Overview of CyberKnife Radiosurgery

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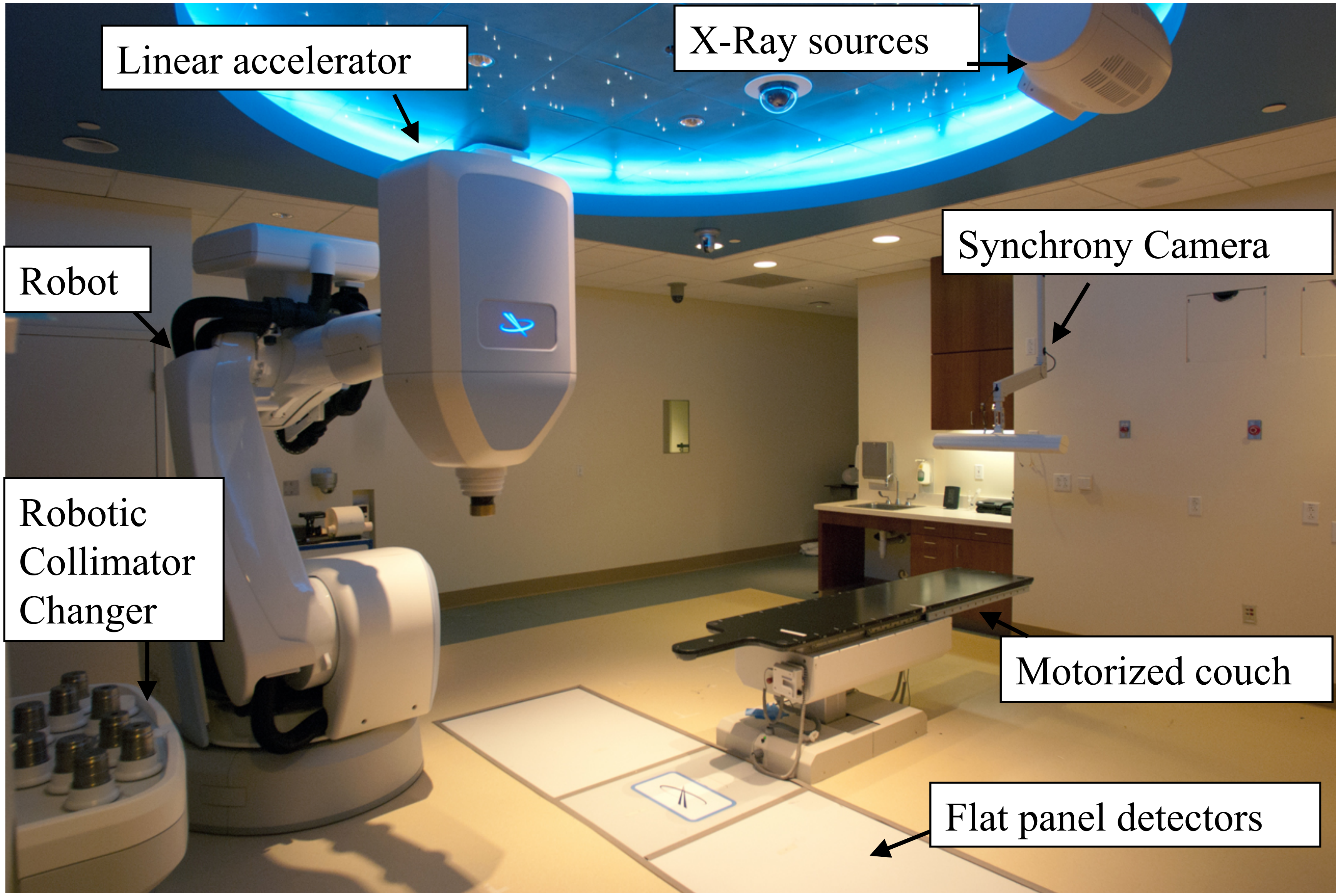
Learning Objectives

