Dosimetry of double orbit cone beam computed tomography (CT) as applied to image guided radiotherapy (IGRT)

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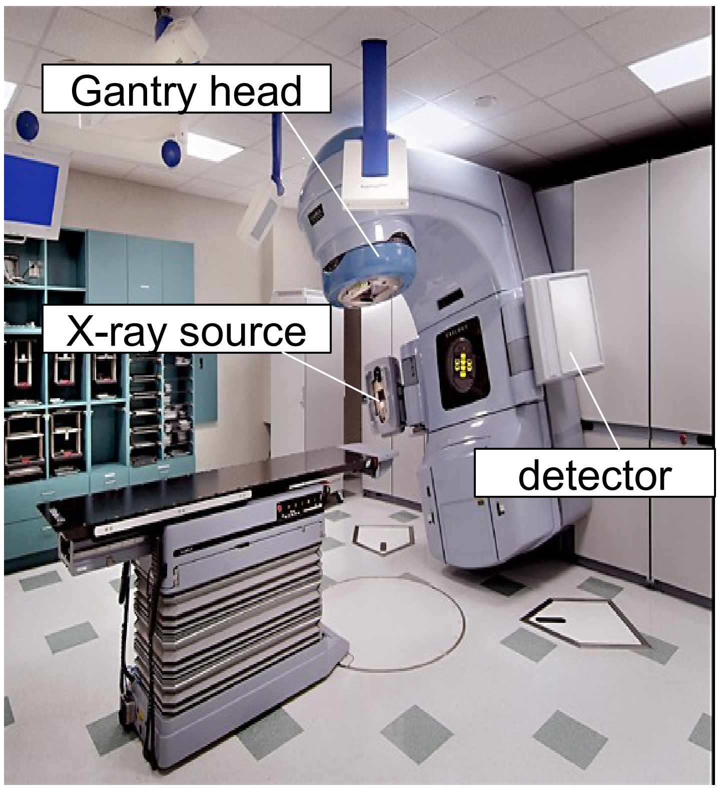
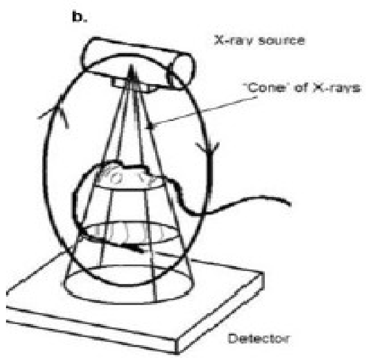
IGRT: current status



- Varian Trilogy linear accelerator with integrated on-board imager
- Efficient imaging systems allow for precise delivery of radiation treatment
  - On Board Cone Beam CT is a relatively new development in image guided radiotherapy

Cone beam CT (CBCT)

