# Gamma Knife and CyberKnife: Physics and Quality Assurance

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SWEDISH

## Acknowledgements


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## Objectives

1) To provide an overview of the physics of Gamma Knife and CyberKnife radiosurgery.
2) To review the quality assurance procedures for the Gamma Knife and CyberKnife.

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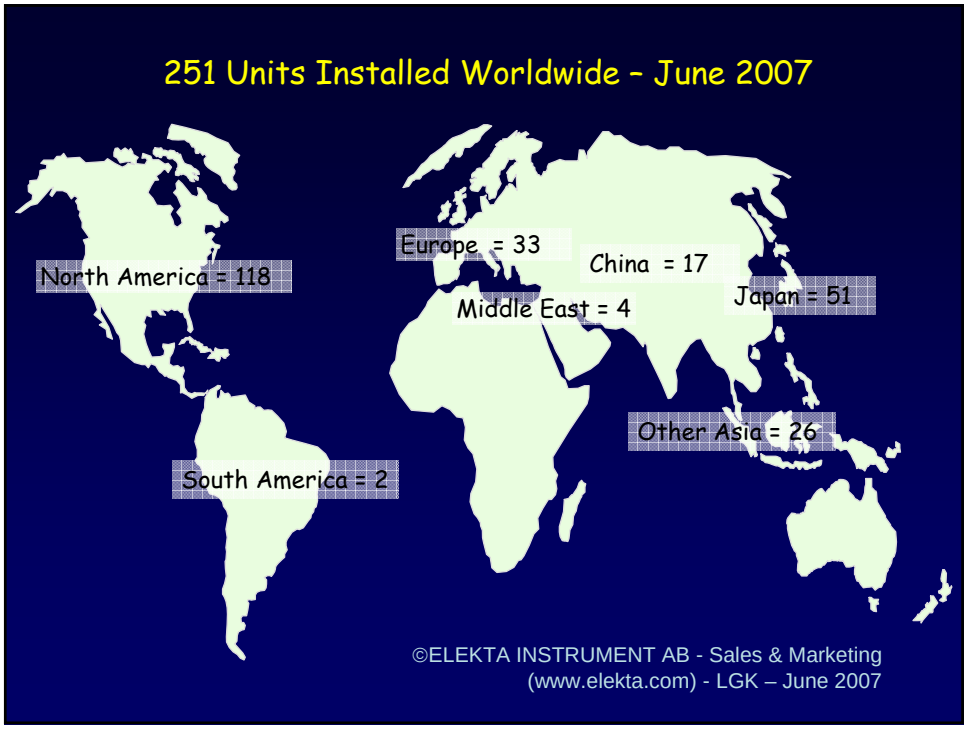
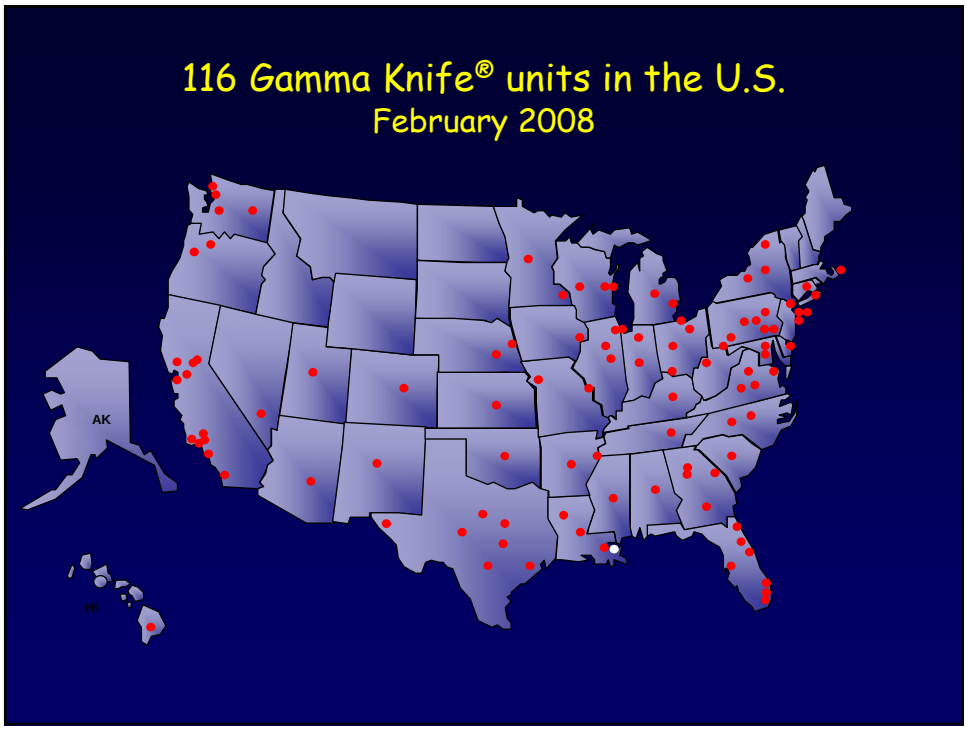
## Gamma Knife - Basics

- A treatment unit designed specifically for intracranial radiosurgery.
- First Gamma Knife built in 1967 under direction of Lars Leksell in Stockholm, Sweden.


251 Units Installed Worldwide – June 2007
North America = 118
Europe = 33
China = 17
Japan = 51
Middle East = 4
Other Asia = 26
South America = 2
©ELEKTA INSTRUMENT AB - Sales & Marketing
(www.elekta.com) - LGK – June 2007


116 Gamma Knife® units in the U.S.
February 2008
AK
HI

## 19 Leksell Gamma Knife® Perfexion™ units
June 2008


## Gamma Knife Evolution

| 1968<br>Model S | 1986<br>Model U | 1987<br>Model B | 1999<br>Model C | 2004<br>Model 4C | 2006<br>Perfexion |
|---|---|---|---|---|---|
|  |  |  |  |  |  |
| *2 delivered* | *27 delivered* | *127 delivered* | *152 delivered* | *49 delivered* | *7 delivered* |
| Sheffield, Buenos Aires | Decreased body dose<br>Computer dose planning | Improved collimator design | Semi-robotic patient positioning<br>Improved dose conformity | Still in production<br>Improved software<br>Merge/fusion capability | Improved conformity<br>Larger cavity<br>Very low body dose<br>Rapid treatment<br>Full automation<br>Expert panel |

Courtesy of David Larson

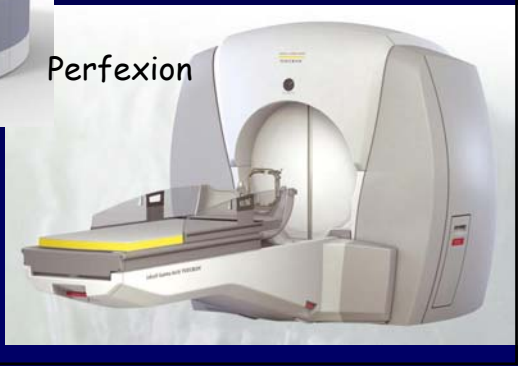
## Recent Advances in Gamma Knife Technology

Model 4C

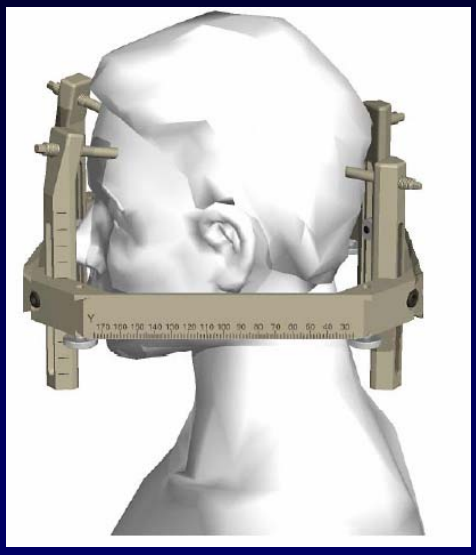
2004

2006

Perfexion



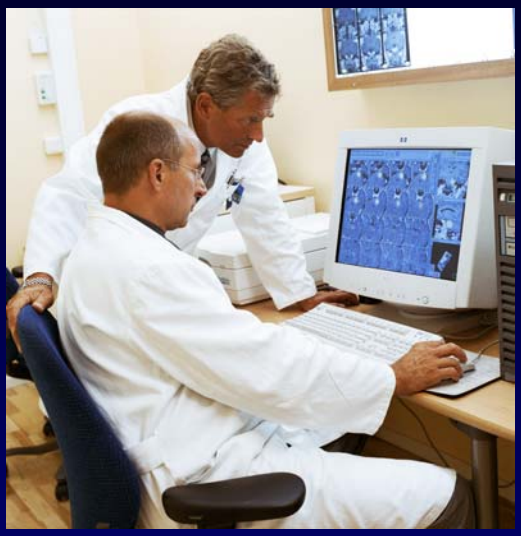
## Model 4C



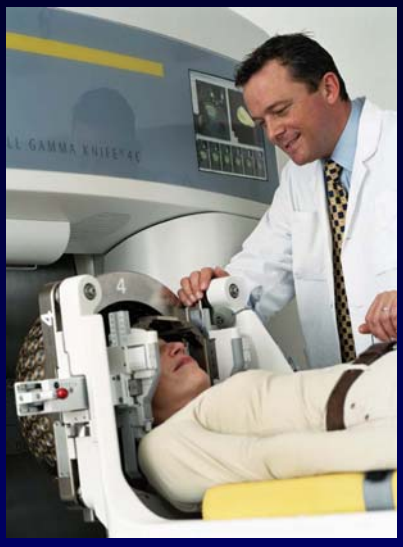
## Gamma Knife Procedure

Step 1: A stereotactic head frame is attached to the patient's head under local anesthesia.

