# Overview of CyberKnife Radiosurgery

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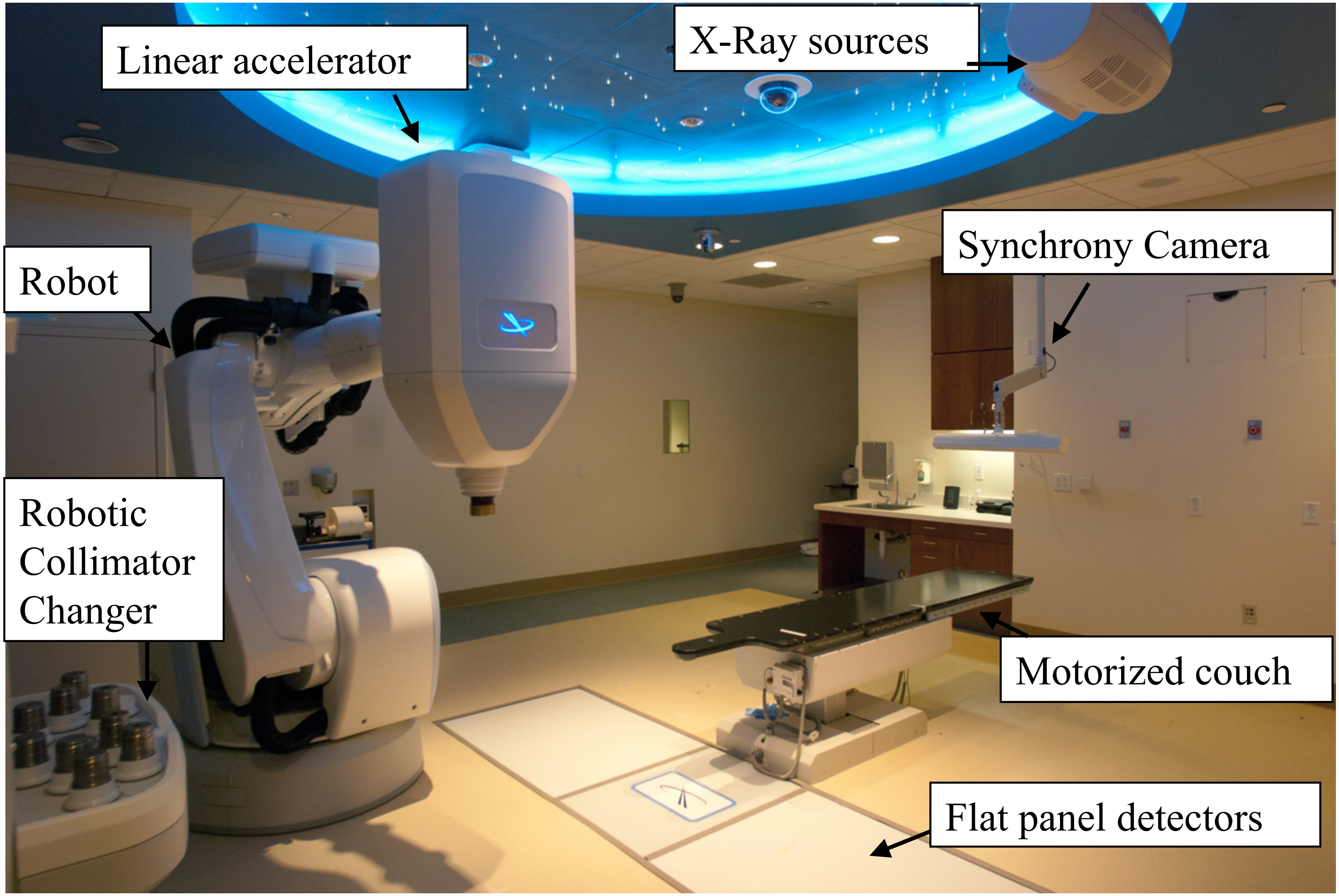
# Learning Objectives