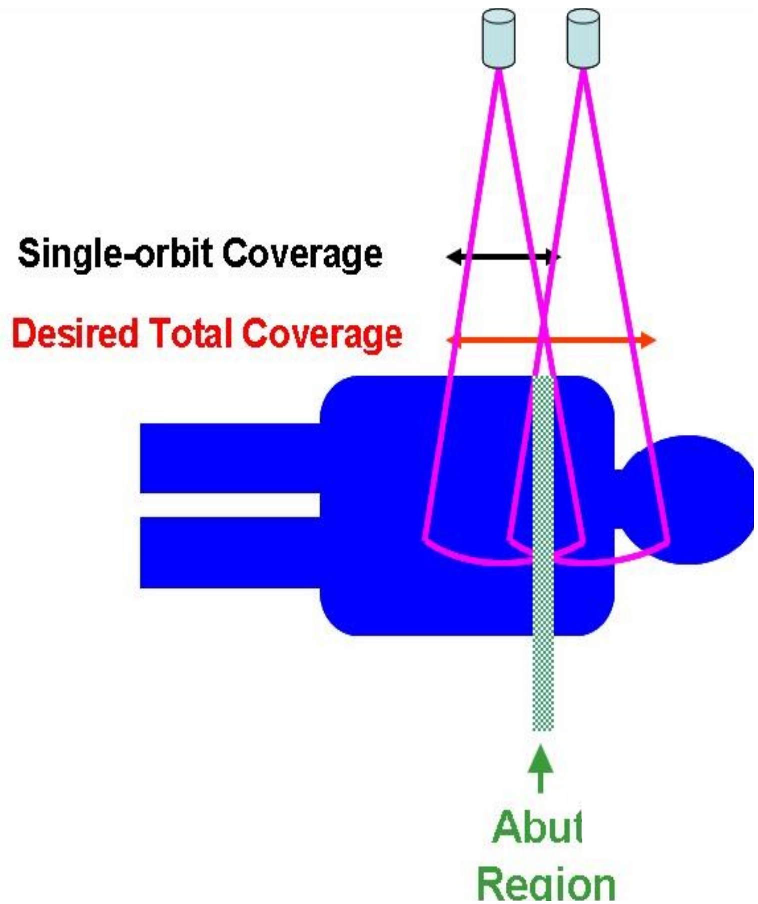


- Pulses of low energy kV x-rays
- 2D projections → reconstruct in 3D
- Complete axial coverage and ~14 cm longitudinal coverage

Double orbit imaging proposal

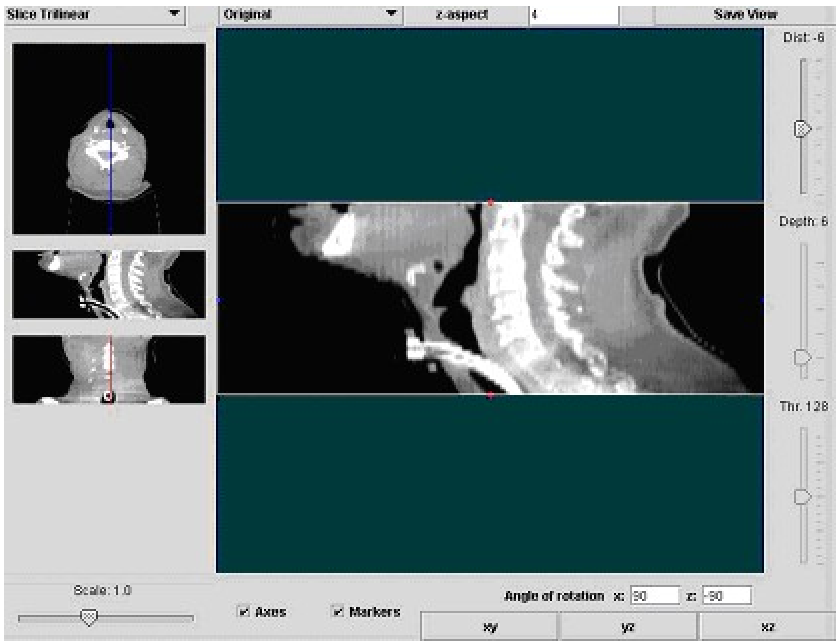
- Objective: extend the longitudinal coverage of our CBCT images by implementing a protocol involving multiple scans in series