Step 2: The patient is imaged using either MRI or CT with a fiducial box attached to the patient's stereotactic frame.

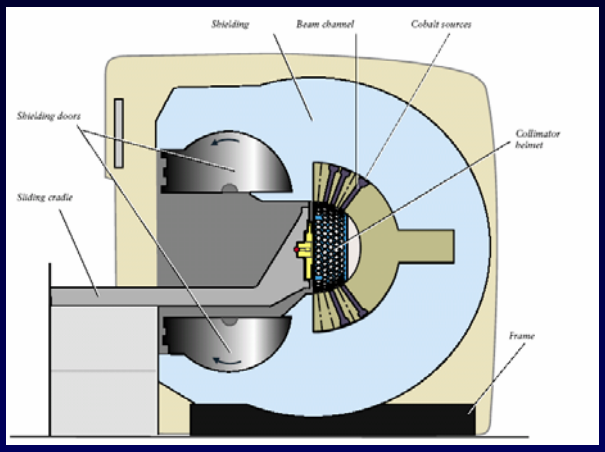


Step 3: A treatment plan is developed.



Step 4: The patient's stereotactic head frame is affixed to the Gamma Knife's automatic positioning system.

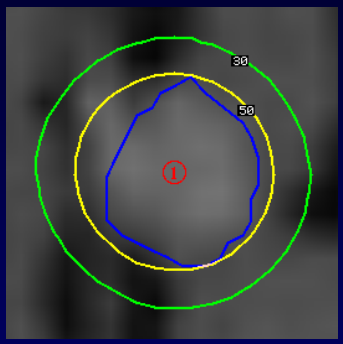
Step 5: The doors to the treatment unit open. The patient is advanced into the shielded treatment vault.




- Inside the shielded vault, the beams from 201 Co-60 sources are focused so that they intersect at a single location.
- An elliptical region of high dose is produced with a rapid falloff in dose outside the boundary of the ellipse.
- Each exposure is referred to as a shot of radiation.

- Four focusing helmets are available.
- Each focusing helmet includes 201 collimators that dictate the size of the shot of radiation (4, 8, 14, or 18 mm).

## Creating the Treatment Plan (1)

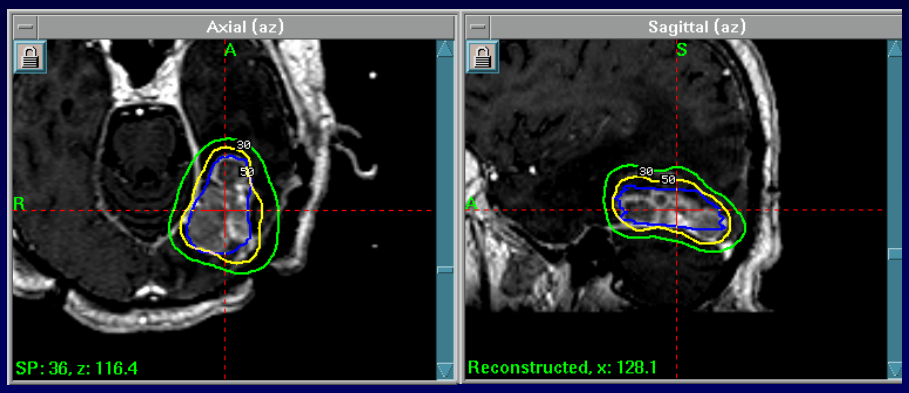



- For small spherical lesions, the planning is straightforward.
- For example, here a single 8mm shot covered the target (6mm in diameter).

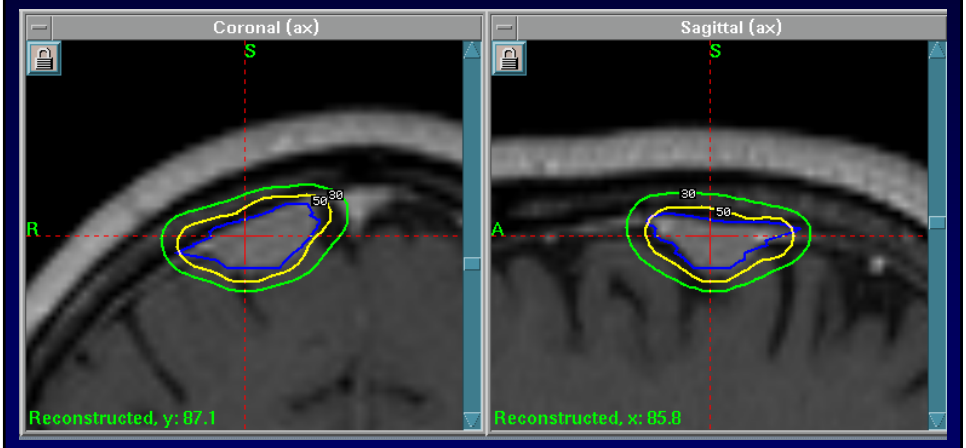
## Creating the Treatment Plan (2)

- For tumors that are large or irregularly shaped, the planning process becomes more complex.
- These cases typically require several shots of radiation.
- Through an iterative trial-and-error approach, the user must determine how many shots to use along with their sizes, locations and weights.

## Met – 8 shots (18mm)




## Meningioma – 12 shots (8mm)



## Leksell Gamma Knife® Perfexion™

## Gamma Knife Perfexion

- Major redesign of the Gamma Knife.
- July 2006 – 1st system became operational at Timone University Hospital of Marseille France.
- August 2006 - FDA issued a 510(k) pre-market clearance for the Perfexion.

## Gamma Knife Perfexion
### Beam Collimation (1)

- The most critical change in the Perfexion is the new collimator system.
- The new system replaces the multi-helmet collimator setup with a single integrated permanent collimator system that incorporates openings for 4mm, 8mm, and 16mm treatment beams.

## Gamma Knife Perfexion
### Beam Collimation (2)

- The collimator is partitioned into 8 independently moveable sectors each delivering 24 beams of radiation (192 total sources).
- Beam size can be changed dynamically by sector.
- Individual sectors can be blocked to provide further shaping of each shot of radiation.

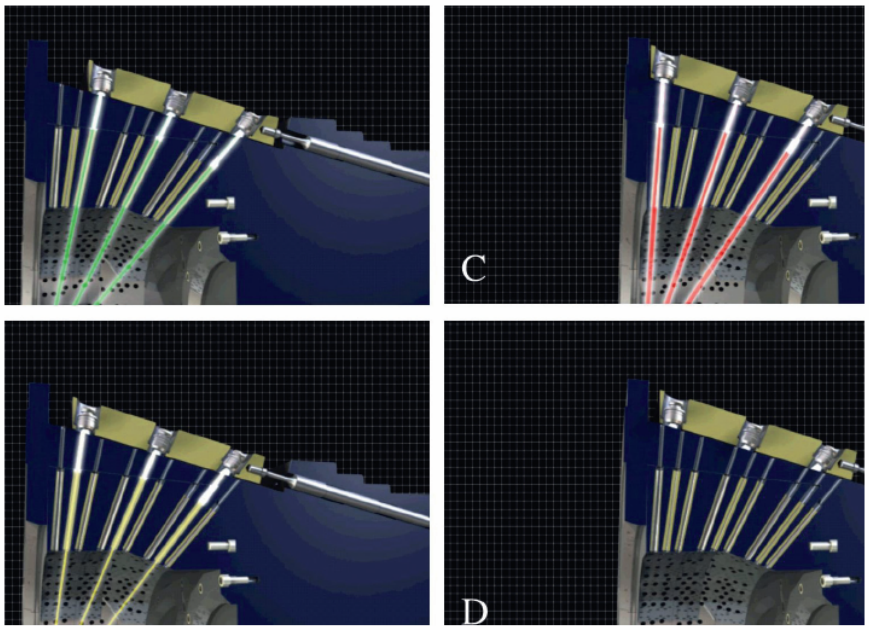
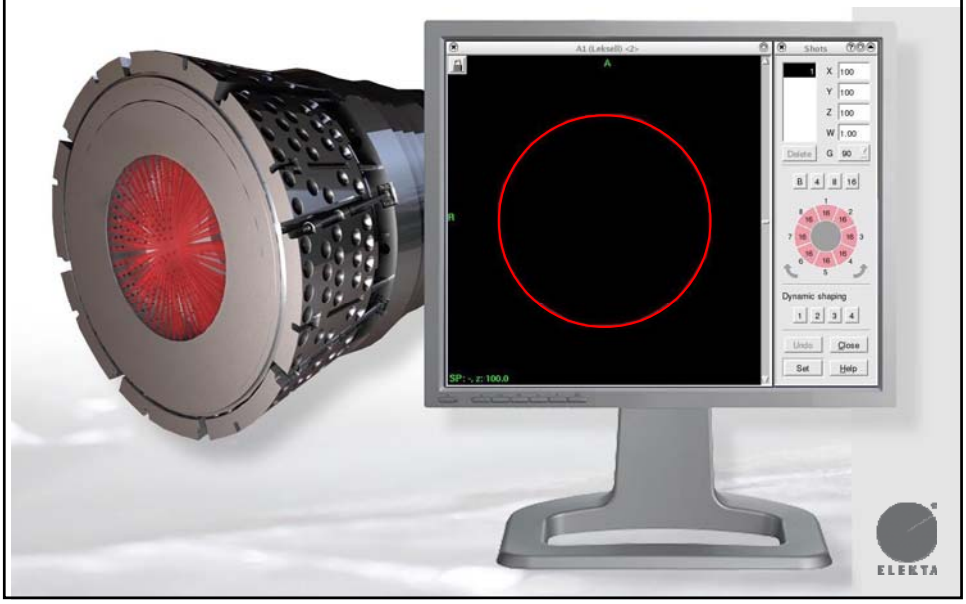
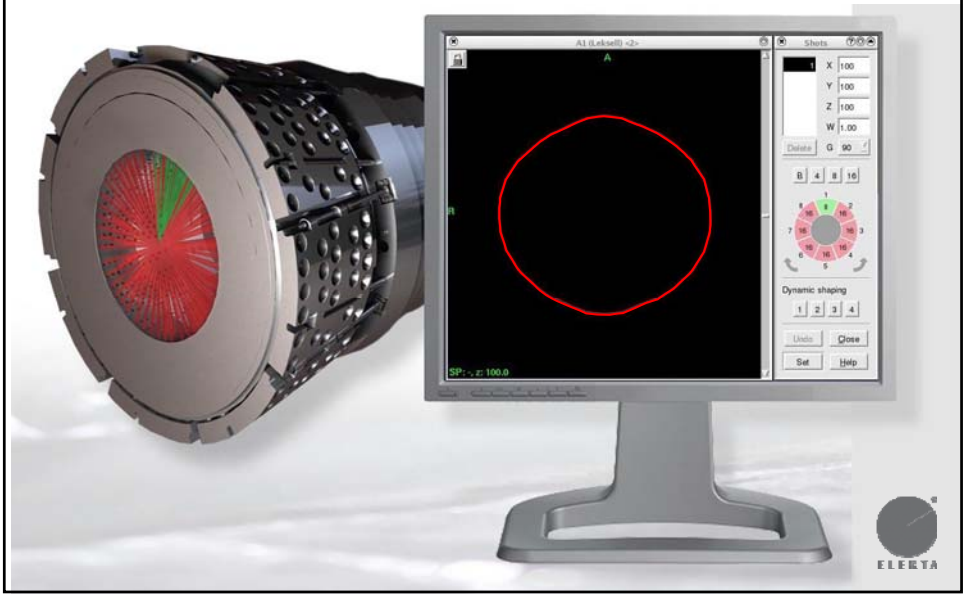



