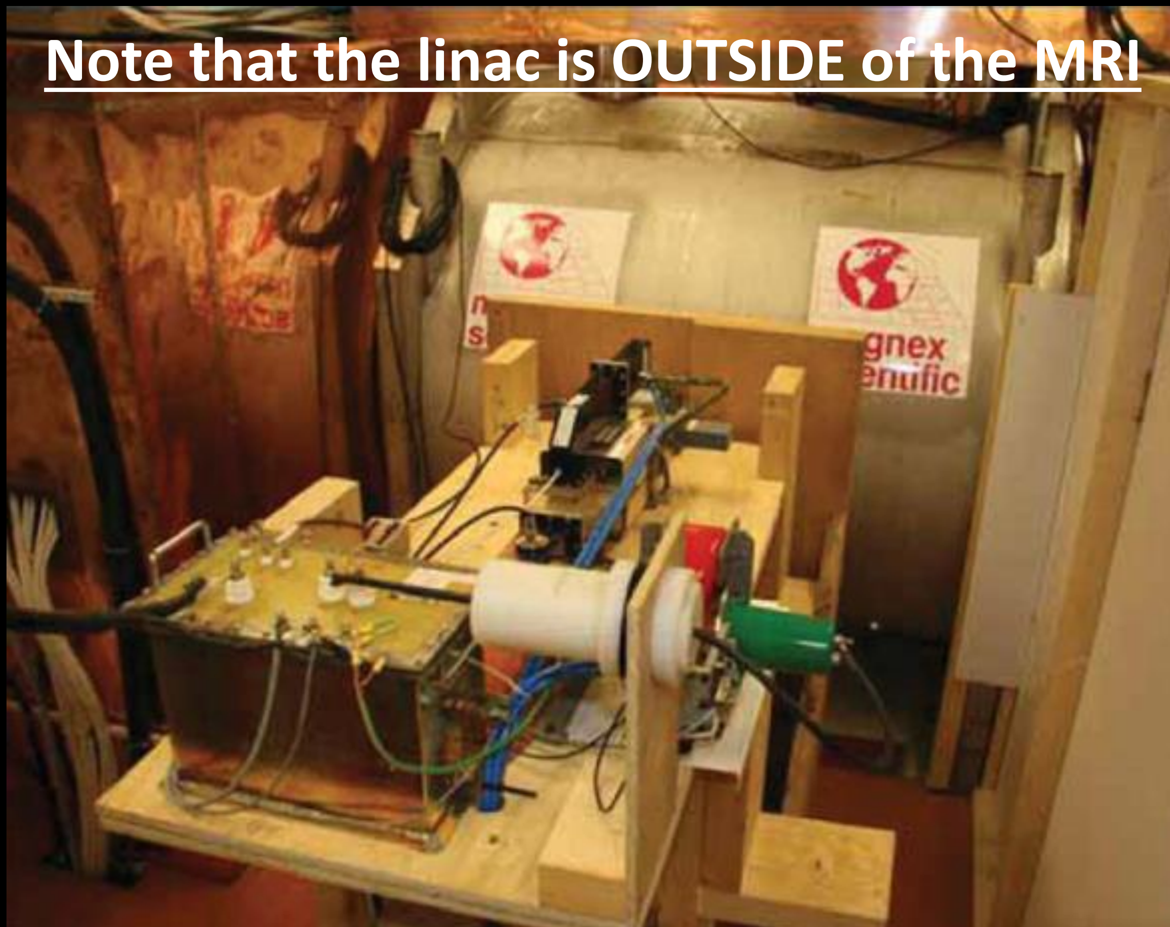
- Cylindrical 1.5T closed-bore MRI
- Linac in z=0 plane outside magnet
- MR parts transparent to beam
- Field-sensitive Linac components to be located in low-field zone
- Proper RF shield between Linac and MR system

<u>Concept from 1999</u>



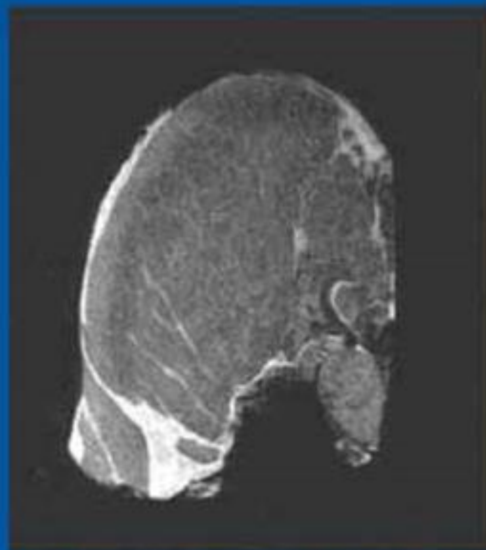
Courtesy: Dr J. Lagendijk

Elekta Unity®



Courtesy: Dr J. Lagendijk

Elekta Unity®



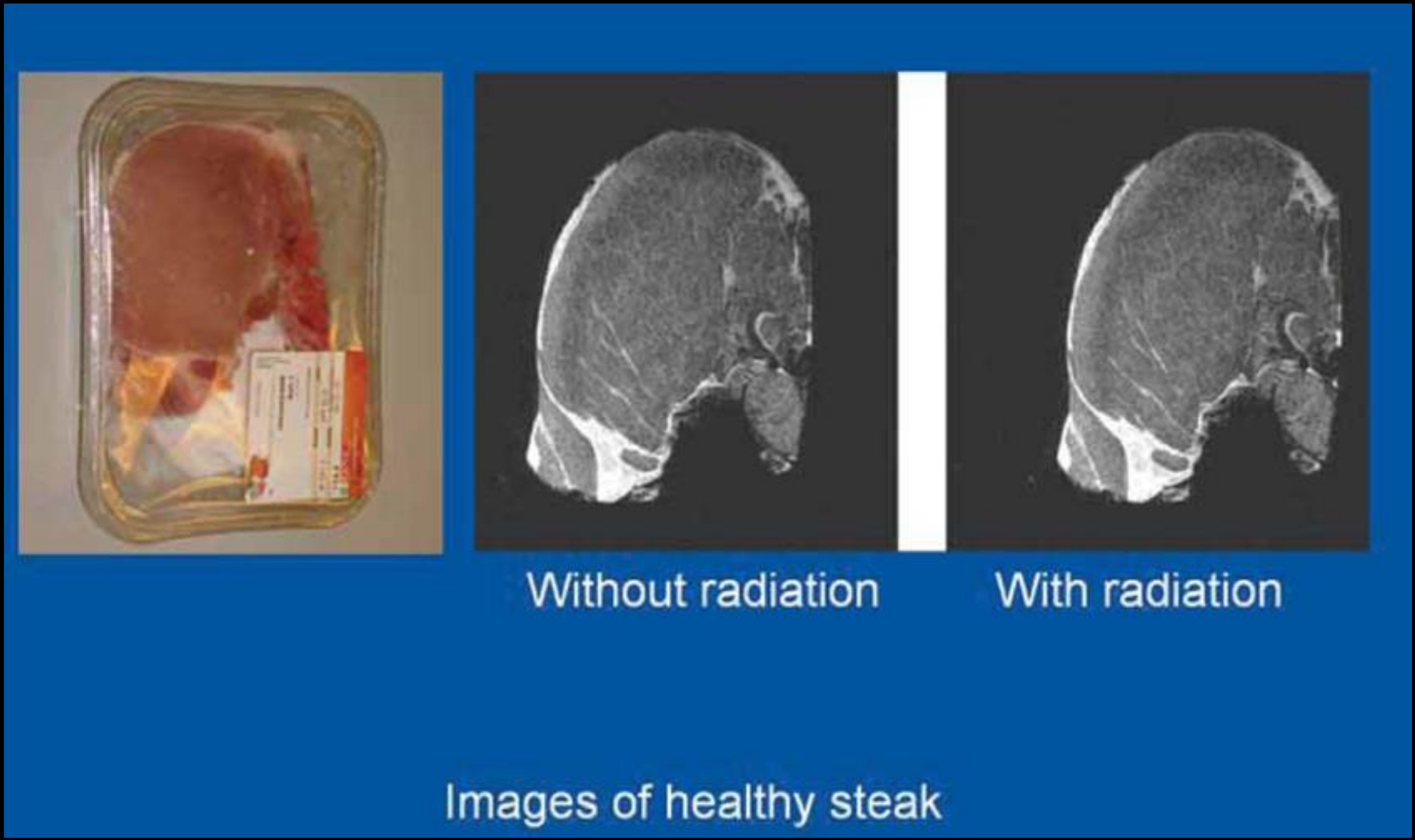
Without radiation

With radiation

Images of healthy steak

Courtesy: Dr J. Lagendijk

Elekta Unity®



Courtesy: Dr J. Lagendijk

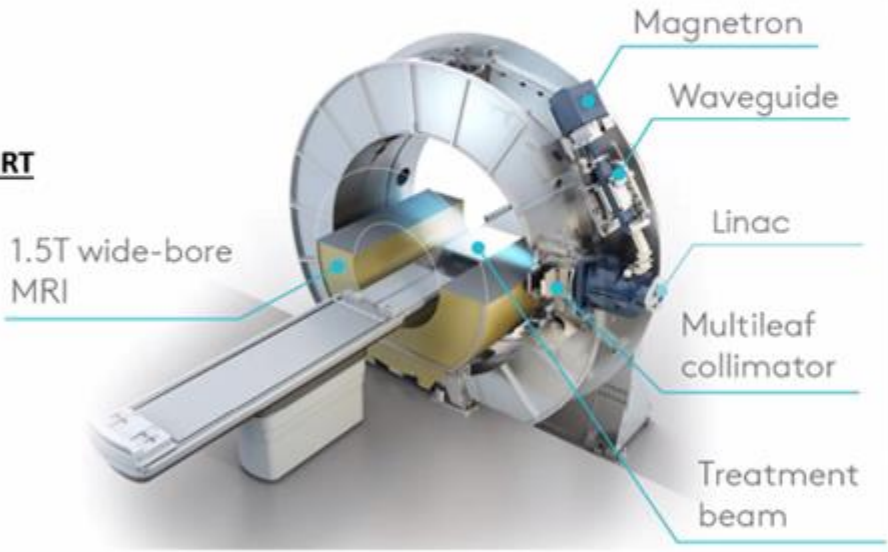
Elekta Unity®

- 1.5T MRI
  - Low B-Field Zone at Linac Gun
  - Gap Between Gradient Coils
  - Cryostat With Reduced Attenuation
- 7MV Photon Mode (non-flat)
- Flattening Filter Free (FFF) Mode
- 143.5cm SAD
- 7-mm MLC at Isocenter @6cm/s
- 425 MU/min
- 6 RPM Gantry Speed
- 57.4cm(W)x22cm(L) Max. Field Size
- Collimator fixed @90°
- Step-and-Shoot IMRT (no VMAT, yet)
- Real-Time *2.5D* MR Imaging
- EPID Near Beam-Stop
- 1D Couch DOF, thus Virtual Couch Shift-Only

Elekta Unity®

Unity overview

- Beam Energy: **7 MV FFF**
- SAD: **143.5 cm**
- Maximum Field Size: **22x57.4 cm²**
- Treatment Delivery: **Step & Shoot IMRT**
- Dose Rate: **425 MU/min**
- Max Gantry Speed: **6 RPM**
- Leaf Speed: **6 cm/s**
- Collimator: **90°**

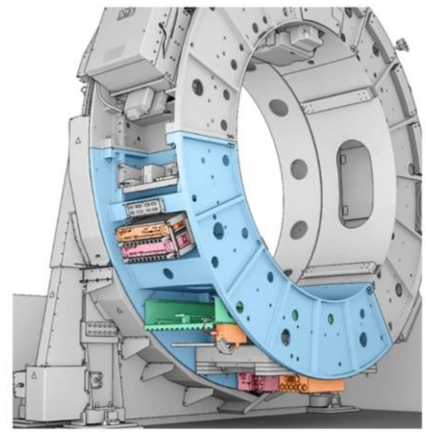


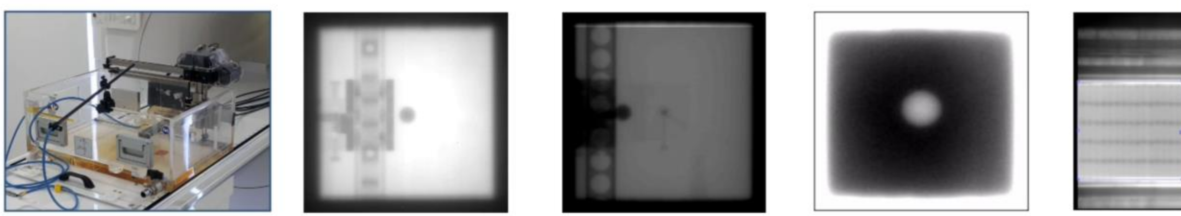
Elekta Unity®

Portal imaging on the MRLinac

An EPID as verification tool

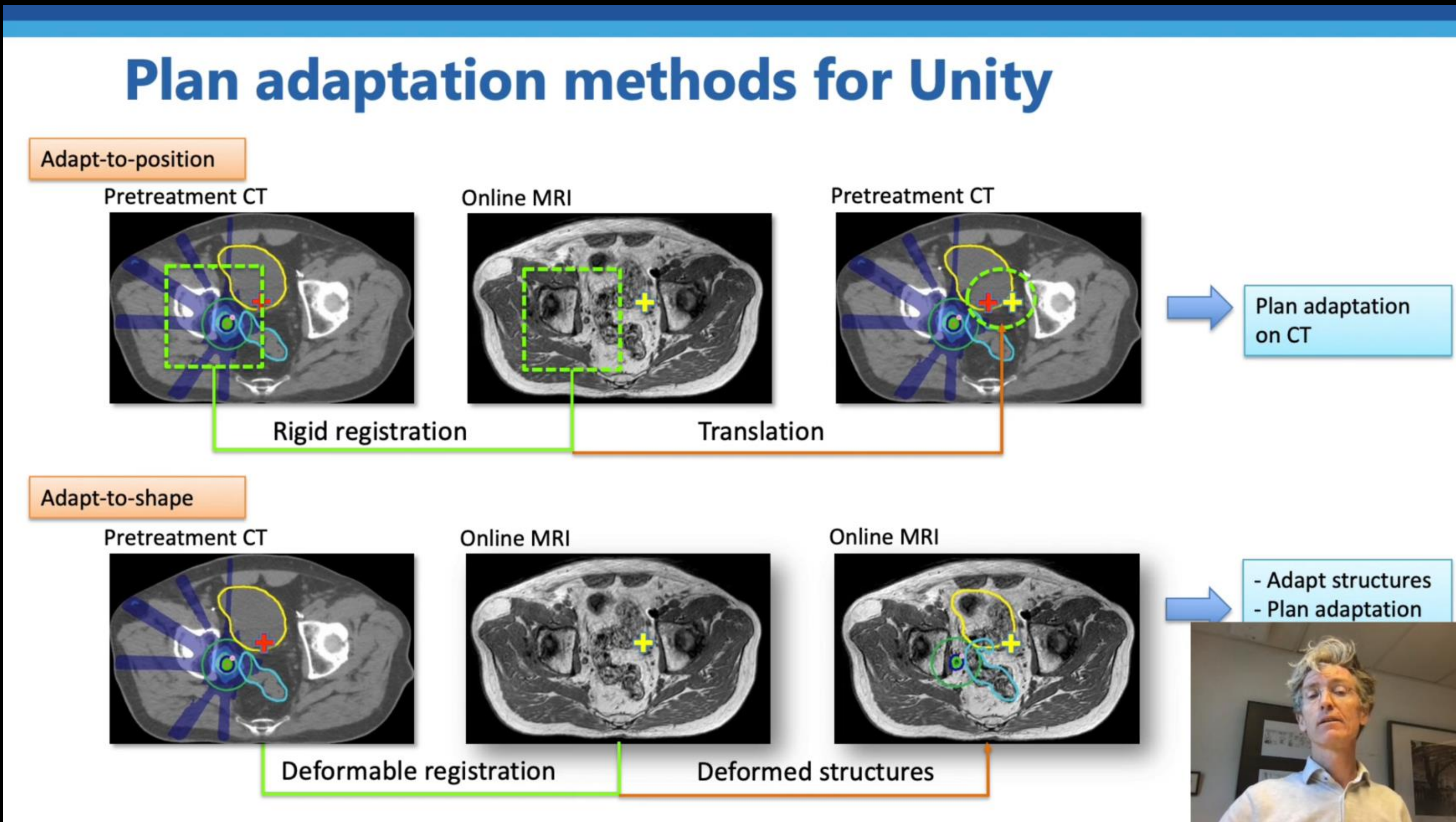
- The geometrical alignment and QA tool
  - Beam alignment
  - MLC calibration
  - Watertank alignment
  - Measurement equipment alignment (IC, 2D/3D detector)
- EPID panel rigidity and alignment <0.1 mm





