PHILADELPHIA CYBERKNIFE

Frameless SRS Using CyberKnife

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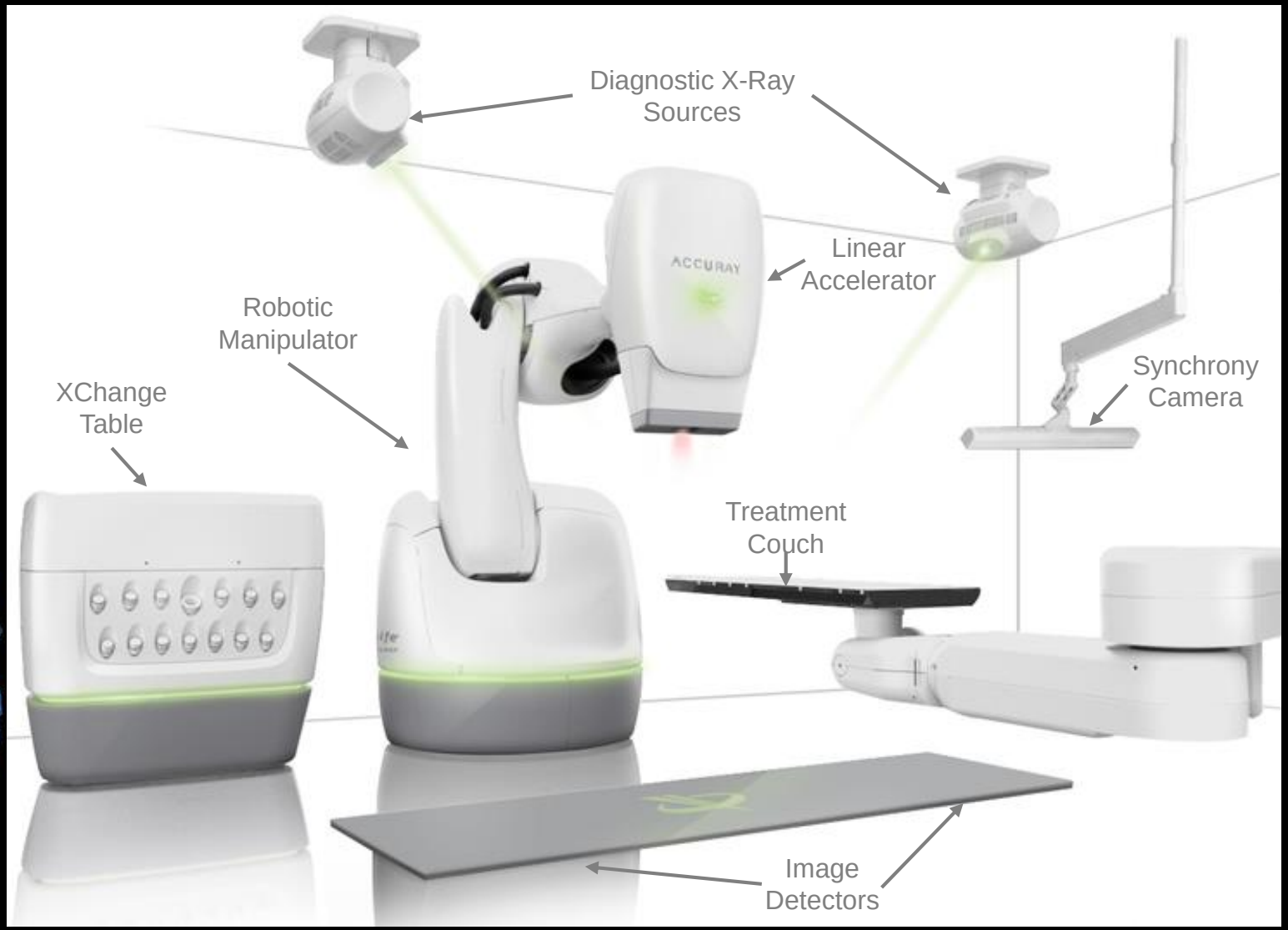
Study Objectives

- Components and Work Flow of CyberKnife
- Motion Management of SRS Cases
- Dosimetry Characteristics
- New Development of CyberKnife
- QA

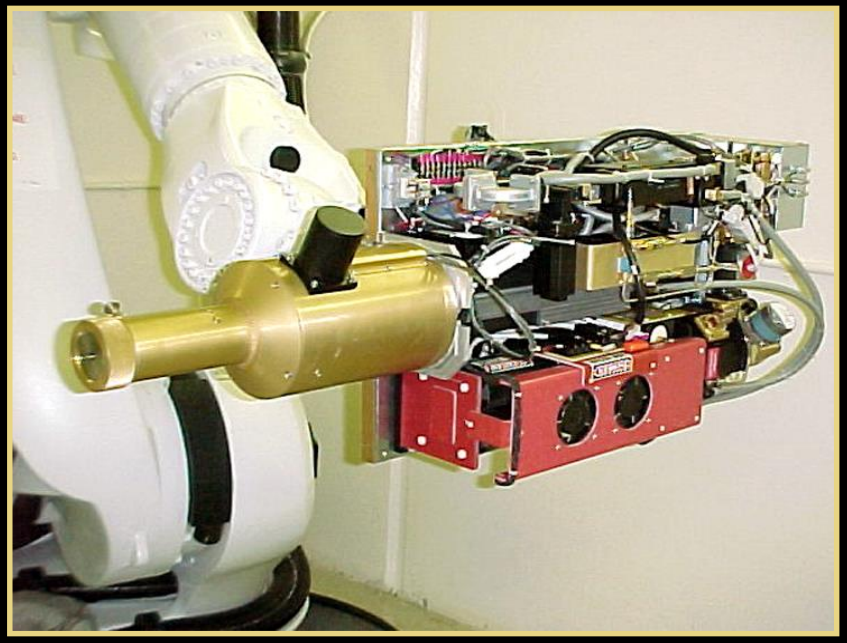
- ✓ CyberKnife Components
- ❑ Motion management
- ❑ Dosimetry
- ❑ Quality Assurance

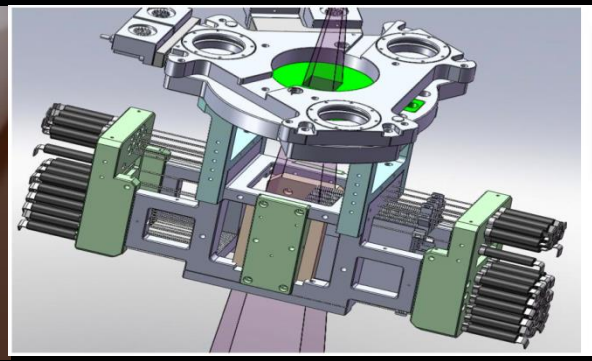
CyberKnife® Components

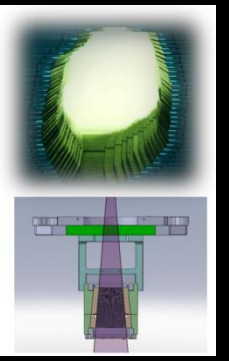


Linear Accelerator

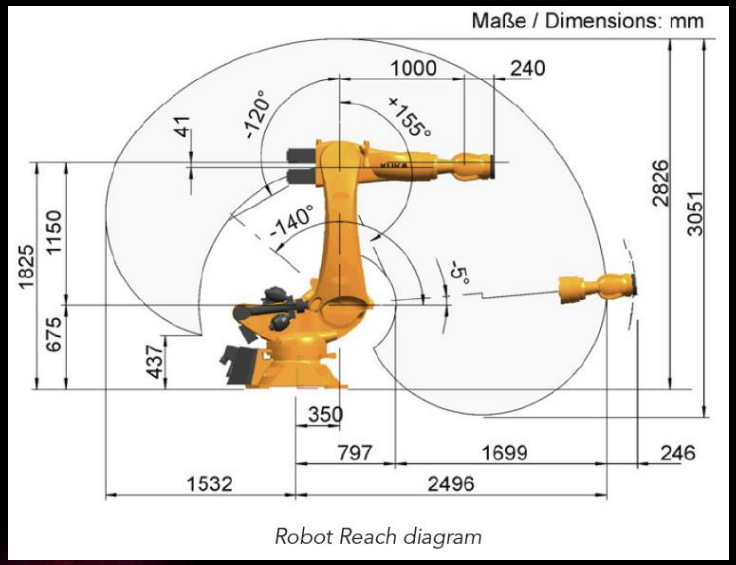
- 330 lbs.
- 6 MV X-ray
- 1000 MU/min ± 10% at 800 mm SAD
- Three set collimators
  - 5 – 60 mm circular collimators
  - 5 – 60 mm dodecagonal (12-sided) IRIS variable aperture collimators
  - 100 x 115 mm Incise™ 2 MLC







Robot Specifications



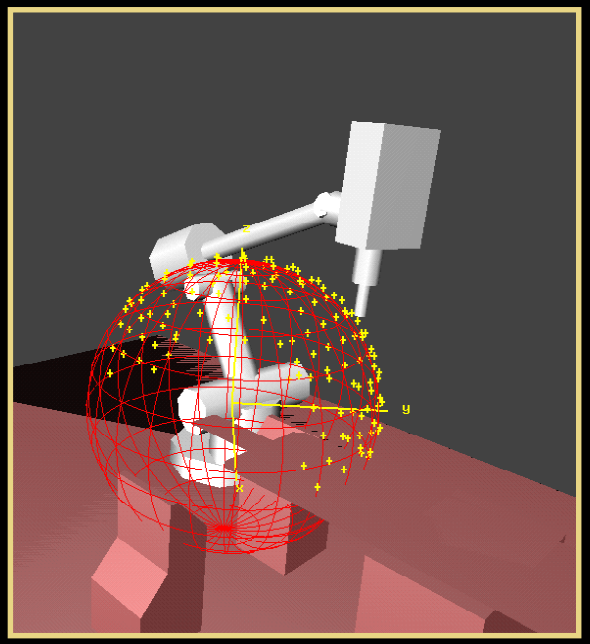
Robot Reach diagram

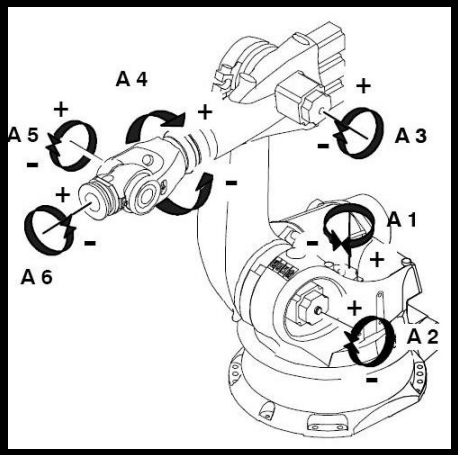
- ***6 axis / joint motion***
- 1,220 Kg
- 300 Kg payload
- 208 VAC, 3 Phase (PDU)
- 0-45 ºC Operating Range
- <75% Relative Humidity
- ***41 m³ Working Envelope***
- ***2500 mm Maxium Reach***
- ***0.12 mm Repeatability***