FIG 4: The original design of the Perfexion. Eight sectors, containing 24 $Co^{60}$ sources each, are moved by 8 servo drives (see Fig. 6). Depending on the sector position the collimator size can be 4 (A), 8 (B) and 16 mm (C) or Blocked/off (D).

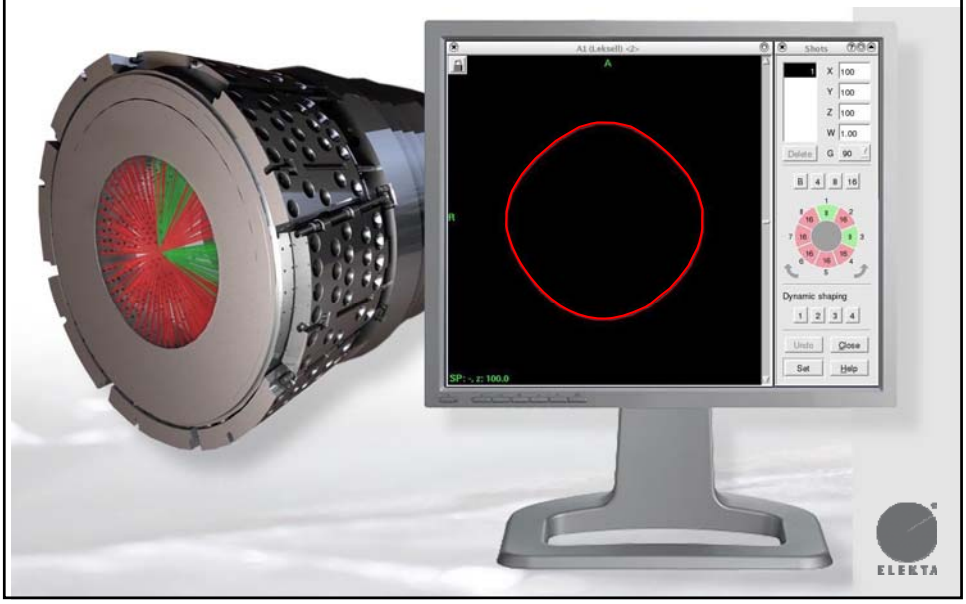
## Collimator system 16-16-16-16-16-16-16-16



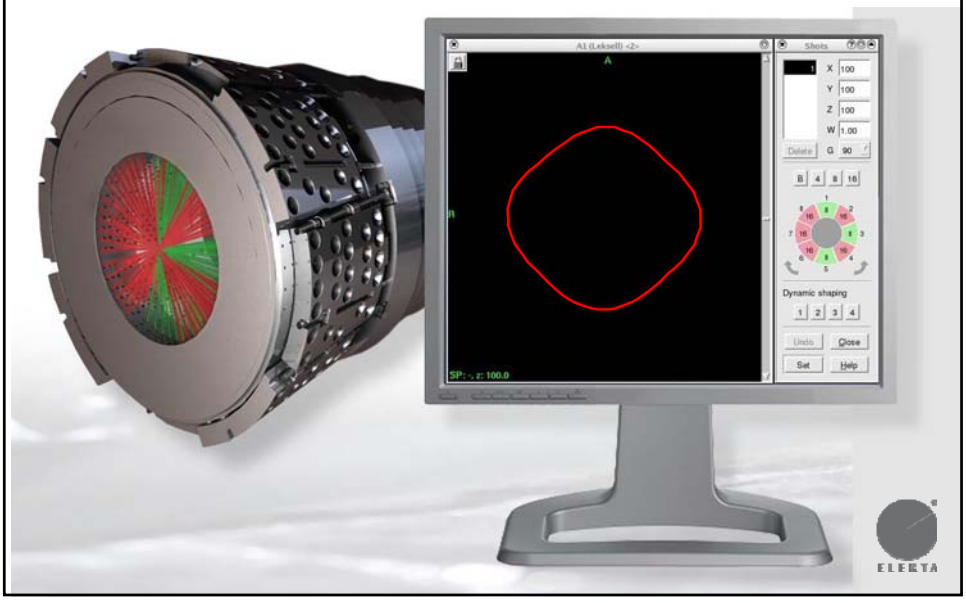

## Collimator system 8-16-16-16-16-16-16-16



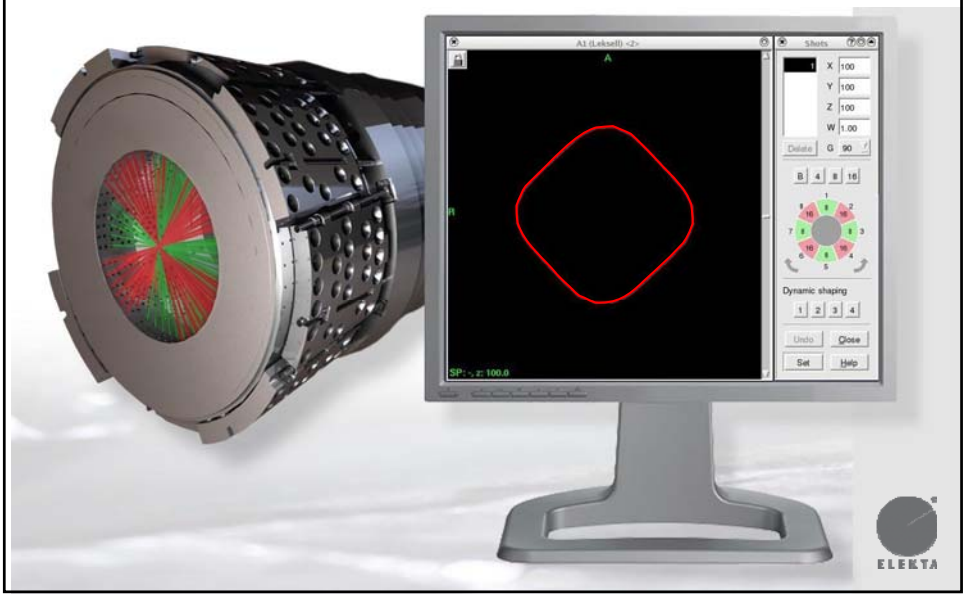
## Collimator system 8-16-8-16-16-16-16-16



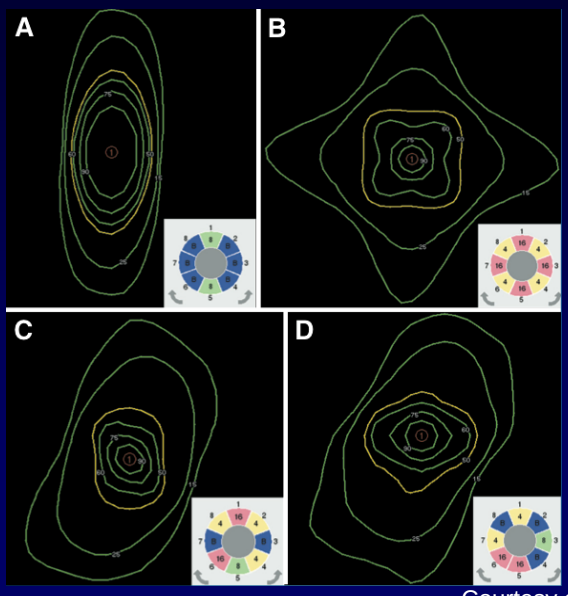

## Collimator system 8-16-8-16-8-16-16-16



## Collimator system 8-16-8-16-8-16-8-16



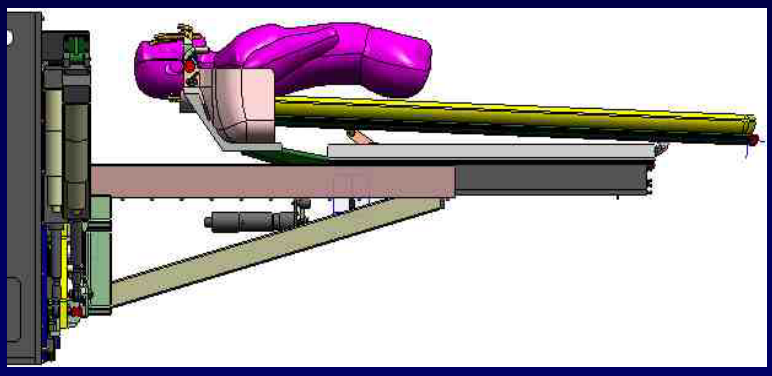

## Single Shot Dynamic Dose Shaping




Courtesy of David Larson

## Positioning System Design

- The GK Perfexion positions the patient by moving the couch rather than moving the patient's head within an APS.
- The transition between shot locations is typically under 3 seconds



Courtesy of David Larson

## Perfexion – Key Advantages

1. Improved patient throughput.
2. Improved patient comfort.
3. Extended anatomical reach.

## Improved Patient Throughput

- No helmet changes.
- All treatments delivered in a single run.
- The patient no longer needs to moved out of the unit between shots because the beams can be moved to the off position.