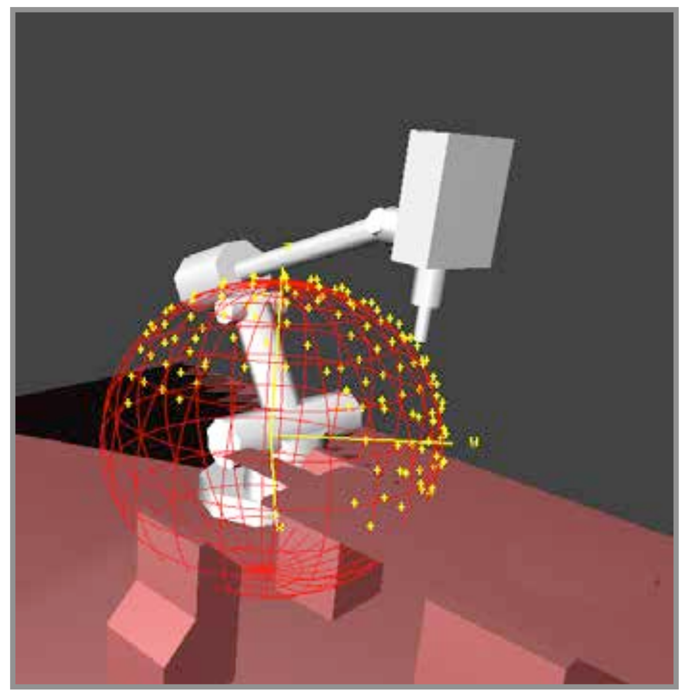
- Review operating principles of CyberKnife
  - System components
  - Target tracking
  - Treatment delivery
- Demonstrate how to create a treatment plan for an intracranial target
- Discuss QA tests

# The CyberKnife System



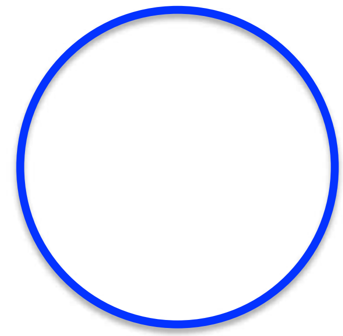
# Linac and Robot

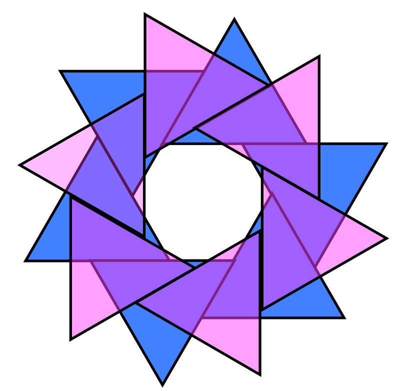
- Linac:
  - 6 MV x-rays
  - Dose rate up to 1000 MU/min
  - No-flattening filter
- Robot:
  - 6 axis joint motion
  - Non-isocentric beam delivery
  - Predefined path sets
  - Nominal SAD 80 cm



# Collimator system

- Fixed:
  - 12 tungsten cone, 5-60 mm diameter
  - Multiple path traversal
  - Advantages: Sharper penumbra, no field size uncertainty
  - Used for small targets, spherical targets
- Iris
  - Dodecahedron
  - Multiple beam apertures per robot position
  - Advantages: Efficient delivery, shorter treatment times
  - Used for spatially complex targets





# MLC collimator

- MLC design:
  - 41 leaf-pairs, 9 cm thickness
  - 2.5 mm width at 80 cm
  - 12x10 cm at 80 cm
  - 100% over-travel and inter-digitation
  - Leakage <0.3% average, <0.5% max
  - Position reproducibility ±0.4 mm
  - Step and shoot mode
- Advantages: Efficient delivery, treatment of large targets

# Imaging System

- The imaging system provides a stereotactic frame of reference
- 2 diagnostic x-ray sources and 2 flat panel detectors
- It enables to track, detect & correct for patient and target motion.
- The isocenter is the reference point for robot calibration, treatment planning and image guidance.

# Image guidance during treatment

- CyberKnife SRS is frameless
- 6D Skull tracking
- Alignment center

- Real-time, live images are compared against DRRs generated from planning CT at 45 degrees angle
- Robot adjusts position based on this comparison

# Patient setup

- Primary goal of immobilization: reproducibility, patient comfort
- Thermoplastic mask
- Soft padding