Courtesy: Dr B. Raaymakers

Elekta Unity®

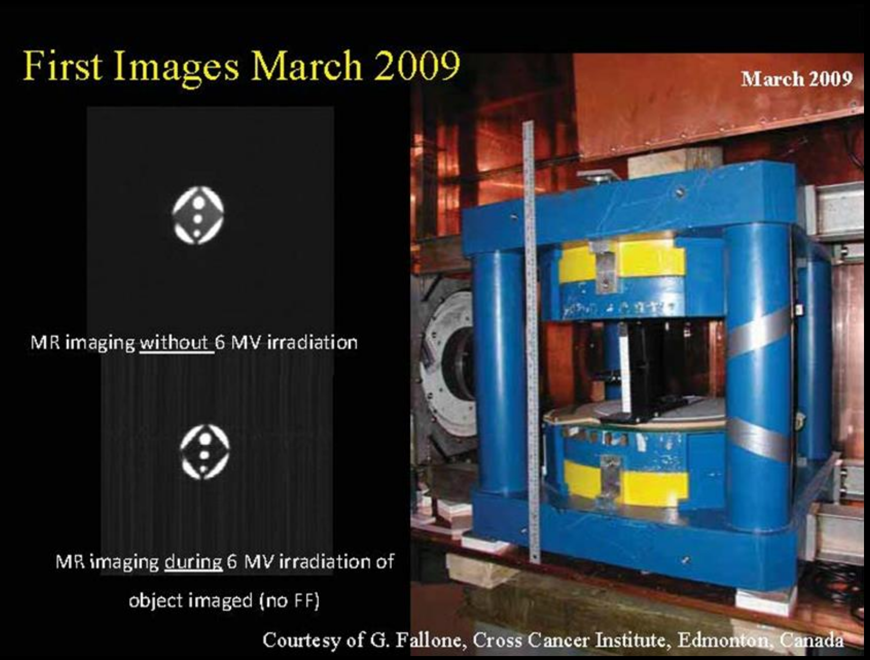


Courtesy: Dr B. Raaymakers

Elekta Unity®

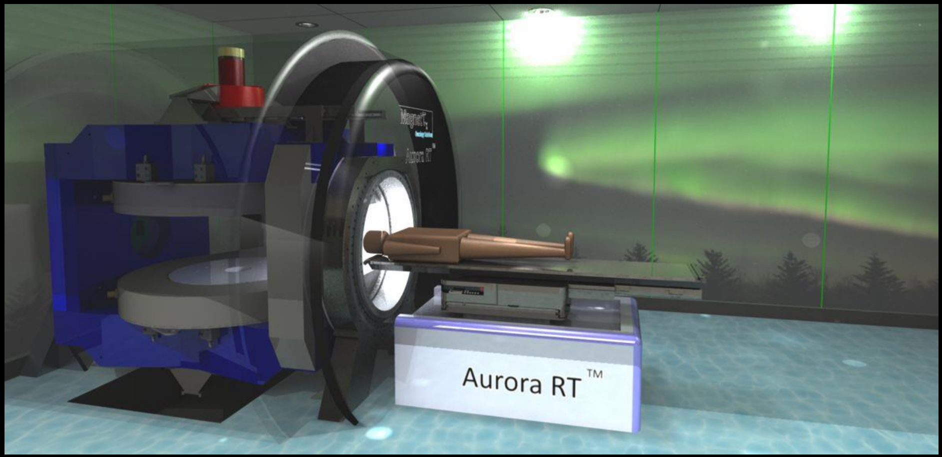
- Future Developments:
  - Improved Contouring and Treatment Planning
    - AI-driven
  - Gating
    - Requires real-time target tracking
  - VMAT
    - Static Delivery Mode
    - and, Helical Delivery Mode?

Aurora RT®



Courtesy: Dr Gino Fallone

Aurora RT®



- Linac Energy: 6 MV
- MultiLeaf Collimator (MLC): 120 Leaves (Standard, Micro)
- MR: 0.5T
- Patient Opening (Braces): 110 cm W x 60 cm H
- Linac-MR Configuration: Aligned – Rotate Together (**No ERE!**)
- MR Position: Rotates 360 Degrees
- Beam-Orientation: Parallel to Magnetic Field (Minimal Dosimetric Perturbation)
- Bunker and Maze Size: Standard for Linacs (Installation Through Maze)
- MR Cryogens and Venting: None Required
- Beam Modulation: IMRT, VMAT
- Soft-tissue Imaging Rate: Four Images Per Sec
- Treatment Planning: Real-Time Adaptive

Australian MR-Linac System

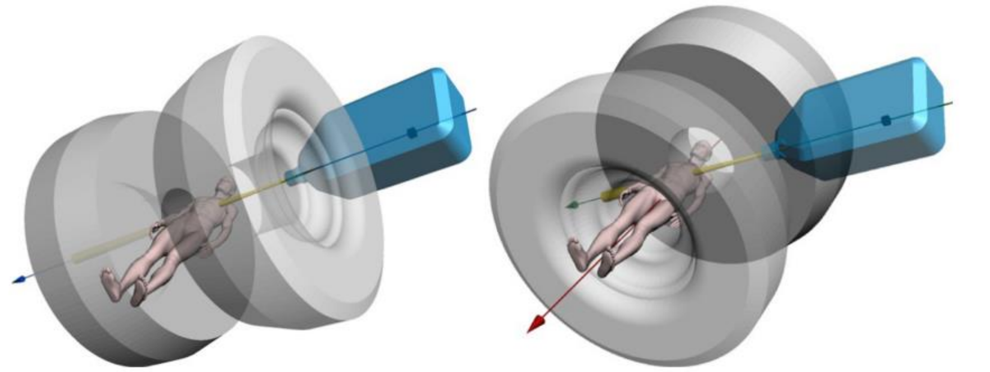


Figure 1 (Left) The inline orientation, that is, linac aligned with B_0. (Right) The perpendicular orientation, that is, linac perpendicular to B_0. Both the orientations are to be experimentally investigated. (Adapted with permission from Constantin et al.[3]) (Color version of figure is available online.)

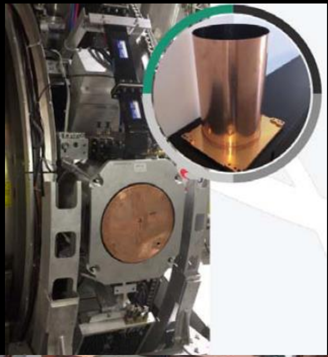
Table 2 A Comparison of the Advantages of the Inline and the Perpendicular Approaches that Will be Experimentally Investigated

Advantages of the Inline Approach (Fig. 1, Left)	Advantages of the Perpendicular Approach (Fig. 1, Right)
No beam attenuation and Compton scatter to the patient from irradiation through the cryostat (if closed bore)	More similar design to mass-produced conventional MRI systems (if closed bore)
Less effect of the B field on electron gun operation	Lower constraints on magnet, gradient coil, and RF design, resulting in higher potential imaging performance and higher B field (if closed bore)
Less effect of the B field on waveguide operation	Lower skin dose
Less effect of the B field on electron transport within the patient: sharper penumbra and no electron return effect	No need to rotate the magnet or the patient
Lower exit dose	
Linac fixed with respect to the magnet. This reduces the need to manage eddy currents or dynamic shimming requirements, where the linac moves with respect to the magnet	

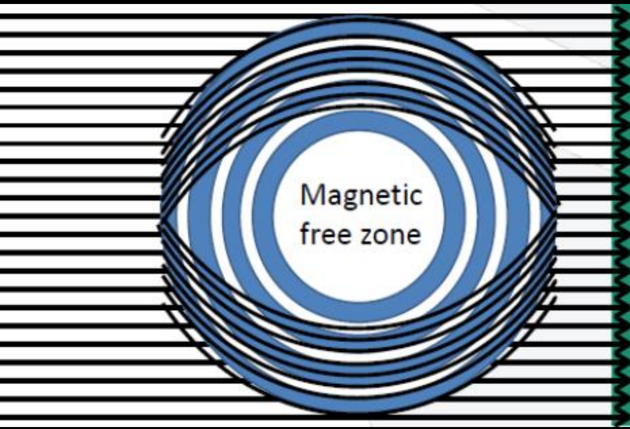
Abbreviation: RF, radiofrequency.

ViewRay MRIdian®

ViewRay MRIdian®

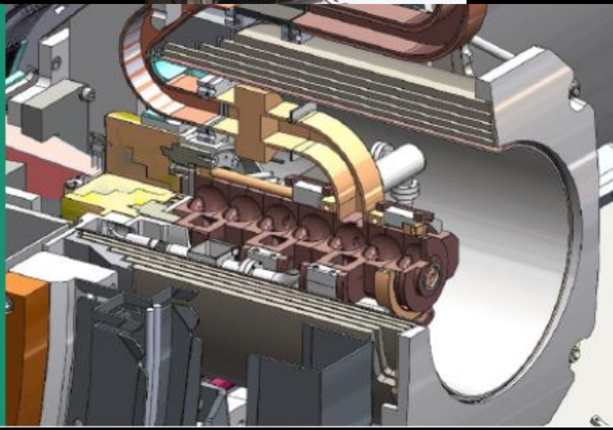


Split MRI necessitates absolute magnetic shielding of the linac

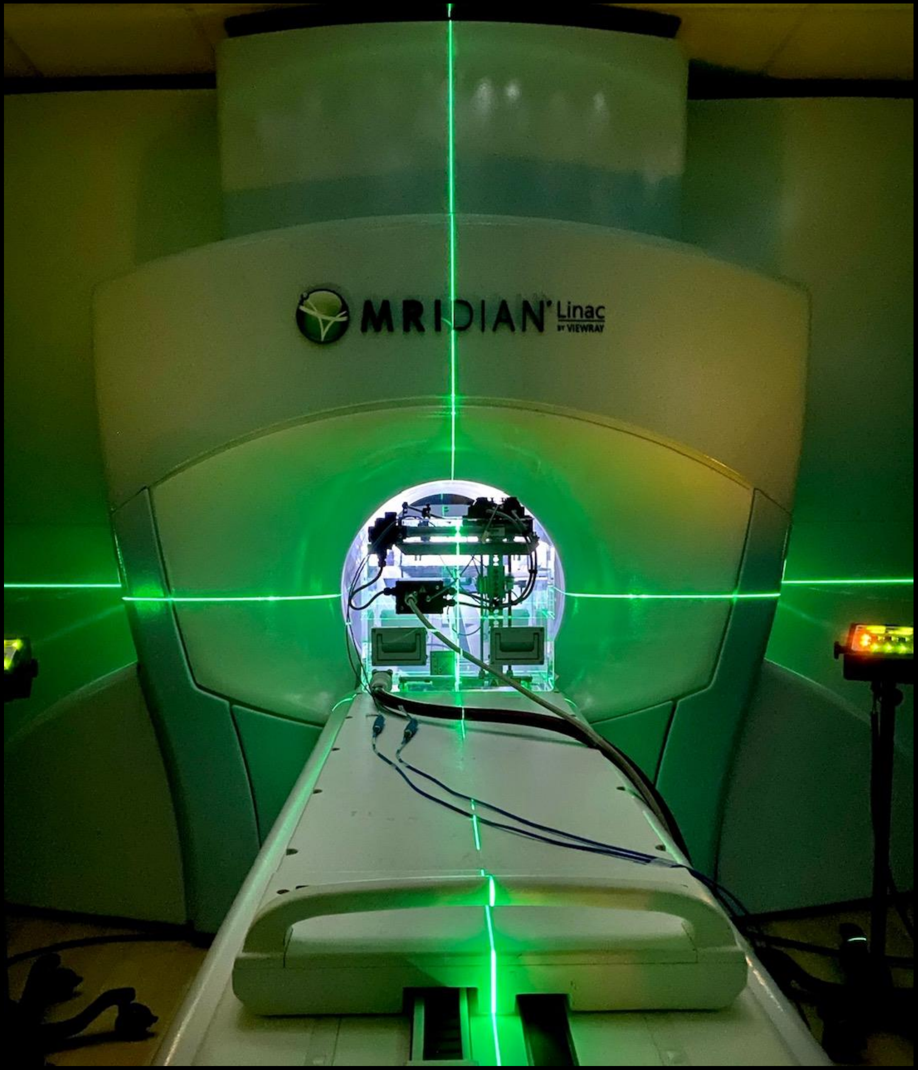


Hide the linac from the MRI

Optimal thicknesses and diameters of 5 concentric cylindrical ferromagnetic (steel) shields, 3 extra (mu-metal) for linac sleeve



MRIdian® @VCU



MRI

Magnet

- 0.35 T split superconducting magnet
  - Minimal susceptibility & chemical artifacts as magnitude $\propto B_o$
- Pop-apart design for non-destructive rigging
- Bore size: Standard 70 cm