Made by KUKA of Germany

Robot Motion During Treatment

- Nodes assigned
  - Approximately 130
  - 12 directions each node
- ~1500 beams total (Simplex)
- Up to 5000 beams (Sequential)
- Treatment path





Treatment Couch

Axum Couch

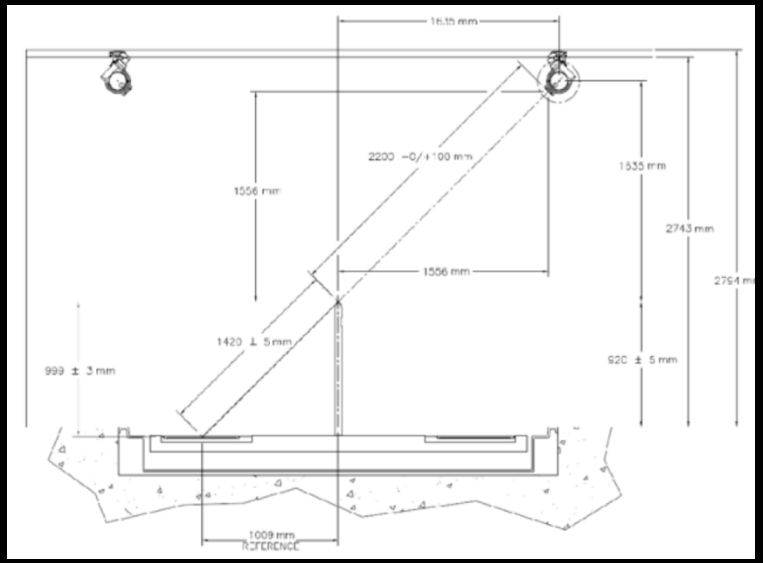
- Accommodates up to 159 Kg patient (350 lbs)
- Motorized control with 5 DOF (no YAW)
- Repeatablity: 0.3mm/0.3º

RoboCouch ®

- Accommodates up to 227 Kg patient (500 lbs)
- Motorized control with 6 DOF
- Repeatablity: 0.1mm/0.1º

Image Tracking System

- Two Diagnostic X-Ray sources
- Two ASi image detectors
- Patient imaged at 45° orthogonal angles
- Image Center: 920mm ± 5mm from floor
- Real-time, live images compared against DRRs generated from CT
- During treatment, Robot adjusts position based on the comparison

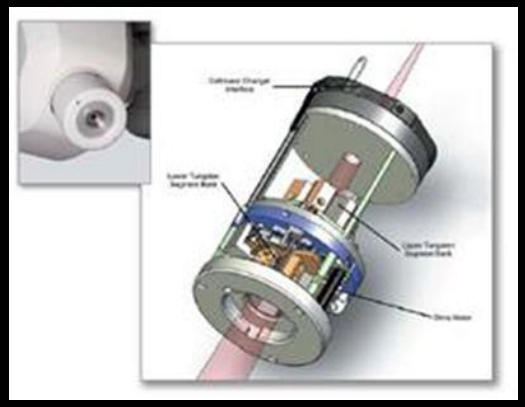


Development of CyberKnife

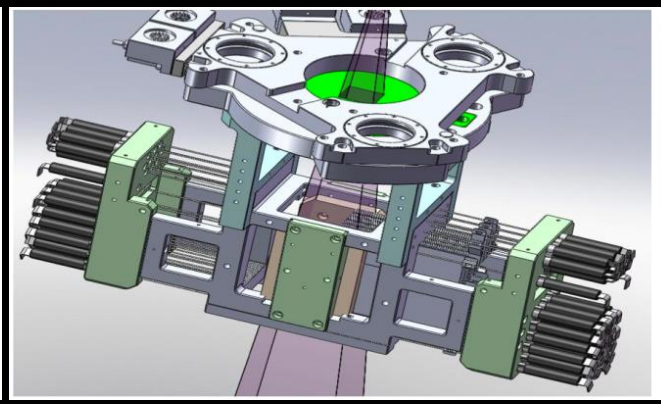
G4 Analog

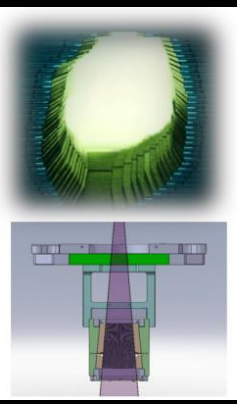
M6 Digital

Fixed Collimator



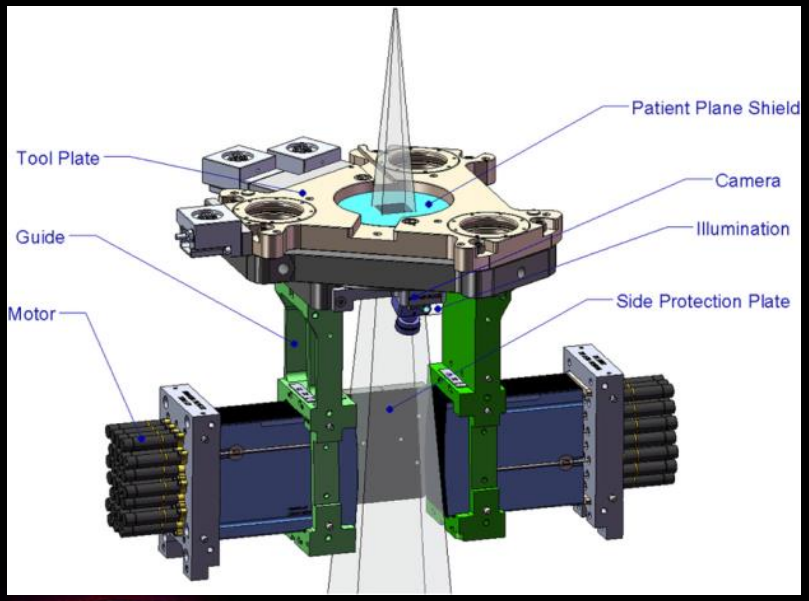
IRIS™ Collimator





Incise™ 2 MLC

Incise™2 MLC



- Number of Leaves: 52 leaf pair
- Leaf Width(at 800 mm SAD): 3.85 mm
- Max Treatment Field Size(at 800 mm SAD): :115 mm x 100 mm
- Leaf Position Accuracy(at 800 mm SAD): <±0.95 mm
- Max Leaf Speed(at 800 mm SAD): 25mm/s
- Leaf Height: 90.0 mm
- Leaf Tip Design: Three Flat, Focused Edges
- Leaf Side Design: Flat, Focused
- Source to Collimator Distance: 400.0 mm
- Transmission: <0.3% average(<0.5% Max) relative to 100mm x 100mm field at 800mm
- Penumbra: <3.5 mm for 10mm x 10 mm
  <12 mm(X)&20 mm(Y) for 100mm x100 mm
- MLC Weight: 54 Kg

- ❑ CyberKnife Components
- ✓ Motion management
- ❑ Dosimetry
- ❑ Quality Assurance

Tracking Methodology

- DRR (Digitally Reconstructed Radiographs from planning CT) pairs used as references
- X-ray image pairs acquired in real time
- Registration between DRR and X-ray images
- The patient’s rigid transformation calculated

Case Specific Tracking Modalities

- ✓ Skull Tracking ----- Intracranial tumor
- ❑ XSight (spine) Tracking ----- Spine tumor
- ❑ Fiducial Tracking ----- Soft tissue
- ❑ Synchrony Tracking ----- Moving Soft tissue
- ❑ XSight Lung ----- Moving visible lung tumor
- ❑ Lung Optimization Treatment ----- a full set of tracking for lung tumor without fiducial