Image of mask

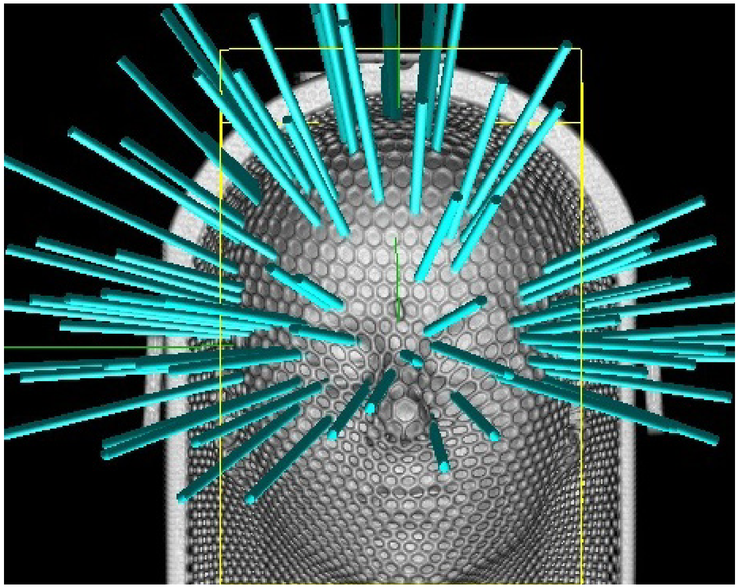
# Imaging studies

- Primary CT scan used for dose calculation and DRR generation
- Secondary images used for target and OAR delineation (MRI, PET, contrast CT)
- Primary CT specifications:
- Contiguous no gap, no contrast
- Square acquisition (max 512x512x512)
- Include anterior and superior aspect of mask with 1 cm margin

Image of fusion MR/CT

# Treatment Parameters

- Number of fraction
- Treatment anatomy: head
- Template path set
- Tracking method: 6D Skull
- Collimator type



# Align Center

- Set up image alignment center
- Maximize information on the DRR
- Align center does not depend on target location

# Contours

- Manual
- Auto-segmentation for Brain
- Skin
- Max of 22 contours
- Need a couple open contours to do VOI operation

# Plan setup

- CT density table
- Density override
- Dose calculation grid
- Beam blocking

# Sequential Optimization

- Principles of sequential optimization
- Collimator selection
- MU limits
- Auto-shells
- Constraints and steps
- Time reduction
- Node reduction
- Beam reduction
- Prescription

# Sequential Optimization

- In conventional optimization algorithms, multiple objectives are grouped in a single cost function.
- In sequential optimization, each objective (step) is optimized in sequence.
- The objective and the order of the steps define the clinical priorities.
- Auto-shells are tuning structures used to constrain the confomality and the extension of the low-dose region.
- Beam reduction removes all beams below a MU threshold and re-optimize the plans with the remaining beams while preserving the plan quality.
- Time reduction reduces the number of beams and nodes to achieve the user-defined time goal.

# Sequential optimization

- Sequential optimization is divided between Maximum Dose Constraints and Dose Volume Constraints (hard constraints) and Dose Objectives (steps)
- Optimizer runs through the steps sequentially
- Objectives:
  - Target objectives
  - OAR objectives
  - Shells objectives
  - MU objectives
- Total number of sample points

# Auto-shells

- Auto-shells are used to control dose conformity around the target and dose fall-off away from the target (dose fingers)

Image of auto-shells

# Collimator size selection

- Spherical tumors – usually one collimator, a little larger than half the tumor size.
- Everything else – usually at least two, which are bound by the smallest target features and the largest collimator that fits in the target.
- Fixed – usually two, similar to these bounds.
- Iris – from the largest down to 12.5 or 10 mm.
- We never use 5 or 7.5 mm for the iris and only use them sparingly for fixed.