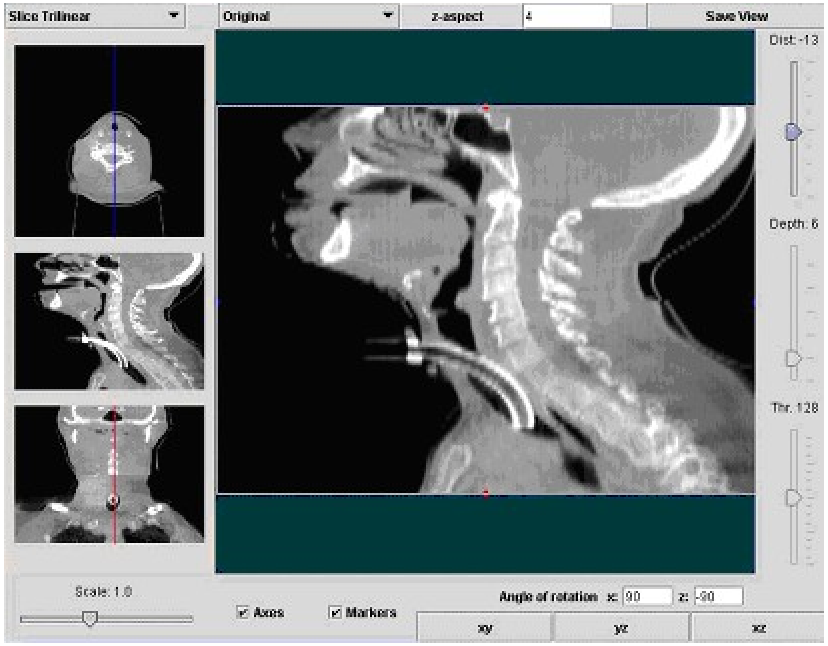
Double orbit procedure



- Step and shoot modality
- Standard protocol: scan superior to inferior
- Abut region: 1.5 cm wide
  - Essential for 3D to 3D image registration
  - Corrects for patient movement

Previous double orbit results



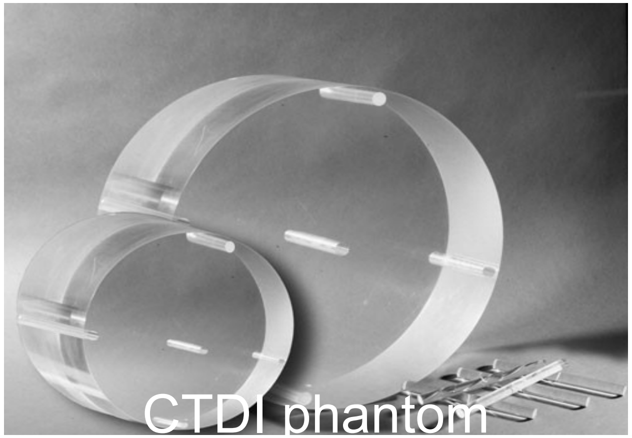


Head and neck patient; single orbit (~14 cm)

Head and neck patient; double orbit (~27 cm)

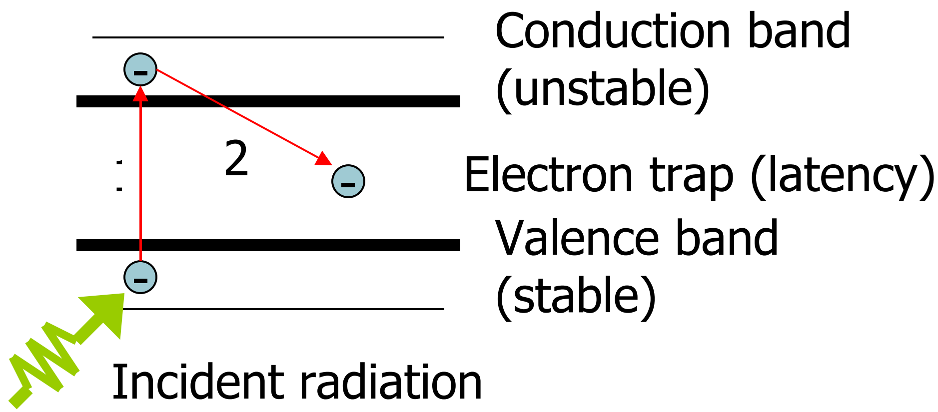
How does this new imaging technique affect the patient?