Skull Tracking and Correction

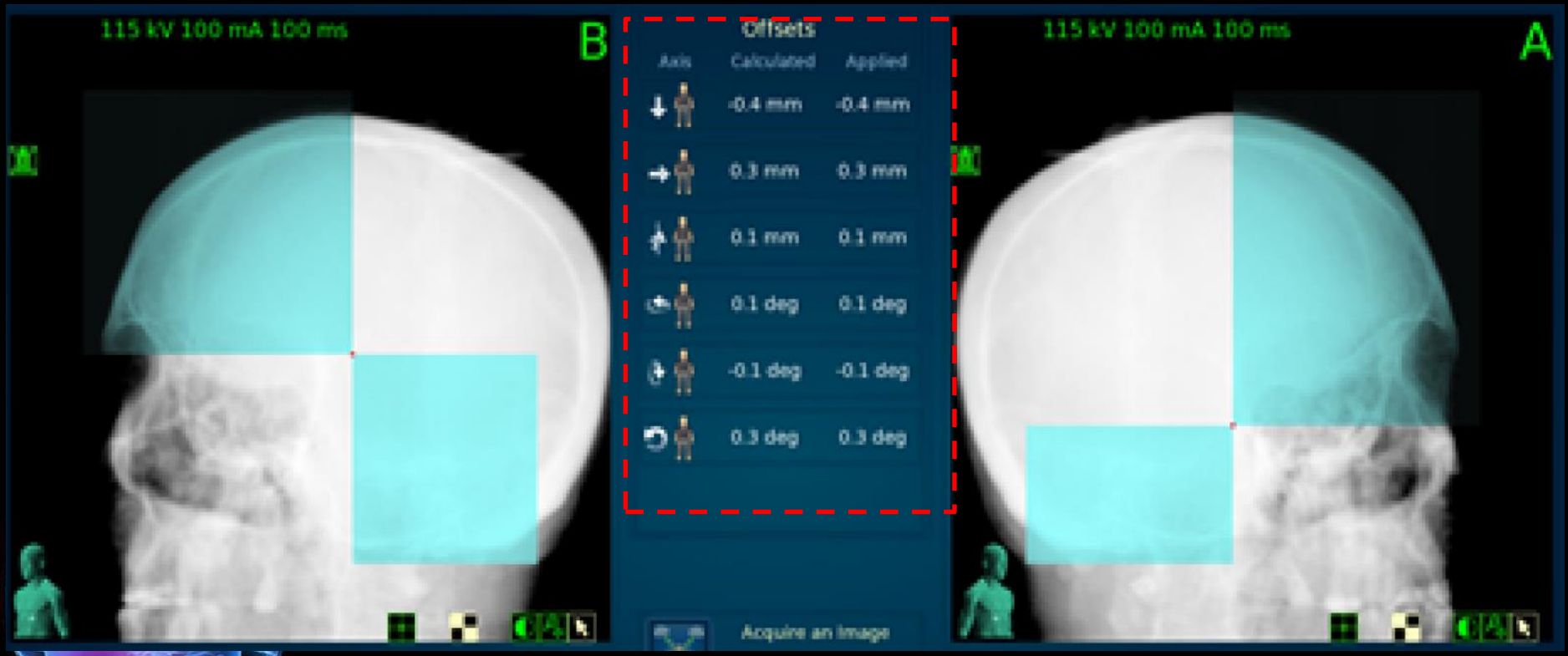


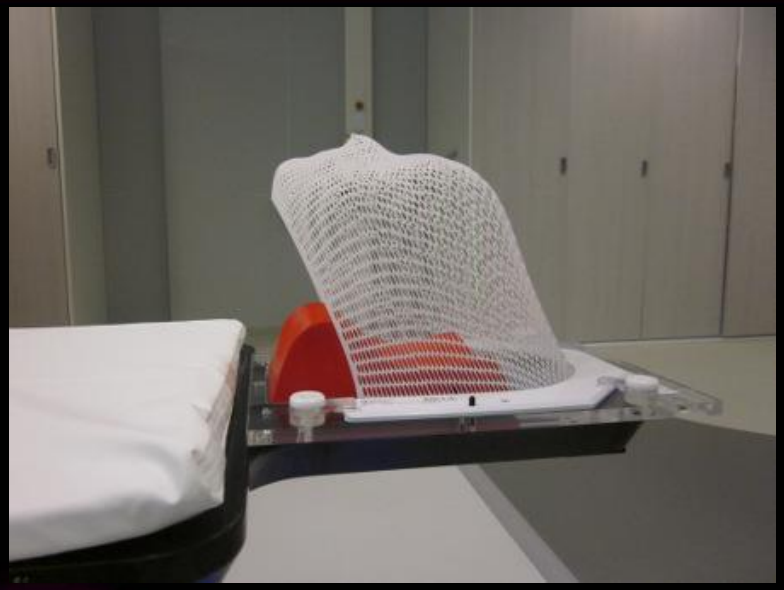
Image Tracking & Robotic Correction

Targeting Accuracy

- Mechanical accuracy
  - 0.12 mm (Kuka Specification 2004)[1]
- Targeting accuracy for targets not affected by respiration
  - 0.95 mm (Xsight® Specification)
  - 0.52 +/- 0.22 mm (Muacevic et. Al. 2006)[2]
  - 0.49 +/- 0.22 mm (Ho et. al. 2008)[3]
  - 0.4 +- 0.2 mm (Antypas and Pantelis 2008)[4]
  - 0.47 +- 0.24 mm (Drexler & Furweger 2009)[5]
- Targeting accuracy for targets that move with respiration
  - 1.5 mm (Synchrony® Respiratory Tracking System specification)
  - 0.70 +/- 0.33 mm (Dieterich et. Al. 2004)[6]
  - 0.47 +- 0.24 mm (Drexler and Furweger 2009)[5]

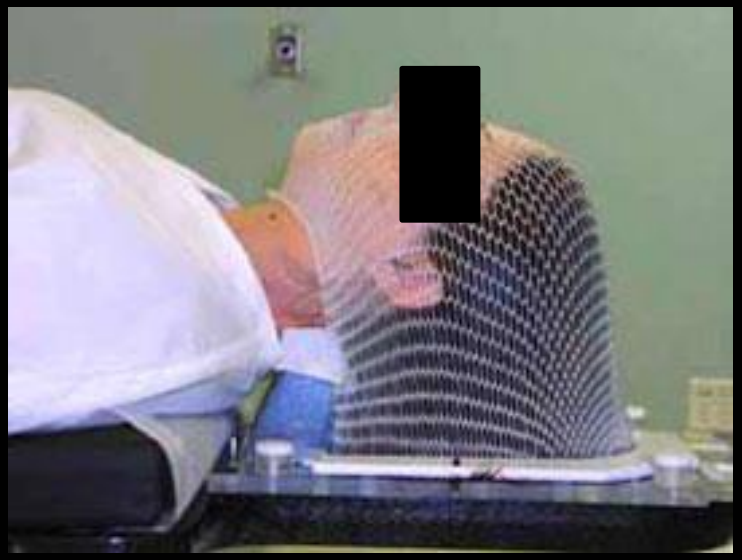
- ❑ CyberKnife Components
- ❑ Motion management
- ✓ Dosimetry
- ❑ Quality Assurance

Immobilization & Simulation



Thermoplastic Mask, Supine

CT without contrast, ~ 1 mm slice thickness, contiguous scan from 2 cm above the superior end of skull to 2 cm inferior to the chin.



T1 weighted MRI scan with contrast, 1 - 2 mm slice thickness, covering the lesion(s), orbits and all ventricles

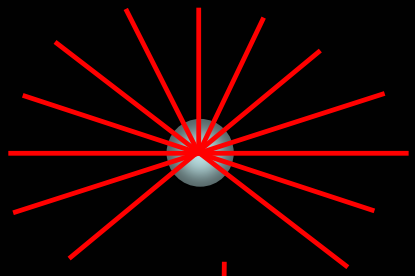
Typical Prescription Doses (Ref Only)

- Brian Mets (Per RTOG 0320)
  - <2.0cm 24 Gy x 1
  - 2.1-3.0 cm 18 Gy x 1
  - 3.1-4.0 cm 15 Gy x 1
- Surgical Bed: 7~9Gyx3, 4~6Gyx5
- Acoustic Neuroma : 6~8Gy x3, 12~14Gy x1
- Trigeminal Neuralgia: 60~90GyX1 Max (Cone, Iris, MLC?)
- Meningioma: 6~8Gyx3, 12~18Gy x 1

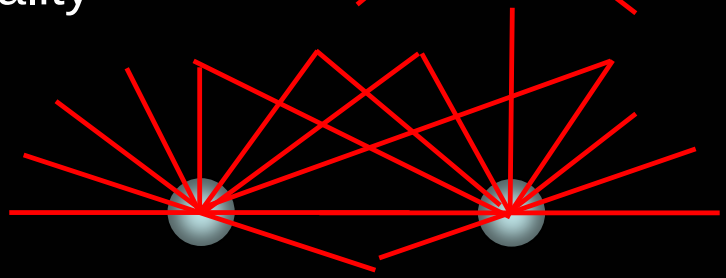
- Typical PTV margin <=1mm except Surgical bed