Image of a
complex target
with features

Courtesy of Neil Kirby

# Dose calculation algorithms

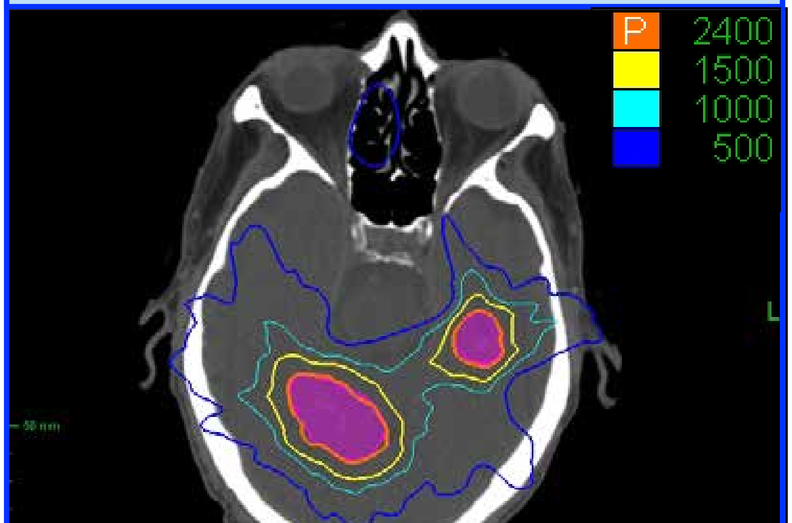
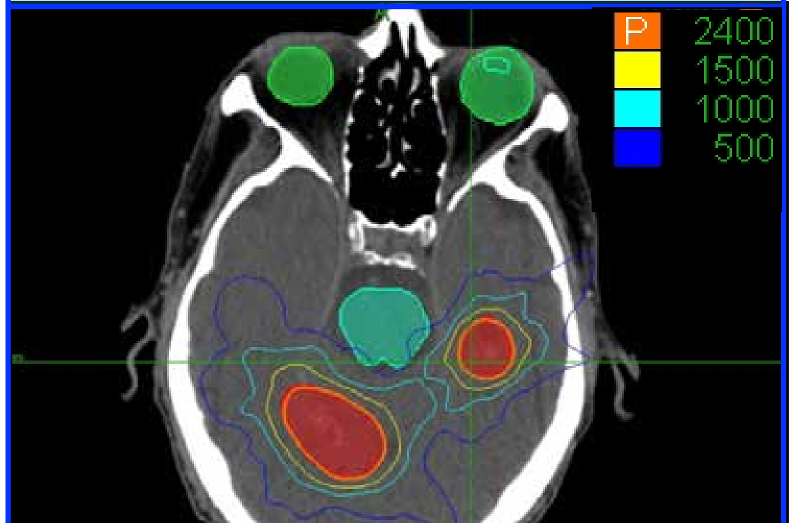
- Ray Tracing:
  - Simple dose calculation method – equivalent path length
- Ray Tracing with contour corrections
  - Improved accuracy for oblique incidence (target near the surface)
- Monte Carlo
  - Most accurate dose calculation method – used in the presence of tissue heterogeneities (lung, spine, brain near the skull or air cavities)
- Ray tracing is adequate for treatment sites in the head with small tissue heterogeneity *

* Wilcox et al, PRO (2011) 1, 251

# Plan Evaluation

- Evaluate the dose distribution <u>everywhere</u> in the patient
- DVH analysis
- Dose conformity – nCI
- Dose homogeneity – 1/IDL
- Low dose fingers
- Beam directions

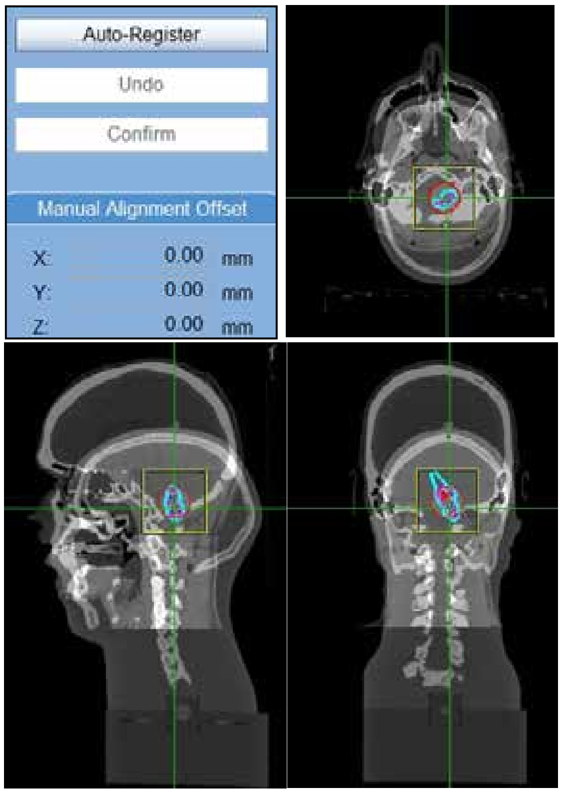
# Multiple targets

| CyberKnife - cones | CyberKnife MLC |
|---|---|
|  |  |
| ❑ 24 Gy x 3 fx to 64% | ❑ 24 Gy x 3 fx to 73% |
| ❑ Beams: 166 | ❑ Beams: 41 |
| ❑ Tx time: 41 min | ❑ Tx Time: 22 min |
| ❑ Total MU: 39,600 | ❑ Total MU: 13,200 |
| ❑ Brainstem $D_{max}$: 10.5 Gy | ❑ Brainstem $D_{max}$: 9.4 Gy |
| ❑ R50%: 4.4 | ❑ R50%: 3.6 |