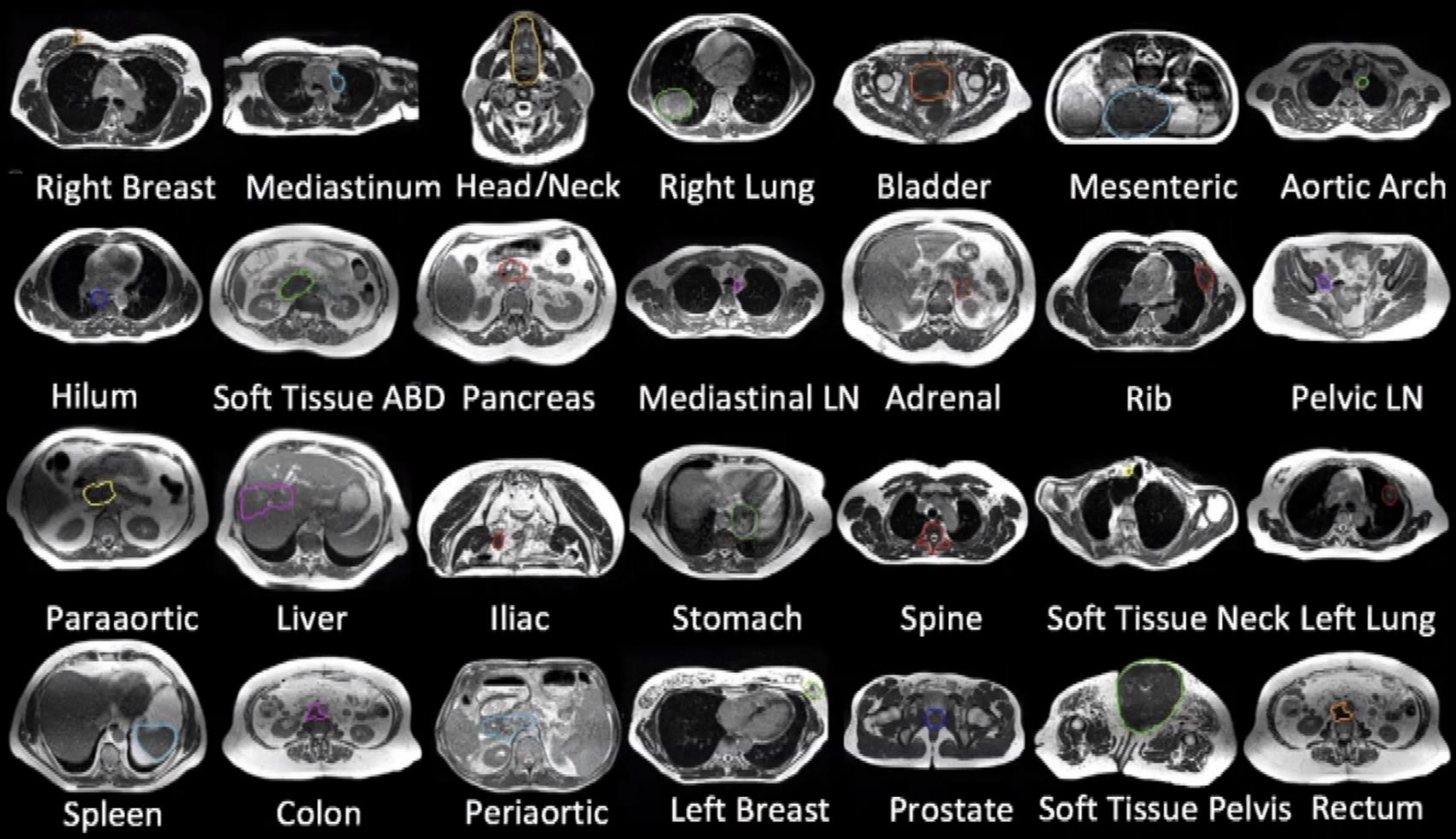
Gradient System

- Optimized gradient cooling
  - 30 kW heat removal for prolonged real-time MRI
- Slew rate performance is equal to the slew rate for standard 1.5 T diagnostic MRIs: Translates to finer slices

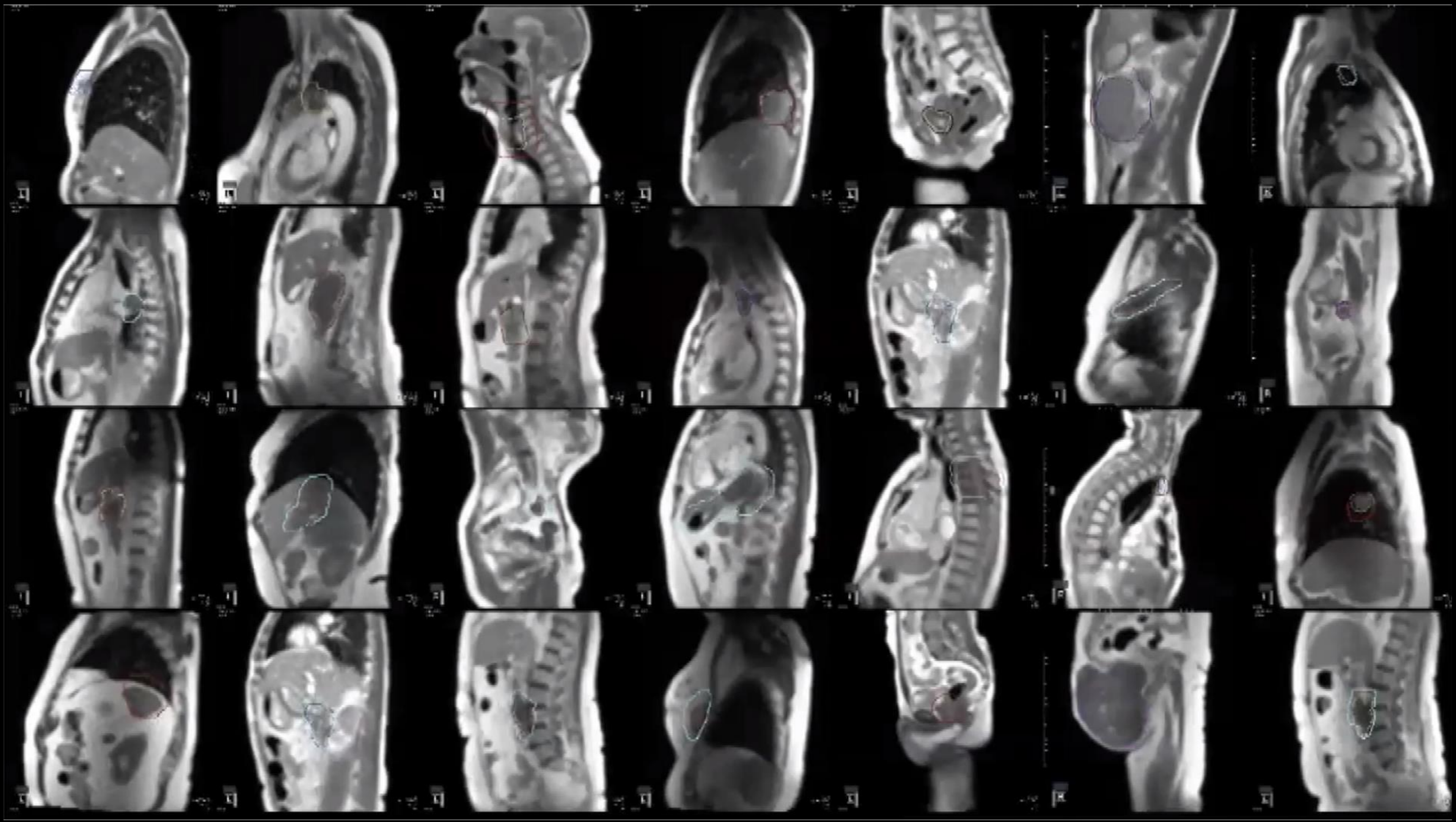
Imaging

- True FISP sequence for 3D imaging, used in planning & ART
- T1w, T2w, DWI/ADC imaging all possible
- 8 frames/sec real time 2D imaging, one plane (e.g., sagittal)
- 19x lower SAR than 1.5T