Dosimetry: Various Beam Arrangements

- Isocentric plan
  - -- Fast dose fall-off
  - -- Limited confomality

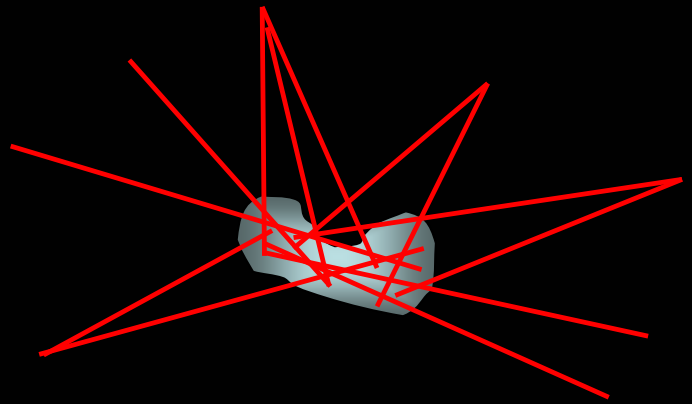


single shot

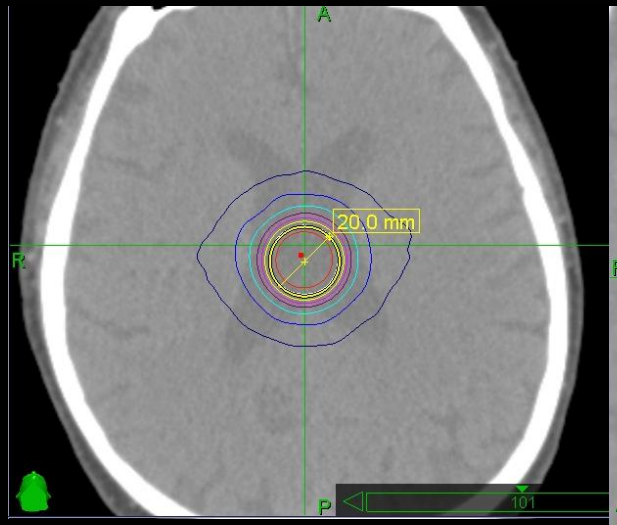


Multi-shot

- Non-isocentric
  - -- Excellent confomality
  - -- Dose fall-off not as fast



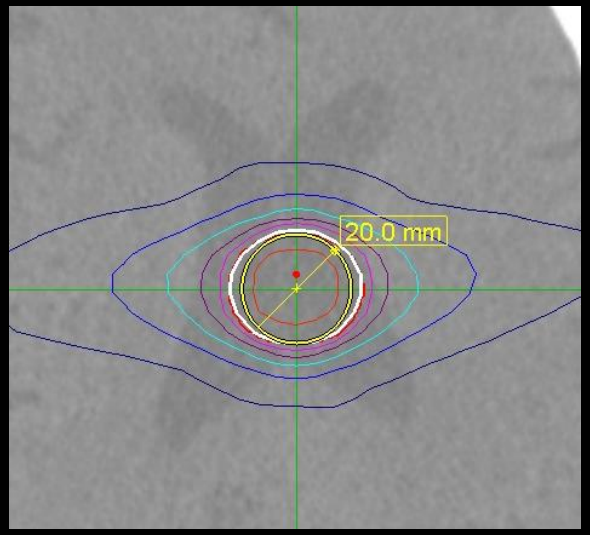
Isocentric Beam Weight Adjustment



Sphere Shape Dose
Equal MU per Beam

Height > Width

Oval Shape Dose

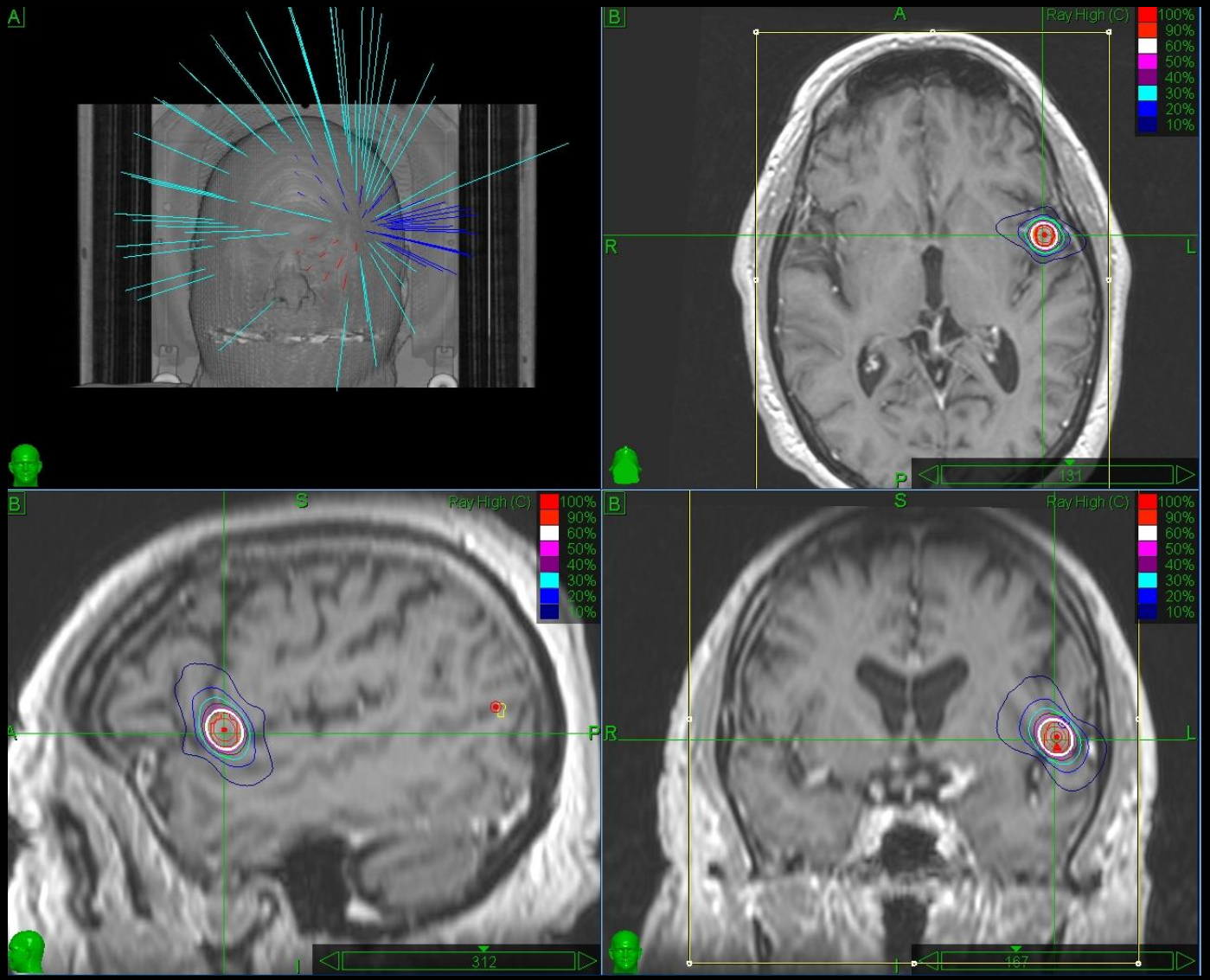


Height < Width

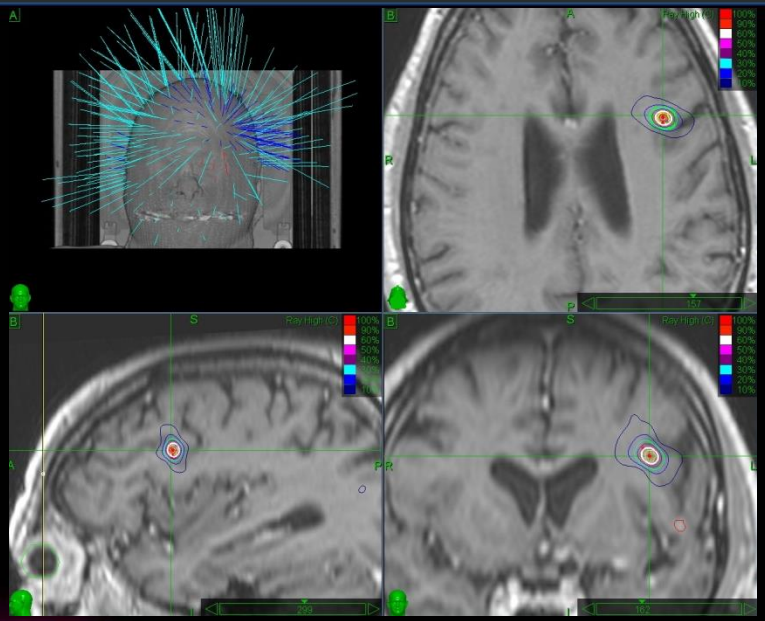
Oval Shape Dose

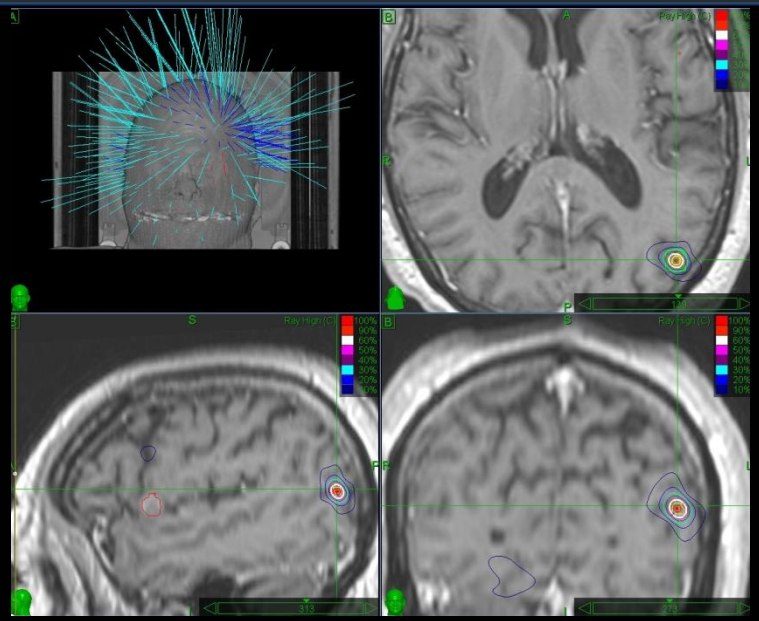
Isoconformal
Unequal MU per Beam
Limitedly Improved confomliaty

