

# Novel Technologies



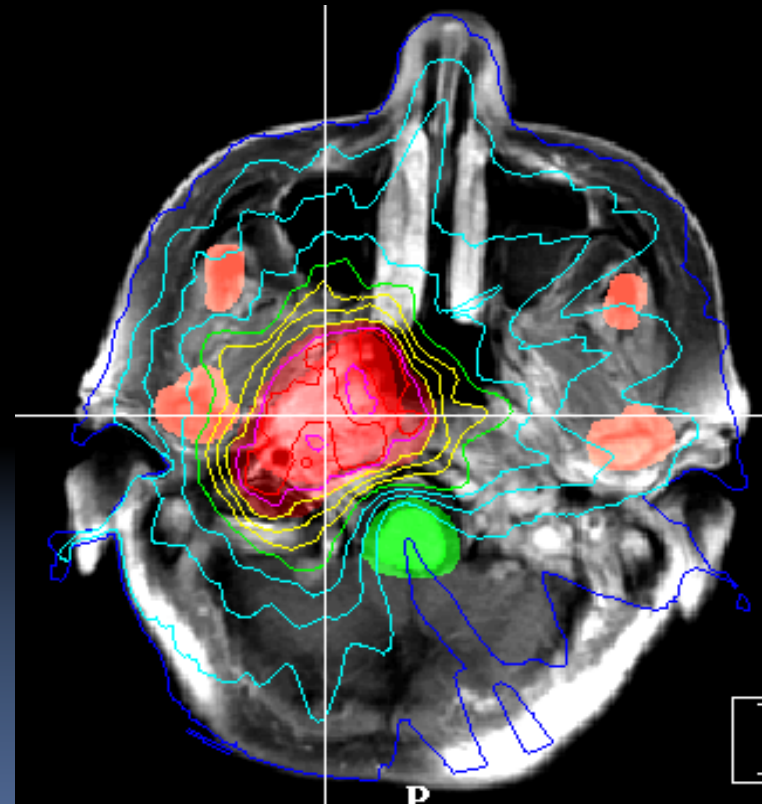
**M. Saiful Huq, Ph.D., FAAPM, FInstP**

Professor and Director, Division of Medical Physics Department of Radiation Oncology

UPMC Cancer Centers, Pittsburgh, Pennsylvania, USA

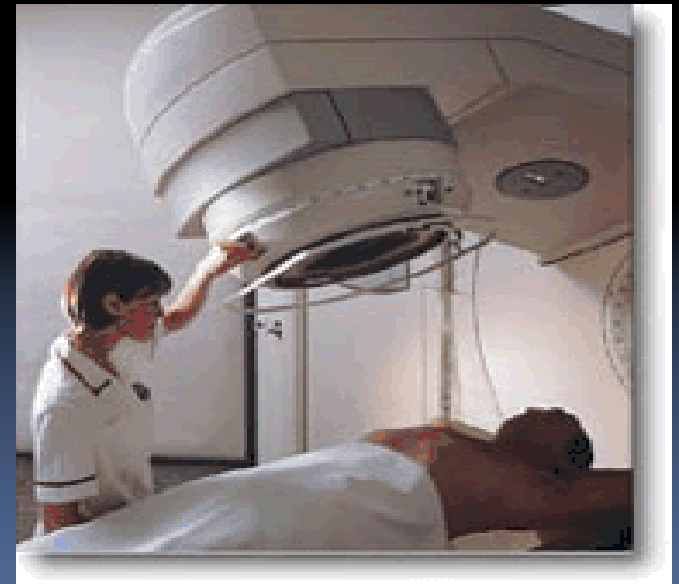
# Goals of Radiation Therapy

Primary goal of RT is to achieve local (or regional) control with limited risk of normal tissue complications



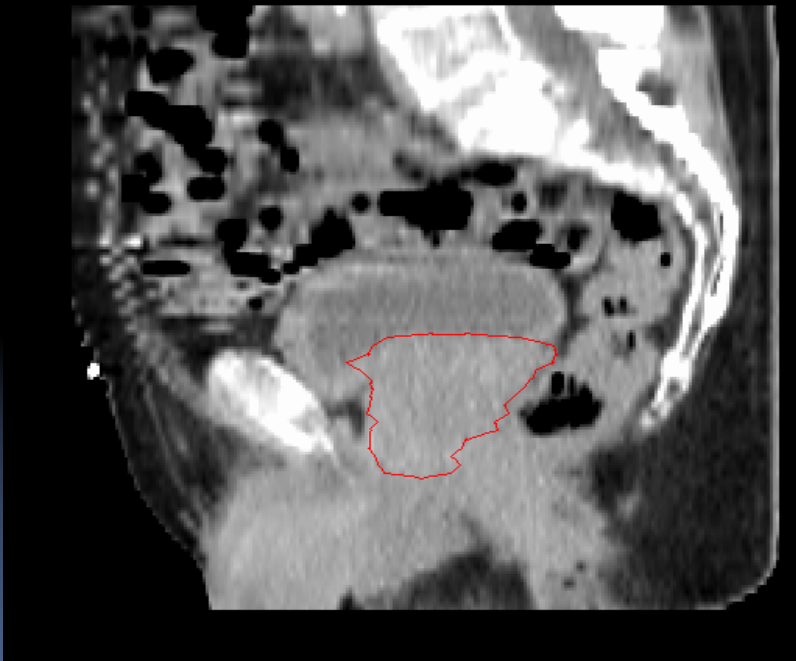
# Steps Needed to Accomplish The Goal of Radiotherapy

- | Find the tumor
- | Delineate the target and OAR volumes as accurately as possible
- | Dose paint or dose sculpt and escalate the dose to the target and spare the OAR
- | Hit the target repeatedly with high energy photons or electrons while sparing the surrounding normal tissues



**But: the patient is alive !**

# Uncertainties in RT



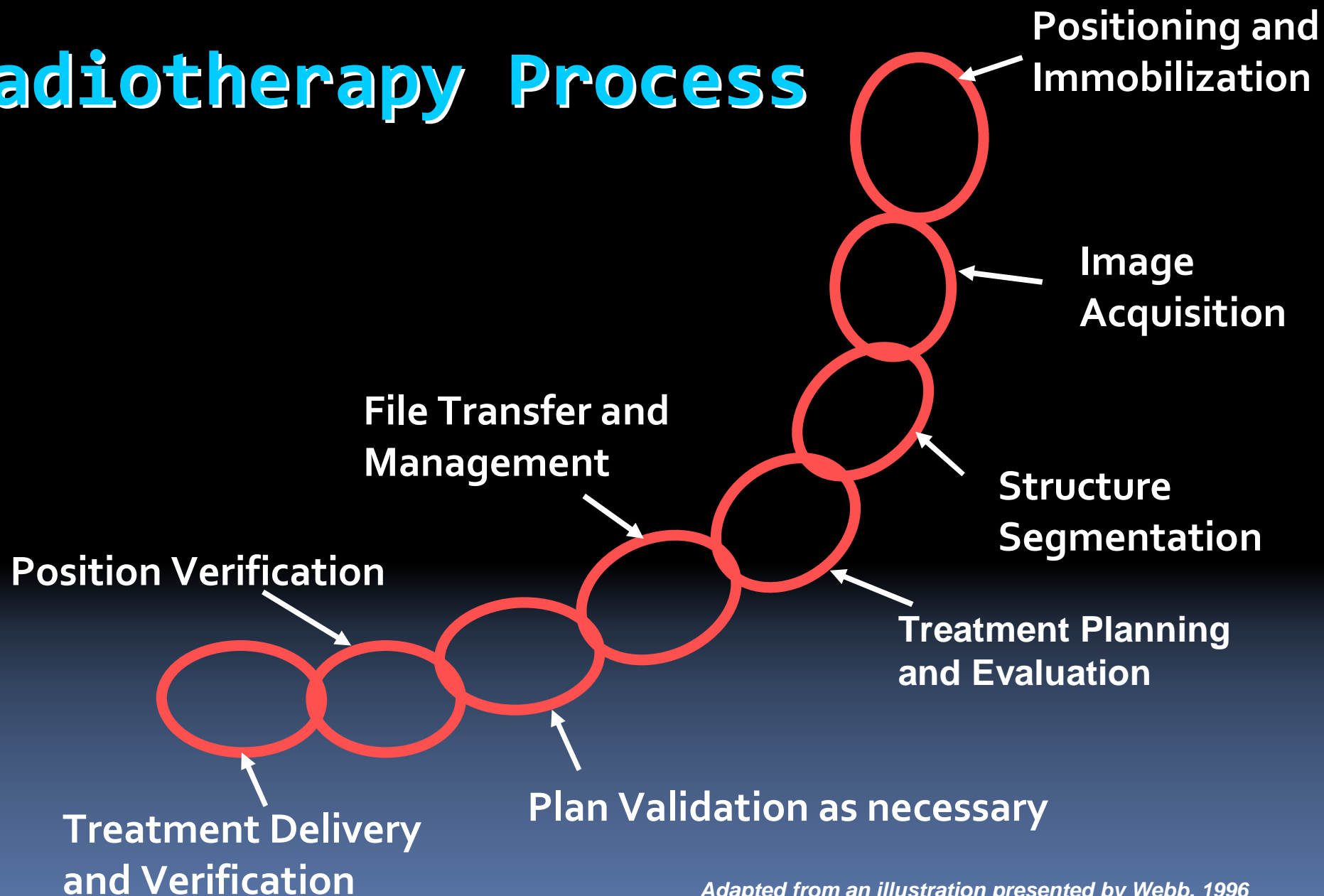
## ↗ patient positioning and target delineation

- setup and reproducibility errors
- organ motion errors
  - Intra-fraction motion errors
  - Inter-fraction motion errors
- Physiological changes and deformation

## ↗ treatment planning

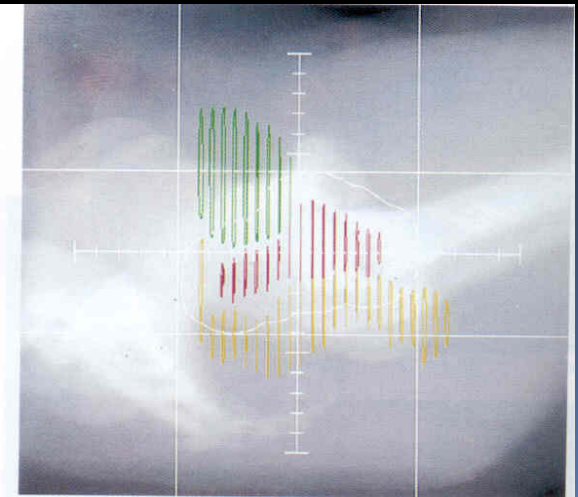
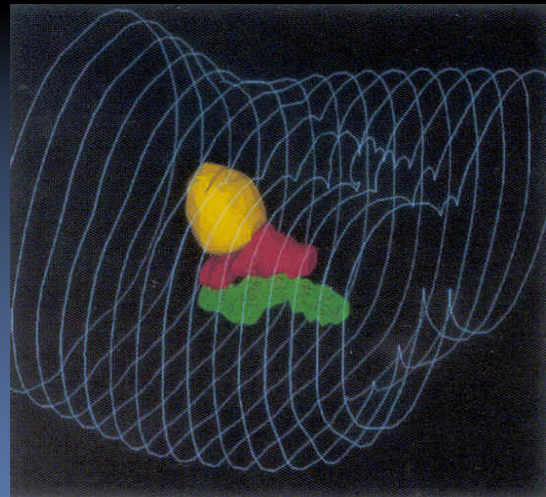
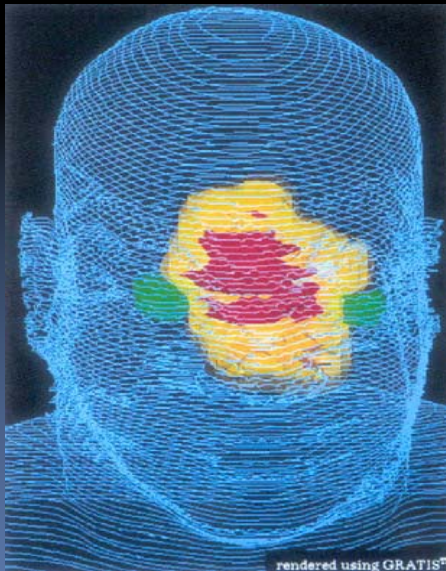
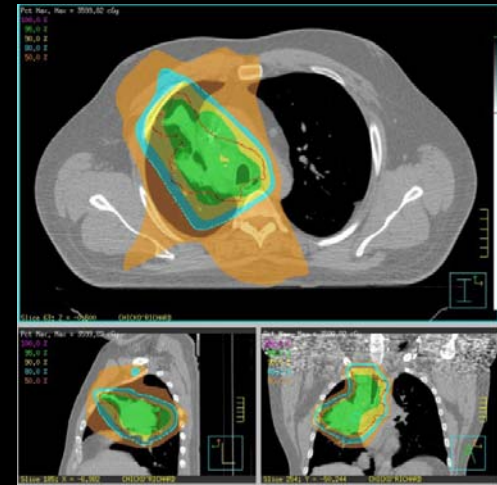
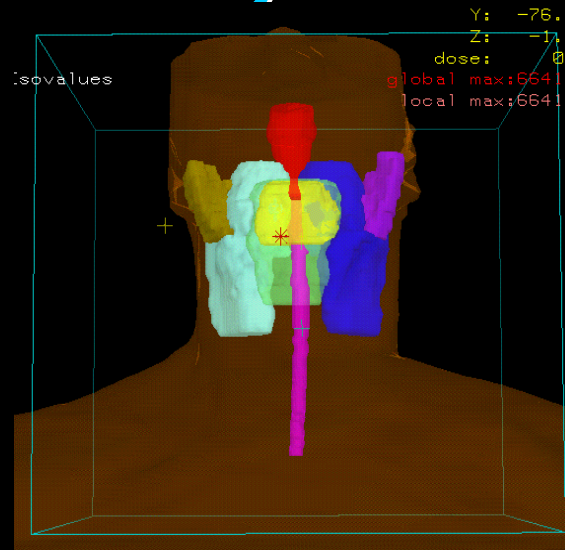
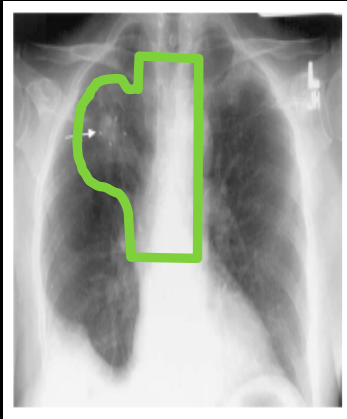
## ↗ delivery systems