*Courtesy of Chris McGuinness, UCSF*

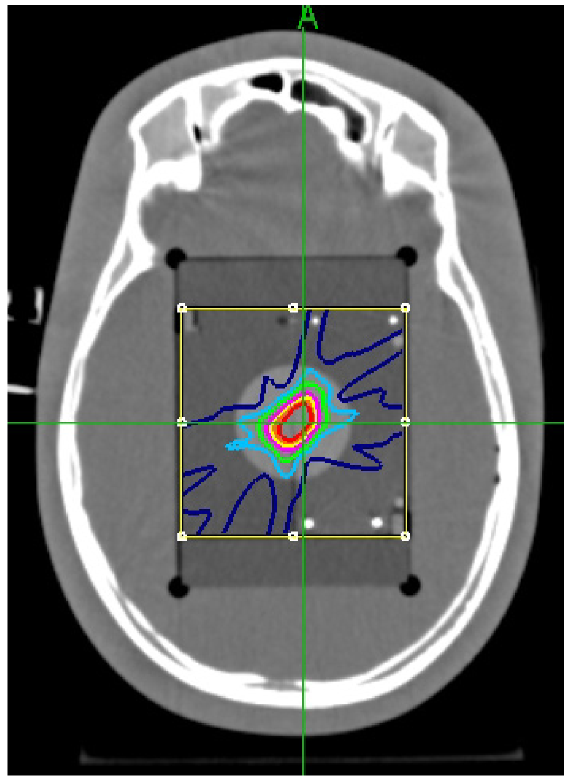
# Dose Delivery QA

## Image Registration



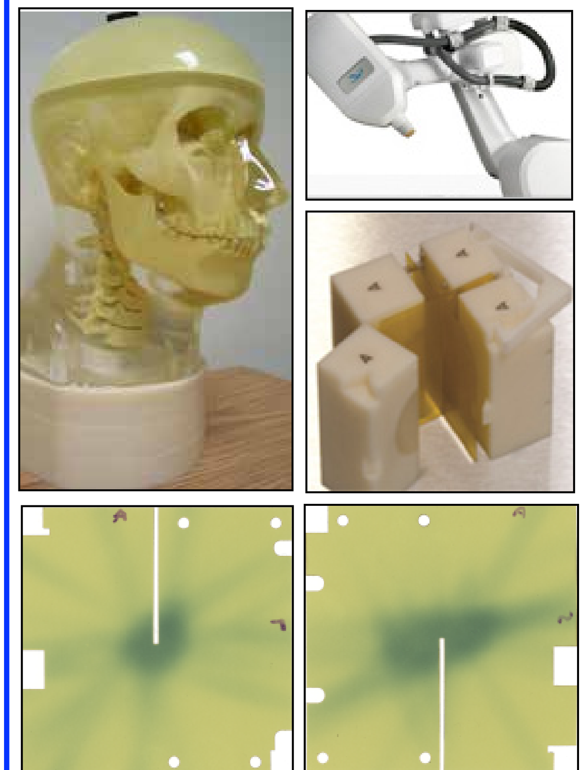

Align center of patient's target with center of phantom's target.

## Dose Evaluation




Calculate corresponding dose distribution
Rescale MU <700 cGy.