Courtesy of Jean Régis

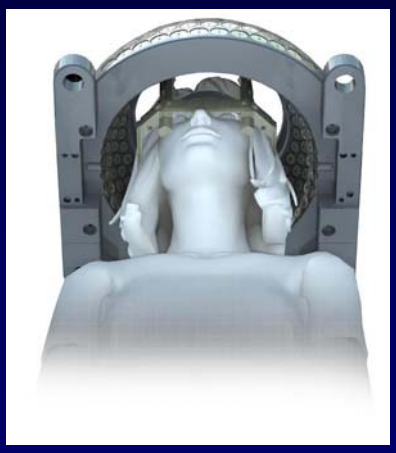
## Improved Patient Comfort

- Increased space inside collimator body leads to reduced patient anxiety.
- The need for eccentric frame positioning is eliminated.

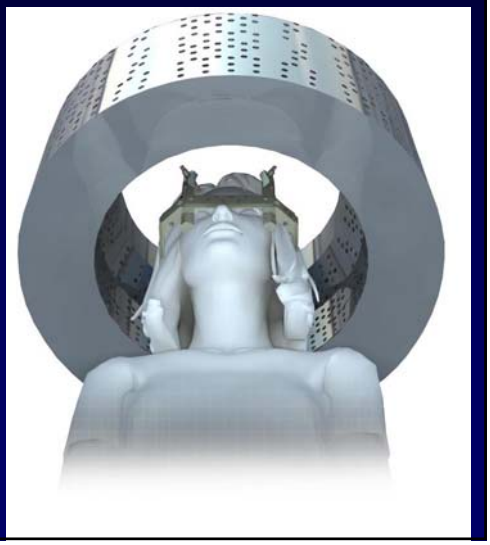
Courtesy of Jean Régis

## Larger Collimator Size

Leksell Gamma Knife® C



Leksell Gamma Knife® Perfexion™



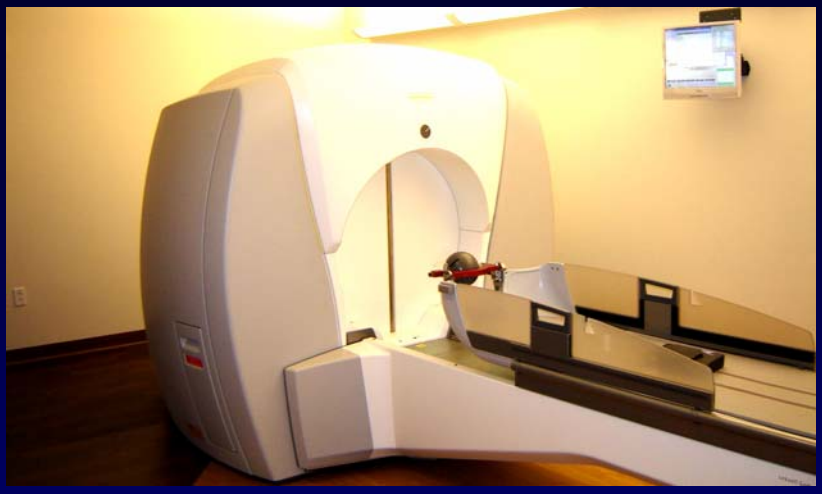
## Extended Anatomical Reach

- Most peripheral lesions can now be treated.
- Elekta is developing a fixation device for cervical spine lesions as well as a repositionable frame for fractionated radiosurgery.
- Lesions in and around the paranasal sinuses, the orbits, and the cervical spine are now accessible.

Courtesy of Jean Régis

## Gamma Knife eXtend™

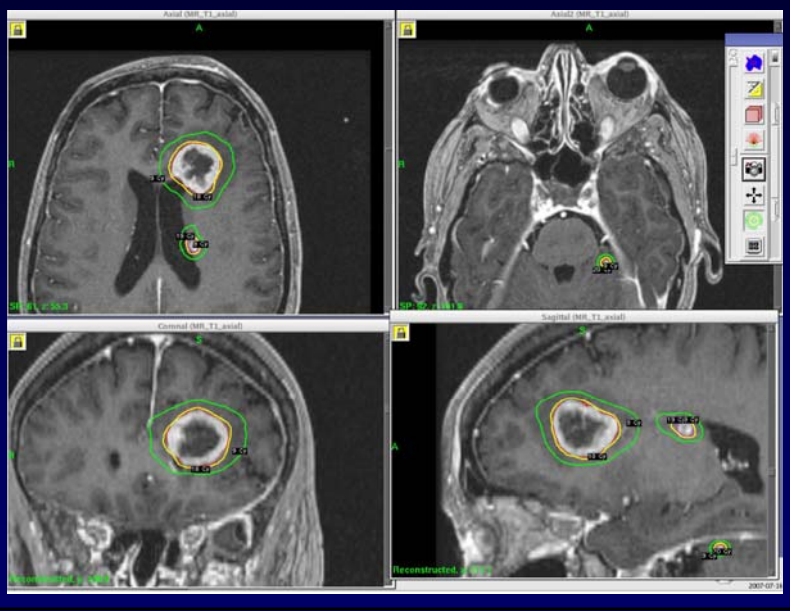
- Starting May 2009, Elekta will offer a toolkit for fractionated treatments in the head and upper neck region.
- The system will use a stereotactic frame with a vacuum assisted bite block.



- First Perfexion in US installed at Washington Hospital, Fremont, CA.
- First patient treated June 2007

## First Perfexion™ Patient at WHHS

3 Mets, 1 Run



## Gamma Knife

Routine Quality Assurance

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## QA Reports and Recommendations

1. ASTRO/AANS Consensus Statement on stereotactic radiosurgery quality improvement, 1993
2. RTOG Radiosurgery QA Guidelines, 1993
3. AAPM Task Group Report 54, 1995
4. European Quality Assurance Program on Stereotactic Radiosurgery, 1995
5. DIN 6875-1 (Germany) Quality Assurance in Stereotactic Radiosurgery/Radiotherapy
6. AAPM Task Group 68 on Intracranial stereotactic positioning systems, 2005

Courtesy of Steven Goetsch

## Gamma Knife Routine QA Procedures

### Daily QA

- Warmup
- Door interlock
- Emergency off
- AV communications
- Radiation monitor

### Weekly QA

- Couch release handle
- Helmet microswitches
- Helmet trunions
- Automatic positioning system

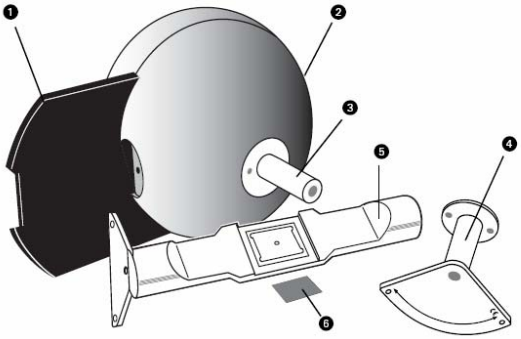
### Monthly QA

- Radiation output
- Computer output vs. measured
- Emergency rod release
- Medical UPS battery check
- Timer constancy, linearity, and accuracy

### Annual QA

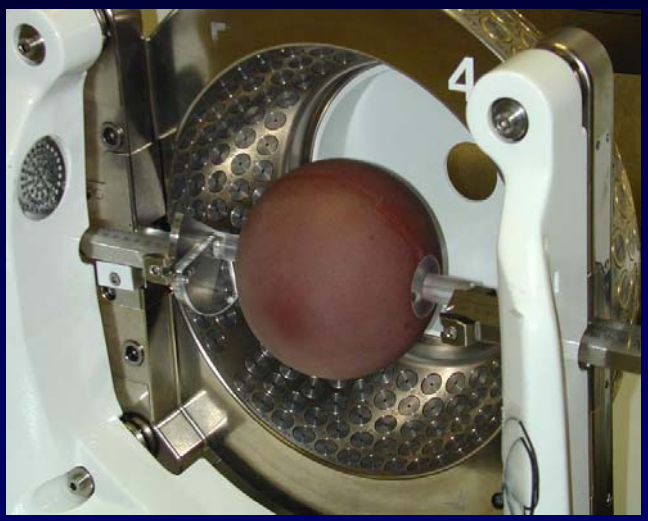
- Relative helmet factors
- Isocenter coincidence
- Film measurements