# Radiotherapy Process

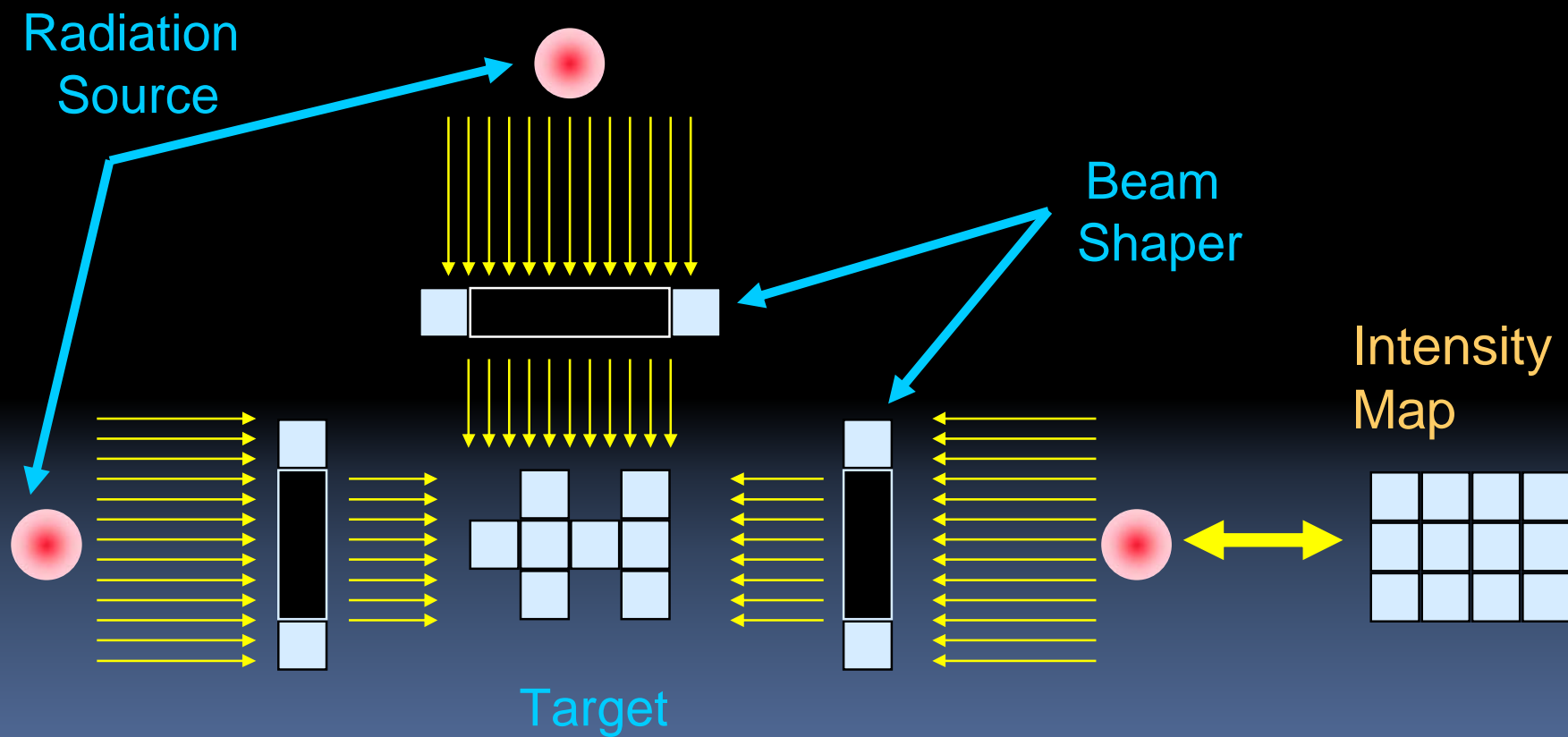


*Adapted from an illustration presented by Webb, 1996*

# 2D and 3D in the Seventies, Eighties and Early Nineties



# Conventional 3D Treatment



# IMRT and IG(A)RT

Computer-controlled shaping of the radiation field during treatment.

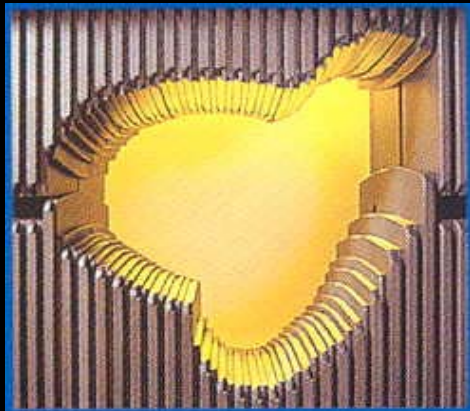
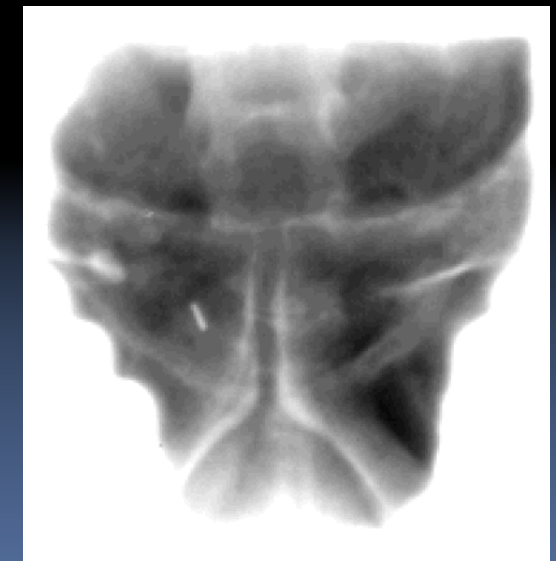
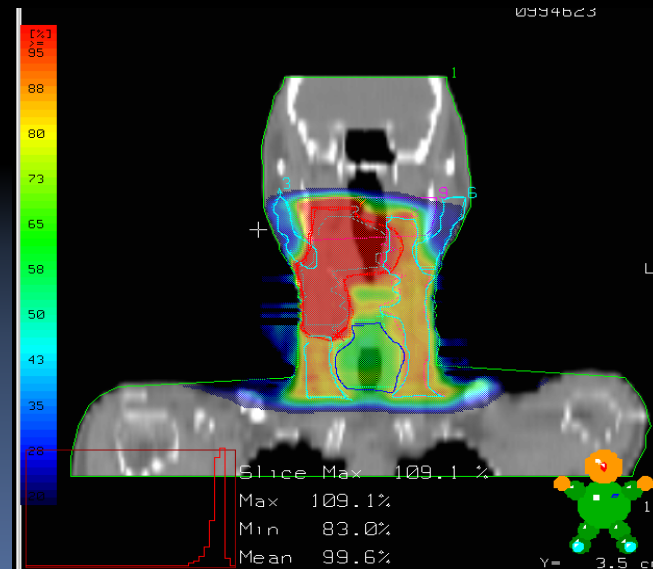
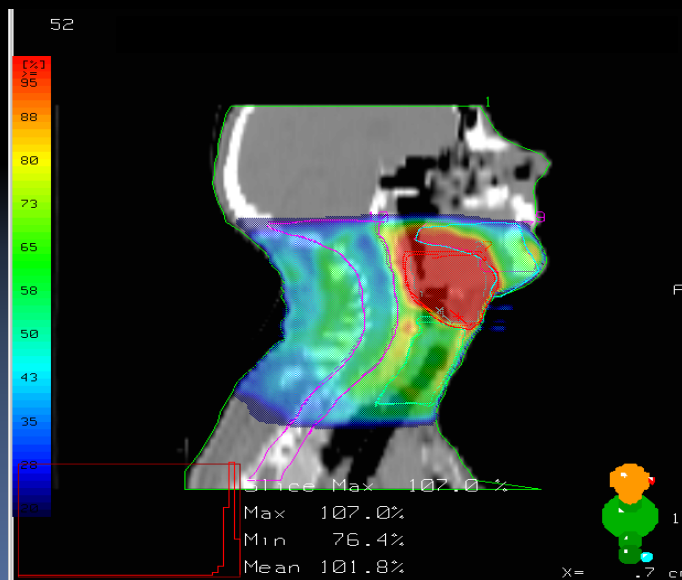
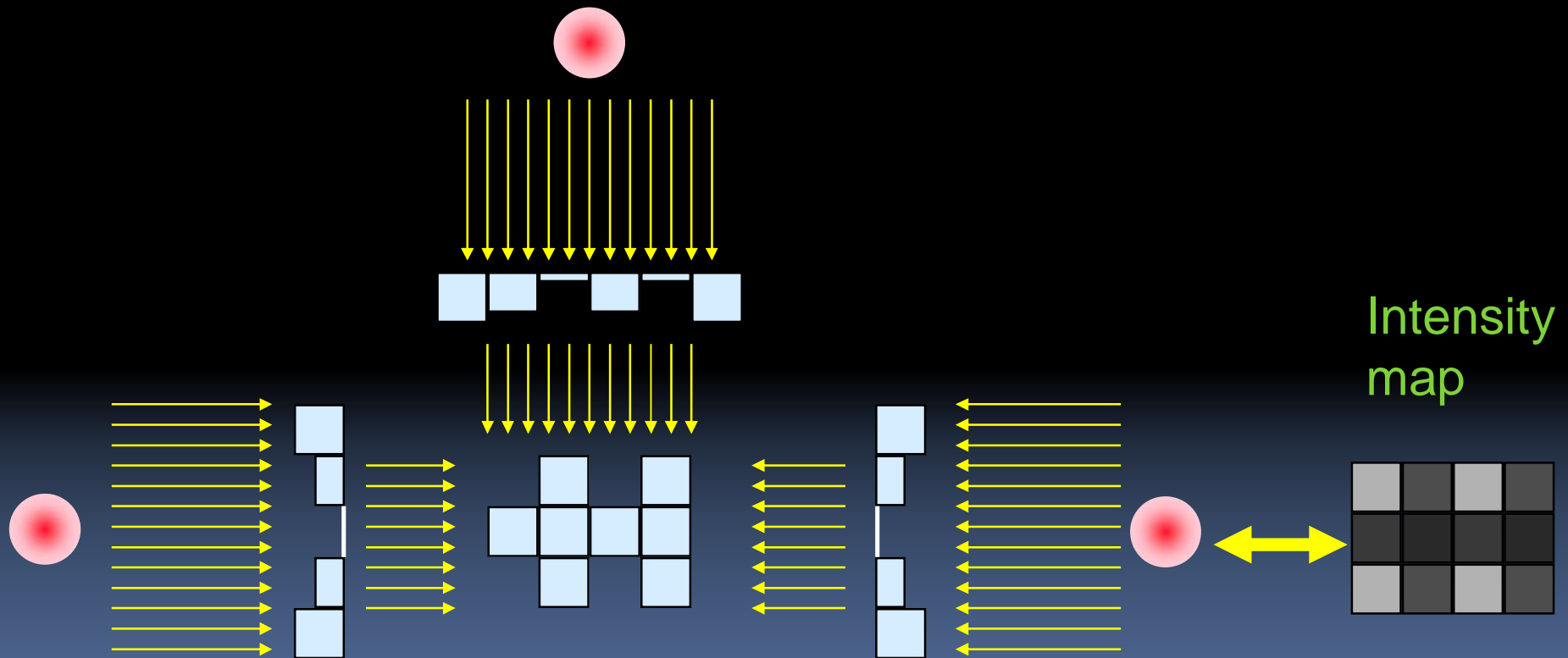