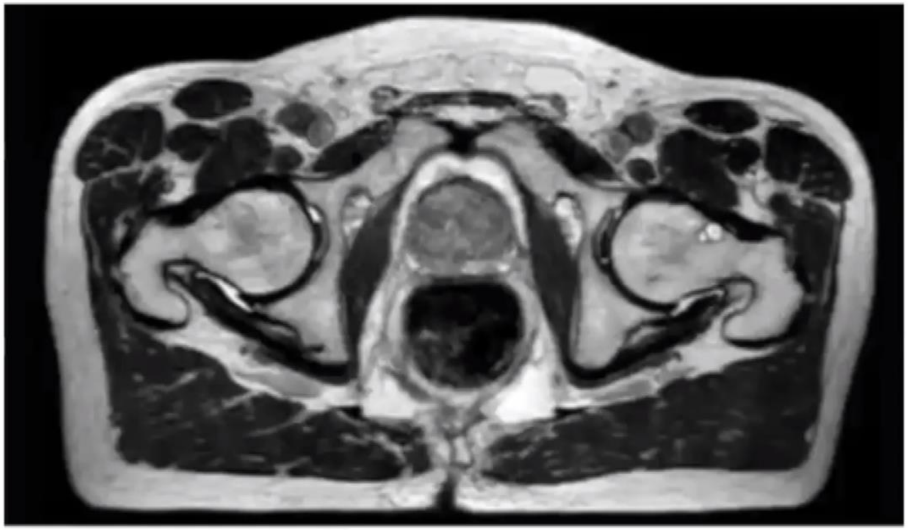
True FISP 3D for Planning



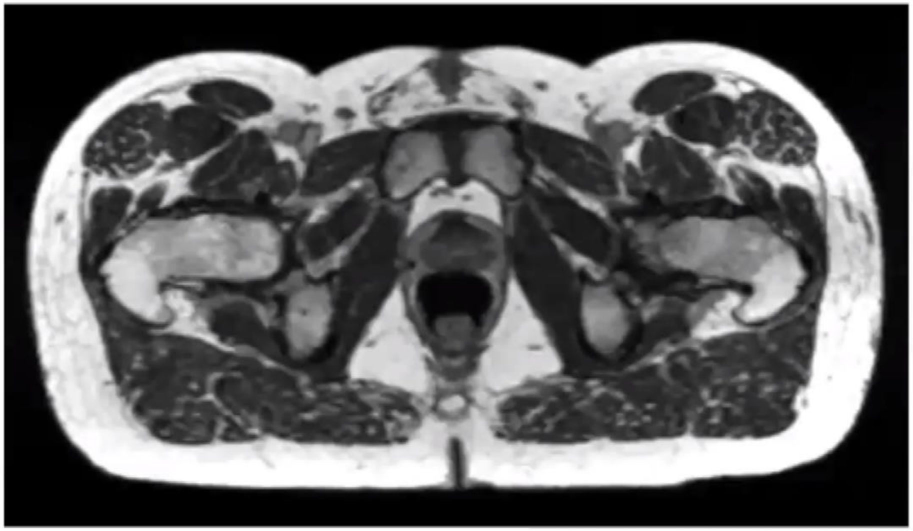
True FISP 2D for Tracking



Head To Head



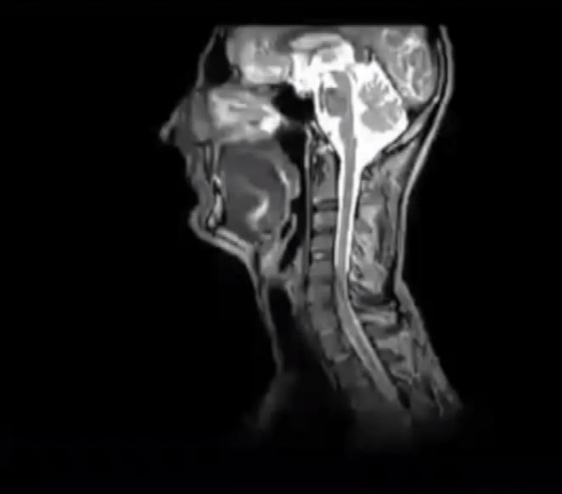
Unity



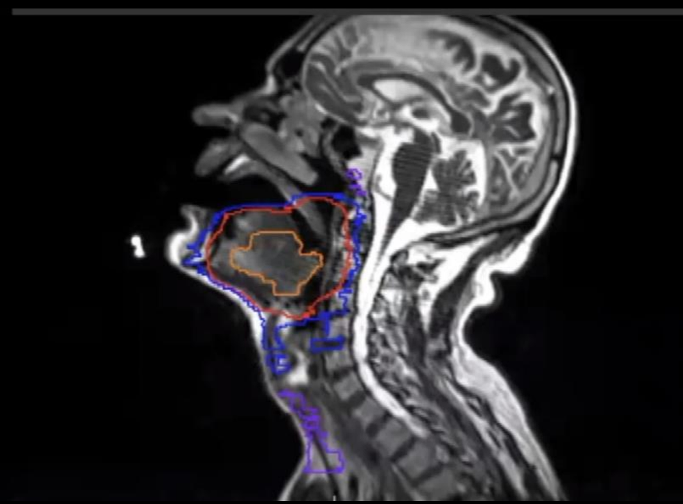
MRIdian

Head To Head

Unity 1.5T



Philips 1.5T

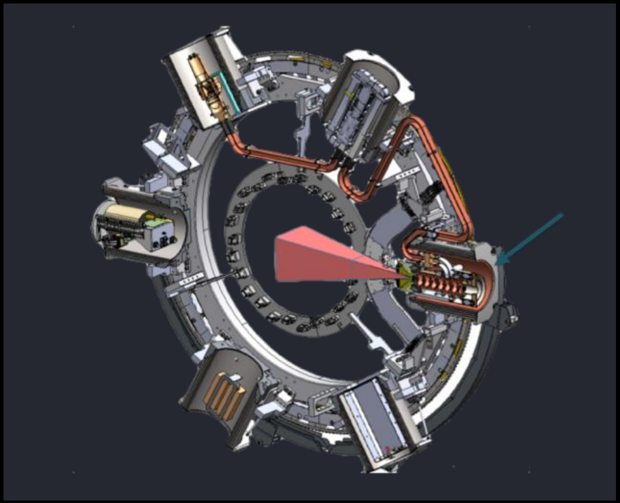


ViewRay 0.35T

Linear Accelerator

Design

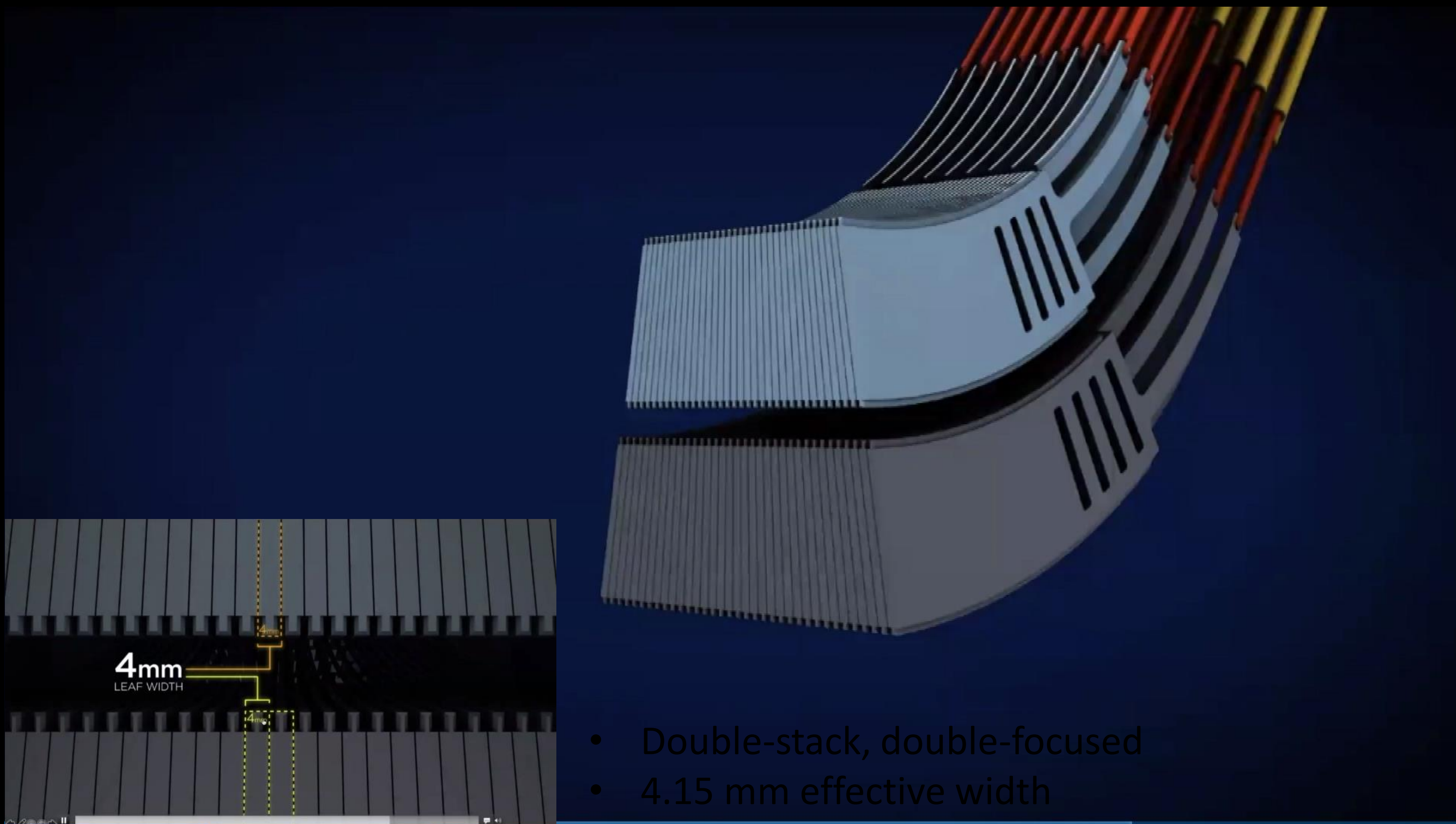
- 6 MV FFF, S-Band
- Triode electron gun designed for low latency beam gating
- Proprietary magnetic and RF-shielding design
- 90 cm SAD (vs 143.5 cm Unity)
- Double-stack, double-focused, 138-leaf MLC
    - Effective leaf width of 0.415 cm @90cm SAD
    - 4 cm/sec speed, for step-shoot IMRT
    - Thus, no secondary jaws
- 27.4 cm x 24.1 cm maximum field size
    - May be limited for whole breast IMRT
- 2 mm x 4 mm minimum field size



Performance

- >~600 cGy/min dose rate @isocenter
- 0.5 mm radius isocenter accuracy

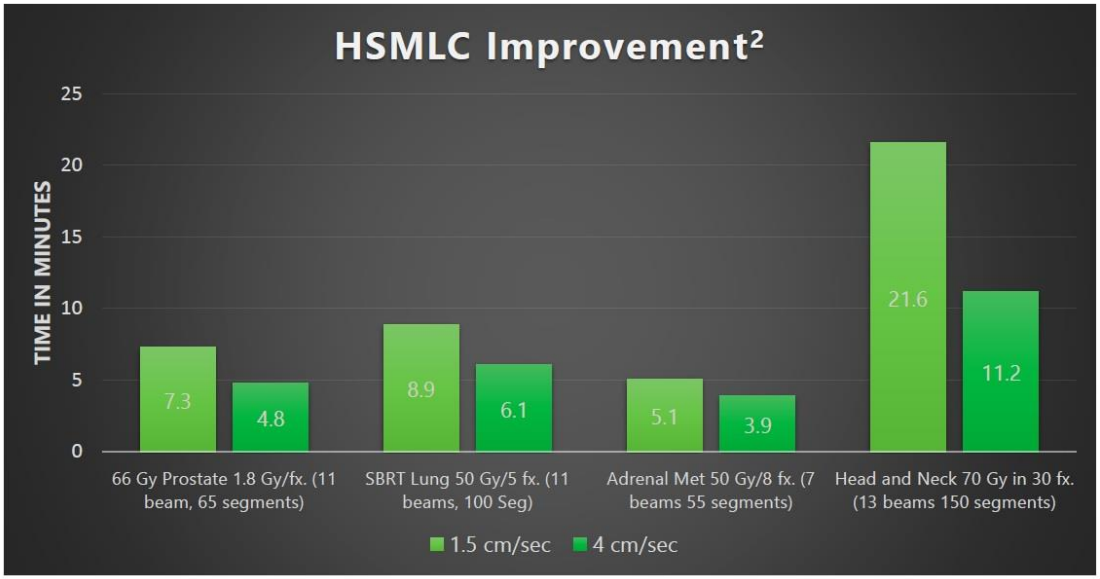
High-Speed MLC



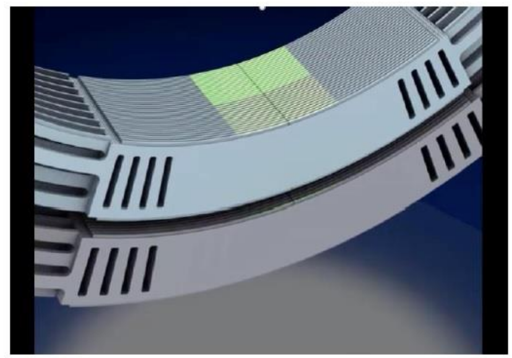
- Double-stack, double-focused
- 4.15 mm effective width

High-Speed MLC

Delivery time improvements from 1.5 cm/sec to 4 cm/sec

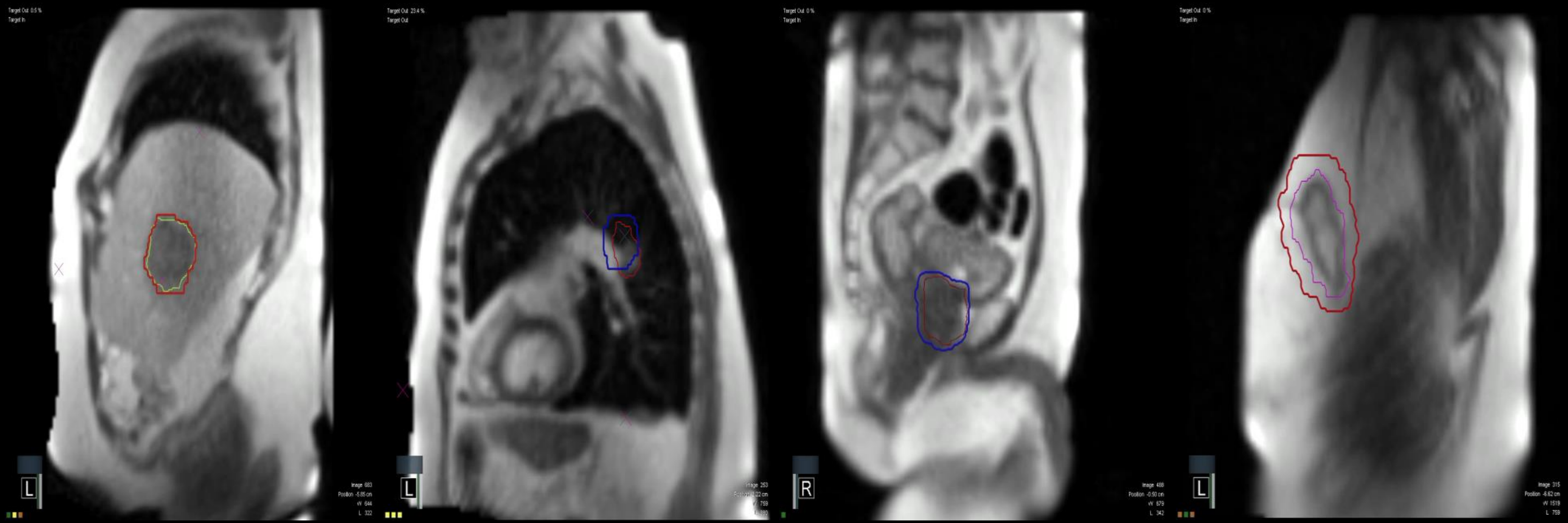


- MRIdian's MLC leaf speed is increasing by almost 300%[1]
- This higher speed will significantly reduce beam delivery times

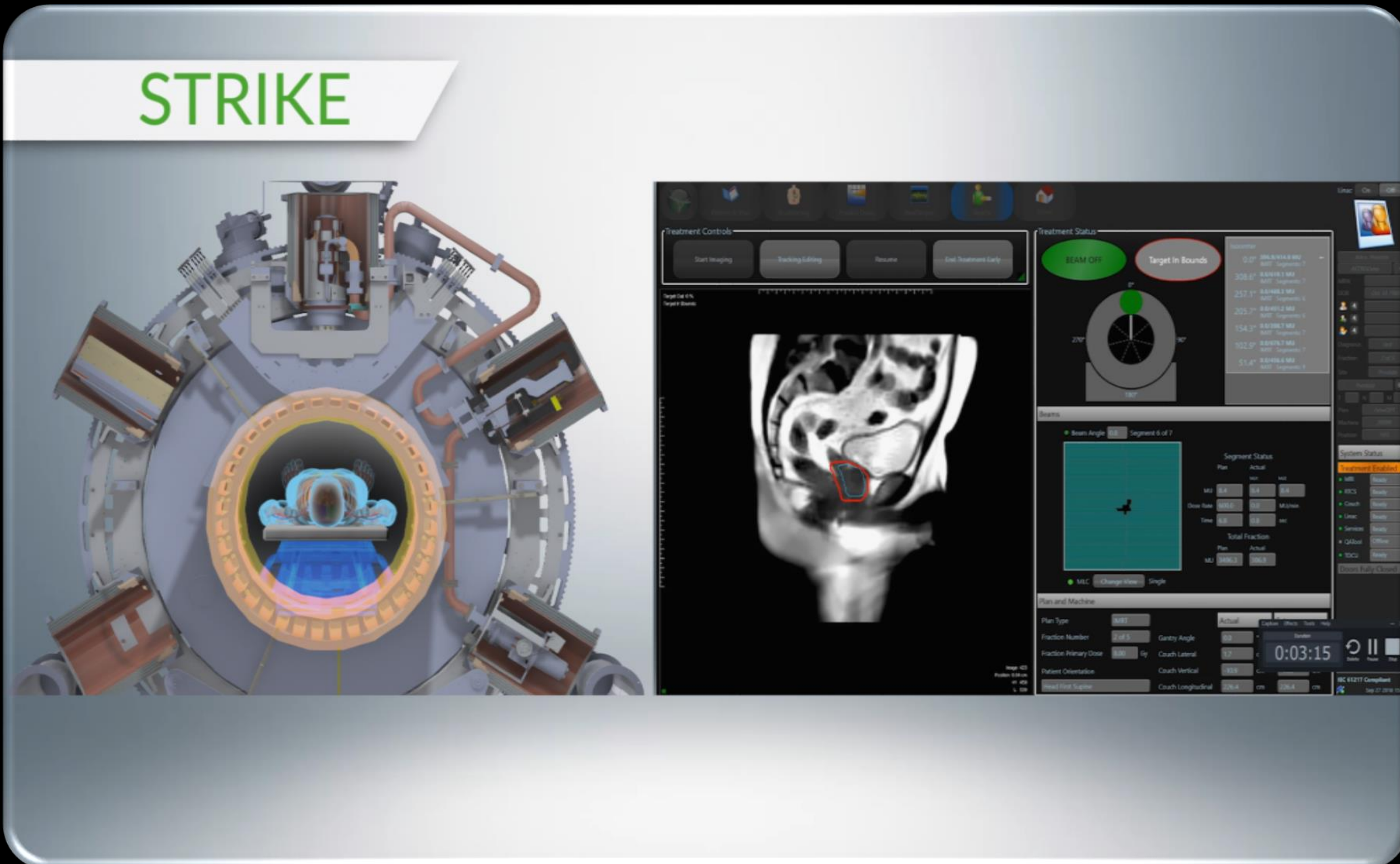


Product may not be available in all countries or regions.

SmartTARGET™

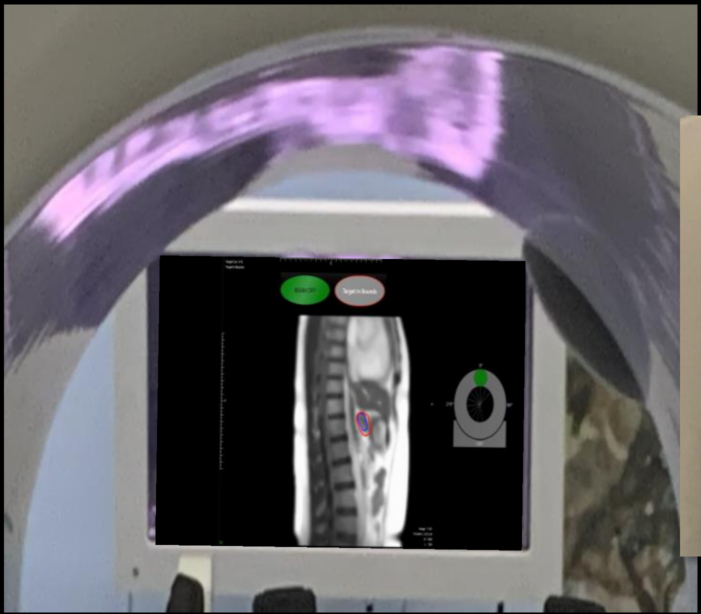


SmartTARGET™



AudioVisual Feedback

- Ideal for breathhold techniqiue(s) – Eliminates ITV!