## Gamma Knife – Spherical Phantom

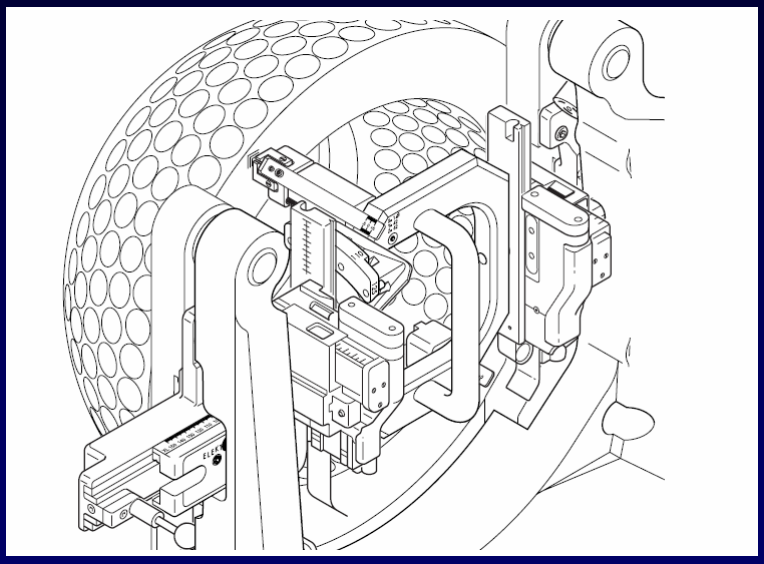



1. Cassette
2. Plastic phantom
3. Phantom holder
4. Phantom holder facilitating two fixed orientations
5. Film holder
6. Film

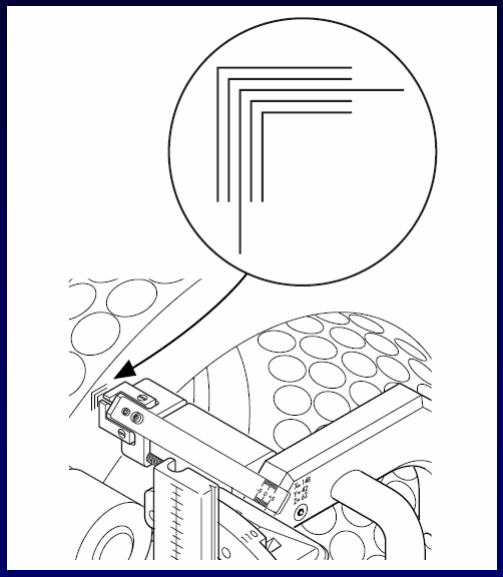
## Gamma Knife – Spherical Phantom



## Gamma Knife – APS QA



## Gamma Knife – APS QA



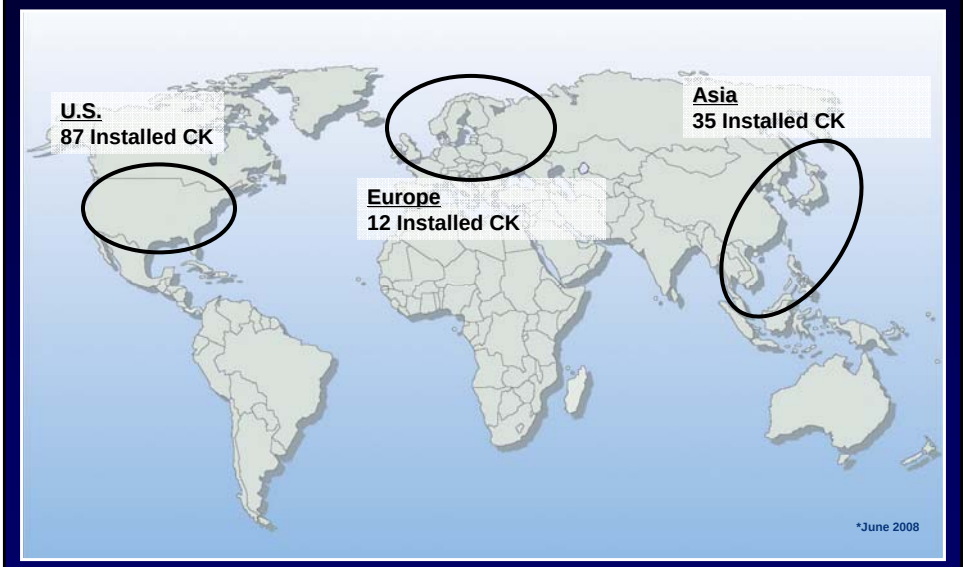
## Additional GK Information at AAPM


## Gamma Knife - Summary

- Radiosurgery delivery technique using beams from Co-60 sources to deliver highly conformal dose distributions.
- Well established technology used for treating patients since 1967.
- More than 250 units installed worldwide with over 350,000 patients treated.

# CyberKnife

## 134 CyberKnife Units Installed Worldwide

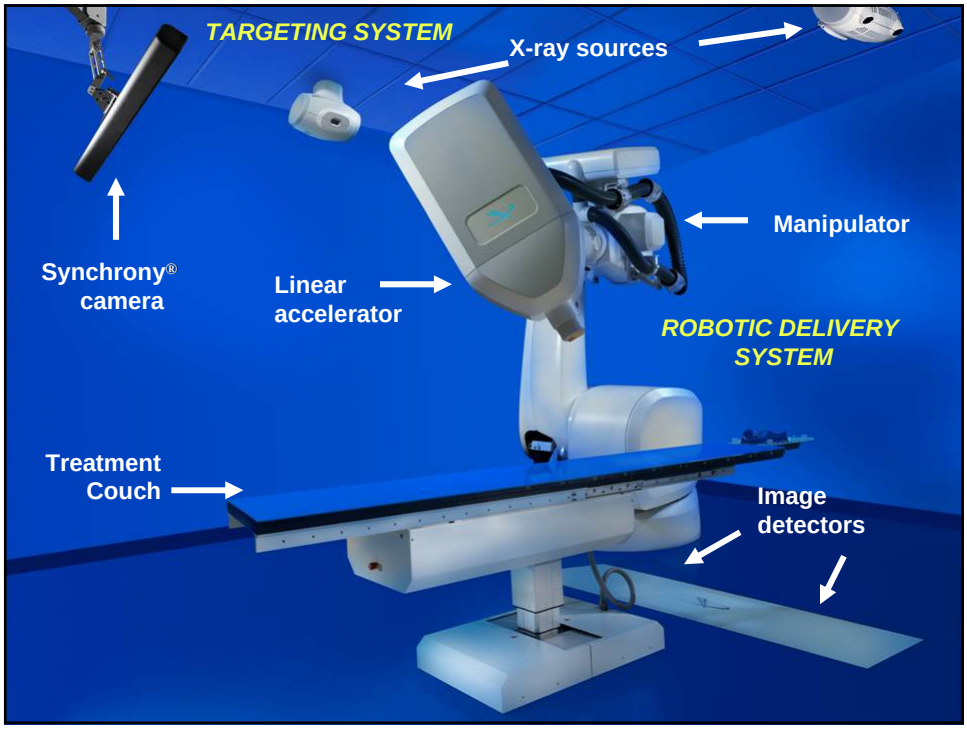



## CyberKnife - Basics

- A treatment unit designed for both intracranial and extracranial radiosurgery.
- CyberKnife uses a compact linear accelerator mounted on a robotic arm, which has 6-degrees of freedom.
- Pencil beams of radiation are delivered sequentially as the robot moves around patient.

## Image Guidance

- The CyberKnife delivers frameless radiosurgery.
- During delivery, the patient position is monitored and the delivery is modified to correct for patient movement.
- Orthogonal kilvoltage (kV) x-ray sources are mounted to the ceiling and directed at amorphous silicon detectors on either side of the table.
- kV images are obtained before and during the treatment to monitor the alignment of the patient.

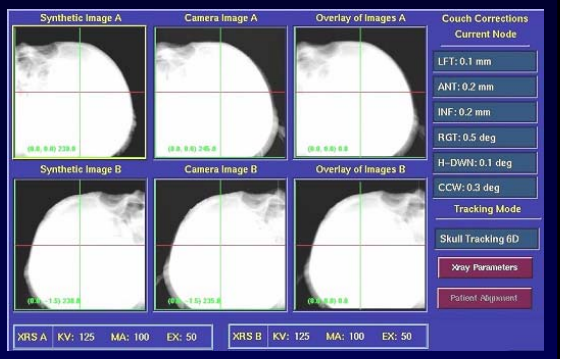



## CyberKnife – Treatment Delivery

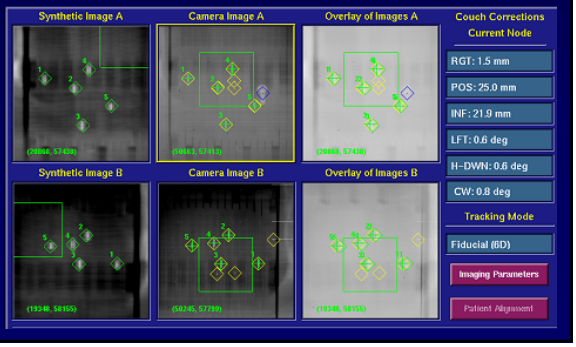
# Frameless Radiosurgery

- Intracranial lesions:
  - Immobilization with aquaplast mask
  - Patient positioning is monitored using bony landmarks
- Extracranial lesions:
  - Immobilization with vacuum bag
  - Patient positioning is monitored using either:
    1) implanted fiducial markers
    2) spine tracking (Xsight spine)
    3) synchrony lung tracking
    4) soft tissue lung tracking (Xsight lung)