Image before treatment

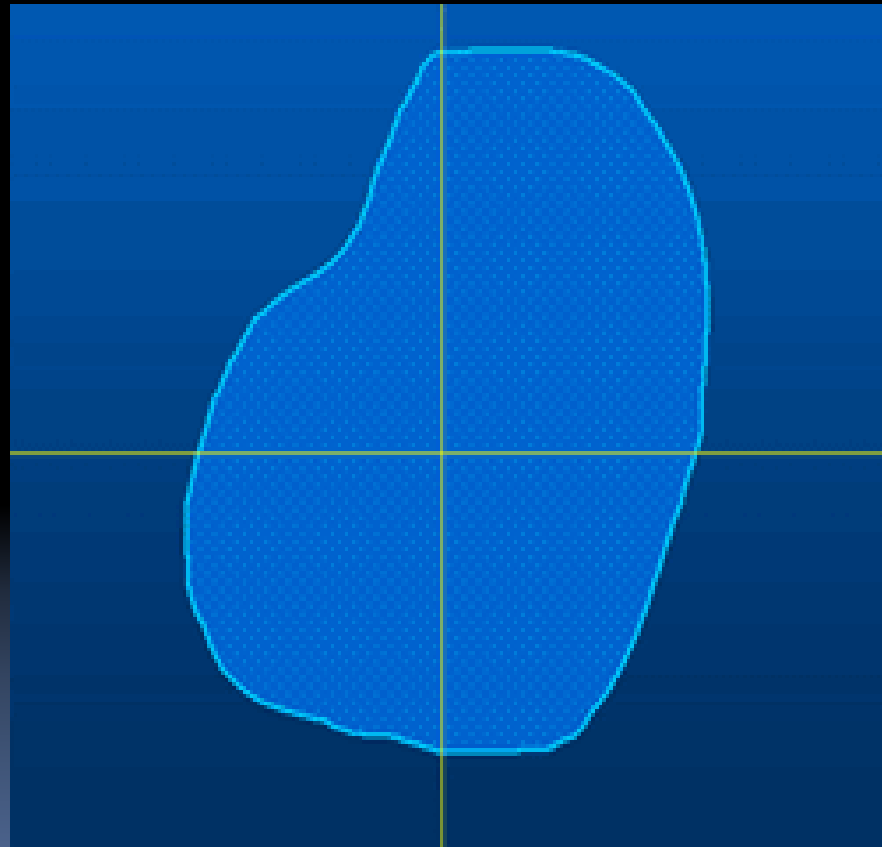




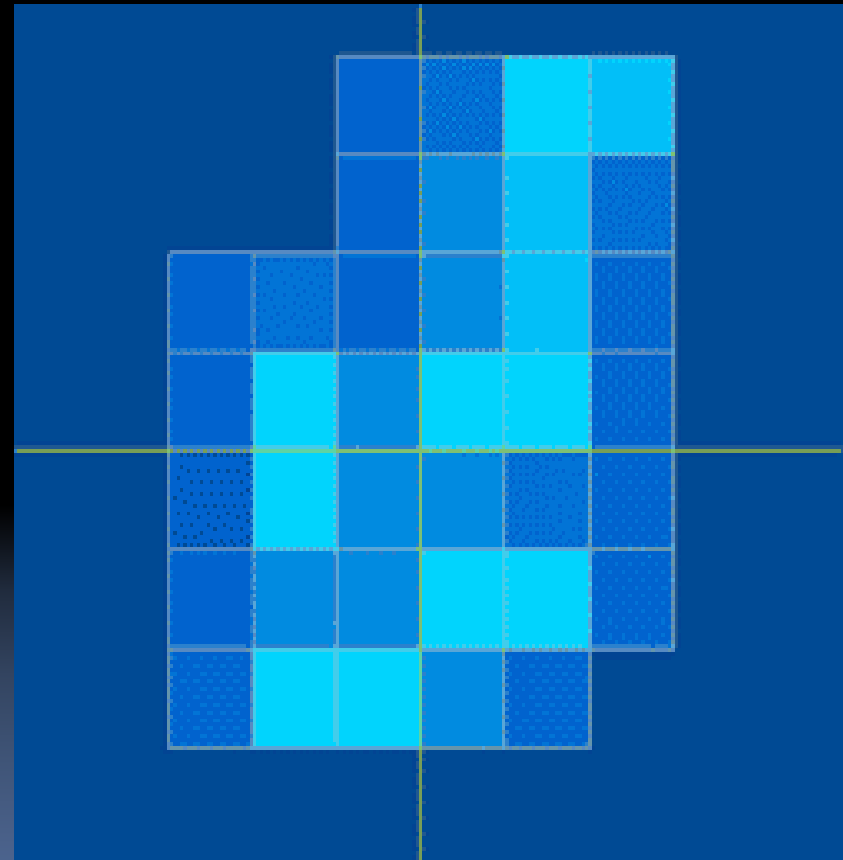
# IMRT Treatment



# 3D versus IMRT

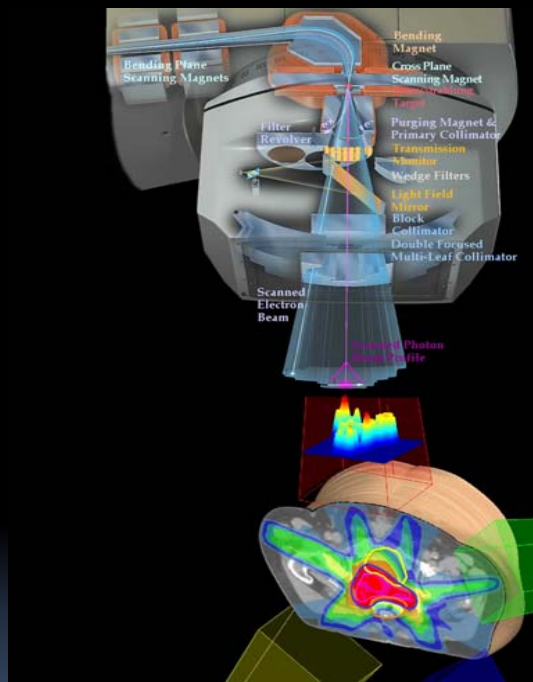
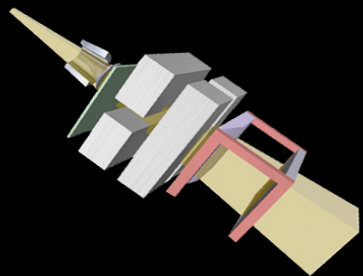


3D Conformal

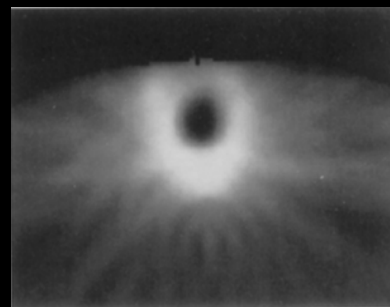


Intensity Modulation

# We Have Made Great Progress in Optimizing Dose Delivery to Static Objects



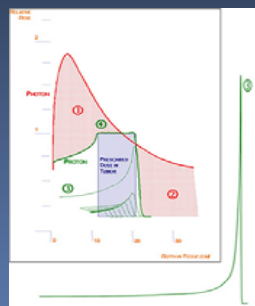
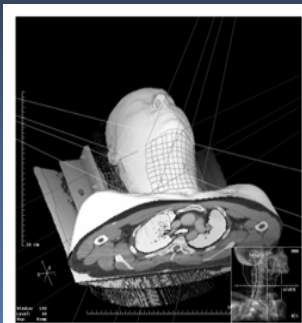
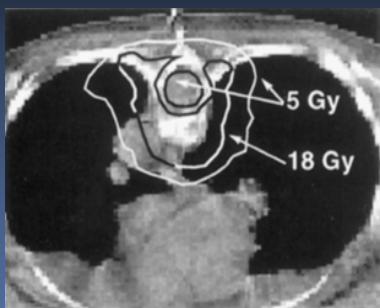
## Evolution of Technology



CT Sim  
Convolution  
IMRT Optimization  
Monte Carlo  
IMPT  
etc.

We have perfected the optimization of dose to static objects

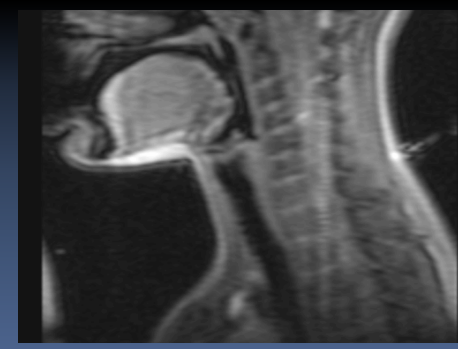
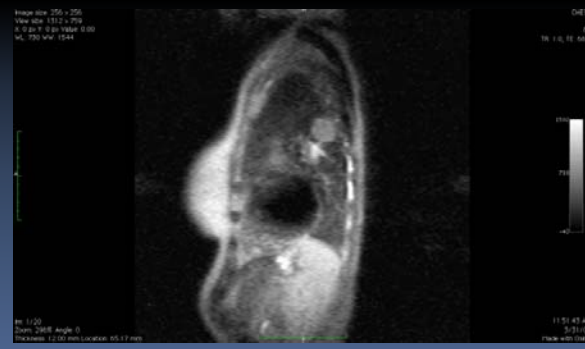
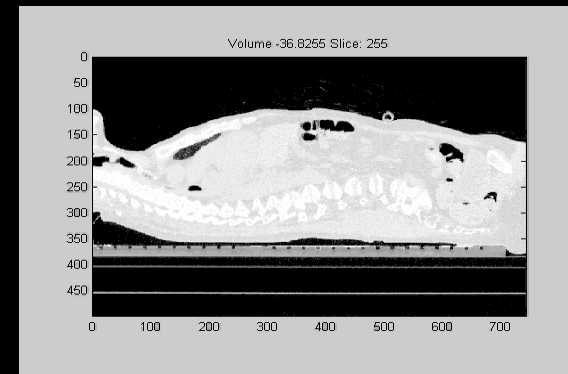
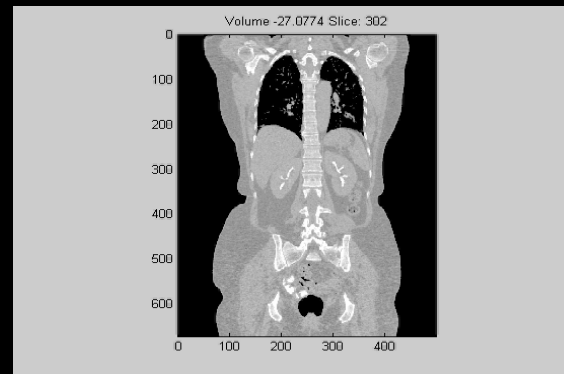
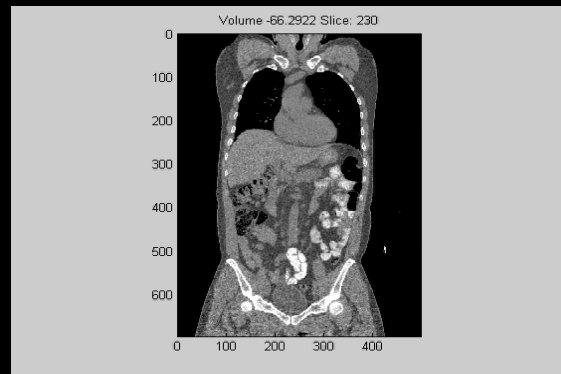
However...



Courtesy: Jim Dempsey

# The Clinical Challenge

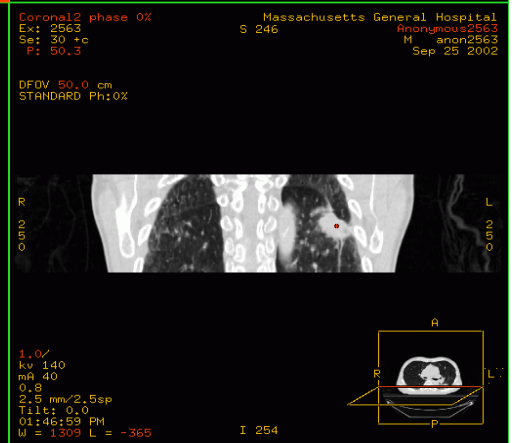
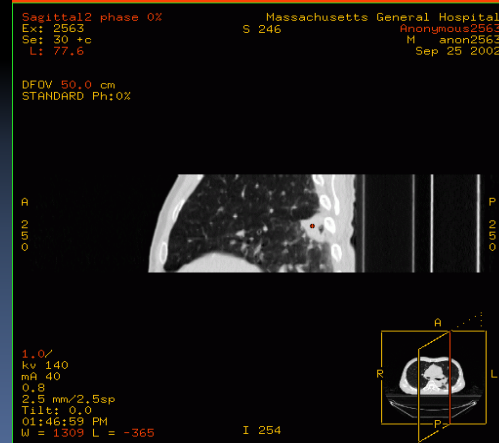
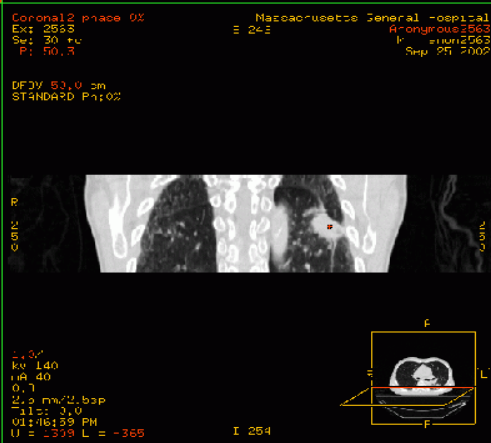
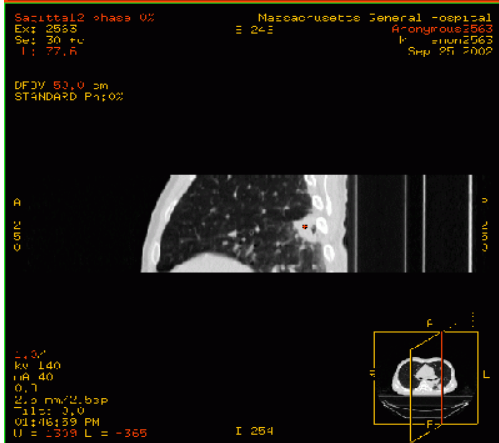
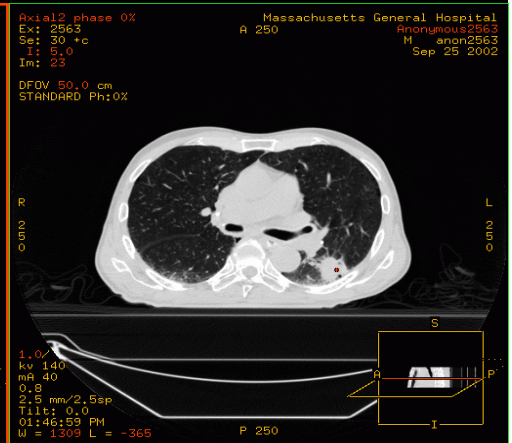
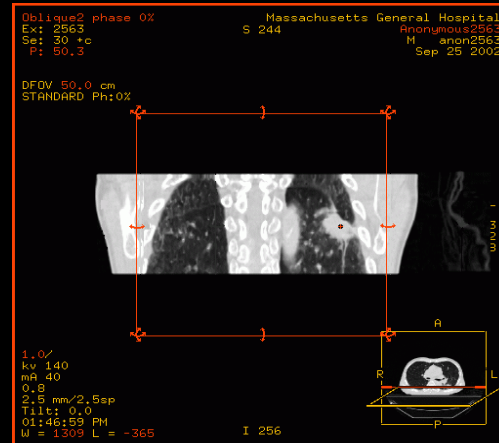
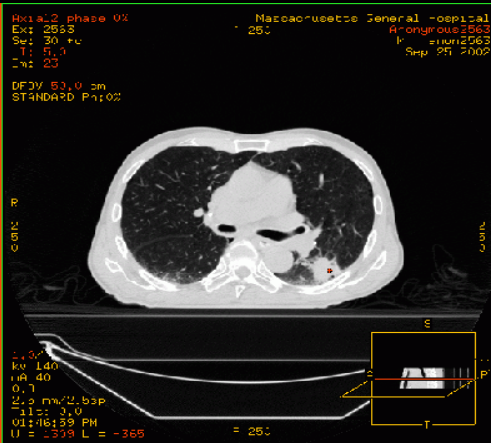
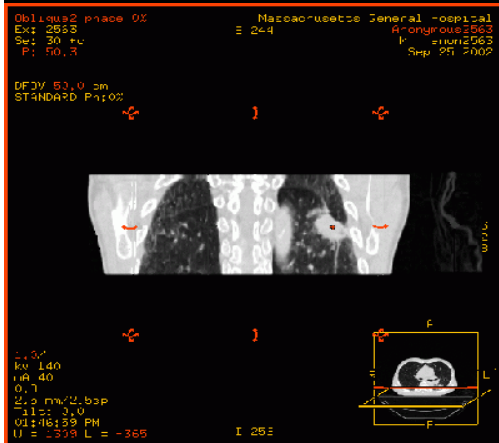
- Accurately deliver ionizing radiation to the real dynamic patient