- Additional absorbed radiation dose
  - We want to obtain a geometric profile of the dose distribution at the center and at the periphery
- CTDI: computed tomography dose index
  - Acrylic material is analogous to the human body
- Thermoluminescent dosimeters

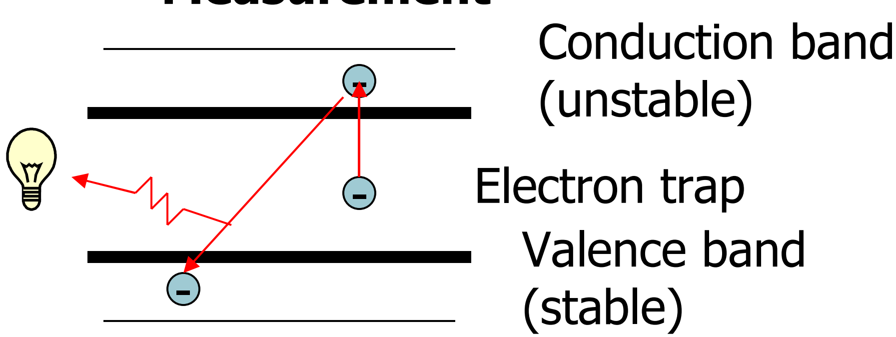


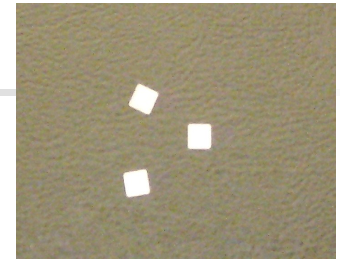
Thermoluminescent dosimeters (TLD)

Irradiation



Measurement





- LiF TLD chips
  - 1/8 inch square by 30/1000 inch depth
- Each chip measures the absorbed radiation for a single point
  - Radiation causes chemical reaction
  - Latent measurement tool

Preliminary tests

- Limitations
  - Their response is energy dependent
  - Non-uniformity of individual chips
- Certain characteristics of our TLD batch were assessed before acquiring data
  - Uniformity of response
  - Linearity of response to dose
  - Reproducibility - does each TLD respond to radiation consistently?