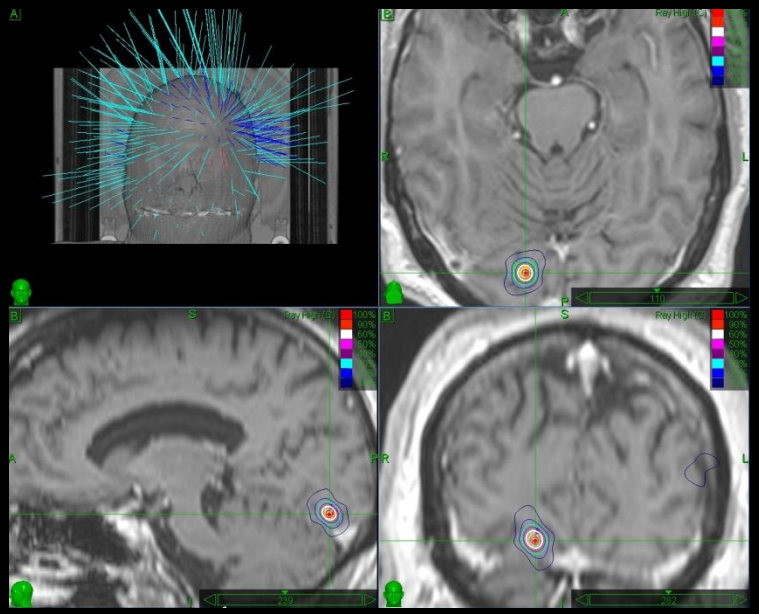
Isocentric Case: Brian mets



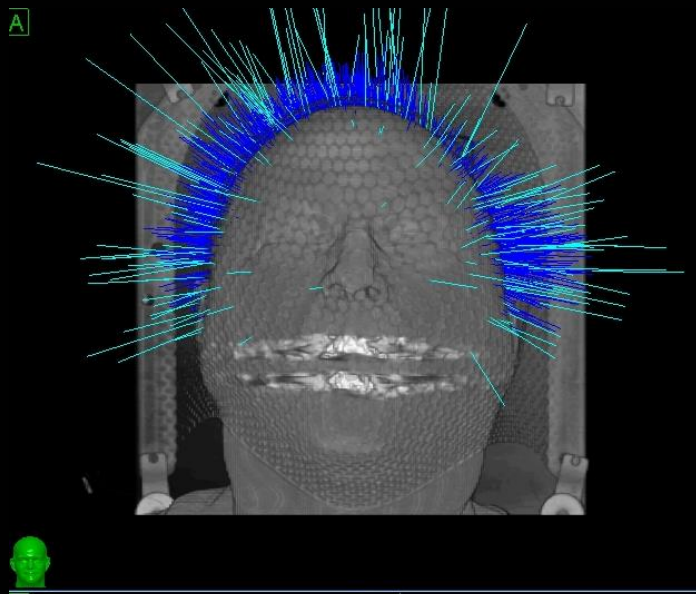
Multi-Isocentric Case: Brian mets

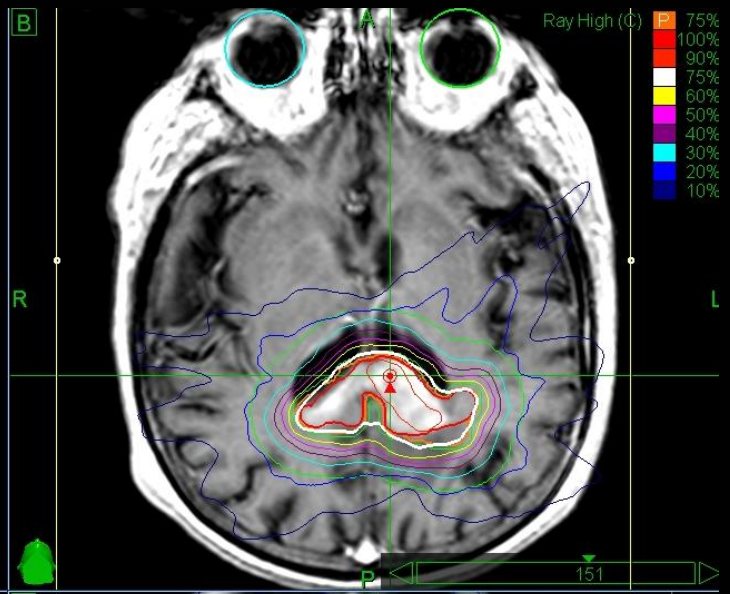


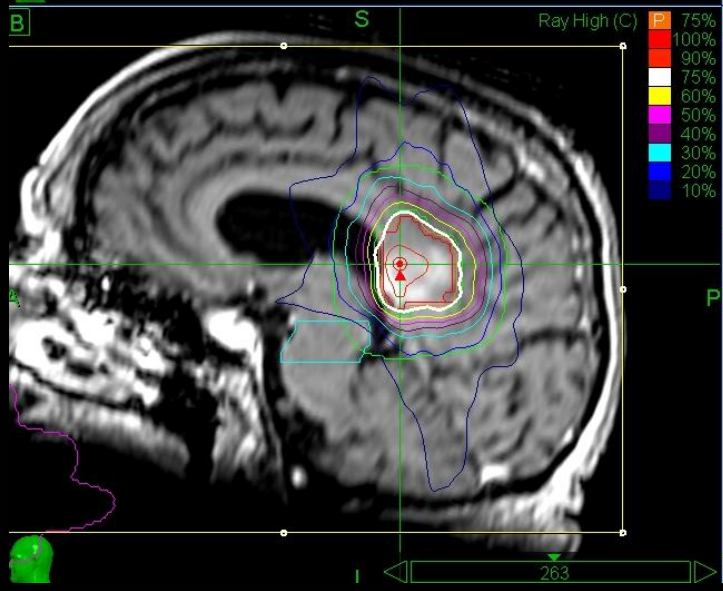


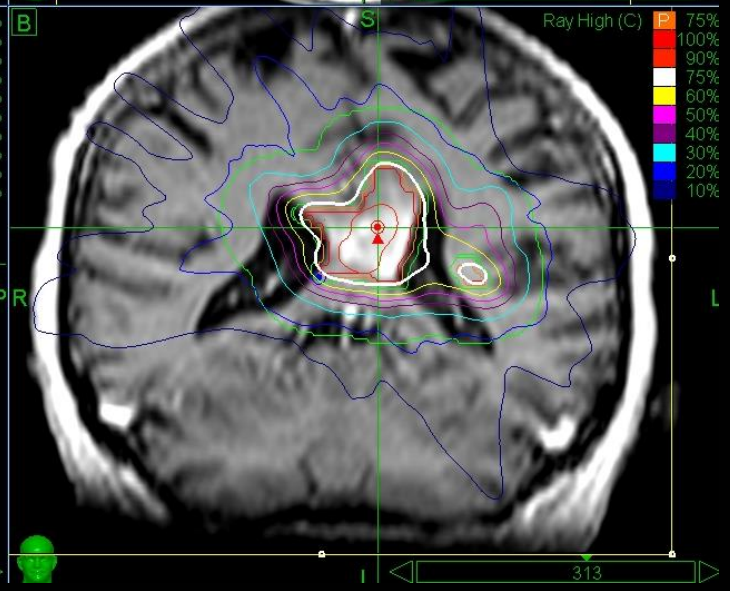


Non-Isocentric Case: Brian mets

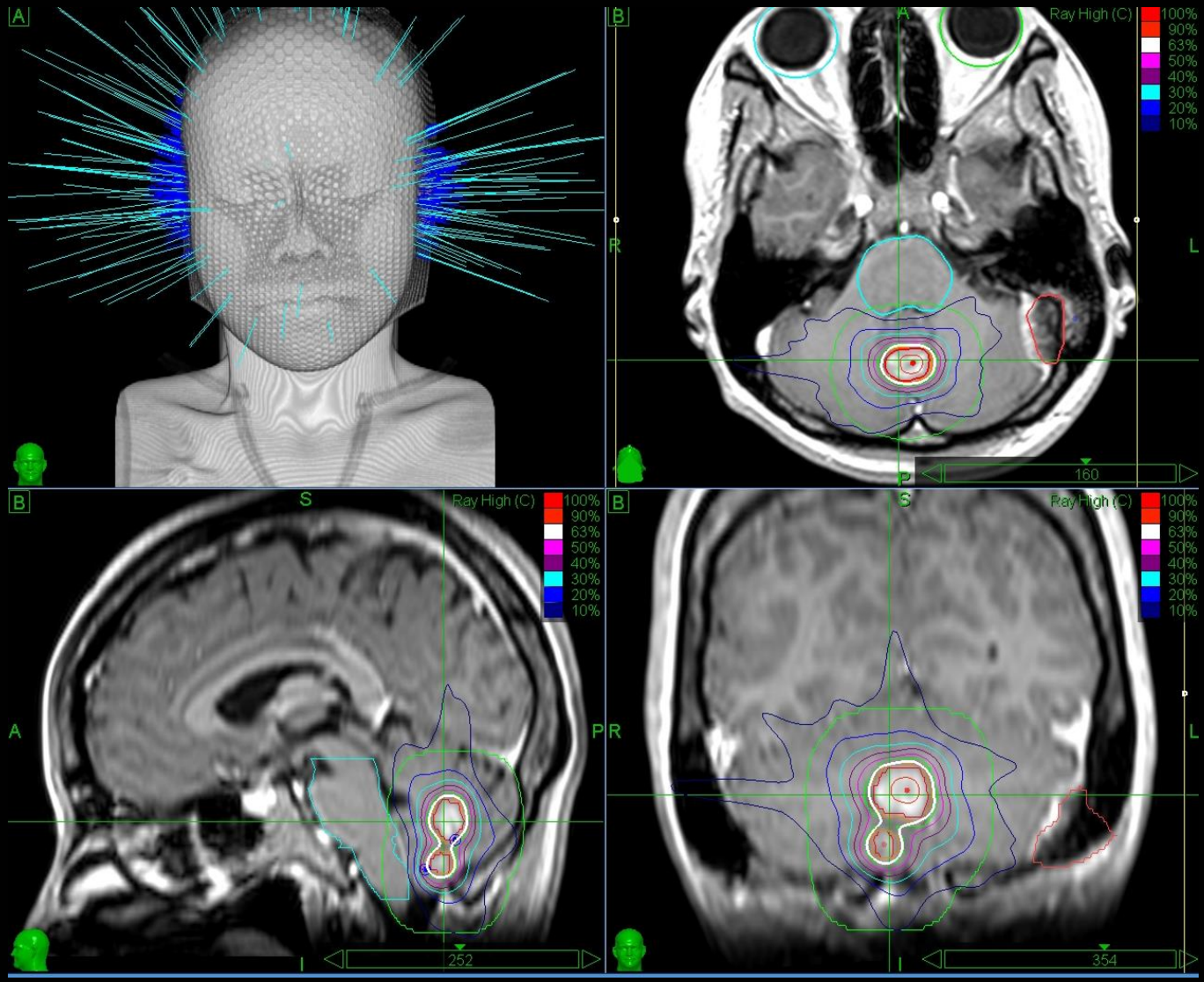




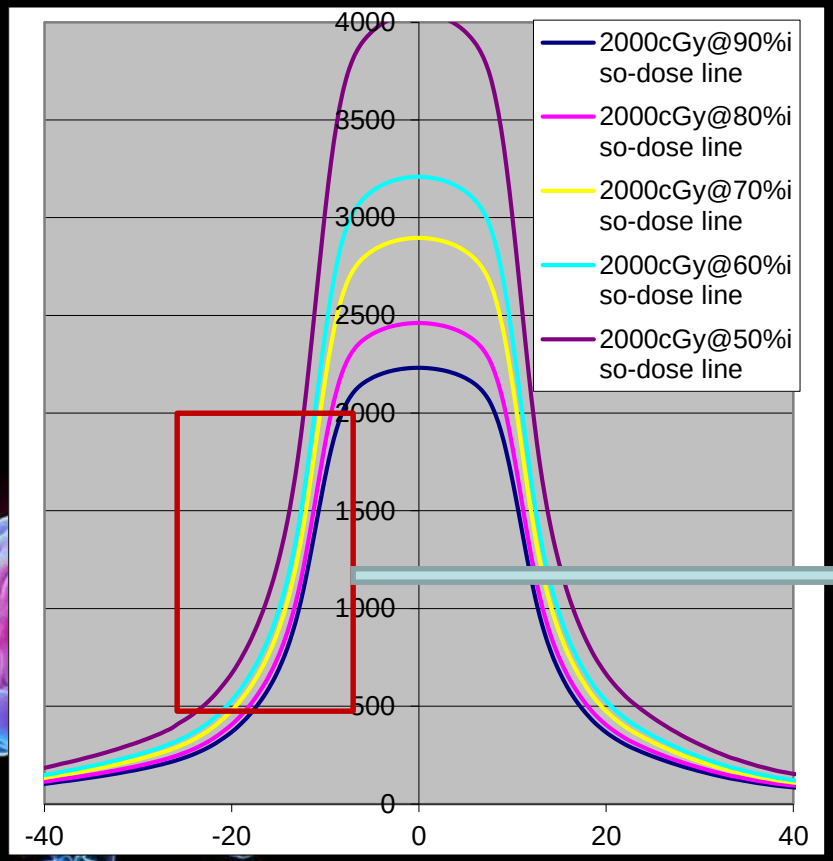


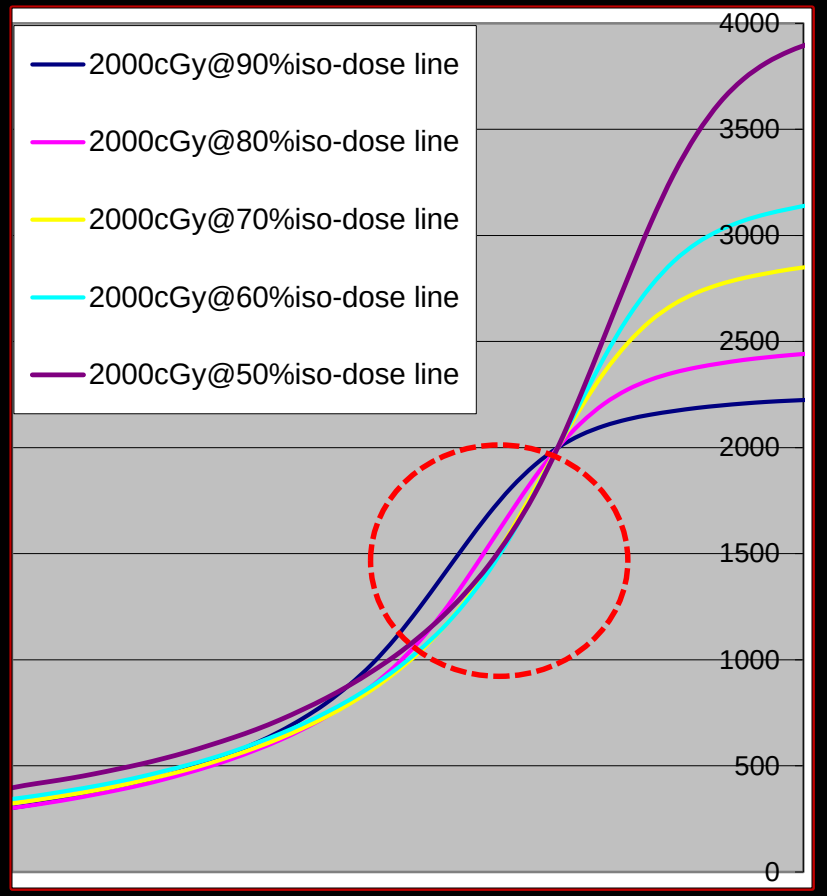


Isocentric + Non-Isocentric Case



Dose Heterogeneity VS Dose Fall off in Isocentric plan



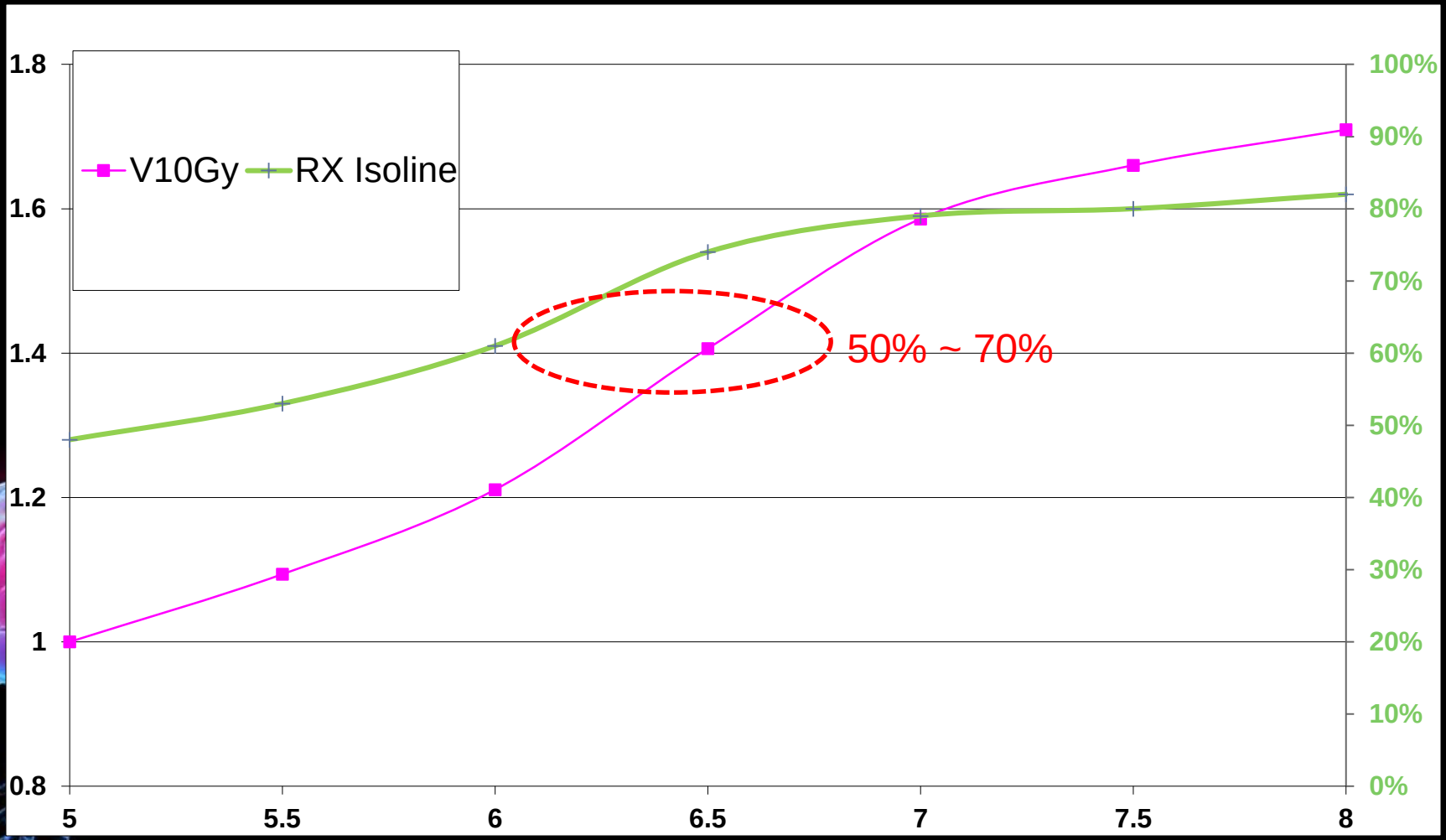


Absolute Dose profiles, with 20 Gy Rx at Different isodose Lines

70% ≈ 60% > 50% > 80% >> 90%

Note: Max Dose = 100%

Dose Heterogeneity VS Dose Fall off in Non-Isocentric plan



Note: Max Dose = 100%

- ❑ CyberKnife Components
- ❑ Motion management
- ❑ Dosimetry
- ✓ Quality Assurance

Absolute Output: TG 51

- 1MU = 1 cGy for 60 mm fixed cone at 800mm SAD with 15 mm Depth;
- $\%dd(10)_x$ measured at 1000 mm SSD with 100 mm Depth;
- Calculated Equivalent Square;
- Interpolate to 800 mm SAD using BJR data;

QA guidelines: TG 135 Quality assurance for robotic radiosurgery. 2011 (New Version coming)

IV.B. Daily QA

Section	Item	Tolerance
II.A.2	Safety interlocks (Door, console EMO, Key)	Functional
	CCTV cameras and monitors	Functional
	Audio monitor	Functional
	Collimator assembly collision detector	Functional
II.B.1	Accelerator warm-up: 6000 MU for open chambers, 3000 MU for sealed chambers	N/A
	Accelerator output	<2%: no change needed >2%: adjust calibration
	Detection of incorrect and missing secondary collimator	Functional
III.B.2	Visual check of beam laser and a standard floor mark.	<1 mm
III.C.1	AQA test	< 1 mm from baseline

IV.C. Monthly QA

Section	Item	Tolerance
II.A.2	Safety interlocks.	Functional
II.B.2	Energy constancy.	2%
	Beam symmetry.	>3%
	Beam shape.	>2% Compared to beam data
	Output.	> 2%
II.C.1	Imager alignment.	1 mm or center pixel ± 2 pixels
II.C.3	Contrast, noise, and spatial resolution of amorphous silicon detector. Homogeneity/bad pixels.	To be decided by user based on available literature