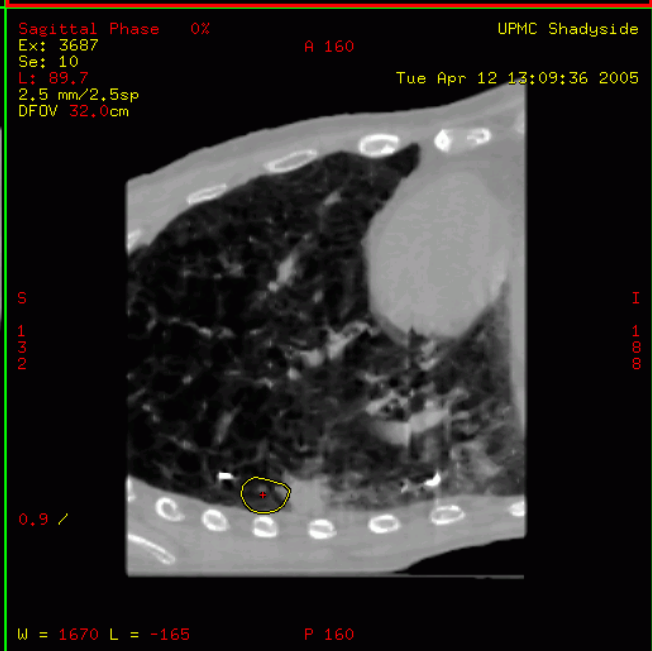
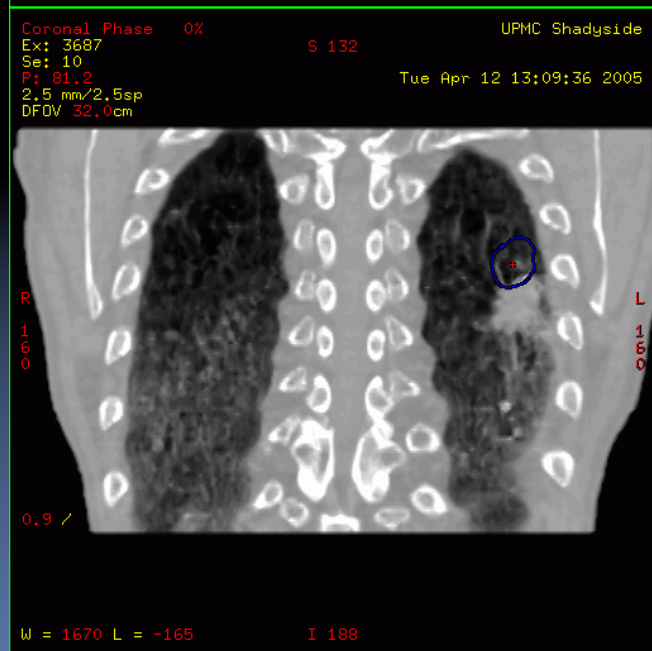
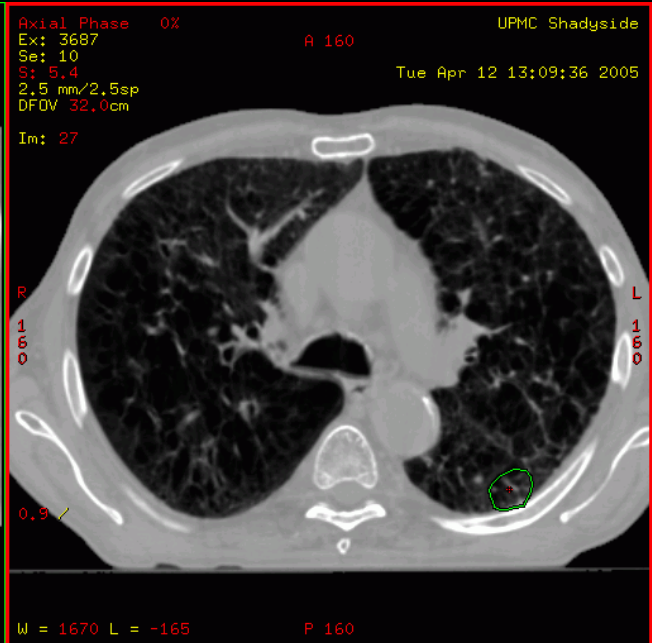
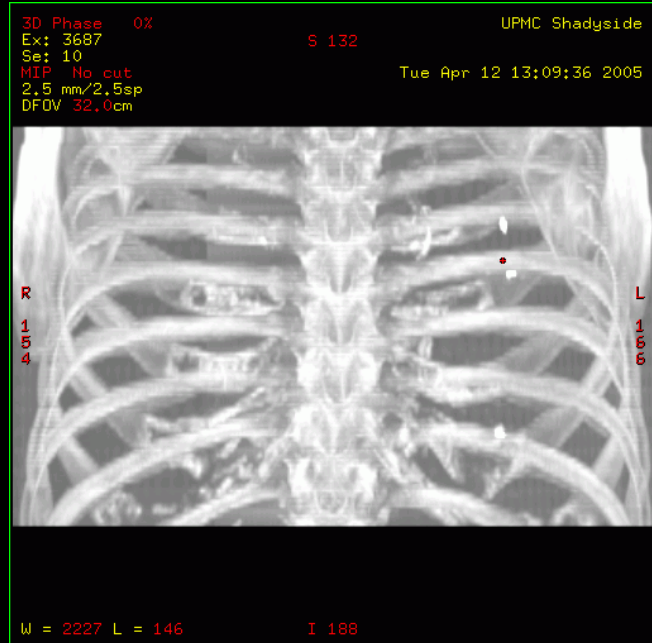
4D CT Data from Low *et al. Med. Phys.* 30(6) (2003) 1254-1263

# 4-Dimensional Radiation Therapy

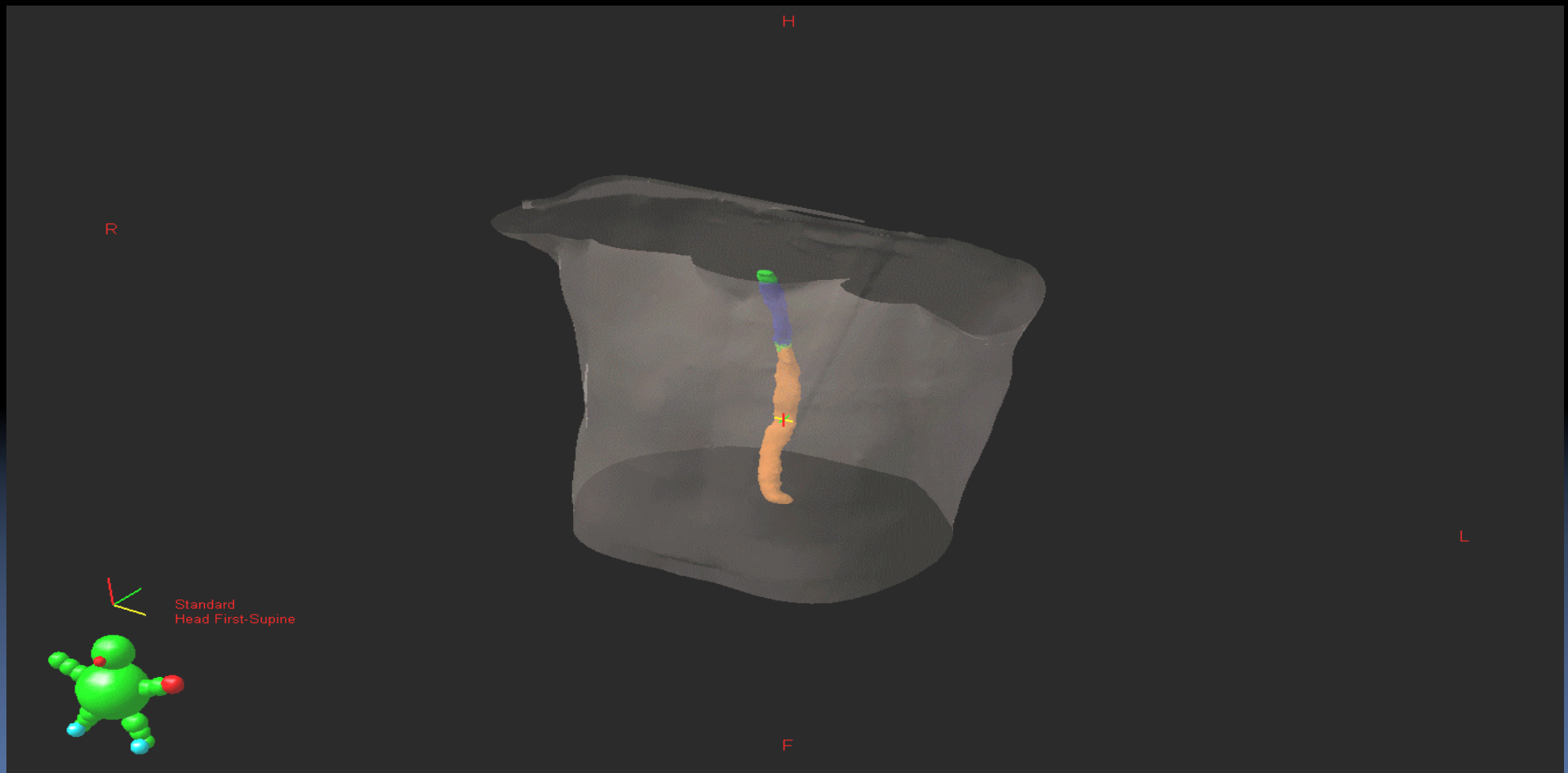
Treatment for the New Millennium—the addition of the TIME dimension



The 3D images  
in  
4<sup>th</sup> Dimension  
of Time



# Esophagus in 4D



# Intra-fraction Motion is Observed During Cone-Beam CT Acquisition

I Rectal gas artifacts seen in prostate for every 1 of 6 cases

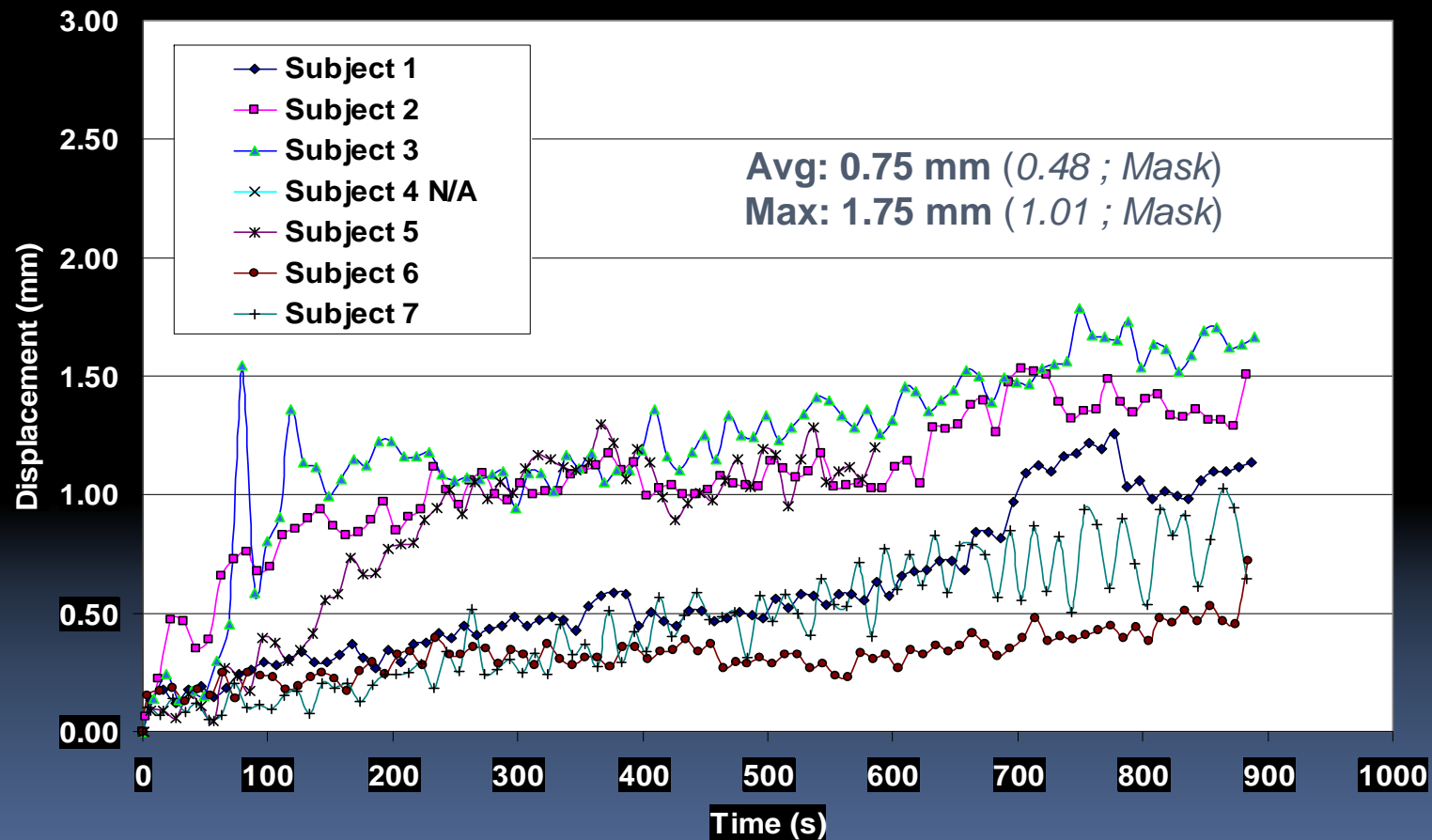
Looking down the CBCT





# Intra-Fraction Patient Motion

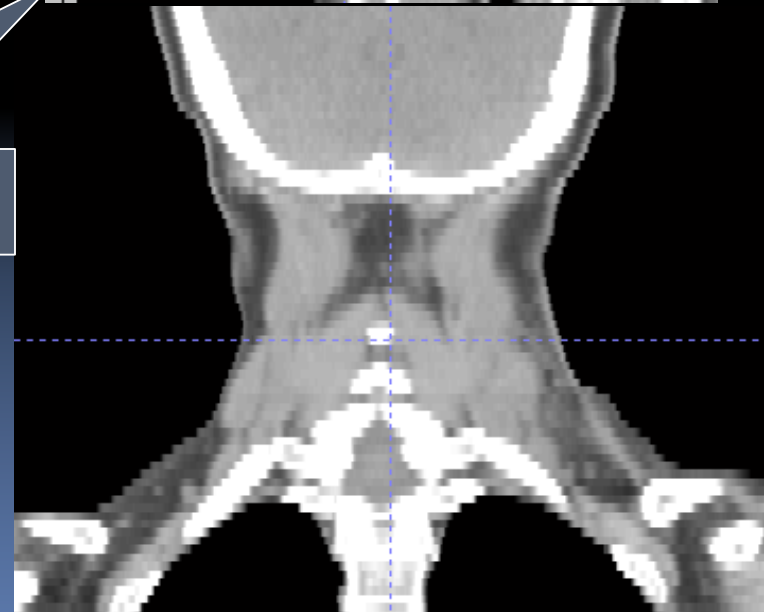
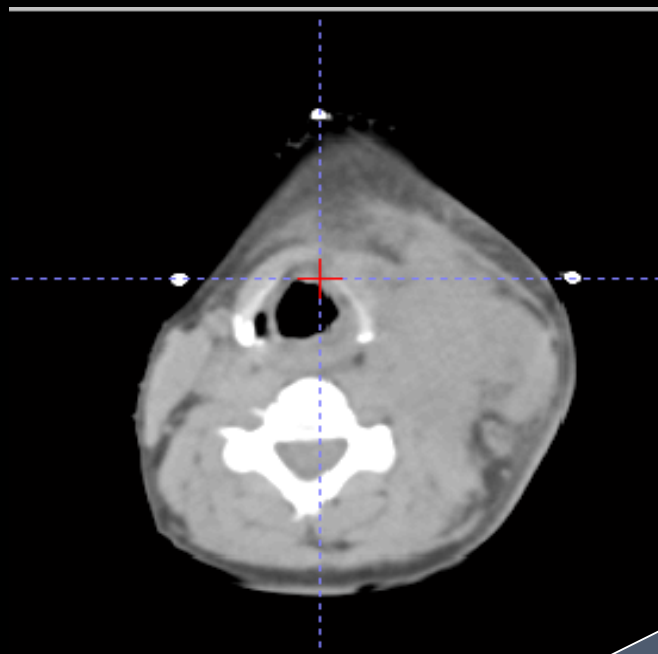
*“Can only be minimized in IMRT but not eliminated”*