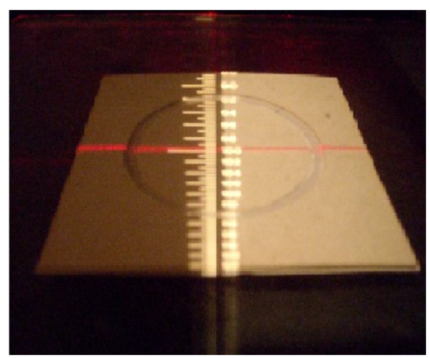
TLD processing steps

1. Annealing

Heat at 400° C for 1 hr, then 100° C for 2 hr

Purpose of annnealing: Set to zero

2. Irradiation



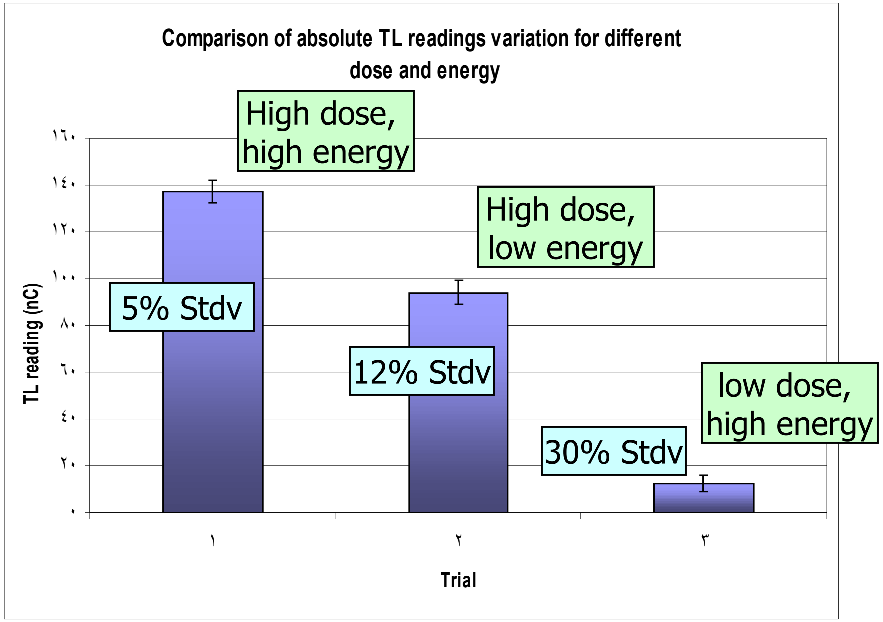
Harshaw 3500 TLD reader

3. Readout

TLD responses are read and recorded individually

Preliminary assessments

- The standard deviation (uniformity) of the TL readings decreased with increased dose
  - Due to the deposition of more photons
  - More photons = higher TL readout
- Our batch showed sufficient linearity in response and reproducibility



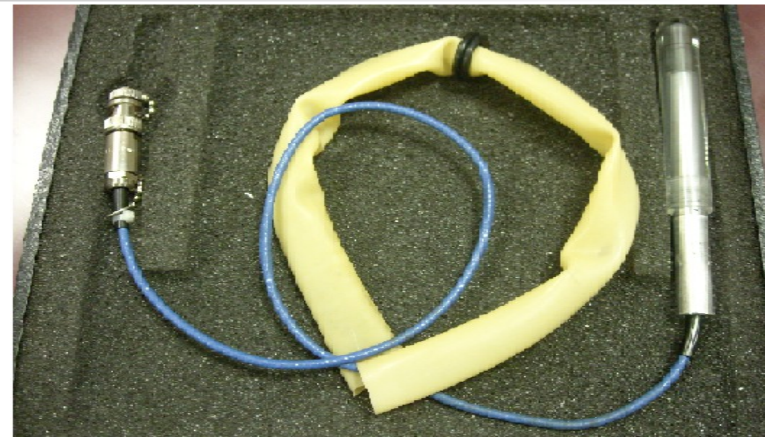
Relating the TL reading to absolute absorbed dose

Harshaw 3500 TLD reader

- The absolute dosimetry of TLDs is not apparent
- Readout in nano-Coulombs
- Convert the nC to absolute dose unit

Ion chamber (IC) calibration

- Place ion chamber inside a disk shaped water phantom (analogous to CTDI acrylic); 5 TLDs set adjacent to the IC
- Perform one double CBCT scan
- Connect ion chamber to electrometer (outputs a reading)



Absolute dose calculation

- AAPM (American Association of Physicists in Medicine) protocol for absolute dose calculation from in-water ion chamber readings (M)