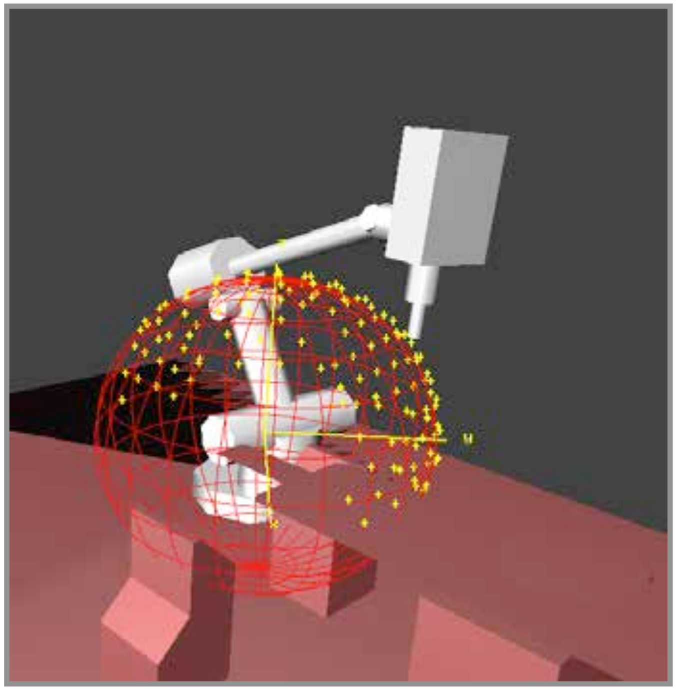
- Review operating principles of CyberKnife
  - System components
  - Target tracking
  - Treatment delivery
- Demonstrate how to create a treatment plan for an intracranial target
- Discuss QA tests

The CyberKnife System



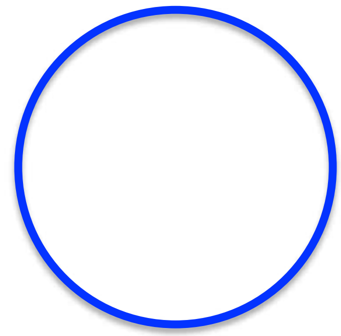
Linac and Robot

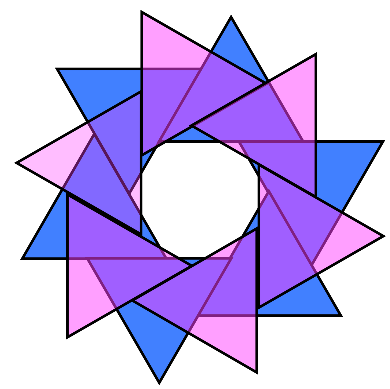
- Linac:
  - 6 MV x-rays
  - Dose rate up to 1000 MU/min
  - No-flattening filter
- Robot:
  - 6 axis joint motion
  - Non-isocentric beam delivery
  - Predefined path sets
  - Nominal SAD 80 cm