*“Patient motion increases as treatment time gets longer”*

S. Kim et. al., IJROBP, 2003

# Setup Uncertainties In Head & Neck Treatment



Elapsed Treatment Days

19 Treatment CT scans acquired during the course of head & neck radiotherapy

Courtesy: Dong MDAH

# Challenges

- How do we account for these intra- and inter-fraction motion ?
- How do we draw target volumes taking motion into account?
- How do we deliver radiation treatment so that the beam is on only for times when the target is enclosed by the beam?
- Novel technologies have been developed to address these challenges

# Retrospective 4D-CT Imaging

Respiration Waveform from RPM Respiratory Gating System



Inhalation

Exhalation

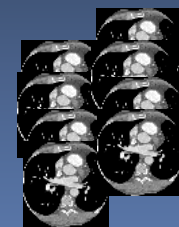
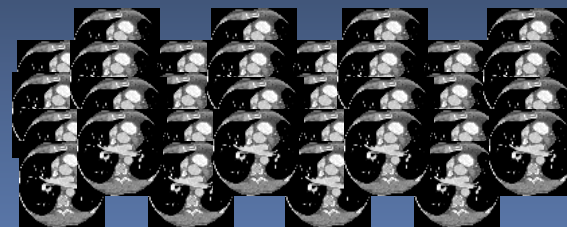
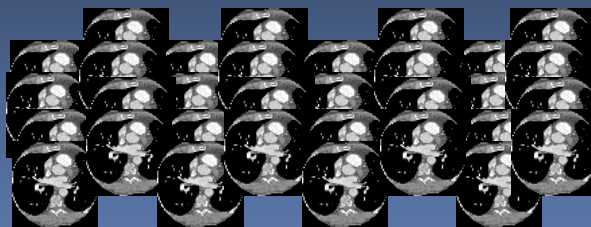
Image acquired" signal to RPM system

X-ray on

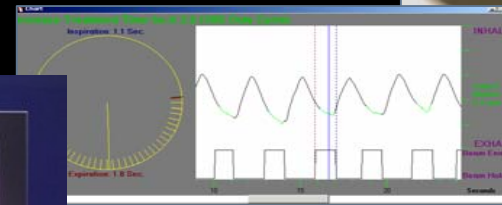
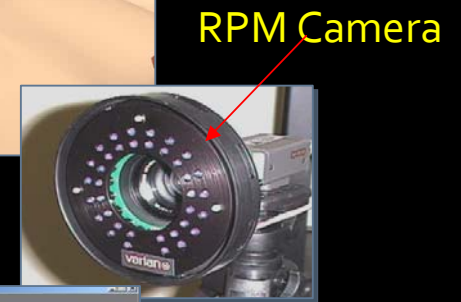
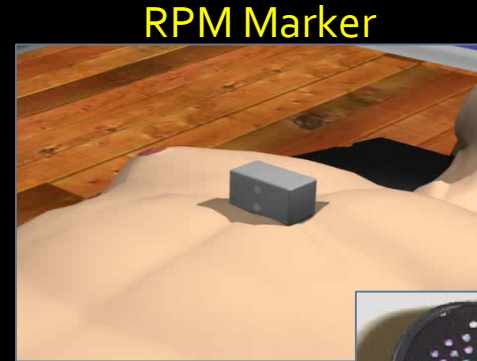
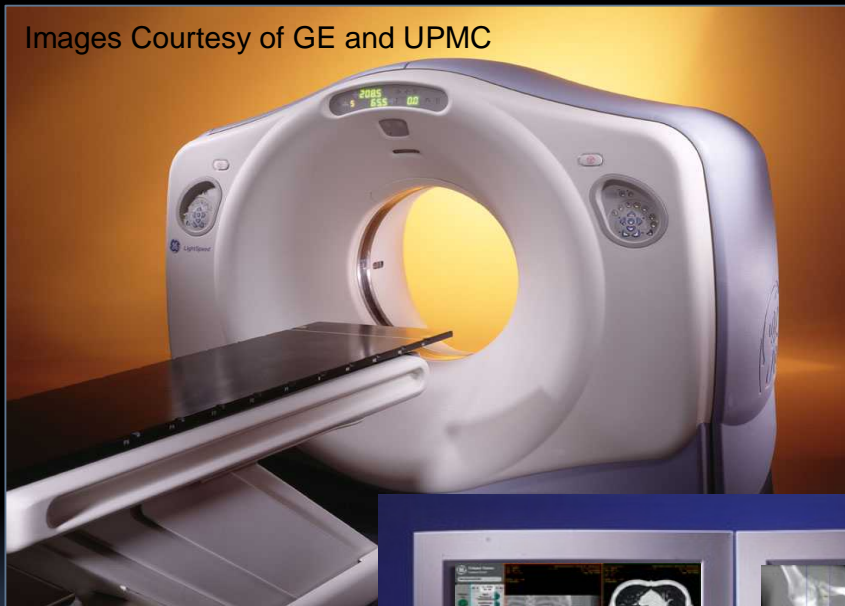
First couch position

Second couch position

Third couch position



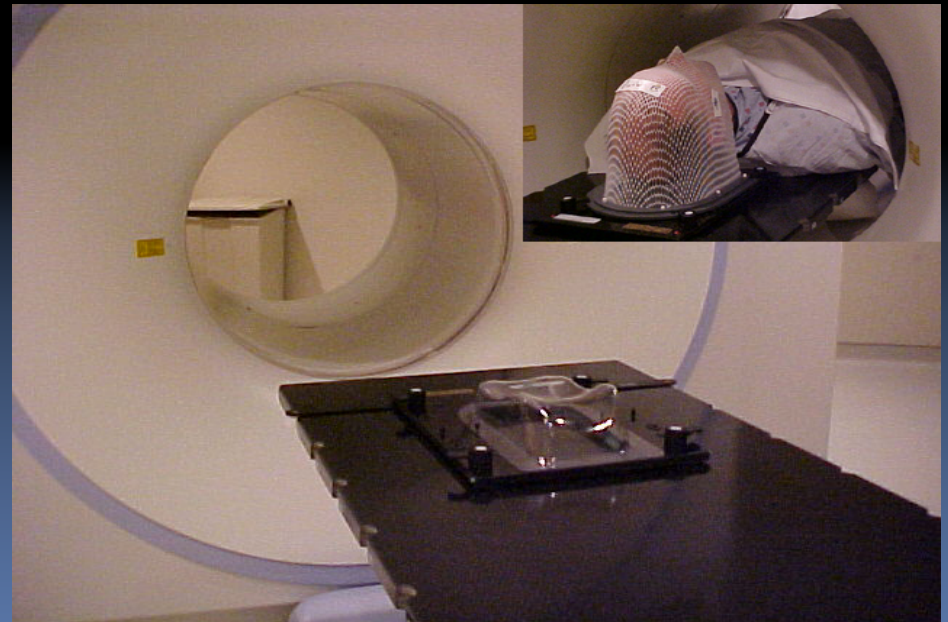
# GE Multi-slice CT Scanners with RPM Respiratory Gating



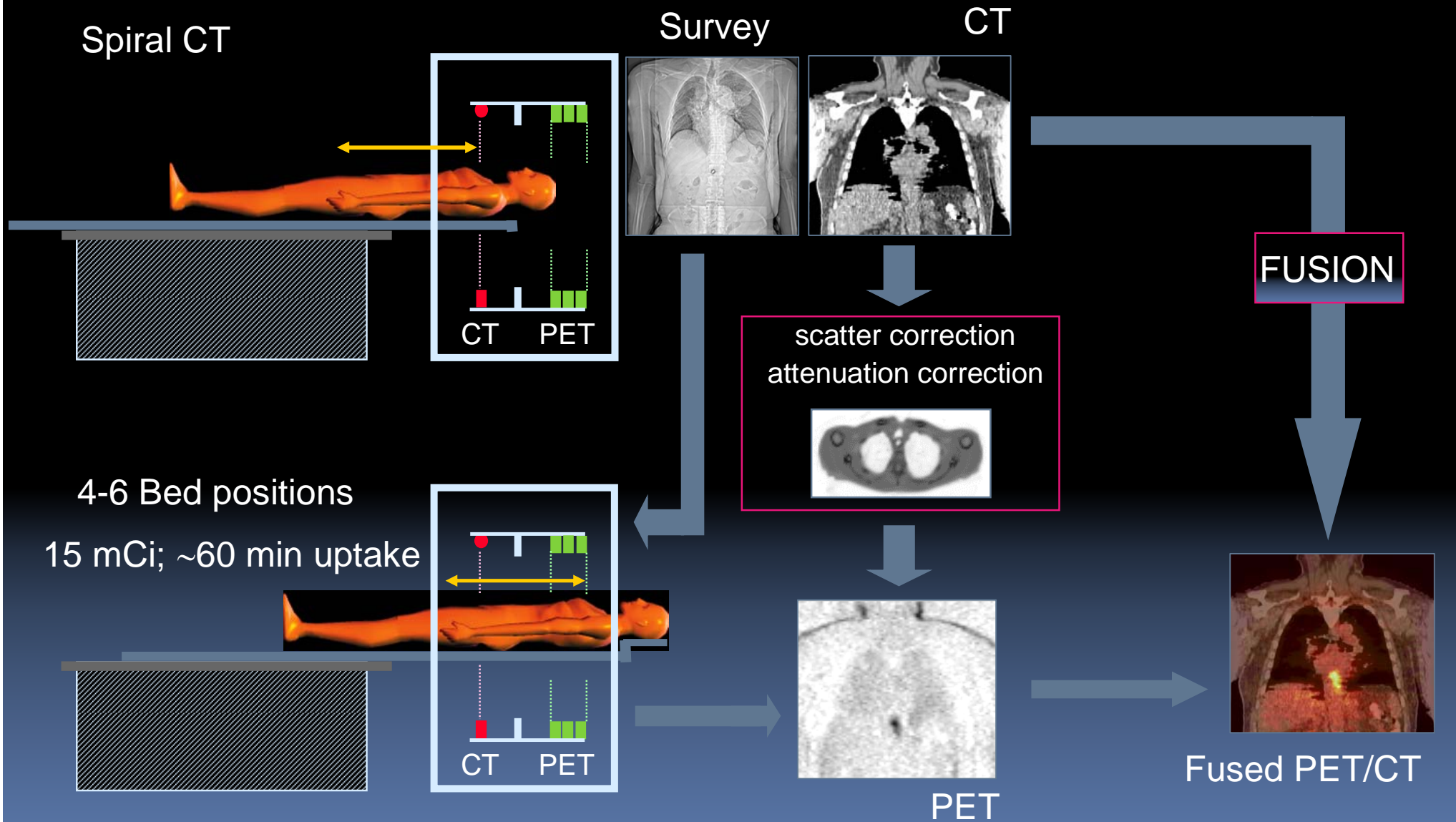
RPM Console Display

Advantage Windows Console

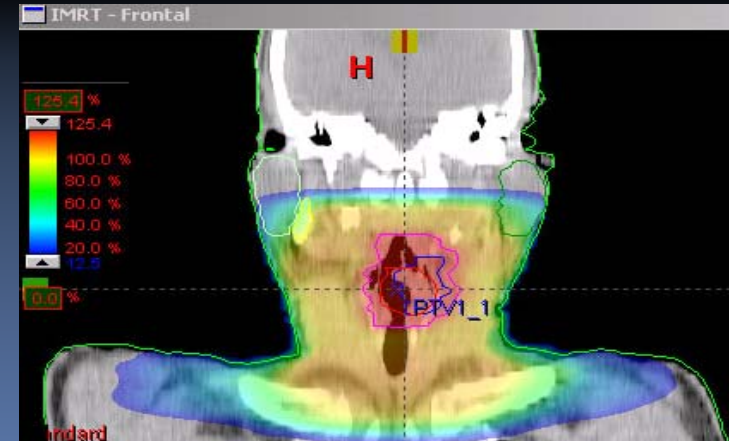
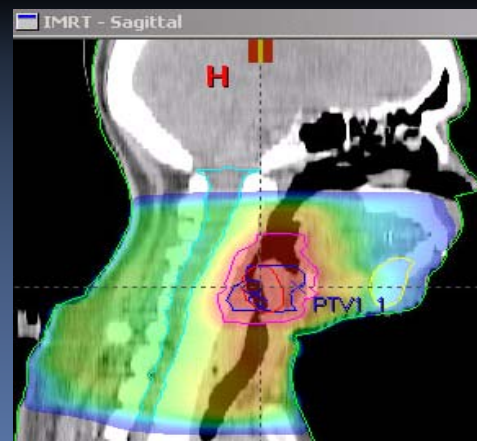
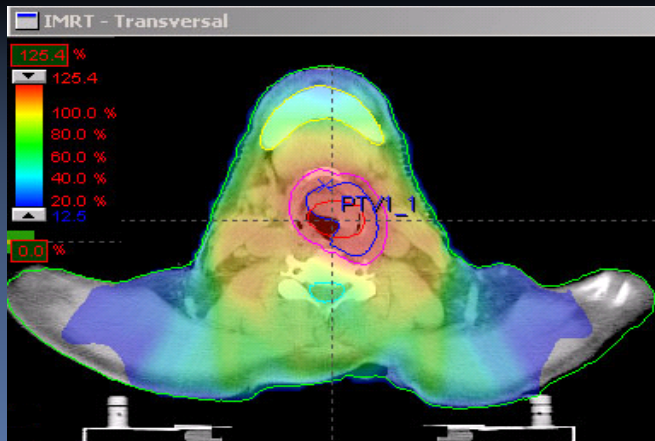
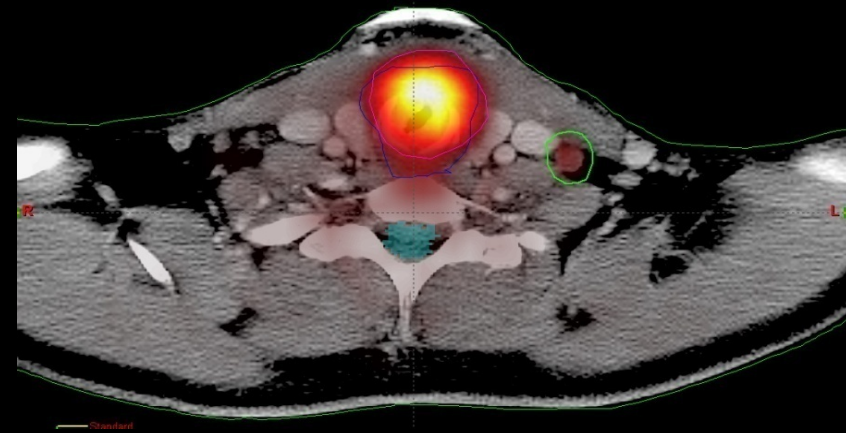
# PET-CT Simulation in Radiation Oncology