II.D	Custom CT model: CT QA (spatial accuracy, electron density).	See TG 66 (Ref. 29)
III.B.1	Verify relative location of beam laser vs. radiation CAX has not changed.	0.5 mm
III.B.2	Visually check isocentric plan to verify beam laser illuminates isocrystal; rotate through path sets each month	Laser on isocrystal for each node
III.C.2	Intracranial and extracranial E2E; set schedule to cycle through each clinically used tracking method and path.	<0.95 mm or <1.5 mm for motion tracking
III.C.3	Nonisocentric patient QA or DQA; ideally performed quarterly.	DTA 2 mm/2%; Synchrony DTA 3%/3 mm
III.D	Observe Synchrony treatment or simulation; listen for unusual noise and visually check for vibrations.	No significant change

IV.D. Annual QA

Section	Item	Tolerance
II.A.2	EPO button	Functional
II.B.3	TG 51 or IAEA TRS-398, including secondary independent check.	Adjust calibration if >1% difference is found
	Beam data checks on at least three collimators, including largest and smallest collimator (TPR or PDD, OCR, output factors).	To be decided by user
	Dose output linearity to lowest MU/beam used.	1%
II.C.2	Imager kVp accuracy, mA station exposure linearity, exposure reproducibility, focal spot size.	See Table 1 for references
II.C.3	Signal to noise ratio, contrast-to-noise ratio, relative modulation transfer function, imager sensitivity stability, bad pixel count and pattern, uniformity corrected images, detector centering, and imager gain statistics.	Compare to baseline
II.D	TG 53 as applicable.	TG 53 (Ref. 26)
	CT QA (in addition to monthly).	See TG 66 (Ref. 29)
	Data security and verification.	Functional
III.B.2	2nd Order Path Calibration; currently only possible with the help of a service engineer.	Each node < 0.5 mm RMS < 0.3 mm
III.D	Check noise level of optical markers.	<0.2 mm
IV.C	Run Synchrony E2E test with at least 20 deg phase shift; analyze penumbra spread.	To be decided by user
IV.C	Monthly QA.	In addition to tolerances listed above, update all parameters and checklists
IV.B	Daily QA.	Update parameters