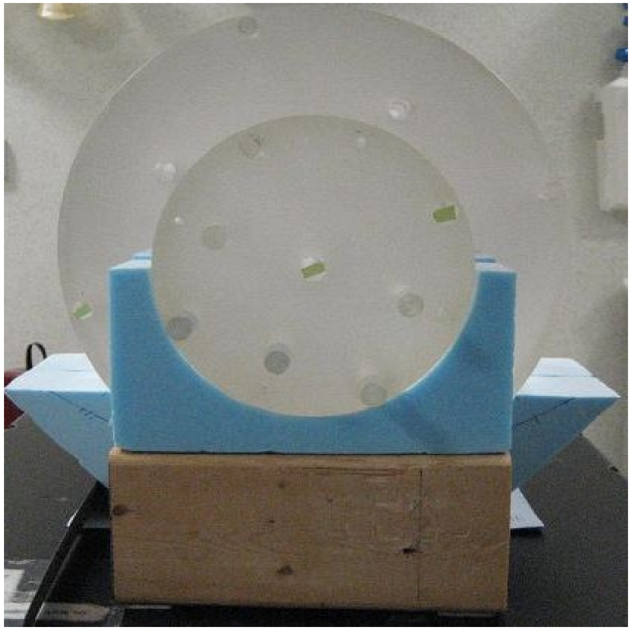
$$D_w = M N_k P_{qcham} P_{sheath}$$

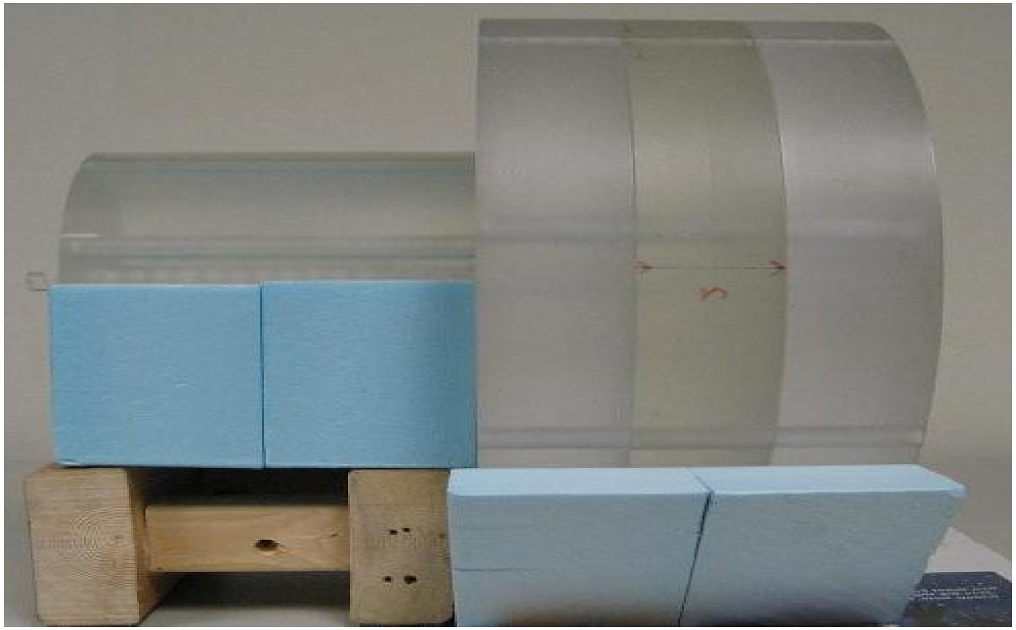
- Dose to water is calculated in Gy
- D_w = 10.29 cGy for one double CBCT

TLD calibration

- Avg TL readout: 51.94 nC
- Calibration factor:
  - 51.94 nC ≈ 10.29 cGy absolute dose

Head and neck patient simulation





Sensitive area is increased by placing the two phantoms
in series; allows for complete coverage of a double CBCT