# UPMC PET/CT Scan Protocol

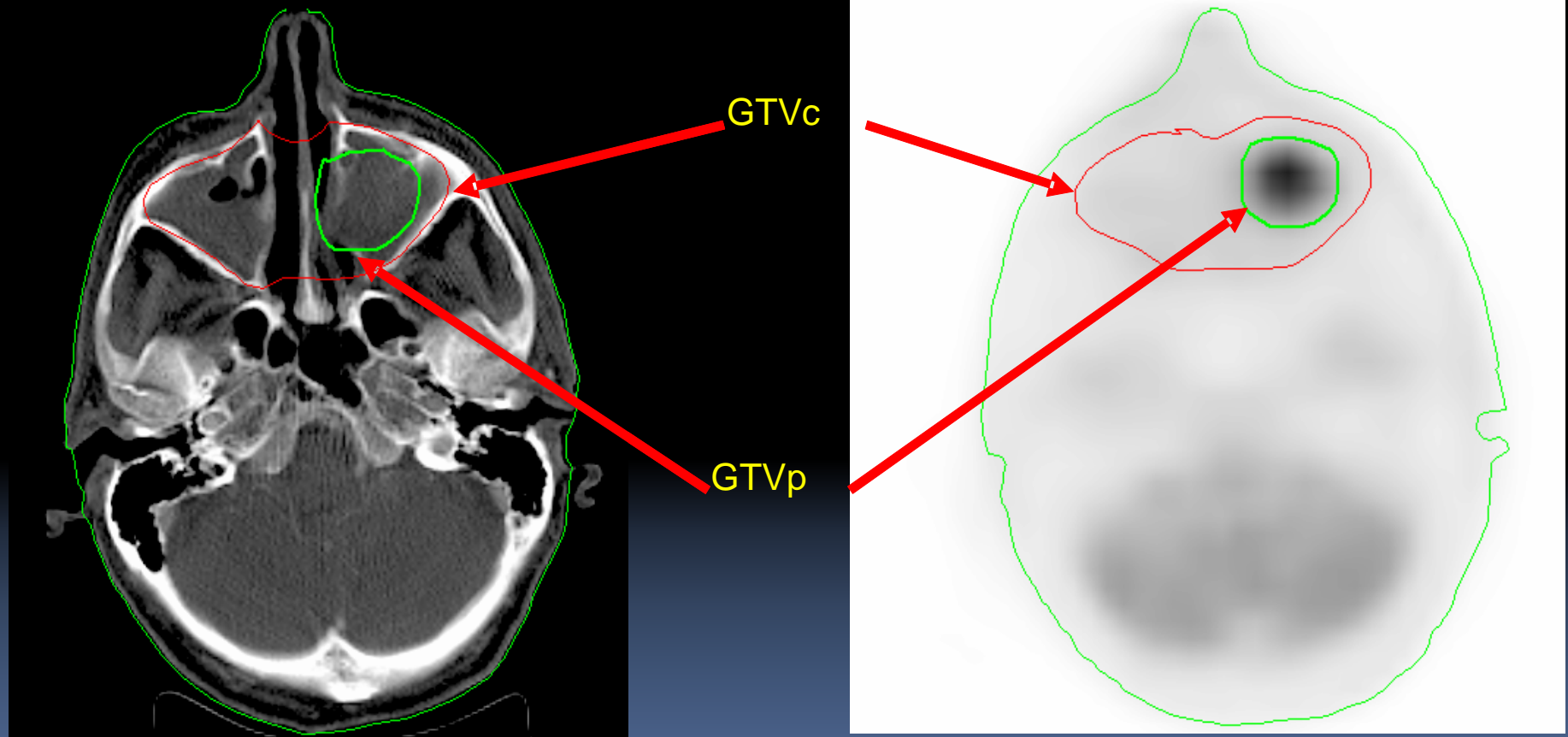


# PET for IMRT Planning



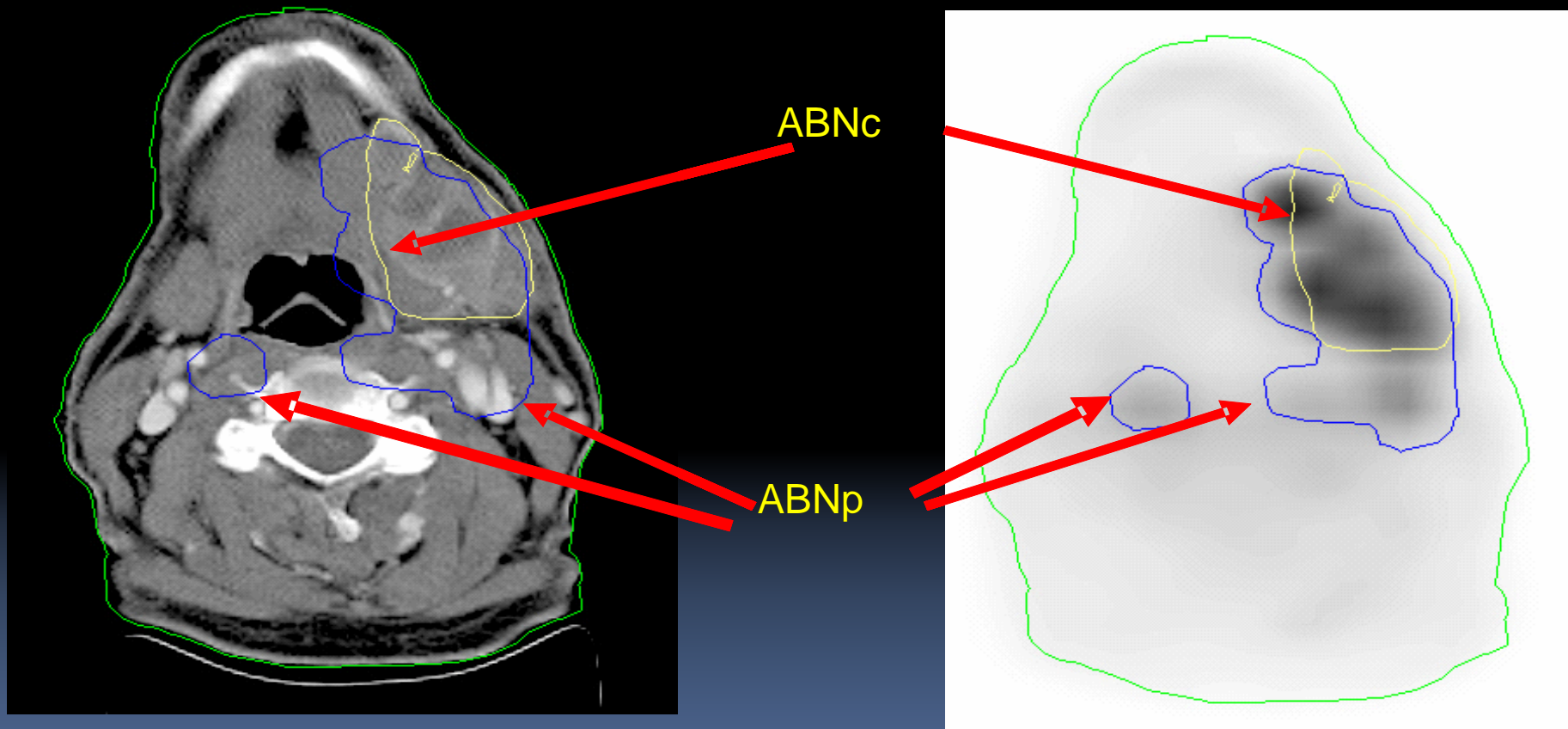


# Hybrid PET-CT



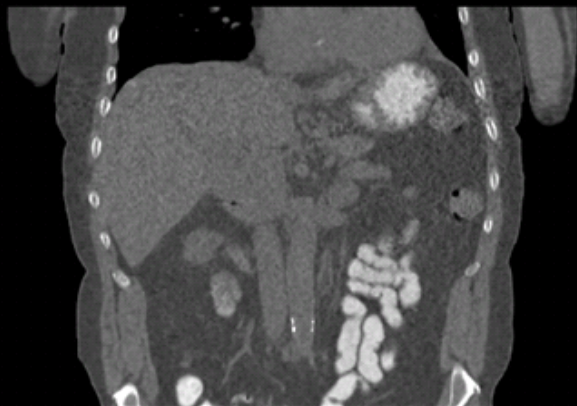
Heron et al NMA 2003

# Hybrid PET-CT

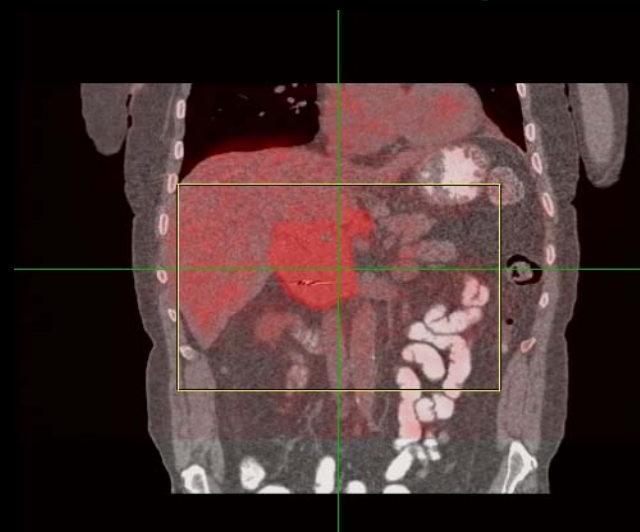


Heron et al NMA 2003

**CT only**



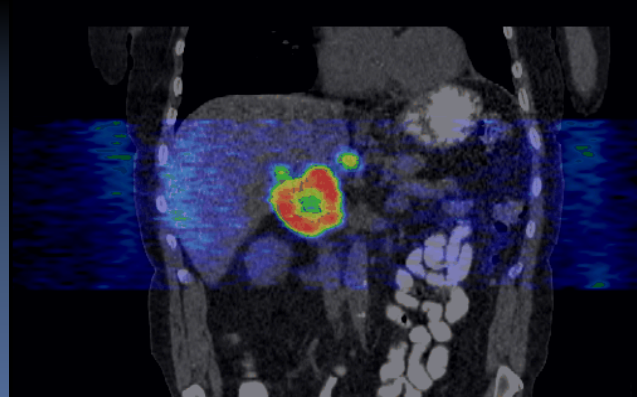
**PET-CT only**

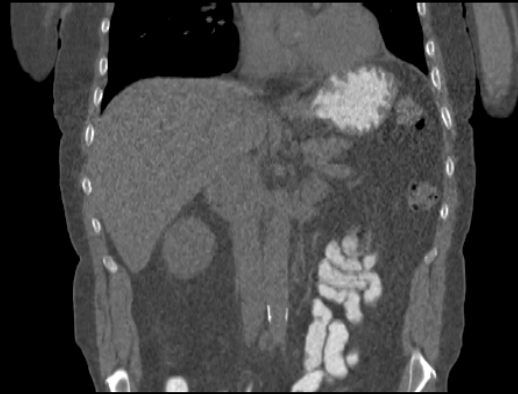


**4D CT only**



**4D PET-CT only**

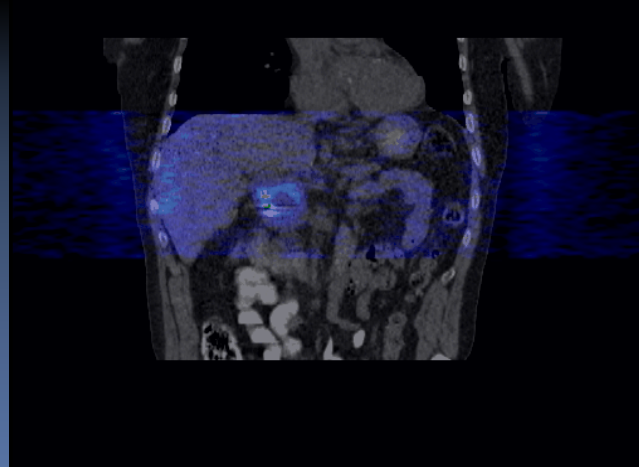
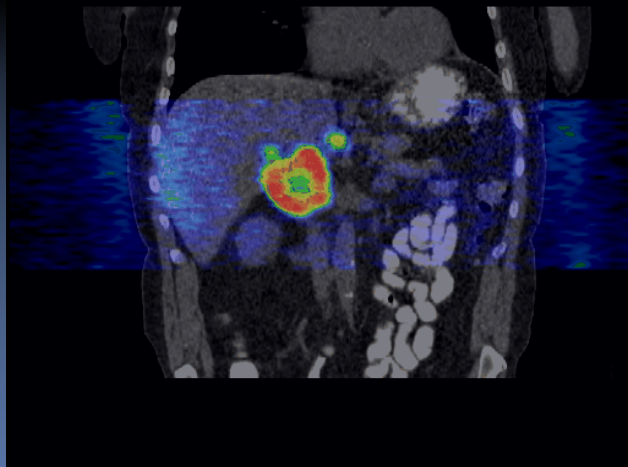




## Assessment of Response with 4D PET-CT

4D-PET/CT pre-treatment

4D-PET/CT post-treatment



**Courtesy**

University of Pittsburgh Cancer  
Institute,

Department of Radiation Oncology

The Varian logo is positioned at the top center of the slide. It consists of the word 'VARIAN' in a serif font, with a small graphic element above the 'I' and 'A'. Below the name, the tagline 'Caring for people. Improving lives.' is written in a smaller, sans-serif font.

VARIAN  
Caring for people. Improving lives.