Skull tracking window:




Fiducial tracking window:

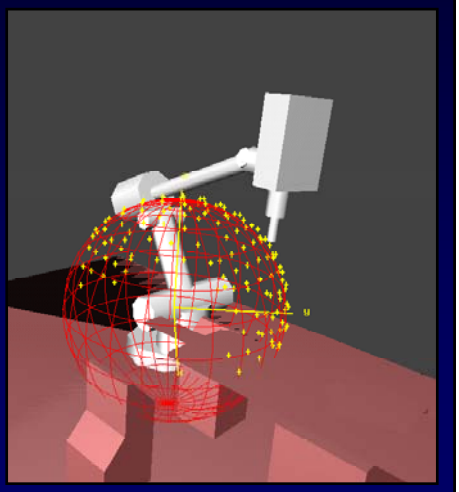


## CyberKnife – Beam Characteristics

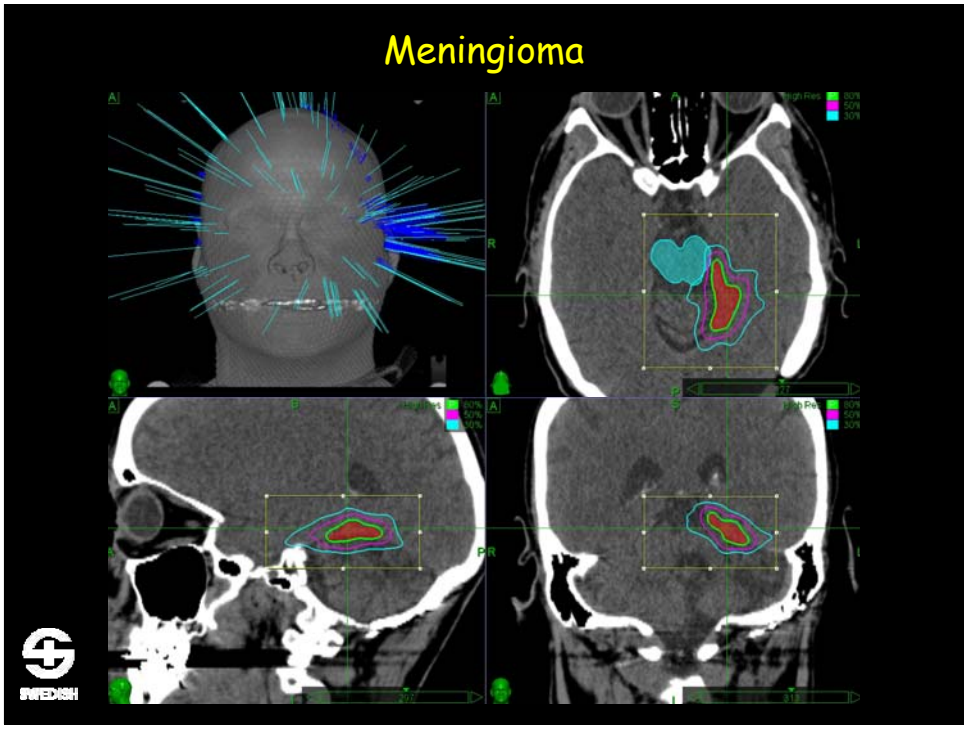
- 6 MV accelerator
- 12 interchangeable circular collimators
- At an SSD of 80cm, collimators provide a beam diameter from 5 to 60 mm
- SSD can be varied from 65 to 100 cm

## CyberKnife – Delivery

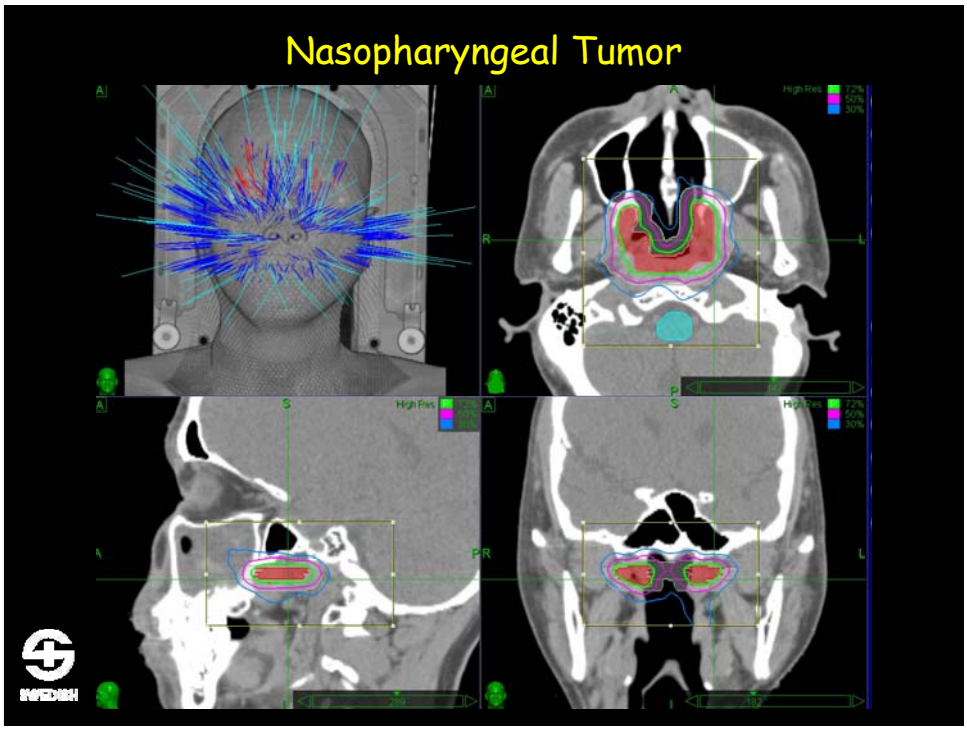
- Radiation is delivered at a discrete set of linac positions (called nodes).
- A typical treatment plan will use 110 nodes distributed approximately uniformly over about one half of a sphere centered on the treatment site.



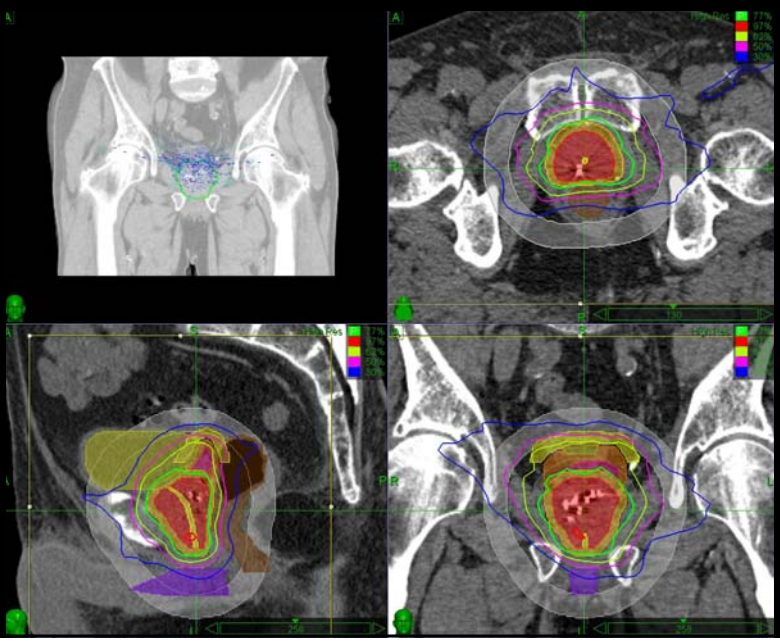
## Meningioma



## Nasopharyngeal Tumor



## Prostate



## Synchrony™ Respiratory Tracking System

- Patient wears a vest with optical markers that serve as a surrogate for tumor position.
- Camera system monitors position of markers.

## Synchrony™ Respiratory Tracking System

- Before the treatment, a correspondence model between the markers and the tumor position is constructed using the camera and multiple orthogonal x-rays.
- Model is updated continuously during treatment by further x-ray imaging.
- During delivery, the tumor position is tracked using the live camera signal and the correspondence model.
- The robot is moved in real-time to maintain alignment with the tumor.

## New CyberKnife Features

- Sequential Optimization
- 800 MU/min accelerator
- Monte Carlo Dose Calculation
- Iris Variable Aperture Collimator
- RoboCouch

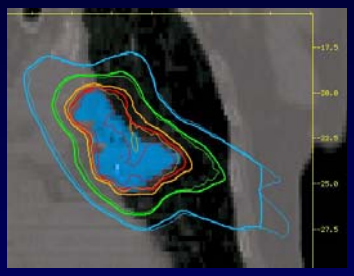
## 800 MU/min. LINAC

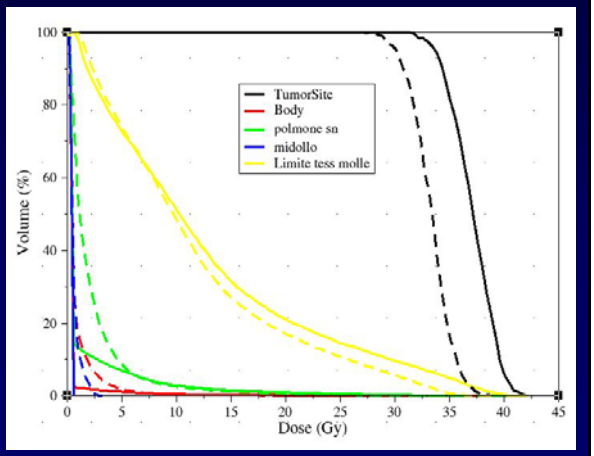
- Provides reduced treatment times relative to existing 600 MU/min design.
- More compact

## Monte Carlo Dose Calculation

- Accuray is now offering a Monte Carlo dose engine.
- This provides a significant improvement in dose accuracy relative to their current ray-tracing algorithm.