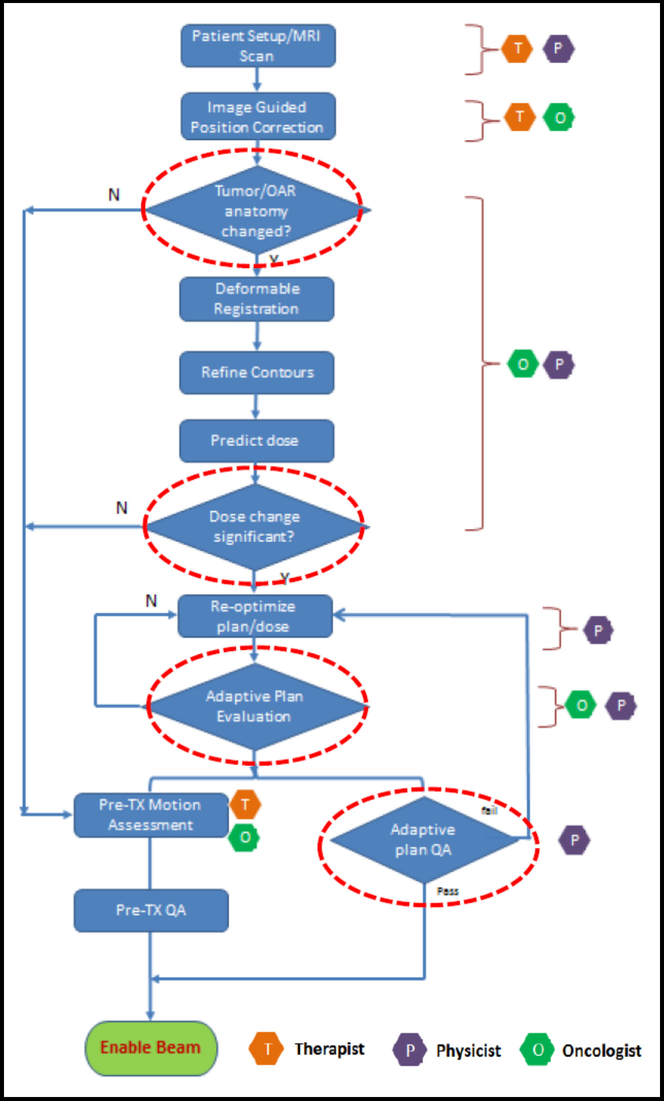


Patient Feedback Display

In-Bore Patient Mirror

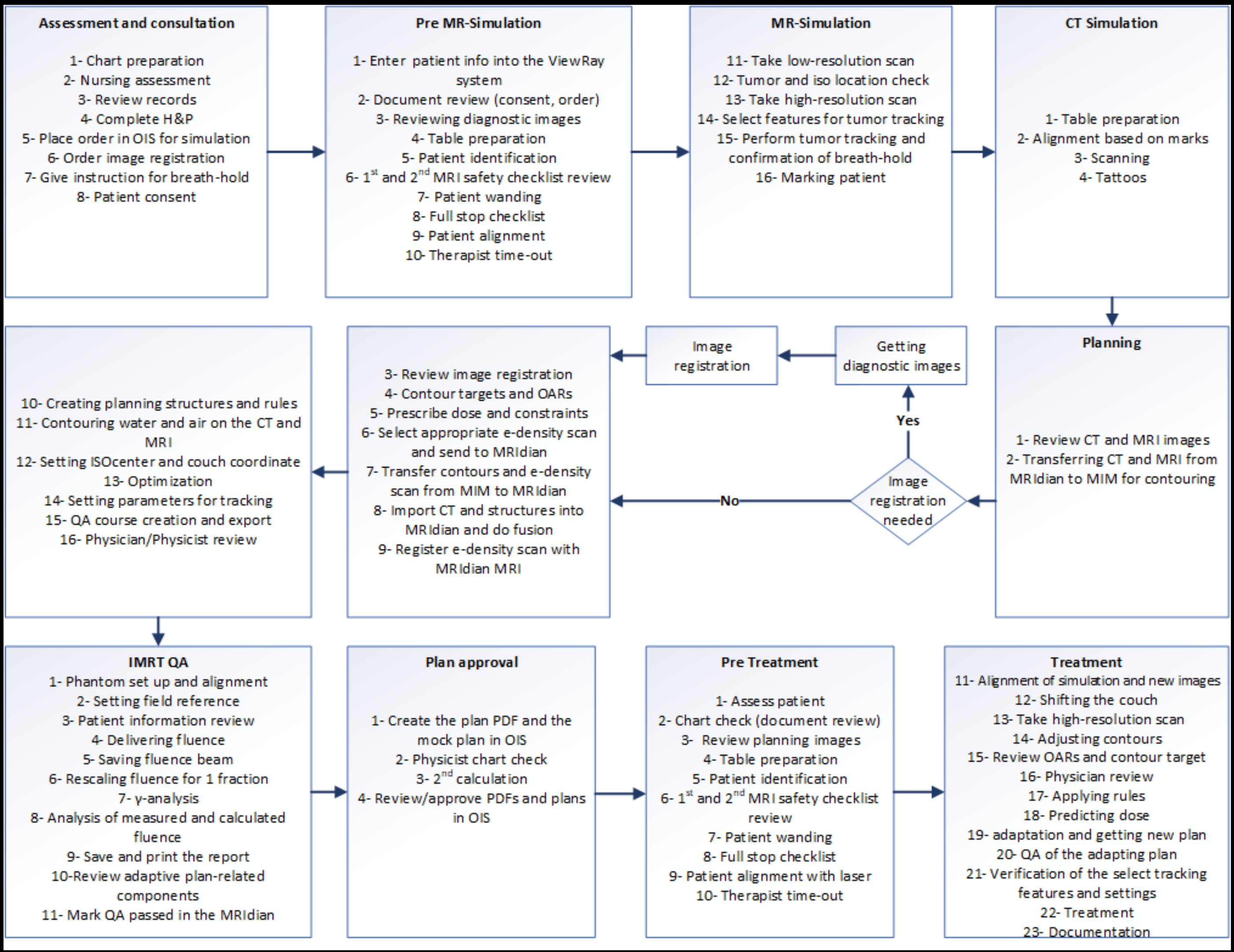
Patient View of Real-Time Tracking

On-Line ART Workflow?



- Image Quality
  - Tumor & Soft Tissue Contrast
  - Imaging Artifacts
- Plan Quality
  - Contouring
  - Electron Density
  - Optimization
  - QA/QC
- Other Factors
  - Time/Process Management
  - Decision Making Process
  - Staff Training & Coordination

TG100 – Process Map @VCU



Courtesy: Dr M. Behzadipour

Failure Modes and Effects Analysis (FMEA)

- Identification of High-Risk Failure Modes (FM)
- A total of 279 failure modes were identified
- 52 failure modes were identified as the top 20% based on their RPNs
- 30 were classified as high-risk failure modes, 55 were classified as medium-risk failure modes, and the remaining failure modes were categorized as low-risk.
- A table was formed showcasing the list of failure modes and their causes and effects
- From this optimal workflow, we extended our analysis to include TDABC

Table 2. List of high-priority failure modes (top 20% RPNs).

Process step	Top 20% RPN failure modes	Potential cause of failure	Potential effects of the failure	O	S	D	RPN	Top 20% severity	Risk level
Dosimetrist: Setting parameters to do adaptive planning and tracking	Selecting the wrong prescription templates	Suboptimal MRIdian tools for management of templates with current software version	Critical constraints can be missed when the wrong or outdated template is selected	7	8	4	224	Yes	
Therapist: Adjusting contours	Not readjusting the ring	Human failure (inattention),	Tissue overdose/underdose	4	8	4	128	Yes	
Therapist and Attending Physician: Adjusting contours	Contouring structures incorrectly	Human failure (inexperience or inattention)	Tissue overdose/underdose	6	7	3	126	Yes	

Courtesy: Dr M. Behzadipour

Time Driven Activity Based Costing (TDABC)

- CCR calculation
- Equipment and space annual costs were calculated based on sales prices and construction costs
- Total annual working hours for each resource type were obtained
- CCRs were calculated by dividing the annual costs by their annual availability in minutes [$/min]

Personnel	Annual Working Days	Daily Working Hours	CCR [$/min]
Radiation Therapist	260	8	$0.71
Certified Medical Assistant	260	8	$0.32
Nurse	260	8	$0.64
Medical Physicist	260	8	$2.34
Attending Physician	260	8	$4.40
Dosimetrist	260	8	$1.14
MP & MD Residents	260	8	$0.59
Space (Vault)	Useful life [year]	Daily usage [hr]	CCR [$/min]
TrueBeam	25	10	$0.31
MRIdian	25	10	$0.36
PET/CT	25	8	$0.08
Equipment	Useful life [year]	Daily usage [hr]	CCR [$/min]
TrueBeam	10	10	$4.04
MRIdian	10	10	$8.01
Cannon PET/CT Simulator	10	8	$3.21
Identify	10	10	$0.47
Orfit® SBRT solution	10	10	$0.05

Courtesy: Dr M. Behzadipour

Time Driven Activity Based Costing (TDABC)

- Comparative Cost Analysis of MRgRT vs CTgRT

- The total personnel costs for five-fraction SBRT treatment with MRgRT and CTgRT are $4,678.13 and $2,770.13, respectively
- The total equipment and space costs for MRgRT are $4,471.15 and $199.04, respectively
- The total costs for five-fraction SBRT MRgRT and CTgRT are **$9,348.32** and **$4,188.95**, respectively

Courtesy: Dr M. Behzadipour

QA & Dosimetry

SNC Patient QA of Dose Distribution

Hospital

QA Date

SUN NUCLEAR corporation

QA Parameters

Patient Name

Patient ID

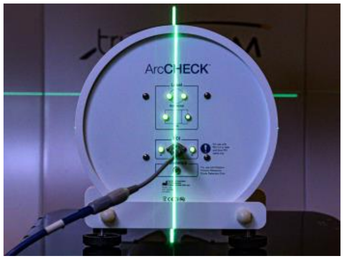
Plan Name

Plan ID

Plan Date

Verified Plan UID

Total MU



Absolute Dose Comparison (DTA/Gamma using 2D Mode)

Threshold (%)	10.0	Use Global (%)	Yes
Difference (%)	3.0	Meas Uncertainty	No
Distance (mm)	2.0	Cavity Dose	N/A

Summary (Gamma Analysis)

Pass (%)	97.5
Pass	546
Fail	14
Total Points	560

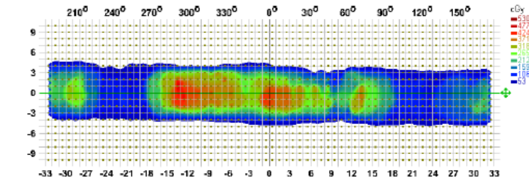
Dose Values in cGy

	CAX	Norm	Sel	Max
Set 1		467.16	418.57	467.16
Set 2	389.11	473.07	420.07	528.05
Set 1-2		-5.90	-1.50	-60.89
% Diff		-1.25	-0.32	-12.87
DTA(mm)	N/A	0.00	0.00	

Notes

Reviewed By

ArcCHECK (Set 1)



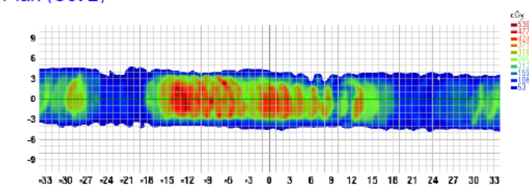
Z:\Viewray\Export\IMRT QA\Pyles_Stephen_Liver\6-Jul-2022-A_measured.txt

CAX Coords (x,y) (mm)
0, 0

Norm Coords (x,y) (mm)
-135.00, 10.00

SEL Coords (x,y) (mm)
-5.00, 0.00

Plan (Set 2)



Z:\Viewray\Export\IMRT QA\Pyles_Stephen_Liver
\IMRTQA_Pyles_Stephen_20173127_Liver_VolumeDose_AC_EXTRACTED.snc

CAX Coords (x,y) (mm)
0, 0

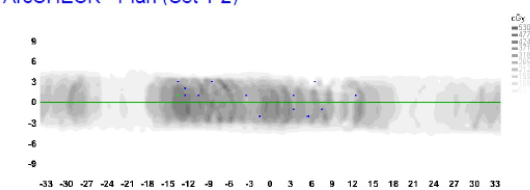
Norm Coords (x,y) (mm)
-135.00, 10.00

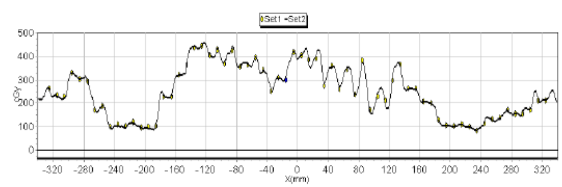
CAX Offset (x,y) mm
0, 0

Dose Scaling Factor
0.2

Isocenter Coords (x,y,z) (mm)
0.000, 0.000, 0.000

ArcCHECK - Plan (Set 1-2)



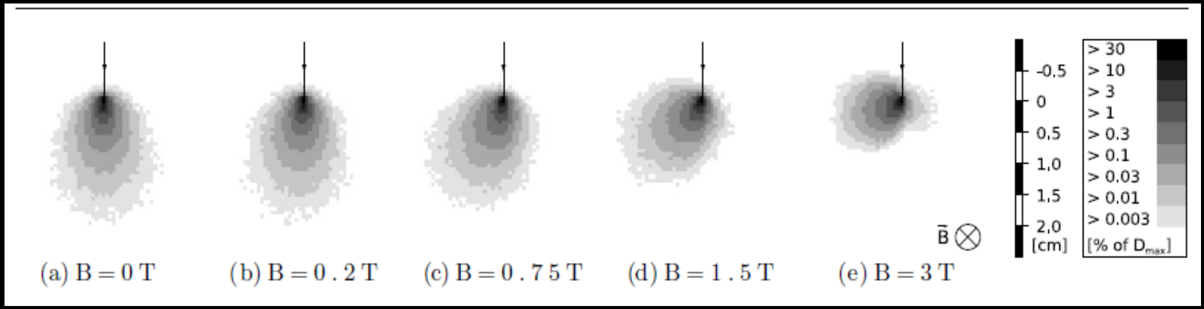


Gamma Index Summary

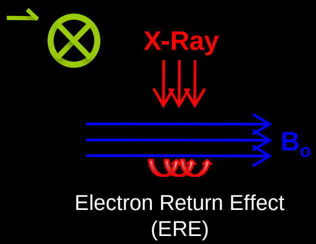
	Min	Max
Points In Threshold	0.00	2.07
All Points	0.00	2.07

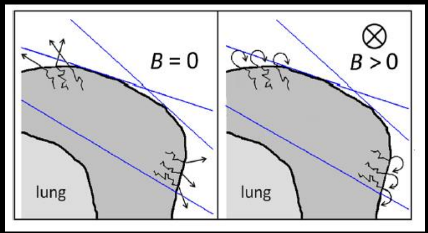
	Average	Stdv
Points In Threshold	0.39	0.30
All Points	0.26	0.23

Radiation Inside MRI?