# Trilogy and or Clinac IX Technology Image-guided Radiotherapy

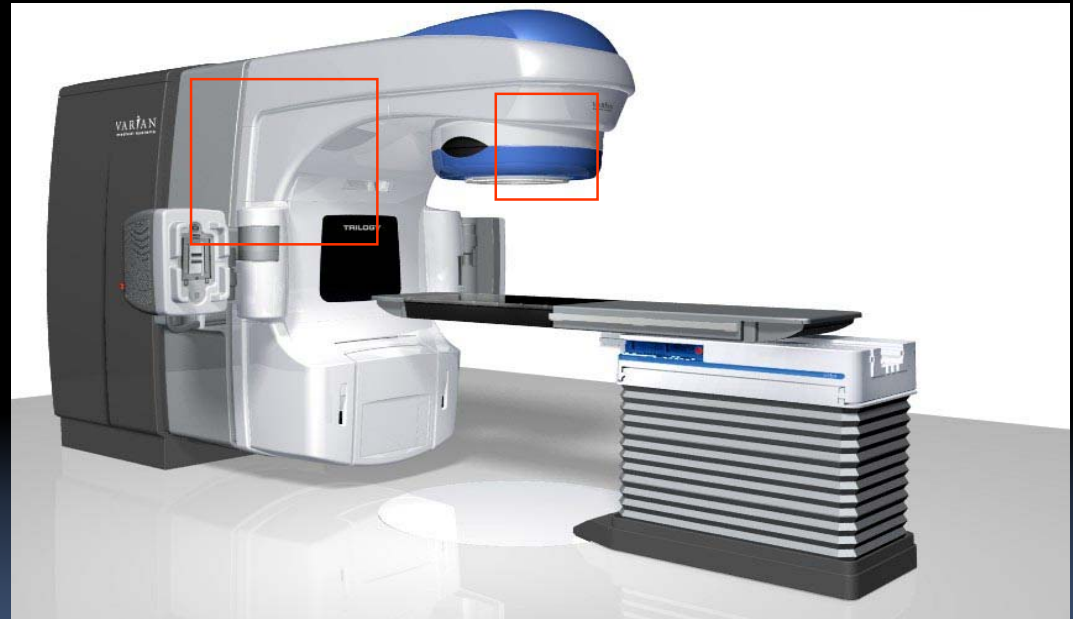
**Intervention strategies for intra- and inter-fraction motion**

The Trilogy logo is located at the bottom center of the slide. It features the word 'TRILOGY' in a bold, uppercase, sans-serif font, centered on a dark grey rectangular background.

TRILOGY

# Image Guidance Capabilities

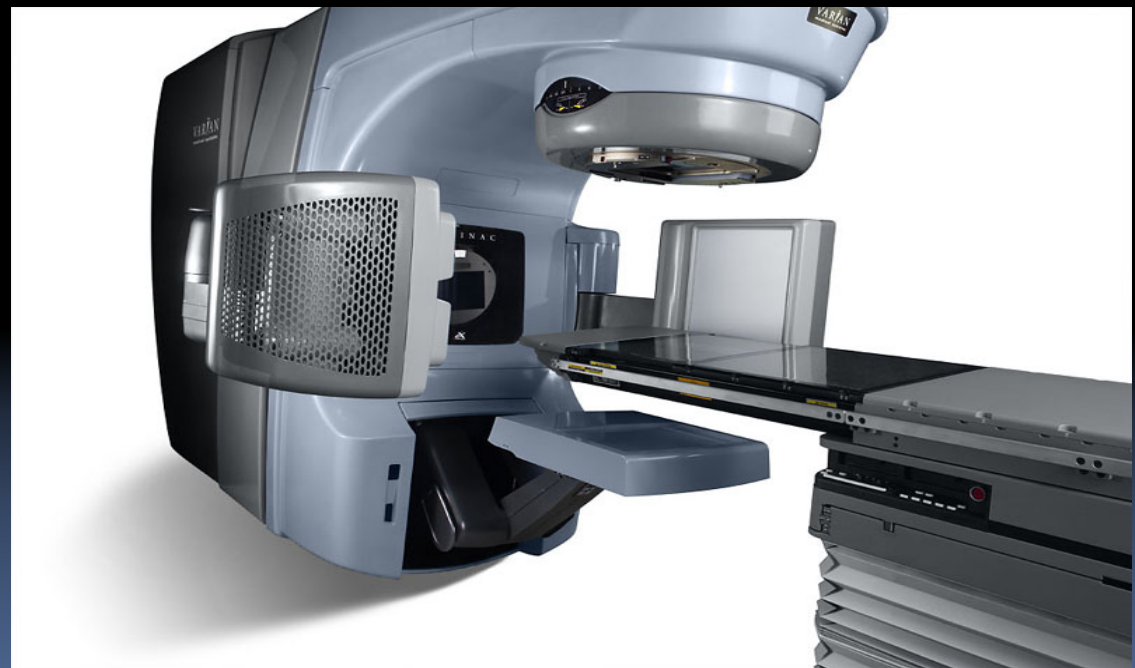
- For image guided radiotherapy, Trilogy includes the On-Board Imager (OBI)
  - Two robotic arms
  - kV X ray source
  - Amorphous silicon imaging panel
  - OBI workstation
- Three modes of operation
  - Radiographic
    - Online setup correction
      - Bony anatomy or markers
  - CBCT
    - Online setup correction
      - Bony or soft tissue anatomy
    - Verification of delivered dose
    - Adaptive radiation therapy
  - Fluoroscopic
    - Verification of gated radiotherapy
    - Fluoro-based gating (\*Future option)



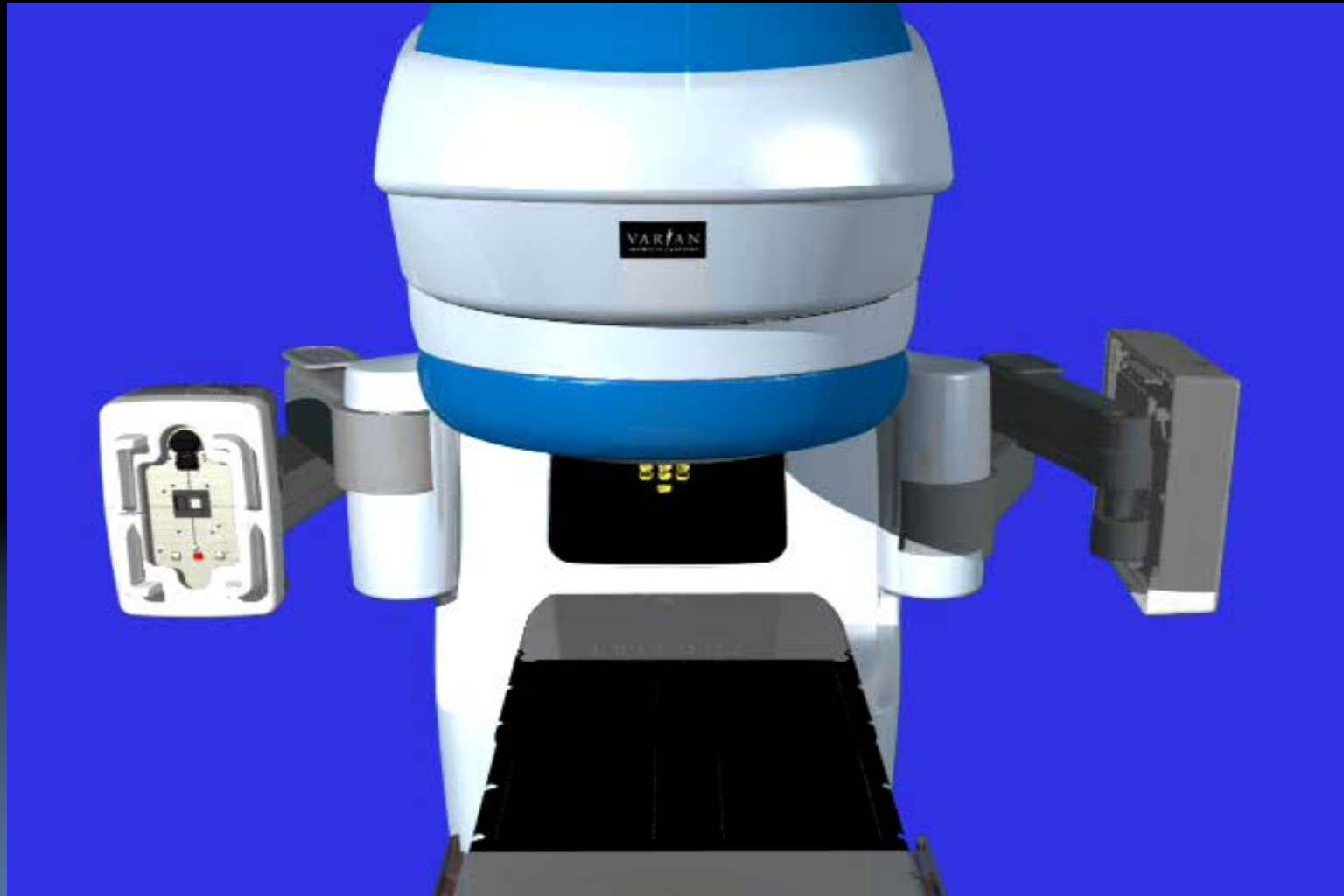
Trilogy and the On-Board Imager

# Intervention Strategy for Inter-fraction Variation (kV CT)

- two types of strategies
  - KV CT: Varian, Elekta
  - MV CT: Tomotherapy
- Radiographic mode
  - Anatomy or marker matching between two kV or MV images
- CBCT
  - Anatomy matching



# On-Board Imager





The Varian logo is centered at the top of the slide. It consists of the word "VARIAN" in a serif font, with a stylized blue and green graphic element above the letter "I". Below "VARIAN" is the tagline "Caring for what matters" in a smaller, sans-serif font.

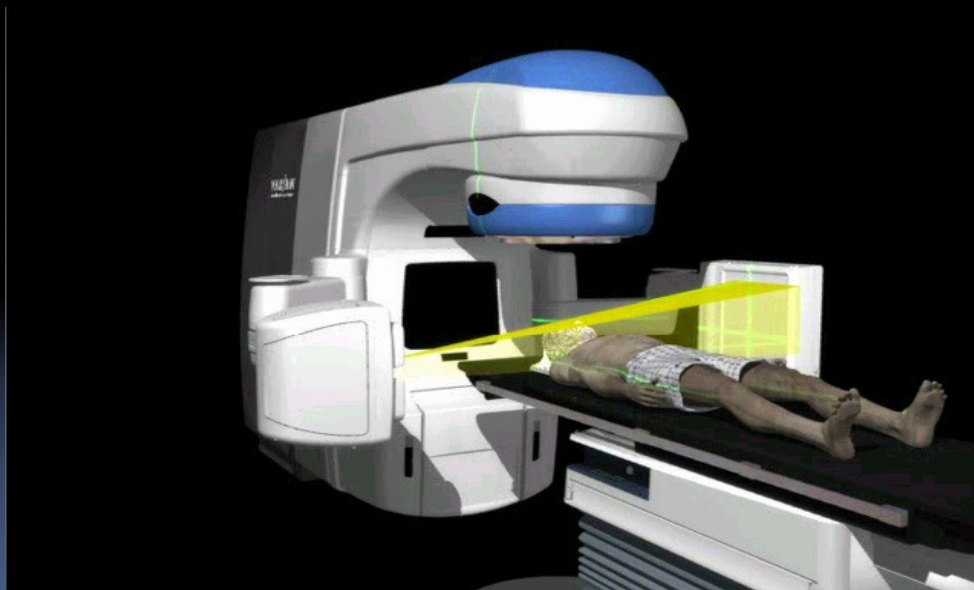
VARIAN  
Caring for what matters

# **Trilogy and or Clinac IX Technology Orthogonal Radiographs for Online Patient Setup Correction**

The Trilogy logo is centered at the bottom of the slide. It features the word "TRILOGY" in a bold, uppercase, sans-serif font, with a light blue glow effect behind the text.

TRILOGY

# Radiographic Mode Acquisition of a Lateral Radiograph



Varian Medical Systems

Head, Phantom 2D / 2D Match

Reference image Acquired image

04/2004  
10:14:31 AM

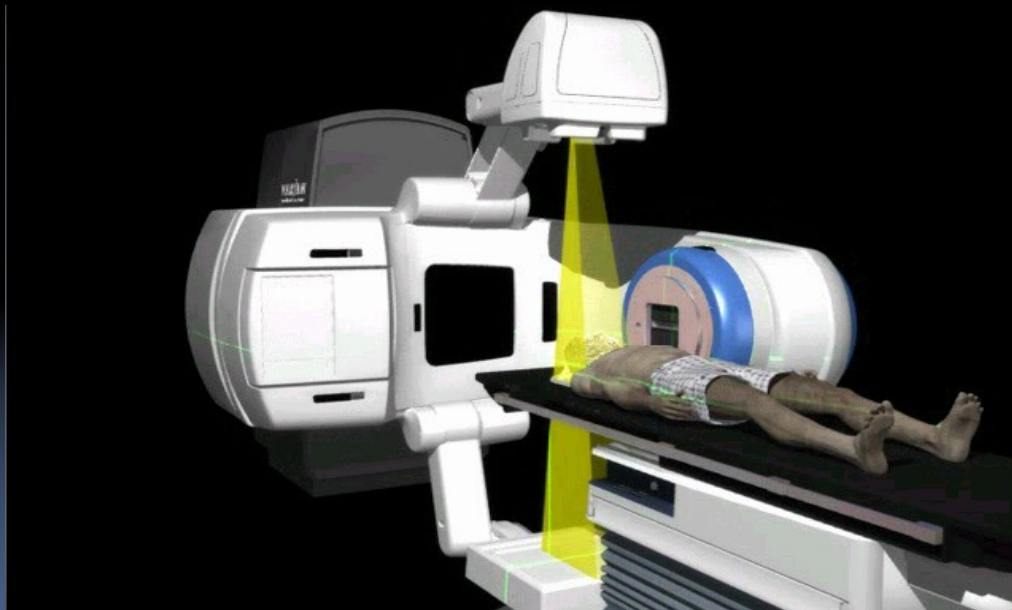
KV Imager Position (EC1217 Scale)				KV Exposure	
TARGET	ACTUAL	TARGET	ACTUAL	Site	
Gantry Rtn	0.0	Blade X1	0.0	Technique	5 Minute Timer <input type="text"/> [Reset]
Source Rtn	270.0	Blade X2	0.0	kV	
SAD	100.0	Blade Y1	0.0	mA	Anode 0.0 % HU
KV Imager Vrt	-50.0	Blade Y2	0.0	Housing	0.0 % HU
KV Imager Lat	0.0				
KV Imager Lng	0.0				

Track Download Axes

All units in cm and degrees

X-Ray Generator locked 1. Acquire Analyze Cancel

# Radiographic Mode Acquisition of an AP Radiograph



Varian Medical Systems

Head, Phantom 2D / 2D Match

Reference image Acquired image Reference image Acquired image

9/4/2004 10:14:31 AM 9/4/2004 10:18:12 AM

KV Imager Positon (ECT1217 Scale)		KV Exposure	
TARGET	ACTUAL	TARGET	ACTUAL
Gantry Ptn	90.0	Blade X1	0.0
Source Ptn	0.0	Blade X2	0.0
SAD	100.0	Blade Y1	0.0
KV Imager Vrt	-50.0	Blade Y2	0.0
KV Imager Lat	0.0		
KV Imager Lng	0.0		