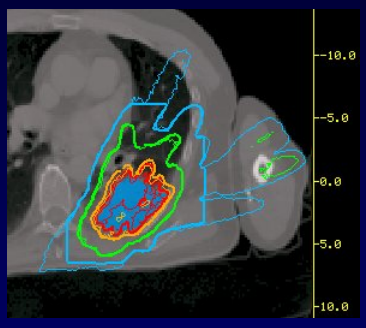
## Dose Comparison – MC and Ray-tracing

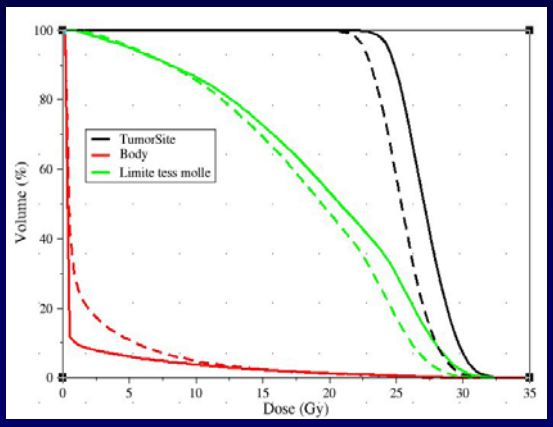




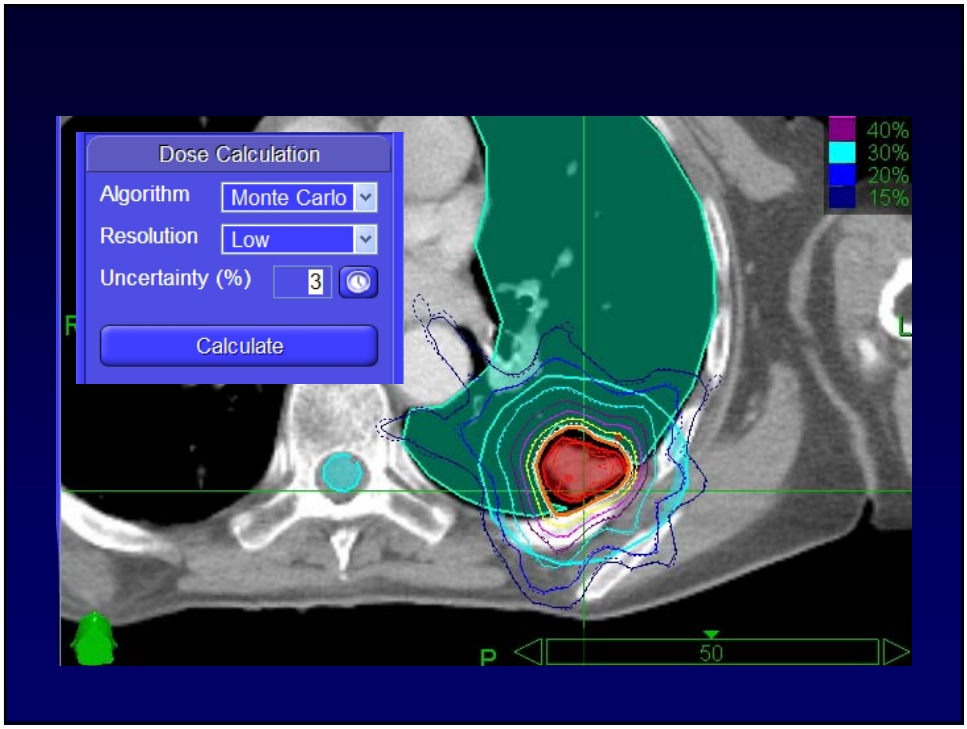

Courtesy of Charlie Ma

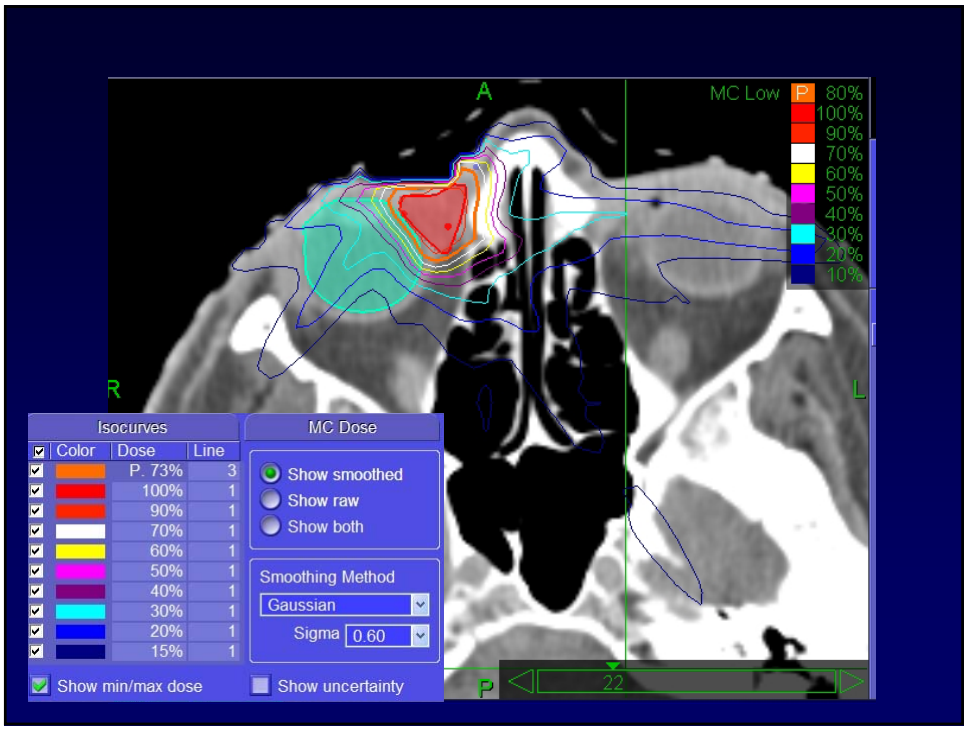
## Dose Comparison – MC and Ray-tracing




Courtesy of Charlie Ma


Dose Calculation
Algorithm
Monte Carlo
Resolution
Low
Uncertainty (%)
3
Calculate
40%
30%
20%
15%
R
L
P
50


A
MC Low
P
80%
100%
90%
70%
60%
50%
40%
30%
20%
10%
R
L
Isocurves
Color
Dose
Line
P. 73%
3
100%
1
90%
1
70%
1
60%
1
50%
1
40%
1
30%
1
20%
1
15%
1
MC Dose
Show smoothed
Show raw
Show both
Smoothing Method
Gaussian
Sigma
0.60
Show min/max dose
Show uncertainty
P
22

## Iris™ Variable Aperture Collimator

- Description
  - 2 stacked banks of 6 tungsten segments creates a 12-sided variable aperture
  - Variable aperture automatically replicates sizes of the existing 12 fixed collimators (5 to 60 mm)
  - All segment are driven by a single motor

## Iris™ Variable Aperture Collimator

- Benefits
  - Can use up to 12 different aperture sizes in a single treatment path
  - Reduces treatment time by consolidating multiple-path sets and multiple-collimators into a single path set
  - Better plan quality can be achieved by using multiple collimators
  - Automatically changes the size of the variable aperture without having to re-enter the treatment suite

## RoboCouch®

## RoboCouch®

- 6D robotic couch
- Converts between seated and flat positions
- 500lb weight capacity

## CK - G4 with 8.0 Delivery Software

- Hillcrest Medical Center (Tulsa, OK) became 1st center to treat with Iris Collimator on 7/10/2008.

## CyberKnife Routine QA Procedures

### Daily QA

- Linac Output
- Various voltages and currents
- Robot perch position
- Safety interlocks
- Test coincidence of treatment beam with imaging center (AQA)

### Monthly QA

- Beam Energy
- Flatness/symmetry/penumbra
- Robot pointing
- End-to-end test

### Quarterly QA

- Laser/radiation coincidence
- Imaging system alignment

### Annual QA

- Spot check beam data
- Treatment planning system beam data and calculation checks.

## Daily QA – Linac Output Constancy

- In air measurement using "birdcage" phantom.
- CyberKnife's ion chambers are vented to the atmosphere.

## Monthly QA - End-to-end Test

- QA test designed to measure total accuracy of the system including localization, mechanical targeting, and planning errors.
- Measurements are performed using an anthropomorphic head phantom loaded with a target ball and orthogonal pieces of gafchromic film.

## Anthropomorphic Head Phantom

## Anthropomorphic Head/Neck phantom

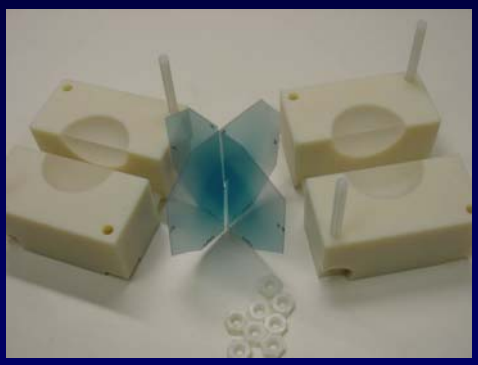
1.25" Ball Cube in neck for Xsight Spine QA

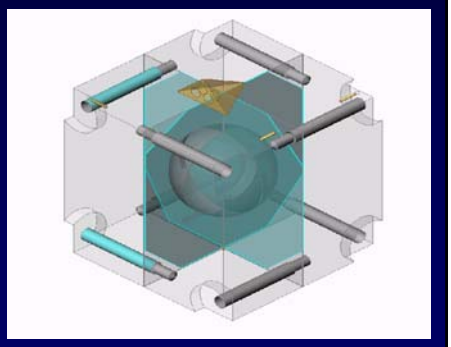
2.5" Ball Cube in cranium for fiducial and skull tracking QA

**Courtesy of Accuray Inc.**

## Ball-Cube Film Cassette

- Allows accuracy measurements using only two films
- Contains fiducials for QA for extracranial treatments.