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

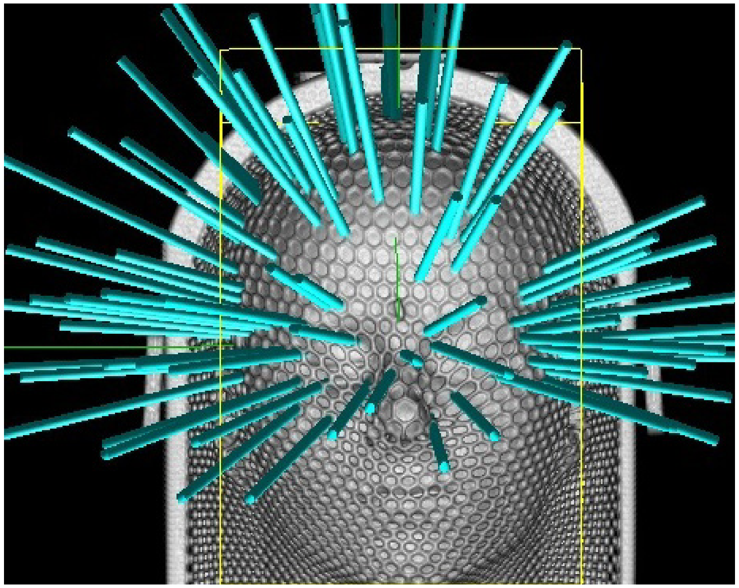
Imaging studies

- 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 *

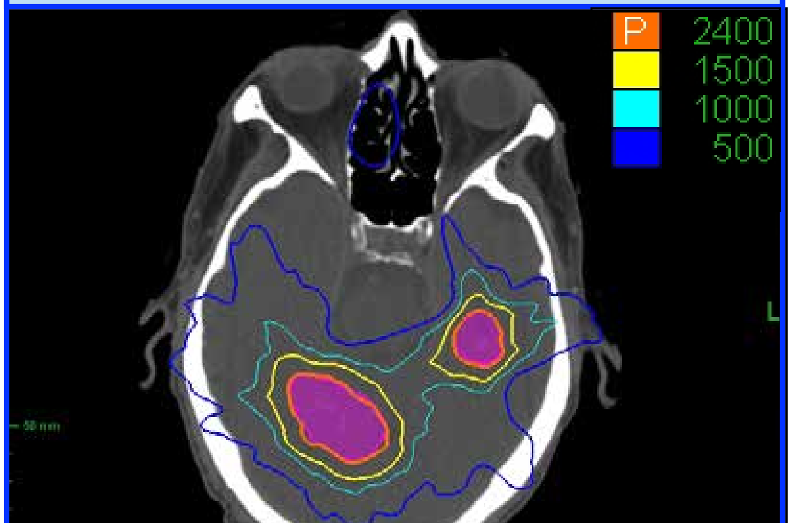
* Wilcox et al, PRO (2011) 1, 251

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

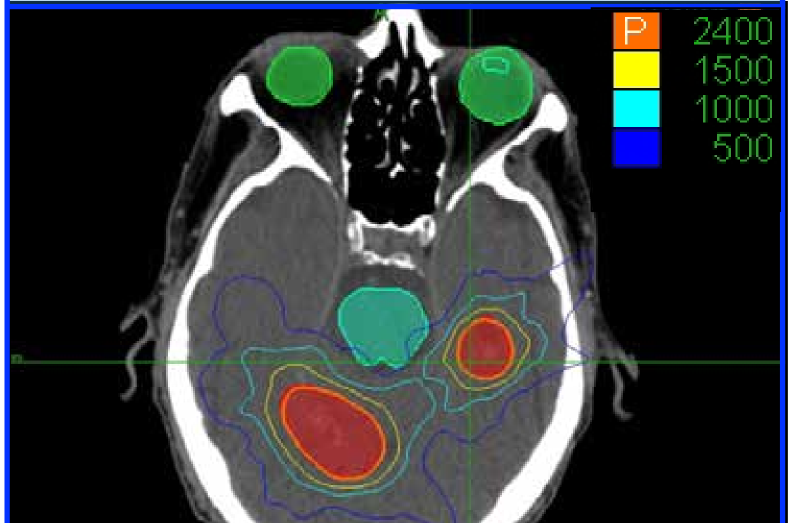
Multiple targets

CyberKnife - cones



- 24 Gy x 3 fx to 64%
- Beams: 166
- Tx time: 41 min
- Total MU: 39,600
- Brainstem D_{max}: 10.5 Gy
- R50%: 4.4

CyberKnife MLC

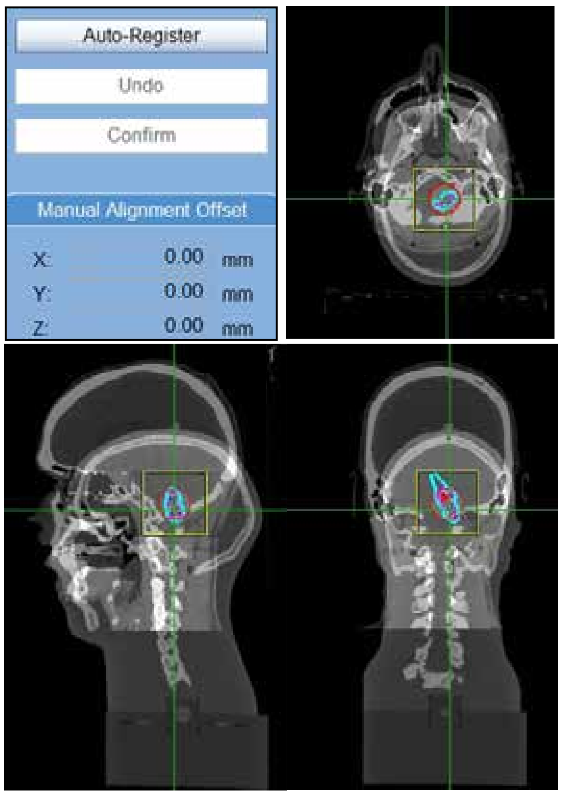


- 24 Gy x 3 fx to 73%
- Beams: 41
- Tx Time: 22 min
- Total MU: 13,200
- Brainstem D_{max}: 9.4 Gy
- R50%: 3.6