Raaijmakers *et al.*, *Phys Med Biol* 2008;53:909-





Tristan *et al.*, *Phys Med Biol* 2013;58:5917-

Lorentz Force

- Affects:
  - Magnetron/Klystron
  - Electron Gun
  - Linear Accelerator
  - Current-Carrying Cables
  - Detectors
  - Patients

Lorentz Force

- At 1.5T:
  - d_{max} Decreases by 5 mm
  - Penumbra Increases by 1 mm
  - 50% Isodose Shifts Laterally by 1 mm
- Can be Mitigated by:
  - Using Lower Magnetic Field Strength
  - Using Multiple Fields
  - Model Magnetic Fields in Plan Optimization and Dose Calculations
  - Aim Beam *Parallel* to the Magnetic Field

Lorentz Force

O'Brien *et al.*: Reference dosimetry in B-fields: Formalism and correction factors

TABLE IV. Values of the depth of maximum dose $d_{\max}$, the percentage depth-dose at 10 cm $\%dd(10)$, and the TPR_{10}^{20} with and without a 1.5 T magnetic field. The depth-dose parameters are shown with and without the electron contamination component. The SSD used for the depth-dose data was 133.5 cm. The values of $\%dd(10)$ for the photon-only beams are equivalent to the values of $\%dd(10)_x$ at this SSD. The measured TPR_{10}^{20} values represent the mean and standard deviation of multiple measurements with three different chambers.

Quantity	$d_{\max}$ (cm)	$\%dd(10)$	TPR_{10}^{20}
Full-head model (includes e^- contamination)			
No magnetic field	1.68	70.0	—
1.5 T magnetic field	1.28	69.3	—
Point-source model (photons only)			
No magnetic field	1.85	71.4	0.697 ± 0.001
1.5 T magnetic field	1.30	69.7	0.695 ± 0.001
Measurement			
No magnetic field	—	—	0.693 ± 0.001
1.5 T magnetic field	—	—	0.691 ± 0.001

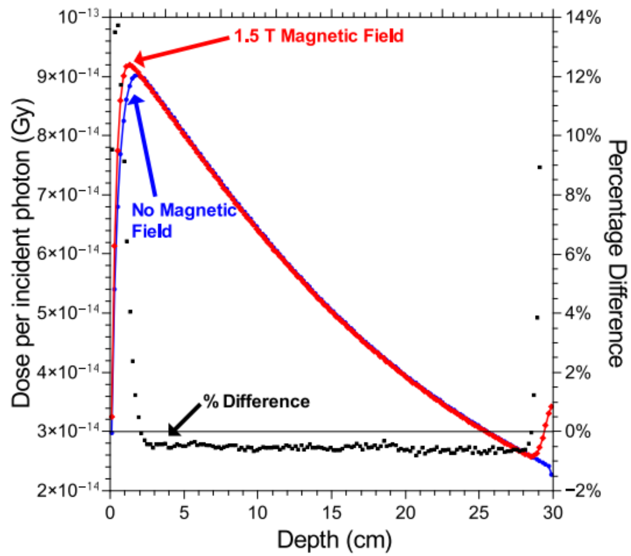
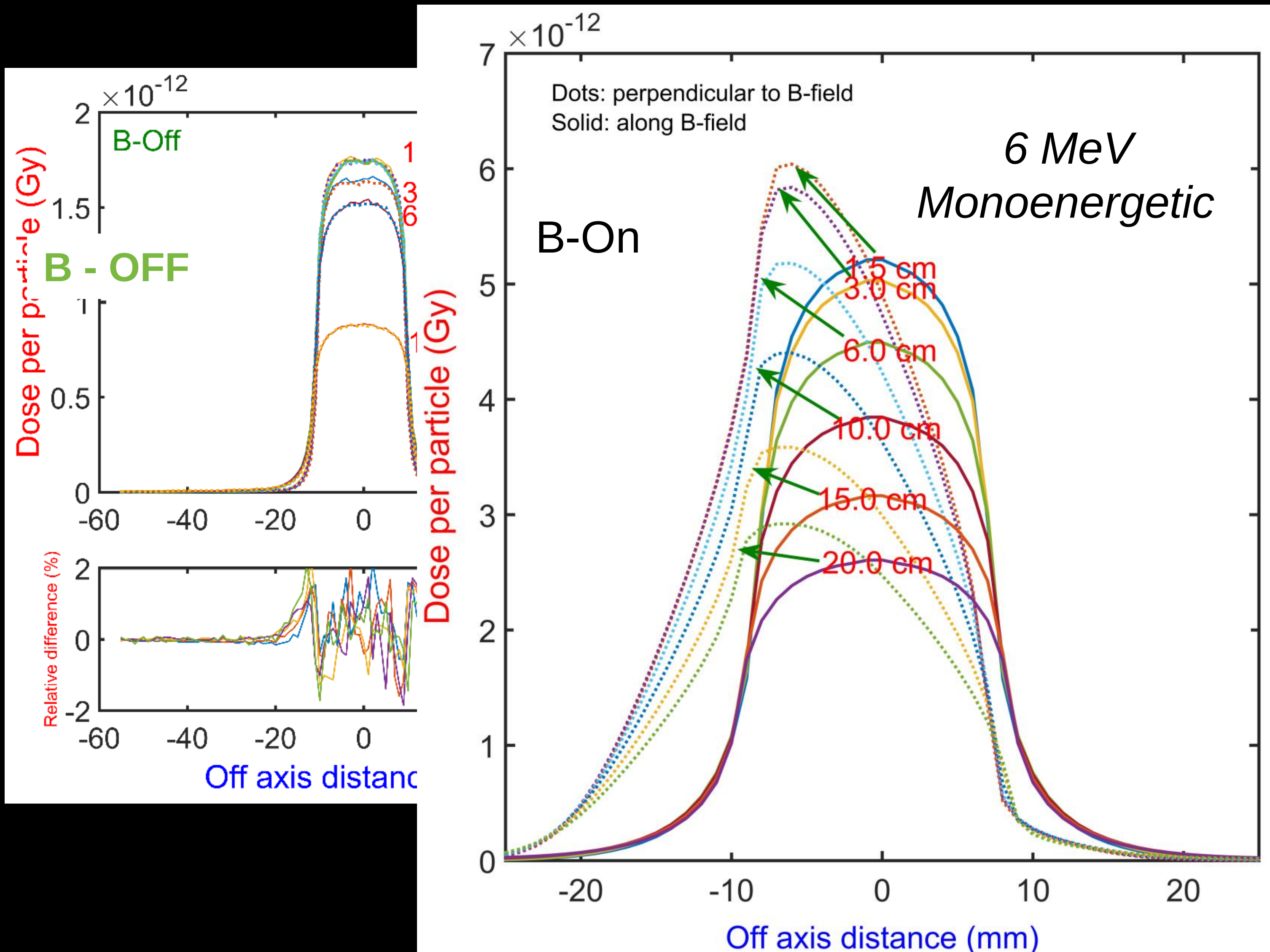
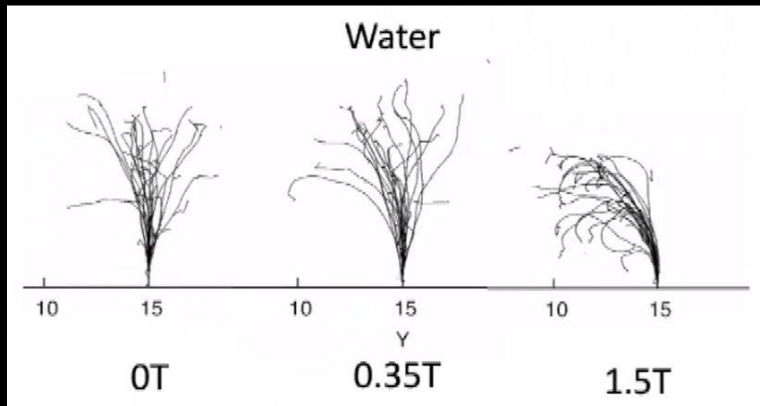


FIG. 4. Depth-dose curves per incident photon with and without a 1.5 T magnetic field and the percentage differences between them, calculated with the GEANT4 point-source model at an SSD of 133.5 cm. Negative differences indicate a lower dose with the magnetic field than without it.

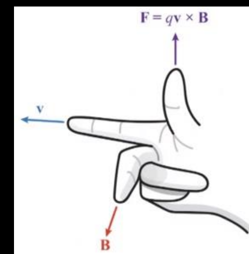
Lorentz Force

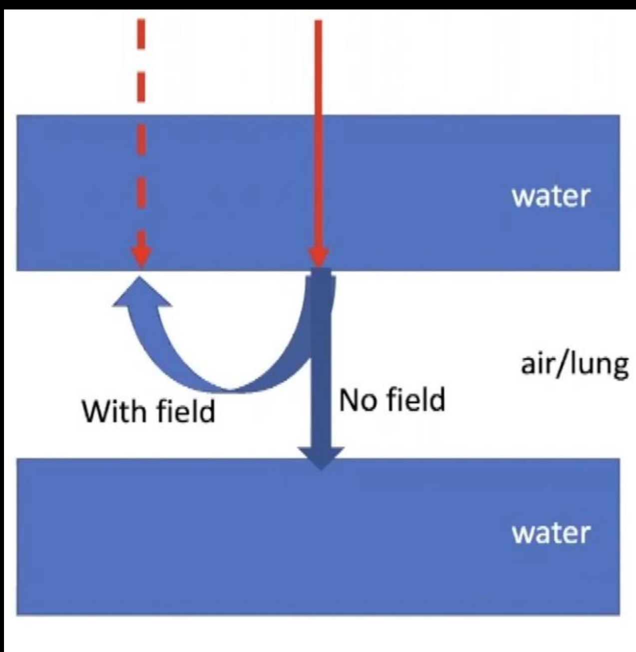


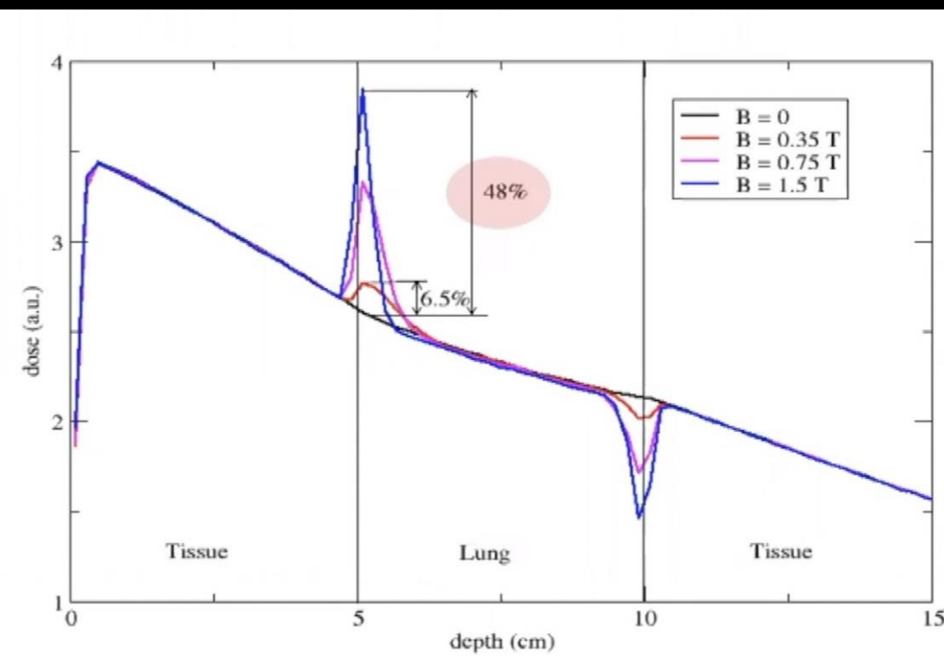
Electron Return Effect (ERE)



Lorenz force







Electron Return Effect (ERE)

Whole Breast: 1.5T

- Utrecht published that Whole Breast Irradiation has unacceptable high skin dose at 1.5 T
  - van Heijst TC, den Hartogh MD, Lagendijk JJ, van den Bongard HJ, van Asselen B. Phys Med Biol. 2013 Sep 7;58(17):5917-30.

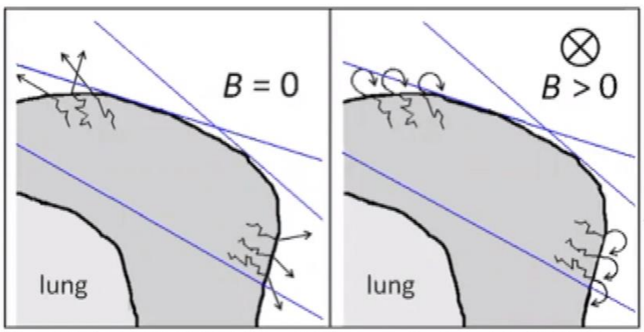
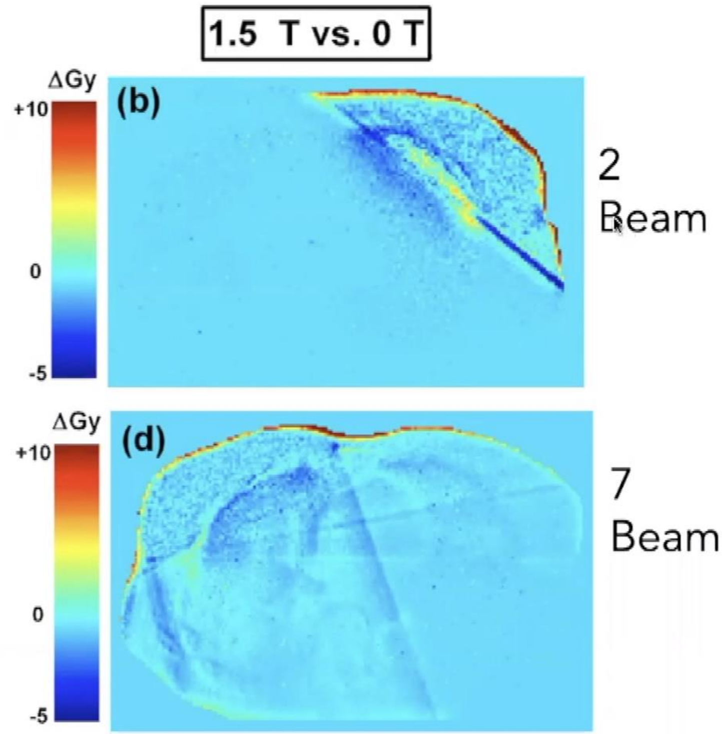


Figure 1 Illustration of the ERE, for left-breast WBI by means of two tangential fields. The edges of the photon beams are depicted by the blue lines. Trajectories of secondary electrons, crossing the skin-air boundary on either exit side of the irradiated breast, are represented by the arrows. The ERE may result in a higher skin dose when comparing the situation of no magnetic field (left) to that of a non-zero magnetic field directed into the plane (right).