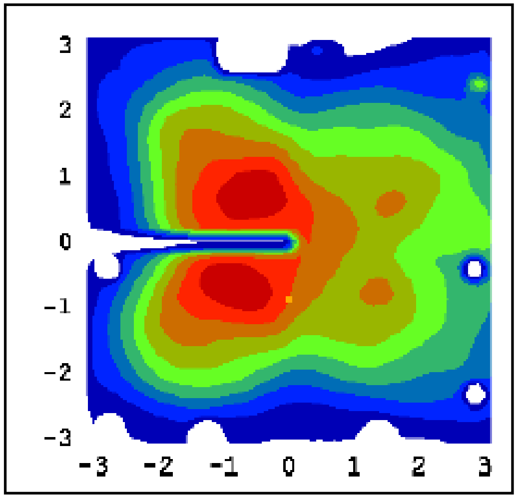
## Plan Delivery



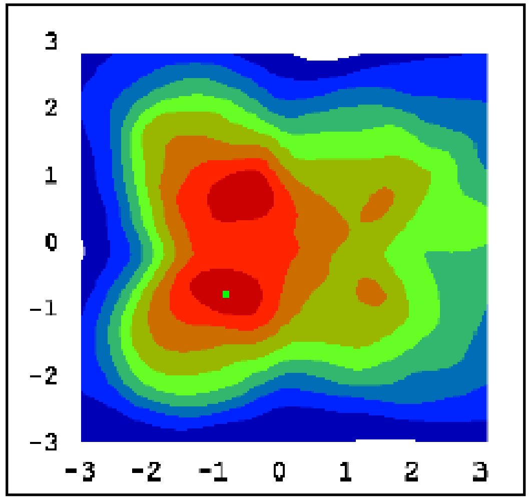
Deliver plan on phantom
Gafchromic EBT2 films
Axial & sagittal planes.

# Film Analysis

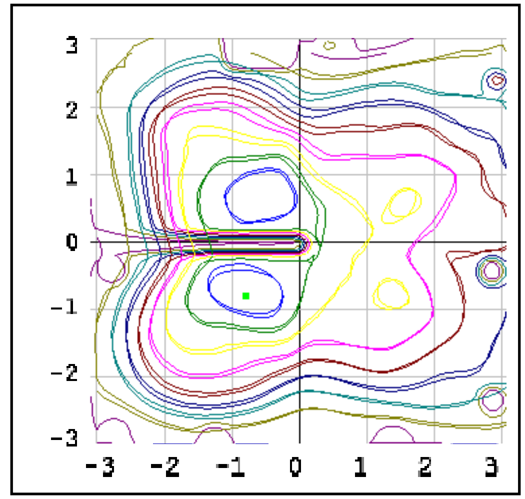
Film



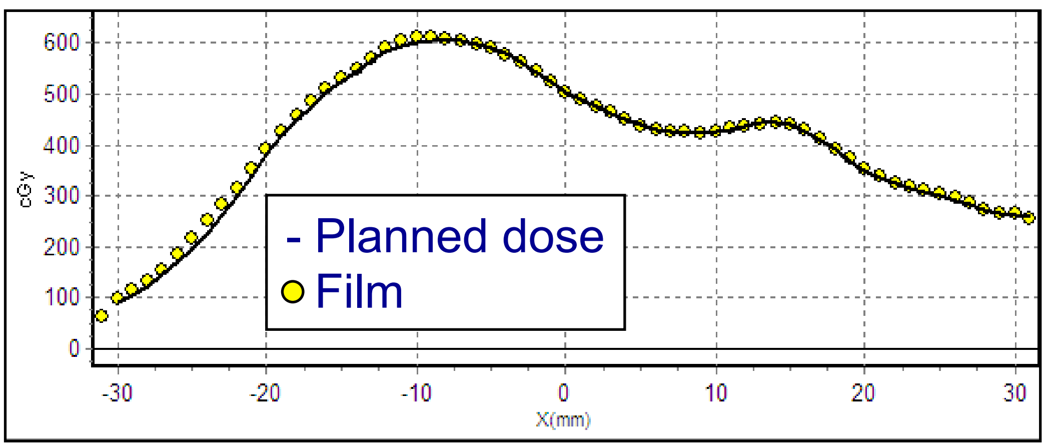

Planned dose



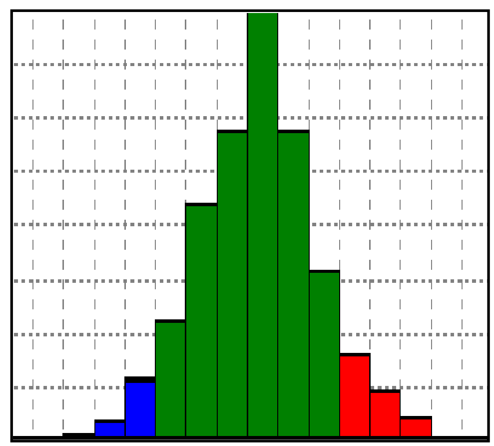

Dose comparison




Dose profile comparison




Statistical analysis



# Targeting accuracy QA

- End to End
- AQA
- Table comparing the different QA test and frequency

# Summary

- Take home message

# Acknowledgments

- UCSF CK team
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