Courtesy of Chris McGuinness, UCSF

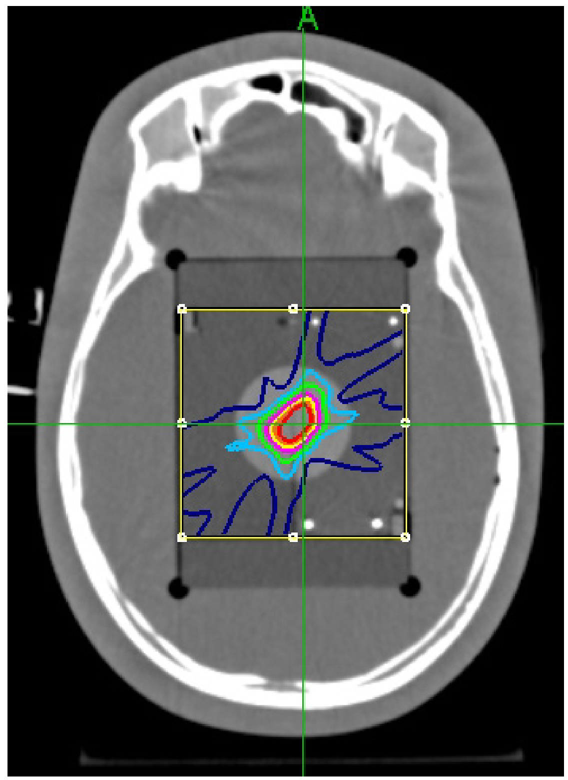
Dose Delivery QA

Image Registration



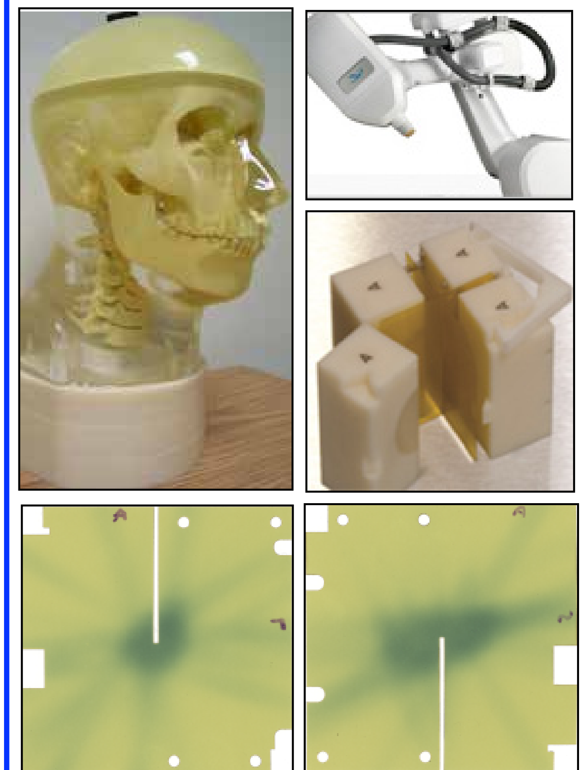
Align center of patient' s target with center of phantom' s target.

Dose Evaluation



Calculate corresponding dose distribution
Rescale MU <700 cGy.