***Exit dose can be reduced with bolus!**

Reference Dosimetry

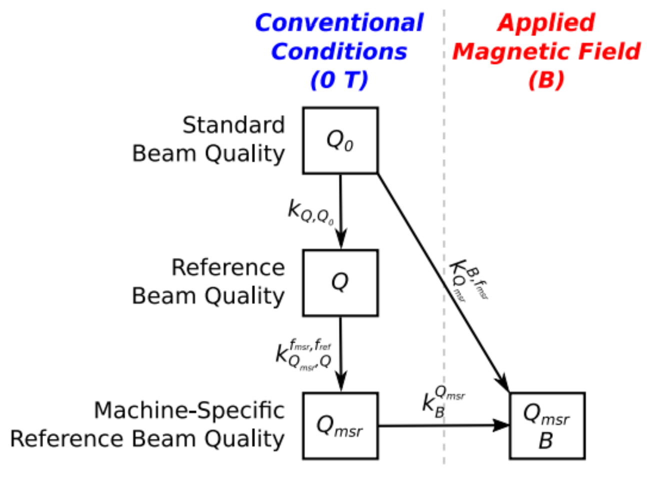


FIG. 1. Illustration of the reference dosimetry formalism and the relationship between beam quality and magnetic field correction factors. References to f_{ref} and Q_0 are dropped from the symbol $k_{Q_{msr}}^{B,f_{msr}}$ but they are implied by its definition.

TABLE III. Ionization chamber magnetic field correction factors and their statistical uncertainties (rounded to the nearest 0.05%) for three orientations: parallel ($k_{B_\parallel}^{Q_{msr}}$); clockwise perpendicular ($k_{B_\curvearrowright}^{Q_{msr}}$); and counter-clockwise perpendicular ($k_{B_\curvearrowleft}^{Q_{msr}}$).

Detector	$k_{B_\parallel}^{Q_{msr}}$	$k_{B_\curvearrowright}^{Q_{msr}}$	$k_{B_\curvearrowleft}^{Q_{msr}}$	Uncertainty (%)
PTW 30013	0.994	0.961	0.976	0.15
PTW 30012[a]	0.992	0.958	0.970	0.25
PTW 30011[a]	1.000	0.958	0.968	0.25
PTW 30010[a]	0.996	0.961	0.975	0.25
NE2571[a]	1.003	0.962	0.973	0.20
NE2571	1.001	0.962	0.973	0.15
Exradin A19	1.005	0.962	0.956	0.25

[a]Chambers modeled with a 1 mm thick layer of PMMA representing a water-proof sleeve.

- Corrections Can be Upwards of 4% in Perpendicular Directions
- Corrections are Small (<1%) in Parallel Direction

Reference Dosimetry

AMERICAN ASSOCIATION of PHYSICISTS IN MEDICINE

Improving Health Through Medical Physics

AAPM COMMITTEE TREE

Task Group No. 351 - Clinical reference dosimetry in MR-guided radiotherapy (TG351)

AAPM Members, Affiliates and Non-Member Affiliates - Login for access to additional information

Charge To develop guidelines for reference dosimetry in MR-Guided high energy photon RadioTherapy (MRGRT) units. The task group will:

- Review and evaluate existing literature on calculated and experimental data sets for magnetic field-dependent beam quality conversion factors.
- Review and determine 'reference setup conditions' for measurement of beam quality and reference dose. This is necessary as in some of the units, the standard TG-51 defined reference setup conditions cannot be achieved.
- Review, evaluate and identify appropriate reference-grade ionization chambers and measuring instruments for reference dosimetry in the presence of a magnetic field.
- Review and evaluate the sources of uncertainty and determine an uncertainty budget for MRGRT reference dosimetry.
- Produce an AAPM Task Group report on reference dosimetry for MR-guided high energy photon radiotherapy based on findings in charges a-d in line with the current internationally accepted reference dosimetry protocols.
- Collaborate with the Ionization Chamber Registry Working Group (WGICR) to incorporate relevant parameters/data for MRGRT appropriate reference-grade detectors into the registry.

Small Field Dosimetry

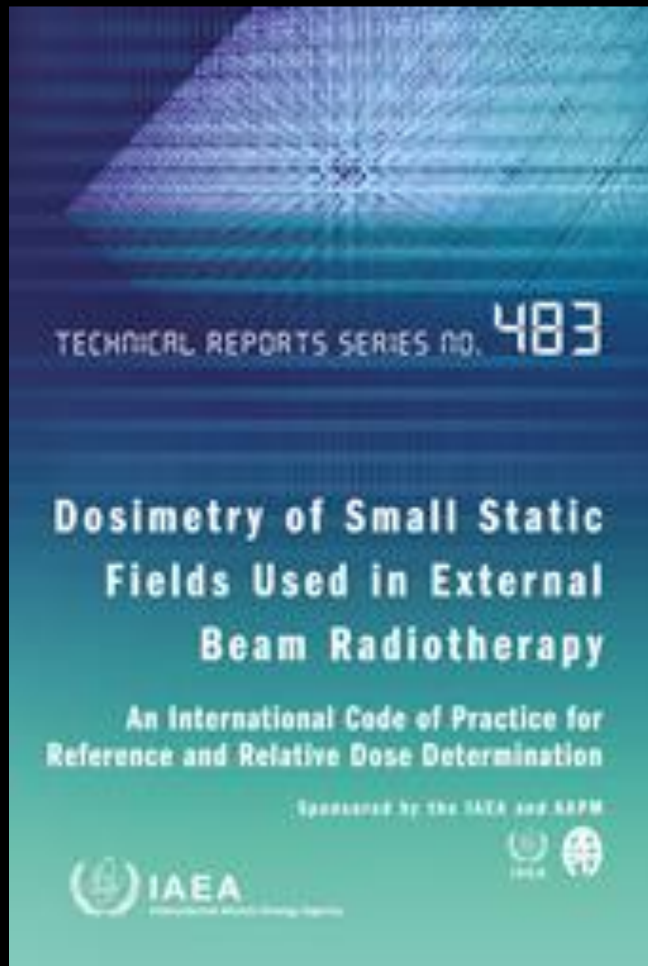
- We initially measured the Field Output Factor (FOF) with the following detectors:
  - W2 - Standard Imaging
  - Edge - Sun Nuclear
  - microDiamond - PTW

- <u>What correction factors to use?</u>

Courtesy: Mateb Al Khalifa

Small Field Dosimetry

- TRS483!



Courtesy: Mateb Al Khalifa

Small Field Dosimetry

1. What about B_0?
2. What about the new double-stack/dual-focused design of MRIdian's MLC?
3. What about the linac geometry?

TRS483 <u>cannot</u> be applied to MR-linacs!

Courtesy: Mateb Al Khalifa

ALL Commercially-Available MR-Compatible Detectors

Reference detectors:

1. Model 10 Scintillator – Blue Physics
2. HS-RP200 Scintillator – medscint
3. Exradin W2 Scintillator System - Standard Imaging
4. Gafchromic EBT3 Film
5. Gafchromic EBT4 Film

Detectors with correction factors needed!

1. Exradin A1SLMR Ion Chamber, 0.053cc – Standard Imaging
2. Exradin A26MR Ion Chamber – Standard Imaging
3. Exradin A28MR Ion Chamber, 0.125cc – Standard Imaging
4. Razor Chamber – iba
5. Nano Razor Chamber – iba
6. EDGE DetectorTM – Sun Nuclear
7. microDiamond – PTW
8. TW60023 – microSilicon – PTW
9. TW31025 – PinPoint 3D MR Chamber 0.016 cc – PTW
10. TW60022 – microSilicon X – PTW
11. TW31022 – PinPoint 3D Chamber 0.016 cc – PTW
12. Semiflex 3D MR Ion Chamber – PTW

Courtesy: Mateb Al Khalifa

Field Output Factors

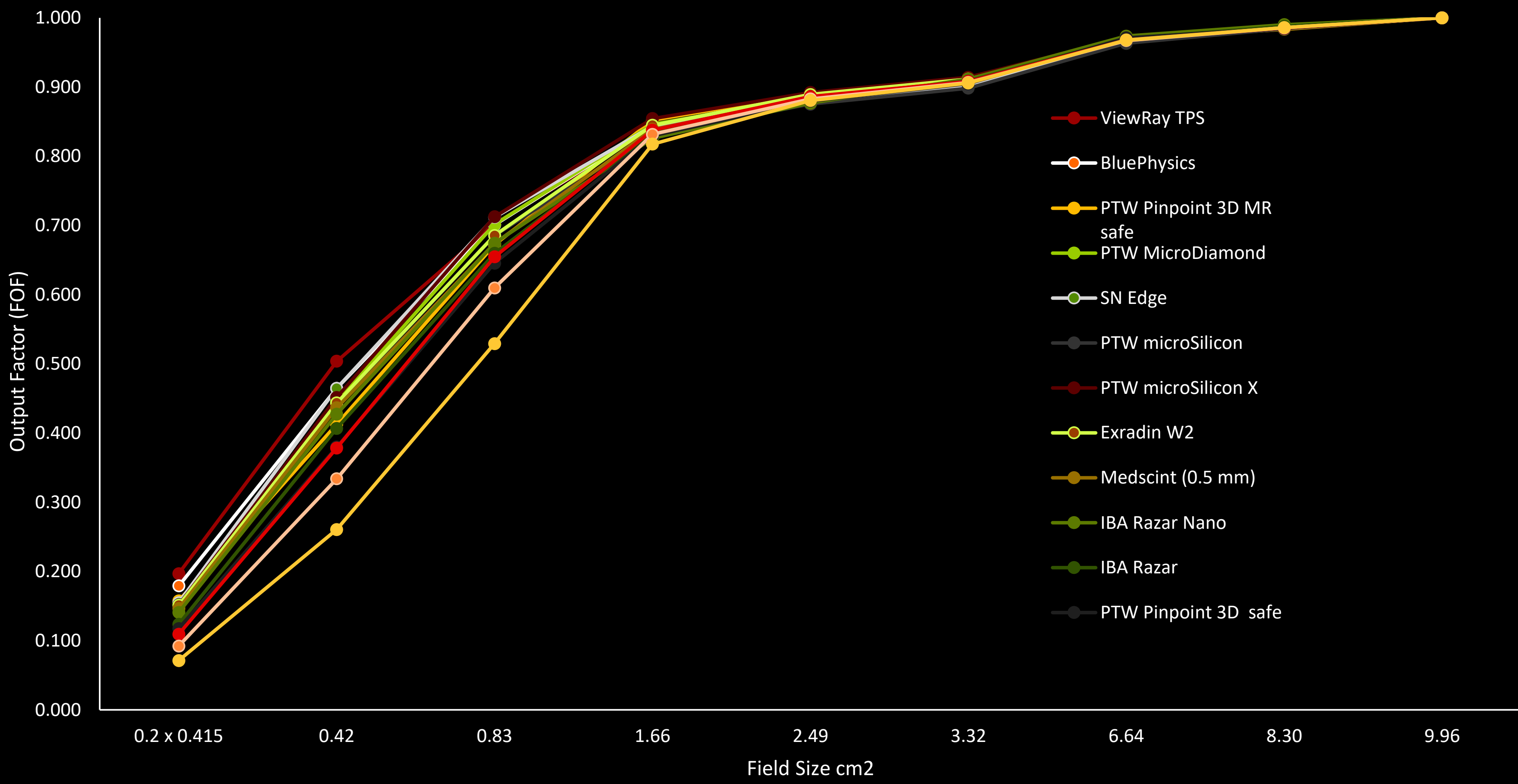
Differences of FOF compared to VR TPS (MC)
SAD=90cm, d=5cm (SSD=85cm), and MU=100

Smallest Diff → **Largest Diff**

FS (cm^2)	BluePhysics	PTW Pinpoint 3D MR safe	PTW MicroDiamond	SN Edge	PTW microSilicon	PTW microSilicon X	Exradin W2	Medscint (0.5 mm)	IBA Razar Nano	IBA Razar	PTW Pinpoint 3D safe	Exradin A26 MR	Exradin A1SLMR	Exradin A28 MR
	% diff	% diff	% diff	% diff	% diff	% diff	% diff	% diff	% diff	% diff	% diff	% diff	% diff	% diff
0.2 x 0.415	-8.97%	-19.97%	-21.29%	-21.36%	-22.70%	-23.05%	-23.19%	-25.56%	-28.46%	-37.13%	-40.28%	-44.42%	-53.08%	-63.77%
0.42	-7.73%	-18.10%	-11.50%	-7.75%	-12.20%	-10.38%	-11.93%	-13.34%	-15.14%	-19.23%	-24.62%	-24.86%	-33.72%	-48.26%
0.83	-0.20%	-4.27%	-0.09%	1.39%	-2.39%	1.50%	-2.35%	-3.97%	-3.96%	-6.02%	-8.05%	-6.75%	-13.14%	-24.62%
1.66	0.42%	1.30%	0.60%	0.30%	-1.12%	1.60%	0.44%	-0.25%	-1.79%	-0.85%	-1.39%	-0.38%	-1.11%	-2.79%
2.49	-0.33%	0.26%	-0.40%	-1.08%	-1.55%	0.36%	0.04%	-0.48%	-1.38%	-0.75%	-1.05%	-0.32%	-0.68%	-0.96%
3.32	-0.17%	0.29%	-0.27%	-0.95%	-1.37%	0.35%	0.06%	-0.22%	0.06%	-0.25%	-0.68%	-0.32%	-0.49%	-0.58%
6.64	-0.21%	-0.18%	-0.25%	-0.53%	-0.71%	0.14%	-0.01%	-0.29%	0.38%	-0.01%	0.11%	-0.23%	-0.29%	-0.22%
8.30	-0.10%	-0.26%	0.13%	-0.06%	-0.20%	0.21%	-0.02%	0.08%	0.42%	0.18%	-0.09%	-0.07%	-0.03%	-0.01%
9.96	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