Minimum QA guidelines: TG 277 AAPM-RSS Medical Physics Practice Guideline 9.a. for SRS – SBRT

Table 2: Minimum equipment QA and tolerances for robotic linac systems

Frequency	Test	Tolerance
Daily* **On days of clinical use*	Head laser alignment check	1.0 mm
	Safety interlocks	Functional
	Automatic QA (AQA) test* **If the clinic has both fixed cones and Iris™ collimator, the AQA test should alternate between fixed cones and Iris™, with each system tested at least weekly*	Total targeting ≤ 1.0 mm from baseline, not exceeding manufacturer's specification
	Accelerator output constancy	± 3%
Monthly	Energy constancy	± 2%
	Beam symmetry, relative	± 3% for 40 mm field, ± 4% for 60 mm field,
	Accelerator output constancy	± 2%
	Imager alignment	1mm or center pixels ± 2 pixels
	Iris Field size spot check	0.5 mm, 3 or more field sizes ≥ 10 mm
	Picket fence for MLC *(if applicable)*	Visual check
Quarterly	E2E localization assessment (Each tracking mode used clinically)	1.0 mm static target, 1.5 mm motion tracking
Annually	Emergency Power Off (EPO) button, safety interlocks	Functional
	Accelerator output	± 2.0%
	MU linearity (>10 MU to highest MU used clinically)	± 2%
	Path verification	≤0.5 mm maximum per node, ≤0.3 mm average
	Imager kVp accuracy, mA station exposure linearity, isopost alignment with center pixel	± 10%, ± 20%, and 1 mm respectively
	Beam laser and radiation beam alignment for cone, Iris and MLC	0.5 mm from baseline
	AQA baseline	Re-check AQA baseline
	Beam data verification - Relative output factors for cones, Iris and/or MLC covering the range used clinically	± 2% from baseline for > 1.0 cm apertures, ± 5% from baseline for ≤ 1.0 cm apertures

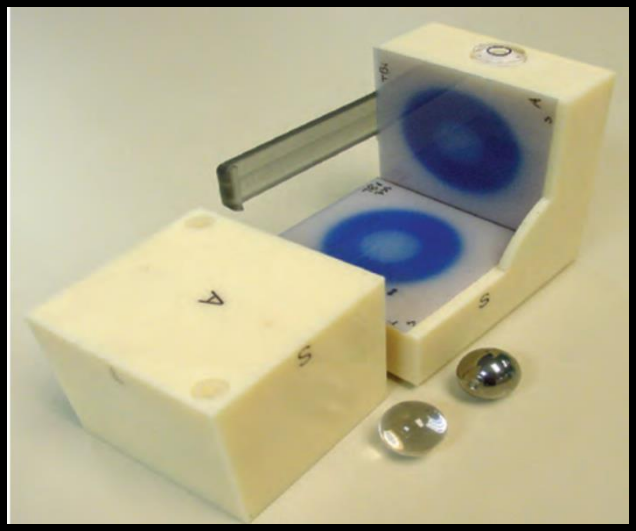
Draft for AAPM Approval

Quality Assurance

- End 2 End test
- BB test
- AQA
- Beam analysis
- Plan Dose Verification
- Image system test
- Daily, Monthly, Quarterly and Annually QA

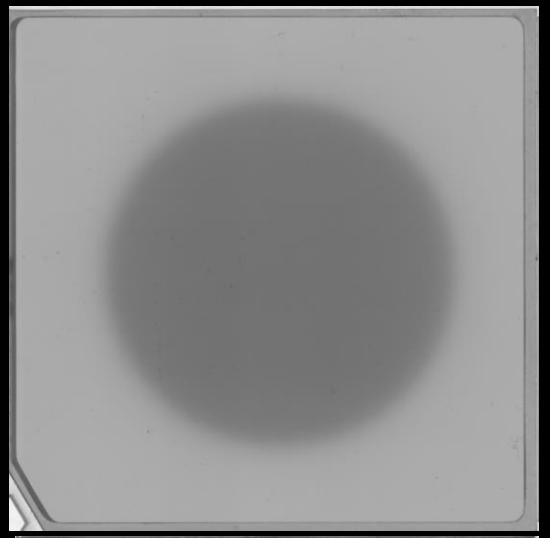
Morning QA - Output

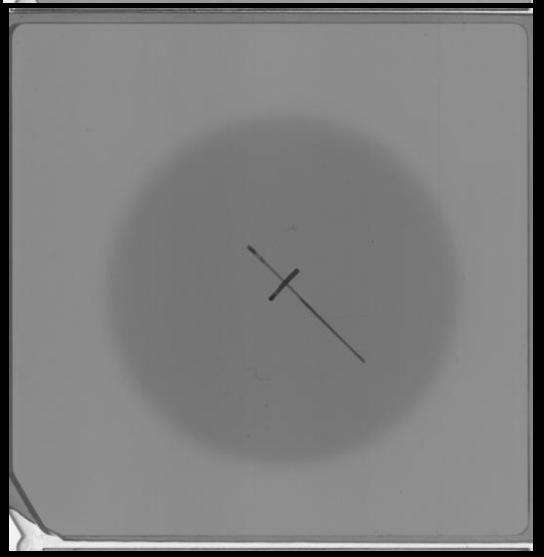
Morning QA – AQA(W-L test)



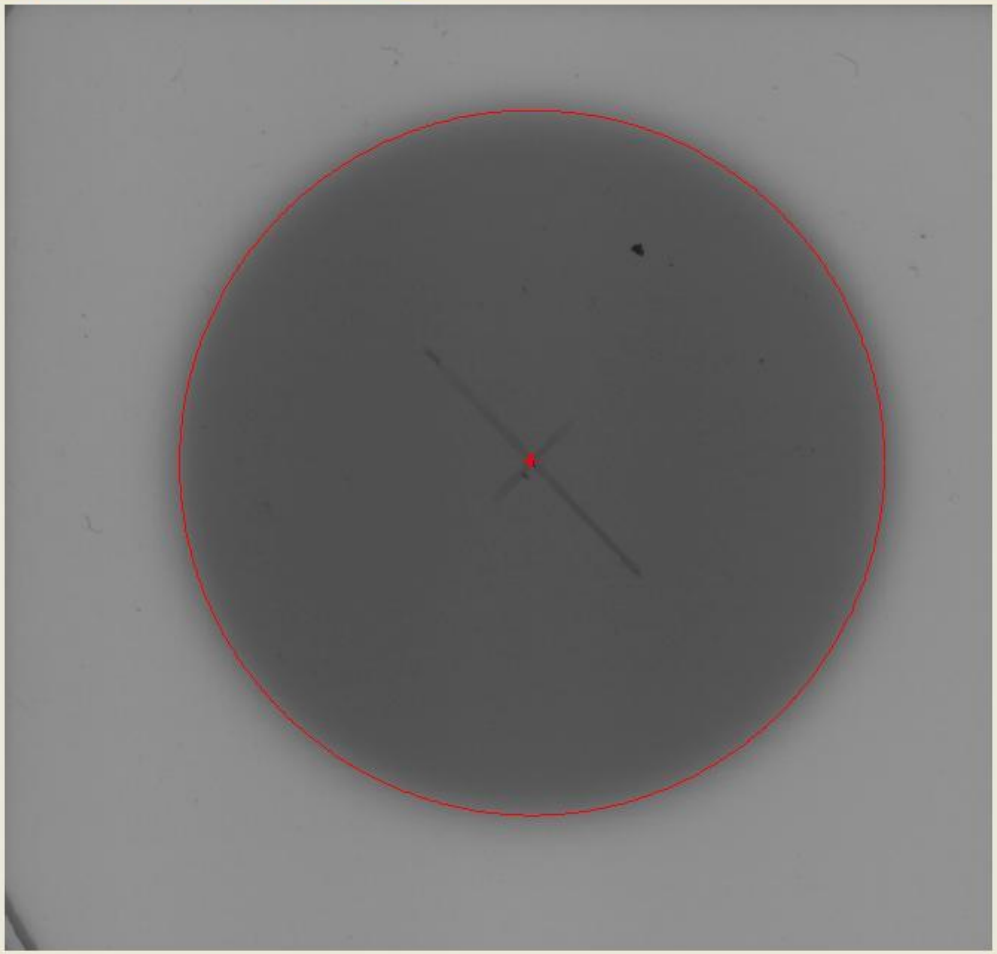
Monthly QA- Output/Energy

Monthly QA – Symmetry and Flatness/ Laser Alignment





Cyberknife Laser Alignment Check Software



Open the Film Image...