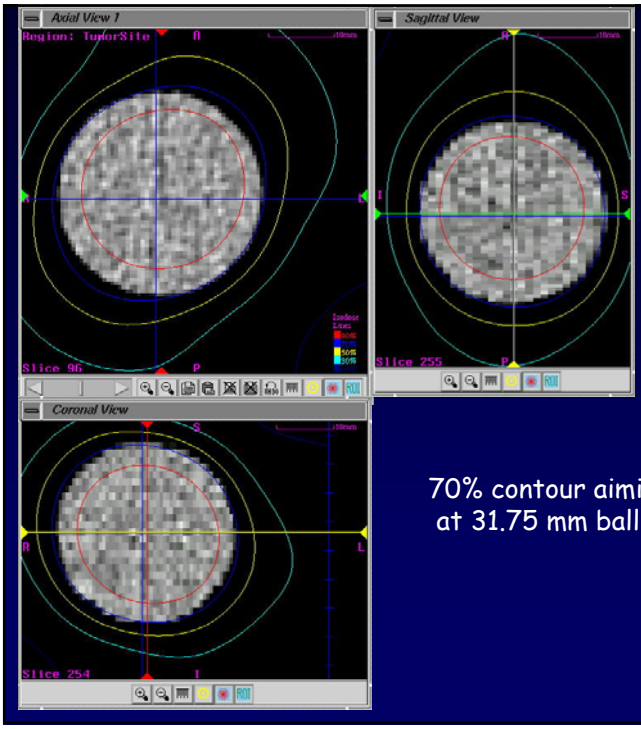




Courtesy of Accuray Inc.

## End-to-end Test

- The head phantom is imaged using CT.
- A treatment plan is developed with the goal of conforming the 70% isodose line to the target ball.
- After the delivery, the orthogonal films are scanned and analyzed using software from Accuray that determines the shift between the centroid of the 70% isodose curve and the center of the film.
- Test is repeated for each tracking technique: skull tracking, fiducial tracking, spine tracking, and synchrony based tracking.

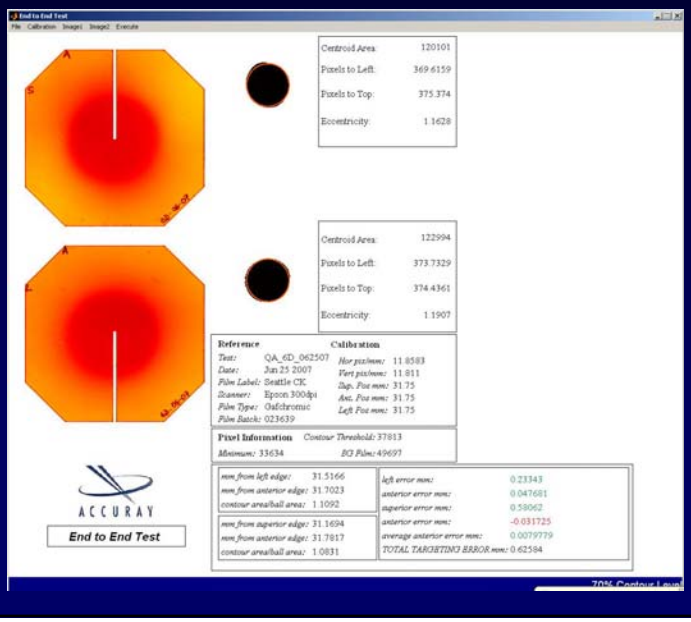



# TPS Images

70% contour aiming at 31.75 mm ball target.

Courtesy of Accuray Inc.

# Digital Centroid Analysis Software

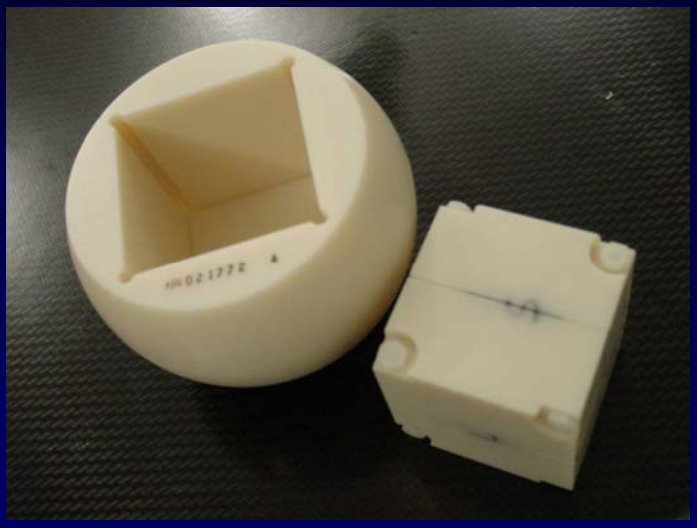


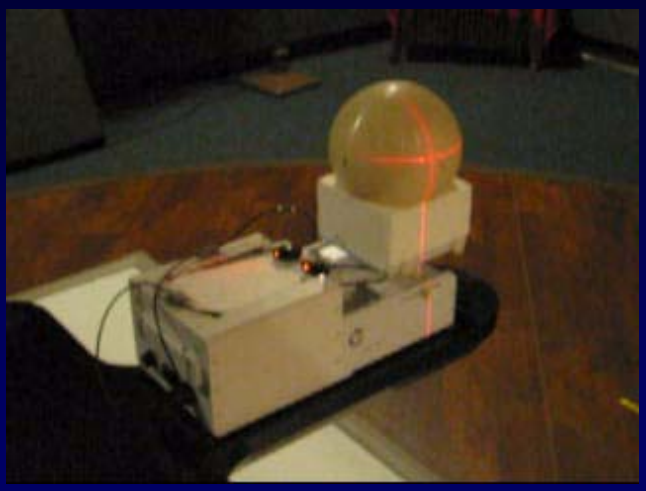
| | |
|---|---|
| *left error mm:* | 0.23343 |
| *anterior error mm:* | 0.047681 |
| *superior error mm:* | 0.58062 |
| *anterior error mm:* | -0.031725 |
| *average anterior error mm:* | 0.0079779 |
| *TOTAL TARGETING ERROR mm:* | 0.62584 |

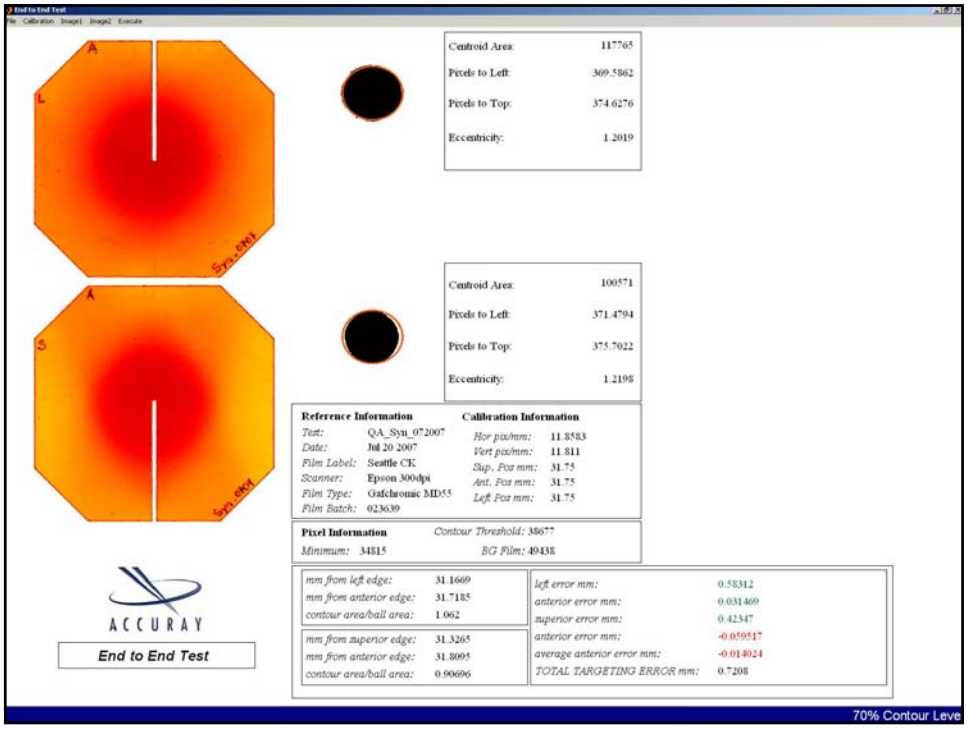
- The total error should be below 0.9mm for skull tracking, fiducial tracking, and X-sight spine tracking.
- The total error should be less than 1.5mm for tracking using Synchrony.

## Synchrony End-to-end Test

## Ball Phantom and Ball Cube








# Additional CK Information

- .

SWEDISH

## CyberKnife - Summary

- Radiosurgery delivered using an x-band linear accelerator mounted on a robotic arm.
- Uses a frameless approach and is capable of intracranial and extracranial radiosurgery.
- Real time image-guidance is accomplished using 2 kilovoltage imagers.