Custom modifications

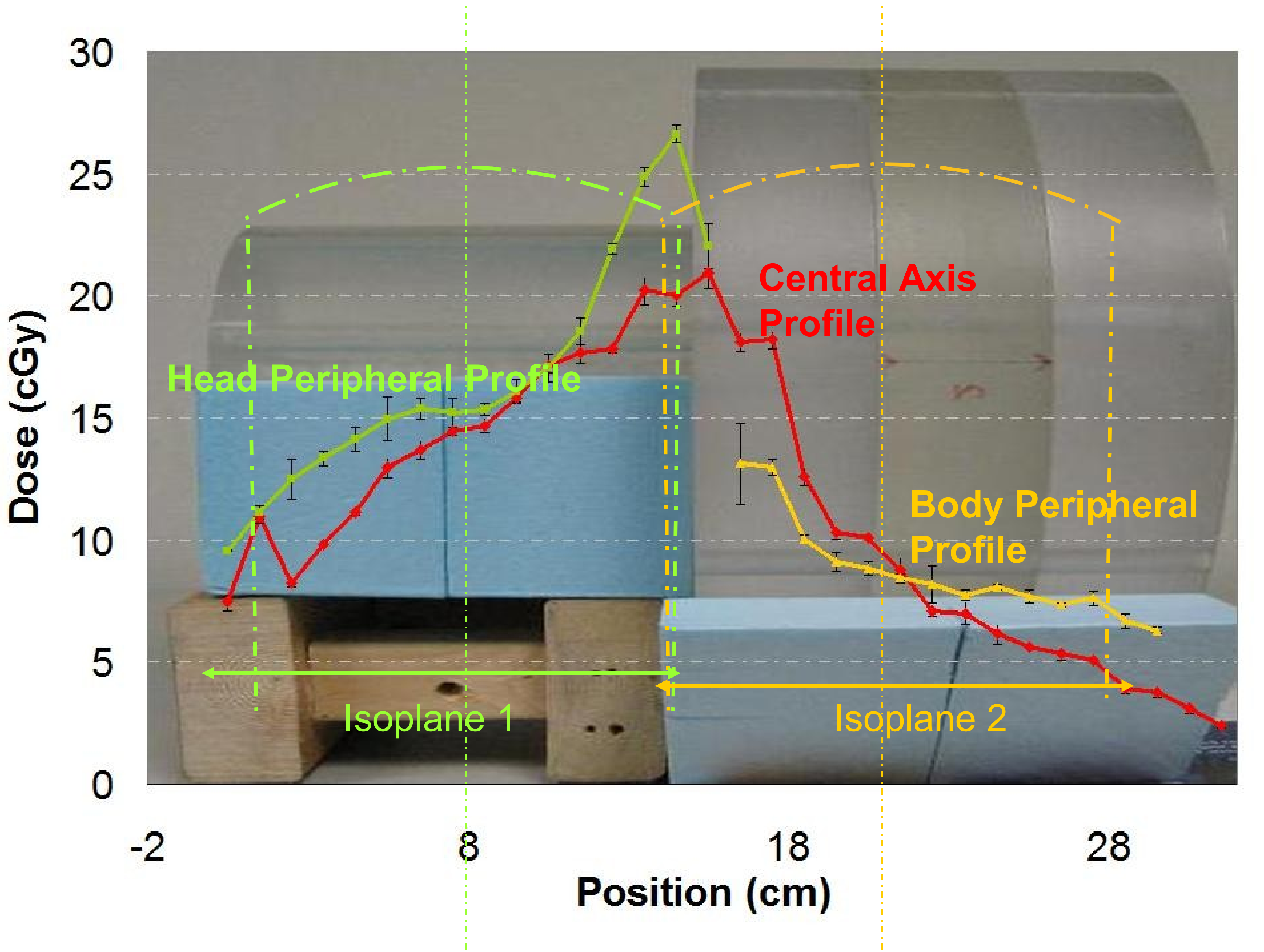
- ThreeCustom holders designed to harbor TLDs
  - 33cm (CAX)
  - 15 cm
  - 16 cm

Setup

- After annealing, two TLDs were placed in each well of the holders
- Holder placement:
  - Long 33 cm holder: central axis
  - 16 cm holder: peripheral channel head phantom
  - 15 cm holder: peripheral channel body phantom

Double Cone beam CT acquisition

- Beam isocenter (first scan): 12 cm from the sup. axial surface
  - Beam length: 13.8 cm (6.9 cm on either side of the isocenter)
  - Isocenter placement accounts for beam scatter
- Second CBCT scan: shift the patient
  - Clinical procedure: 12.3 cm shift
- 4 double cone beam CT scans were performed
  - 8 scans total



30
25
20
15
10
5
0
Dose (cGy)
-2
8
18
28
Position (cm)
Central Axis Profile
Head Peripheral Profile
Body Peripheral Profile
Isoplane 1
Isoplane 2

Conclusions

- The overlap in the abut region causes a marked increase in the absorbed dose
  - Is the extra dose warranted?
- Next step: Investigate methods of lowering the resulting absorbed dose while maintaining the integrity of our images
  - Develop better image registration techniques
  - Experiment with lowering the current-time (mA·s) product through the x-ray tube

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