Pickup Background 36957.6544

Pickup Peak 20805.9909

Film Scan Resolution: 300 DPI

Contour Line: 50 %

Draw the Contours

Pick Laser Point

Result

Center: Radium:

X: 31.92 mm 21.29 mm

Y: 27.73 mm

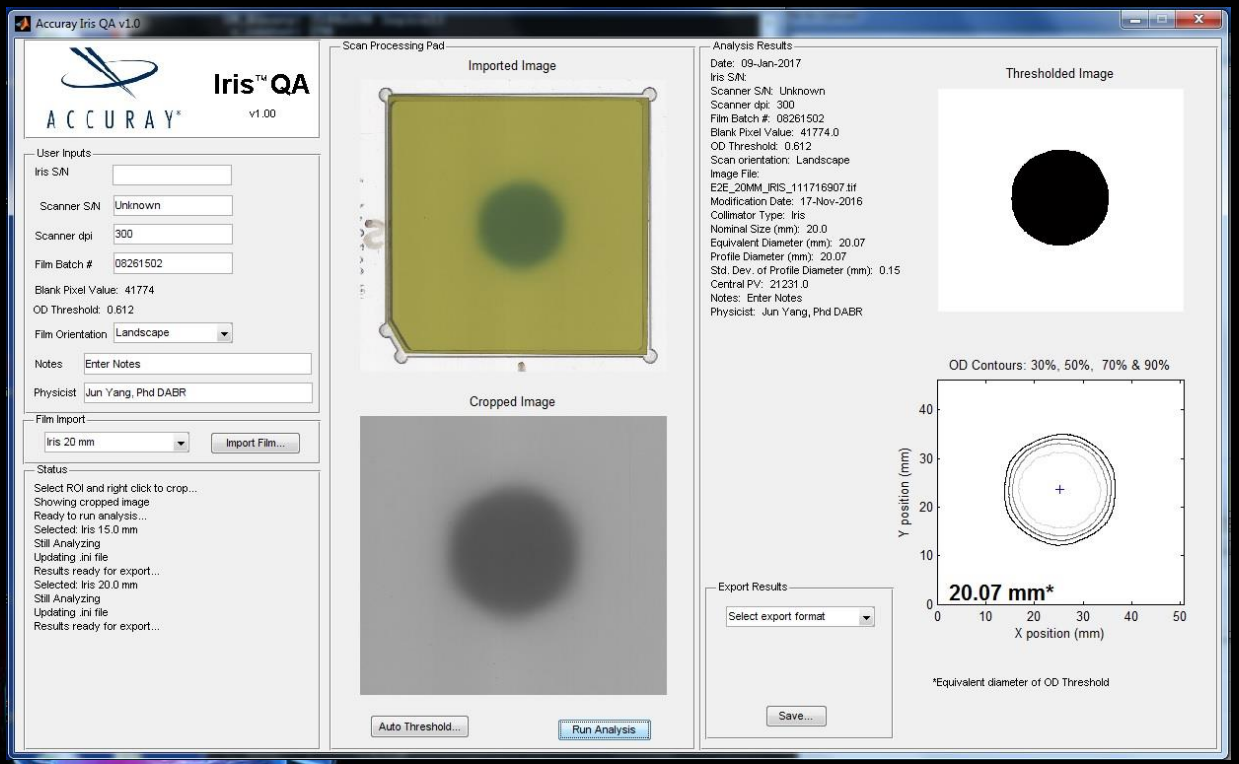
Laser from the Center

Laser Point

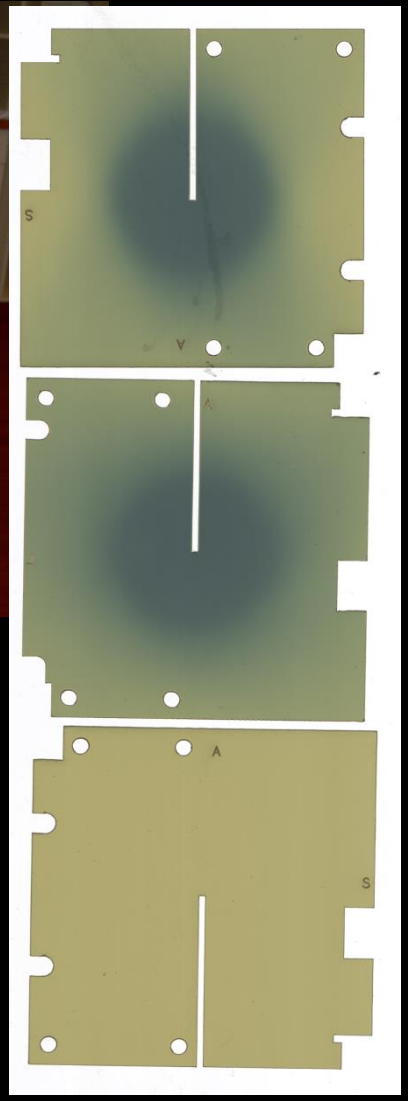
X: 0.00 mm

Y: -0.17 mm

Monthly QA – IRIS Collimator Field Sizes



Monthly QA – E2E



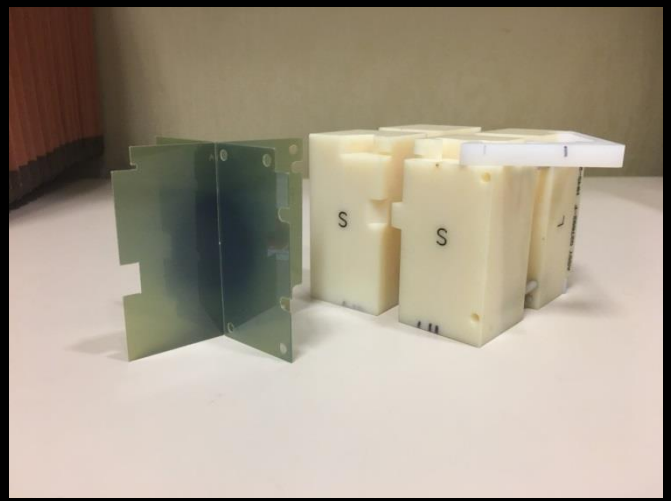


Image 1

Ant.

Left

Right

Post.

Image 2

Ant.

Sup.

Inf.

Post.

ACCURAY

End-to-End (E2E) Film Analysis

Image 1 Threshold Area

Image 1 Threshold Area Information

Centroid Area:	140171
Pixels to Left:	376.13
Pixels to Top:	373.2
Eccentricity:	1.12

Image 2 Threshold Area

Image 2 Threshold Area Information

Centroid Area:	111116
Pixels to Left:	381.65
Pixels to Top:	375.96
Eccentricity:	1.36

Image 1 Multiple Threshold Contours

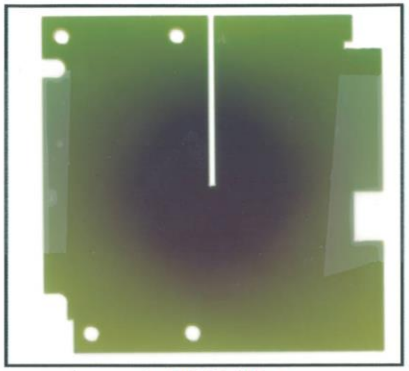
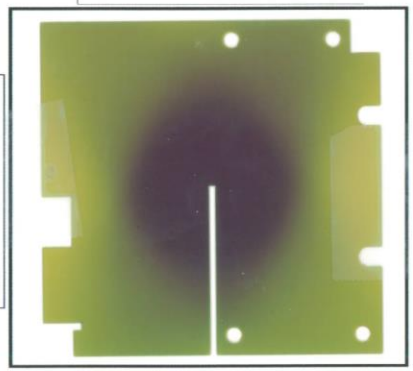


Image 2 Multiple Threshold Contours



E2E Reference

Test:	IRIS FUD
Date:	11/17/2016
Film Label:	
Scanner:	Epson 1680
Film Type:	EBT 2
Film Batch:	
Analysis Color	RED
Image Bit Depth:	48

Calibration Information

Hor pix/mm:	11.9
Vert pix/mm:	11.81
Sup. Pos mm:	31.75
Ant. Pos mm:	31.75
Left Pos mm:	31.75

Pixel Measurement *Contour Threshold:* 25272

Minimum: 19644 *BG Film:* 45489

Image 1 (A/L Image) Info

mm from left edge:	31.61
mm from anterior edge:	31.6
contour area/ball area:	1.26

Image 2 (A/S Image) Info

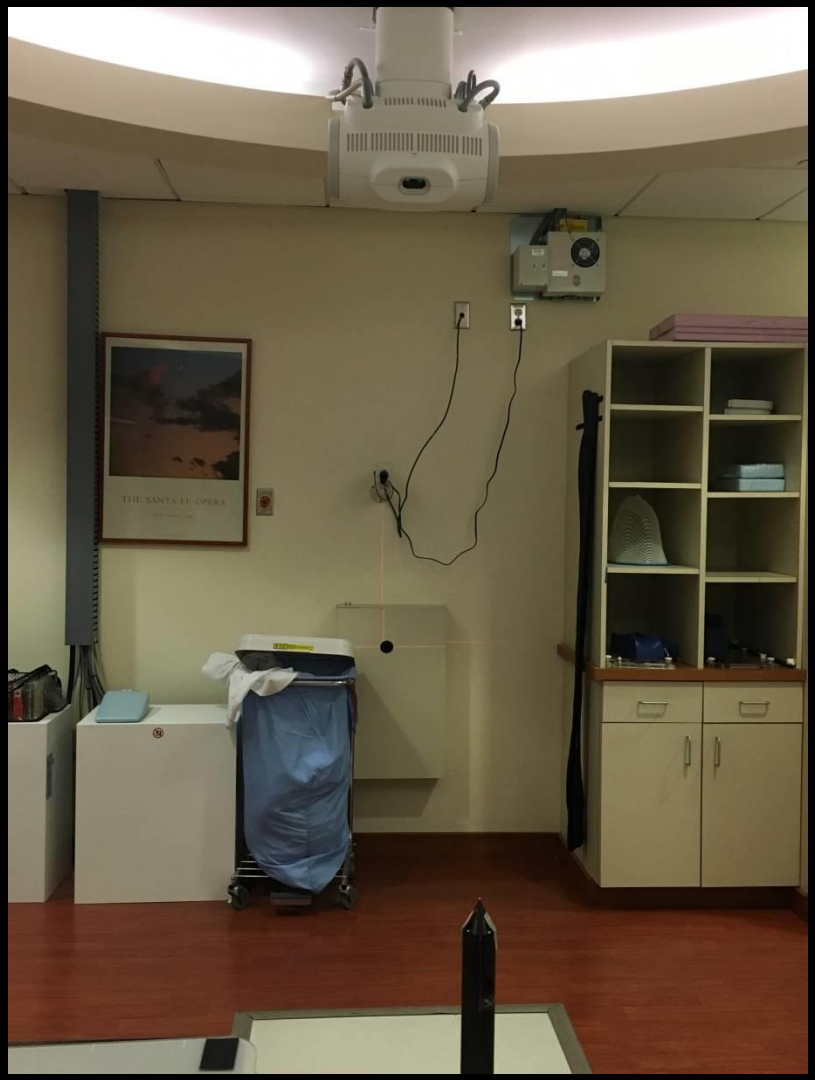
mm from superior edge:	32.07
mm from anterior edge:	31.83
contour area/ball area:	1

Error Information

left error mm:	0.14
anterior error mm (A/L image):	0.15
superior error mm:	-0.32
anterior error mm (A/S image):	-0.08
average anterior error mm:	0.03
TOTAL TARGETING ERROR mm:	0.35

70% Contour Level

Monthly QA – Imaging Center



Thanks