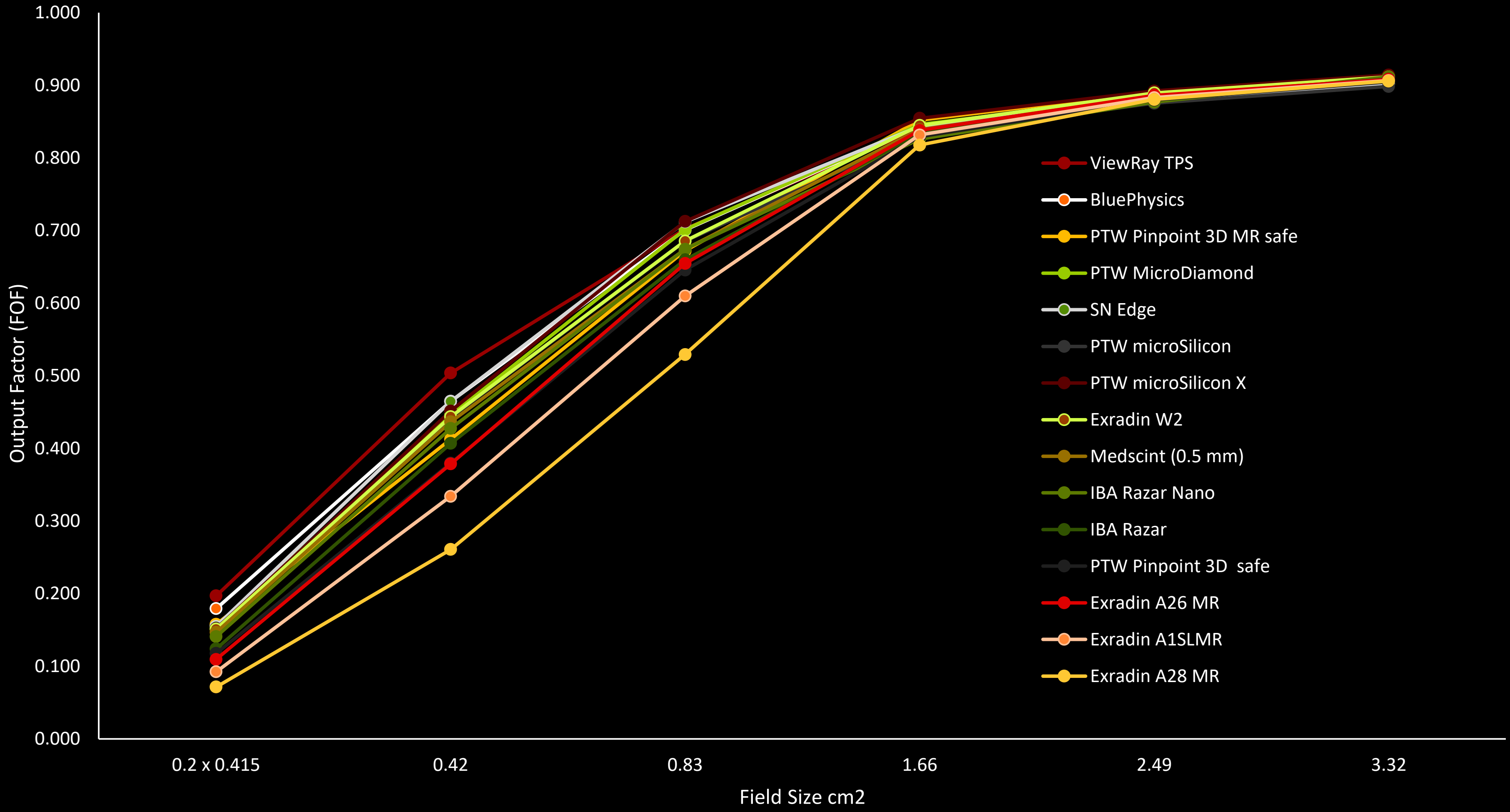
Courtesy: Mateb Al Khalifa

Field Output Factors



Courtesy: Mateb Al Khalifa

Field Output Factors



Courtesy: Mateb Al Khalifa

MR Safety

- MR Safety is a New Paradigm for RT Staff
- Resources:
  - ACR Guidance Documentation on MR Safe Practices, 2013
  - ISMRM Reports
  - Online Safety Modules
  - Safety Courses
  - Hospital Policies - Typically from Radiology

Staffing

- ISMRM Safety Committee:
  - MR Medical Director
    - Ultimate Operational Responsibility
    - Oversees Investigation During Adverse Events
  - MR Safety Officer
    - Responsible for Enforcing Policies/Procedures
    - Develop Documentation
  - MR Expert
    - Serve as a Resource for Medical Director & Safety Officer
    - Provides High-Level Advice on Engineering, Scientific, and Administrative Issues
    - Provides Advice on MR Protocols

Staffing

- ACR Guidance:
  - Non-MR Personnel
    - Those Not Having a Formal Training in MR Safety in the Last 12 Months
    - Should be Accompanied By or Under the Immediate Supervision of and in Visual/Verbal Contact With a Level 2 Personnel for the Entirety of Their Duration in Zone 3 & 4
  - Level 1 Personnel
    - Those Passing Minimal Safety Educational Efforts and Working Within Zone 3
    - Permitted to Work Within Zone 3 & 4 But Not Responsible for Non-MR Personnel in Zone 4
  - Level 2 Personnel
    - Those With Extensive Training and Education in Broad Aspects of MR Safety
    - Responsible for Supervision of Non-MR Personnel in Zone 4

Staffing

- All Personnel Working in Radiation Oncology Will Have Basic MR Safety Training
  - Facility/Maintenance Staff
  - Housekeeping
- Radiation Oncology Staff is to Have In-Depth Lectures & Annual Proficiency Exam
  - Physicians, Physicists, Dosimetrists, Therapists, Nurses, and CSRs
- Staff to Work in Zones 3 & 4 Need to Complete:
  - 80 Hours of Accompaniment With Trained Staff
  - Demonstrate Proficiency Performing Screening of Patients, Non-MR Personnel, Etc.

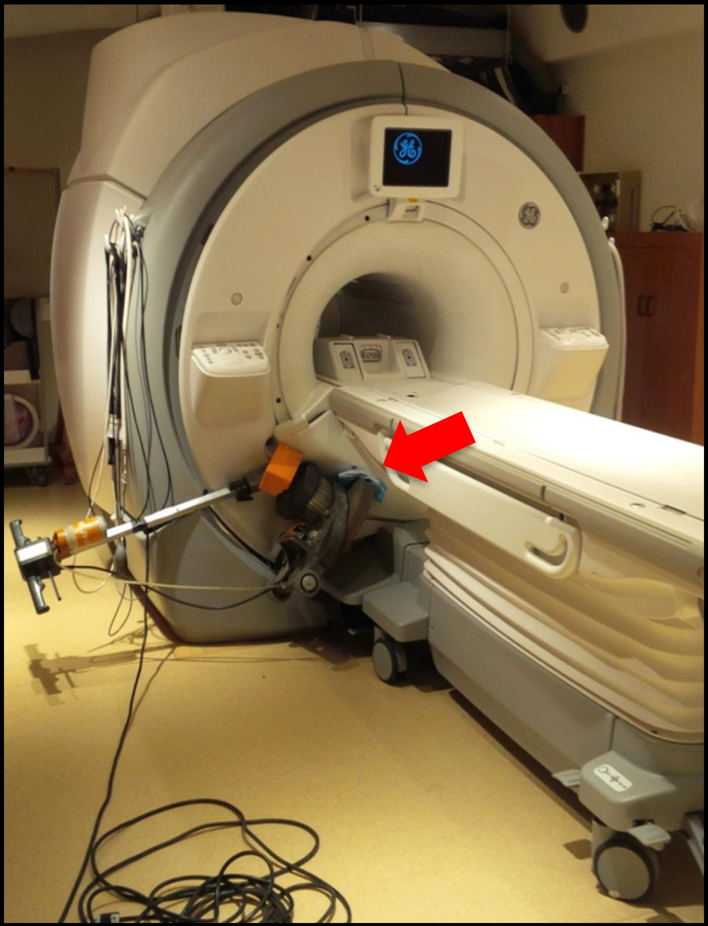
Screening Form

- Expansive List of Possible Implants, Devices, Markers, Etc.
- Any Biological Conditions to Consider Including Piercing/Tattoos, Adverse Effects of Contrast, Claustrophobia, Etc.
- Documentation of Specific Scanning Guidelines
- Checklist
- Re-screening for Each Treatment

Screening Form

Figure 2. U.S. Food and Drug Administration labeling criteria (developed by ASTM [American Society for Testing and Materials] International) for portable objects taken into Zone IV. Square green "MR safe" label is for wholly nonmetallic objects, triangular yellow label is for objects with "MR conditional" rating, and round red label is for "MR unsafe" objects.

Instill Safety Culture



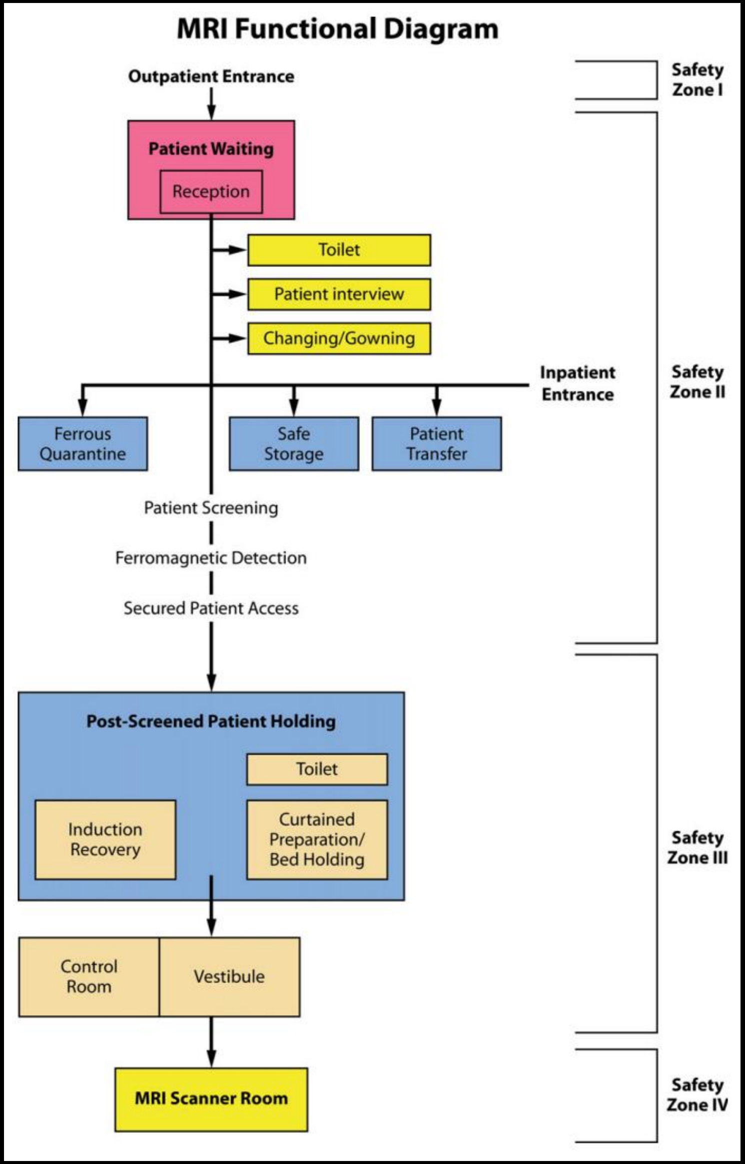
1) Safety Culture
2) Education & Hands-On Training
3) Policies & Procedures

ACR Guidelines for Safety Zones

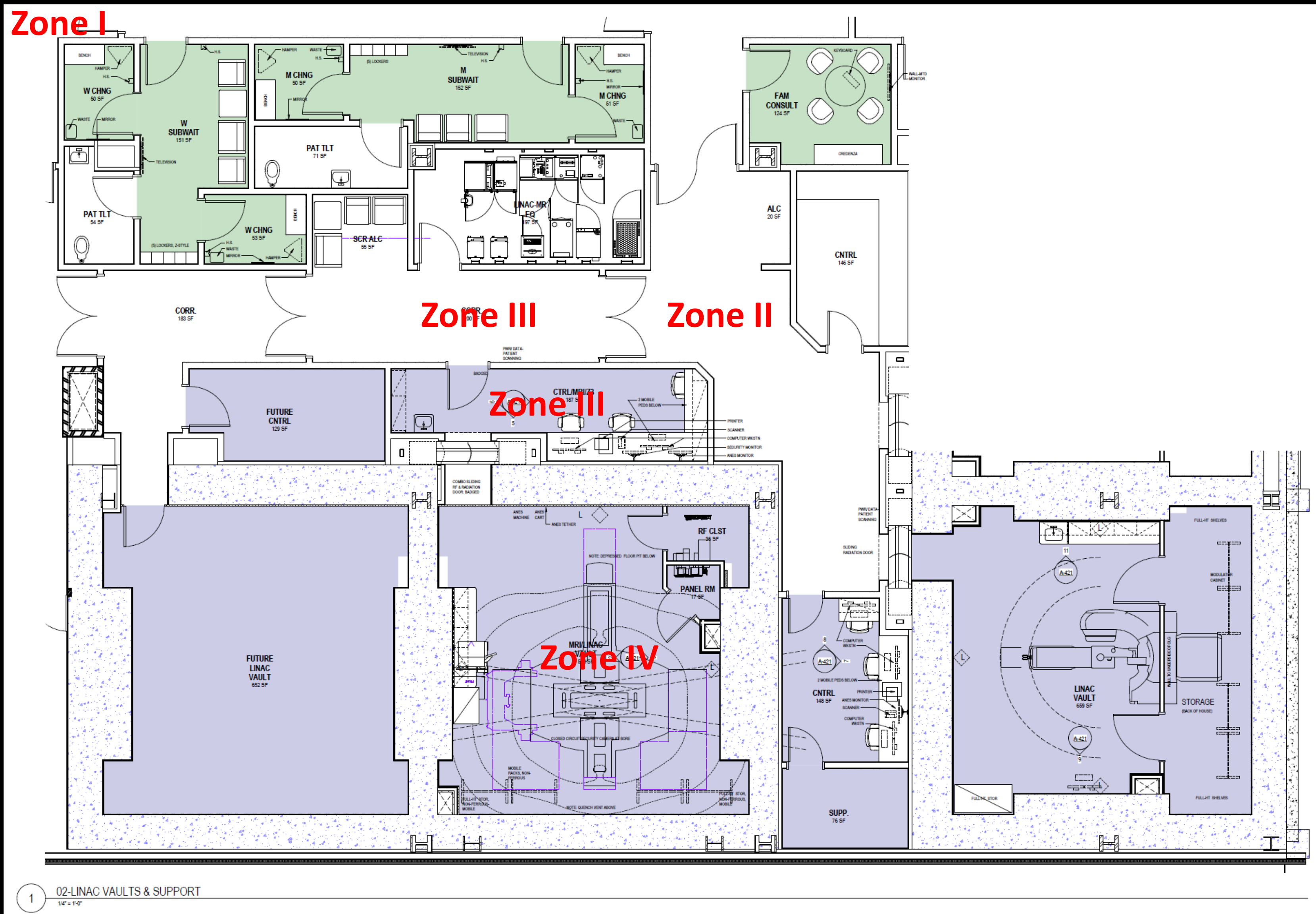
- Zone I
  - Includes All Areas Accessible to the General Public
- Zone II
  - Interface Between Zone 1 & Zones 3-4, Accessible by Patients
- Zone III
  - Restricted Access to MR Personnel, Non-MR Personnel, and Post-Screened People
- Zone IV
  - Inside MRI Scanner Room

ACR Guidelines for Safety Zones

- Zone I
- Zone II
- Zone III
- Zone IV



VCU Footprint 2022-



Summary

- MR-linacs are a reality now
- 4 major design platforms available, 3 are *US FDA-approved,* and all 4 have begun patient treatments
- On-line ART workflow is evolving
- On-line target tracking & gating possible, no ITV!
- AI will drive adoption & future workflow designs
- *Careful planning, dosimetry, QA, and adoption of new technologies are essential – <u>Need for Medical Physicists & training requirements will rise</u>*