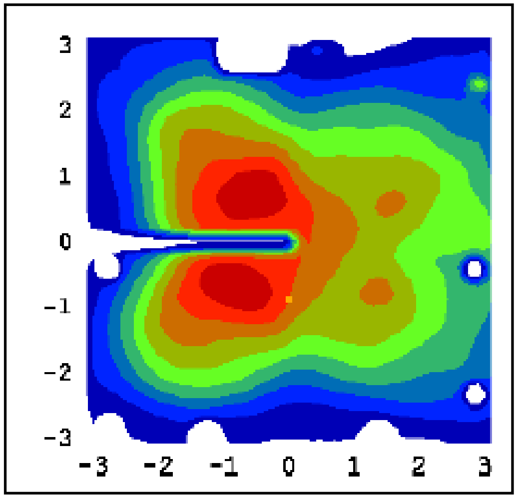
Plan Delivery



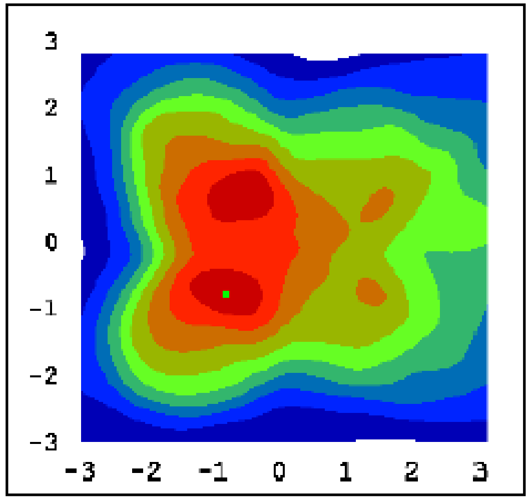
Deliver plan on phantom
Gafchromic EBT2 films
Axial & sagittal planes.

Film Analysis

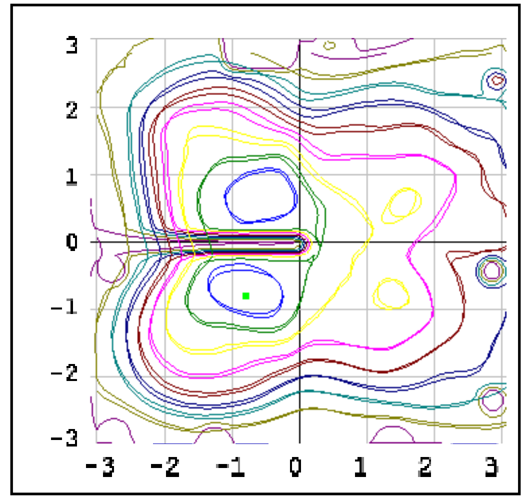
Film



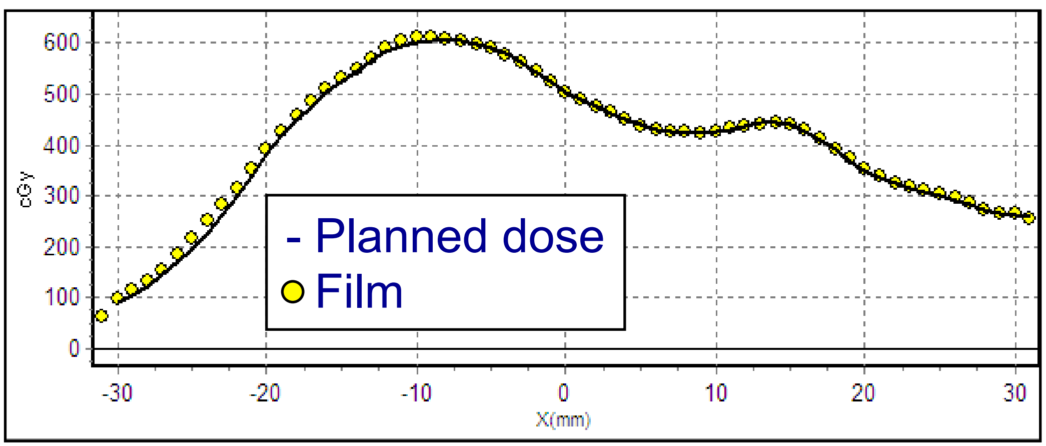
Planned dose



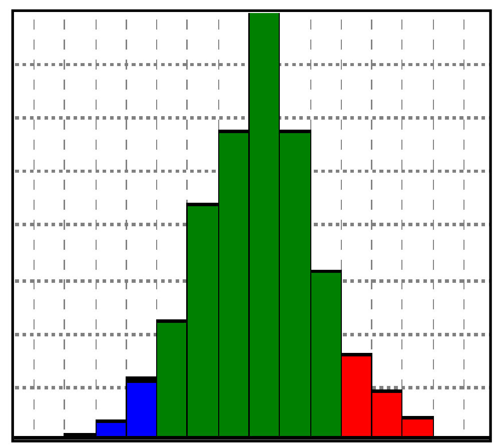
Dose comparison



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

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