Site:   
Technique:   
kV:   
mA:

5 Minute Timer

Anode 0.0 % HJ  
Housing 0.0 % HJ

1: Acquire 2: Analyze

Ray Generator locked

# Match Analysis - Split Screen

Varian Medical Systems

Head, Phantom 2D / 2D Match

Setup Lat Setup AP

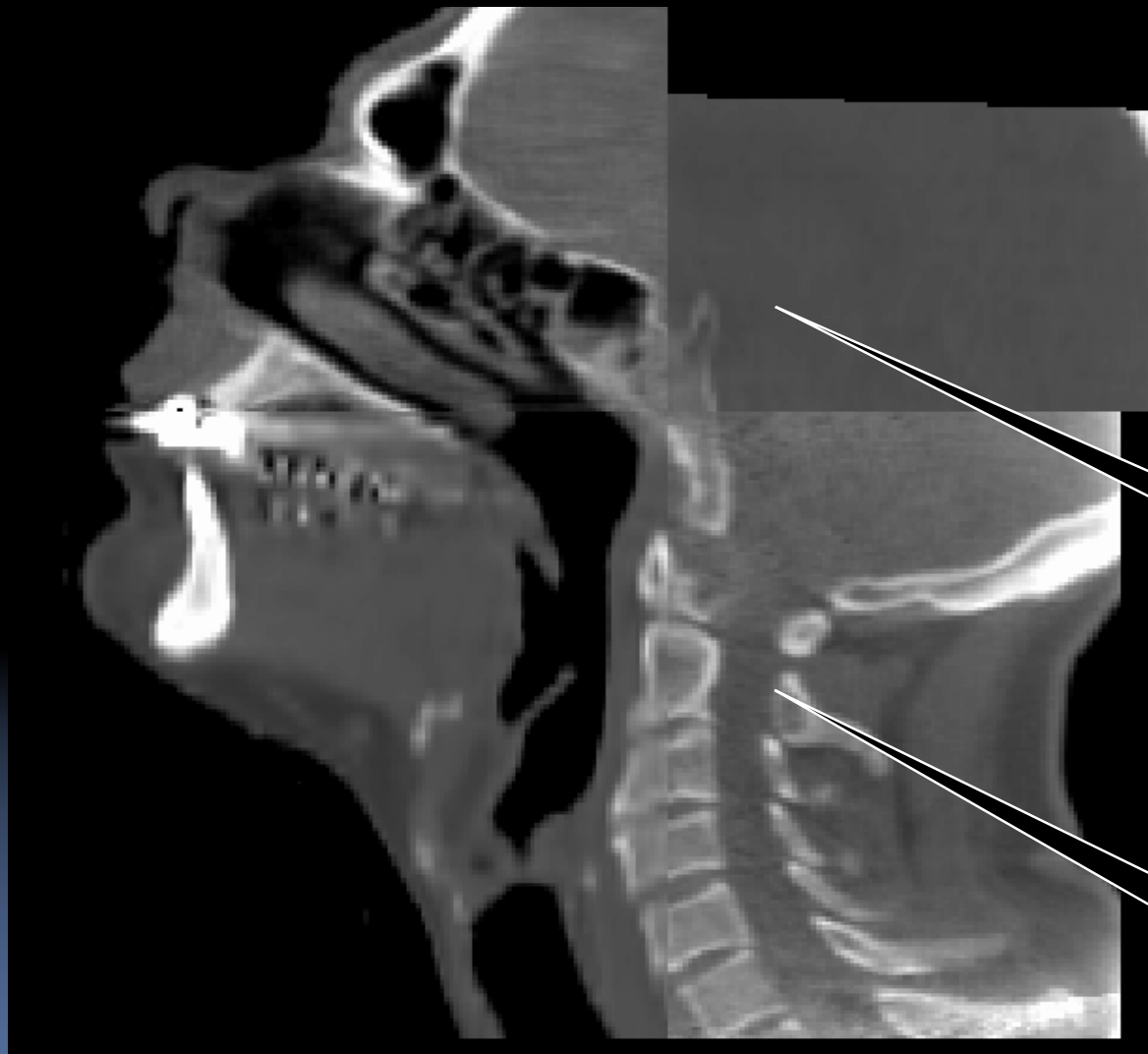
	TARGET	ACTUAL	SHIFT		TARGET	ACTUAL	SHIFT	
Couch Vrt	0.0	0.0	0.0	<input checked="" type="checkbox"/> Include	Couch Lat	0.0	0.0	0.0 <input checked="" type="checkbox"/> Include
Couch Lng	50.0	50.0	0.0	<input checked="" type="checkbox"/> Include	Couch Rtn	0.0	0.0	0.0 <input checked="" type="checkbox"/> Include

All units in cm and degrees

Perform the anatomy match

1. Acquire 2. Analyze Cancel

Footswitch  
Beam Off ?  
Reset Shift  
Apply Shift

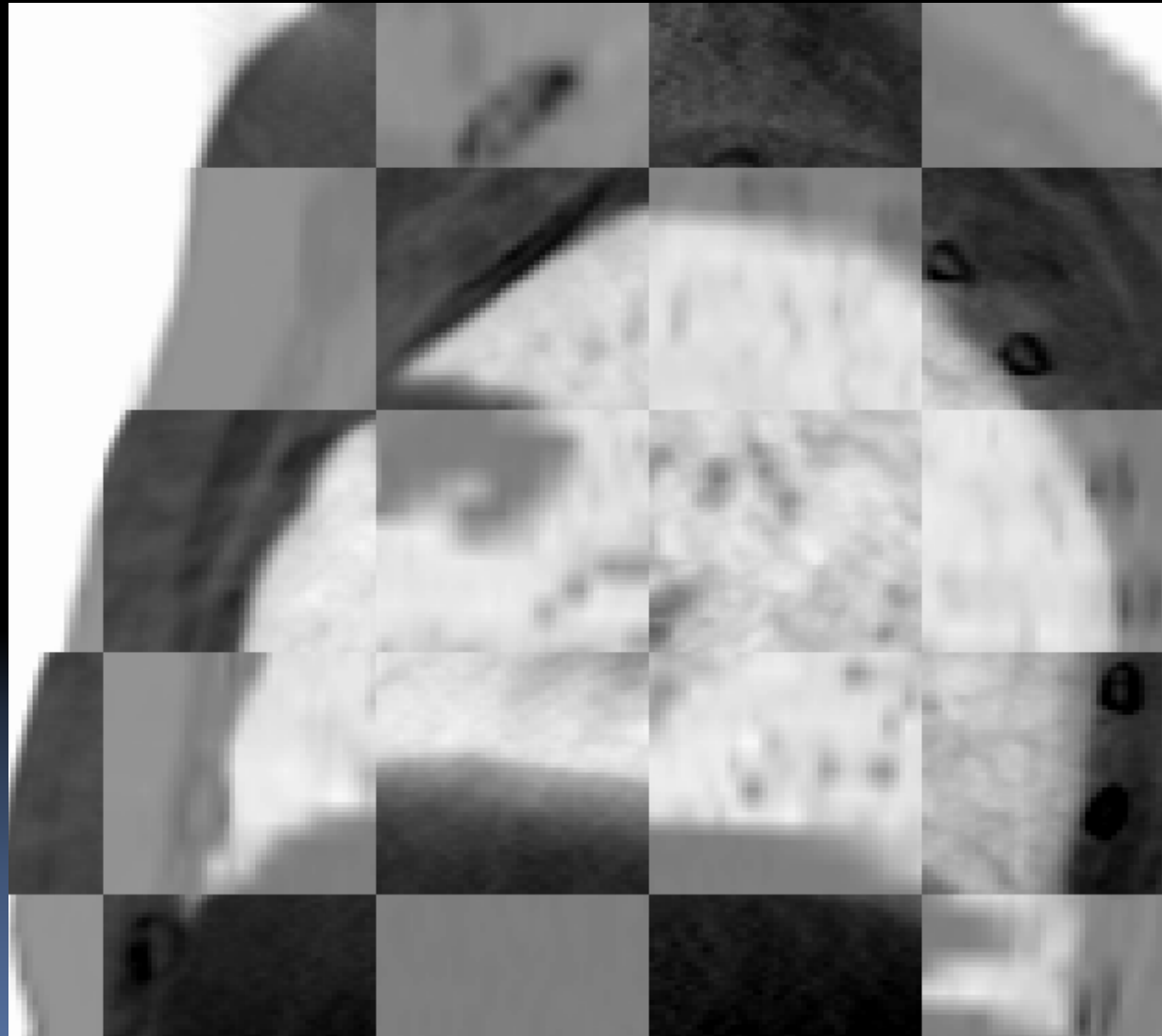


- Compare to reference image

- ★ Grey-scale display

Planning  
CT

CBCT



- Compare to reference image
- ★ Grey-scale display

The Varian logo is positioned at the top center of the slide. It consists of the word "VARIAN" in a serif font, with a stylized blue and green graphic element above the letter "I". Below "VARIAN" is the tagline "Caring for life" in a smaller, sans-serif font.

VARIAN  
Caring for life

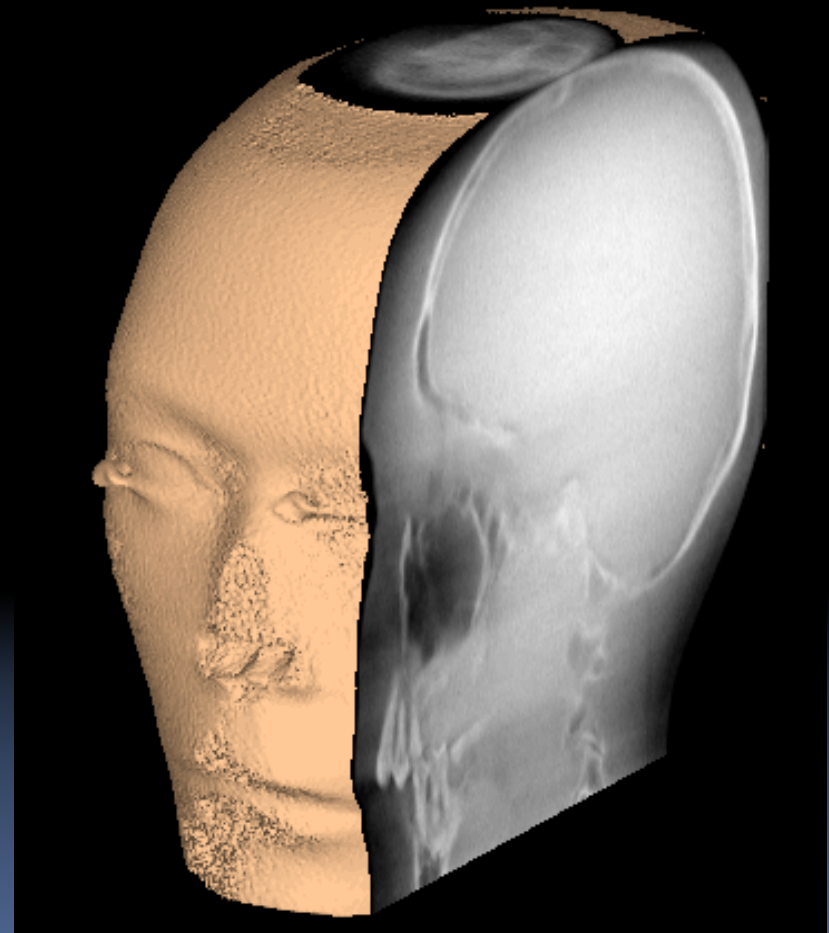
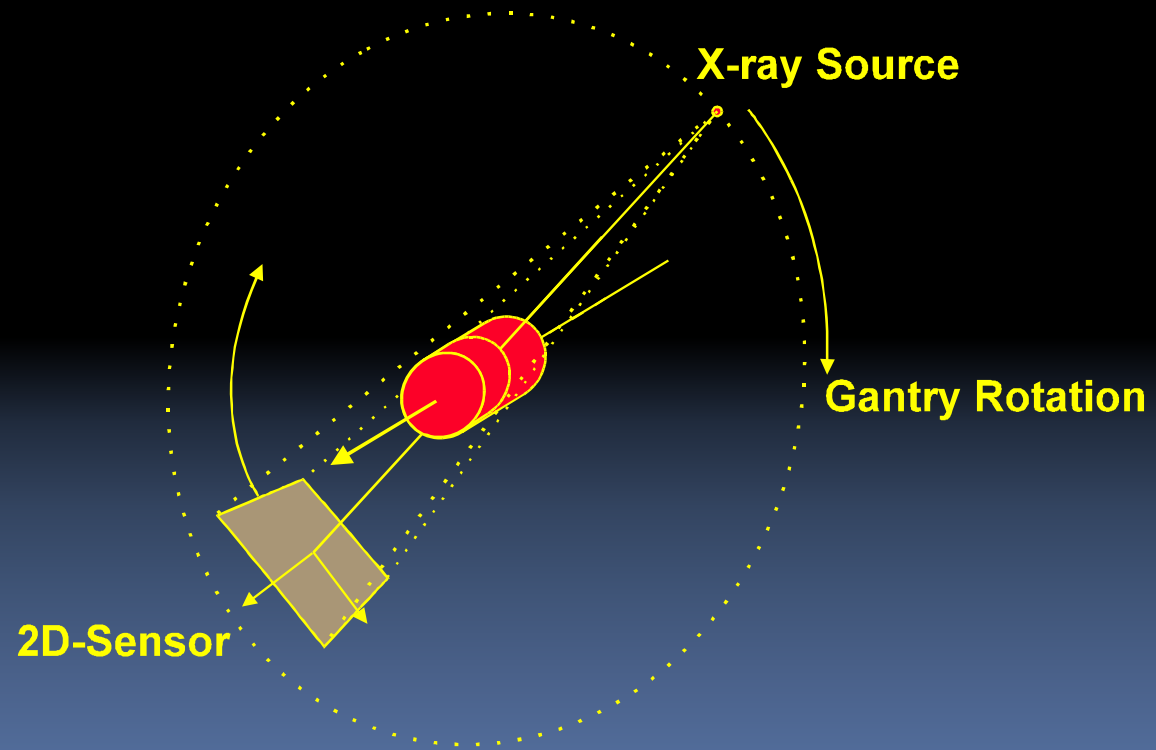
# **Trilogy and or Clinac IX Technology Cone beam CT for online patient setup correction**

The Trilogy logo is located at the bottom center of the slide. It features the word "TRILOGY" in a bold, white, sans-serif font, centered on a dark grey, rounded rectangular background.

TRILOGY

# Conebeam CT

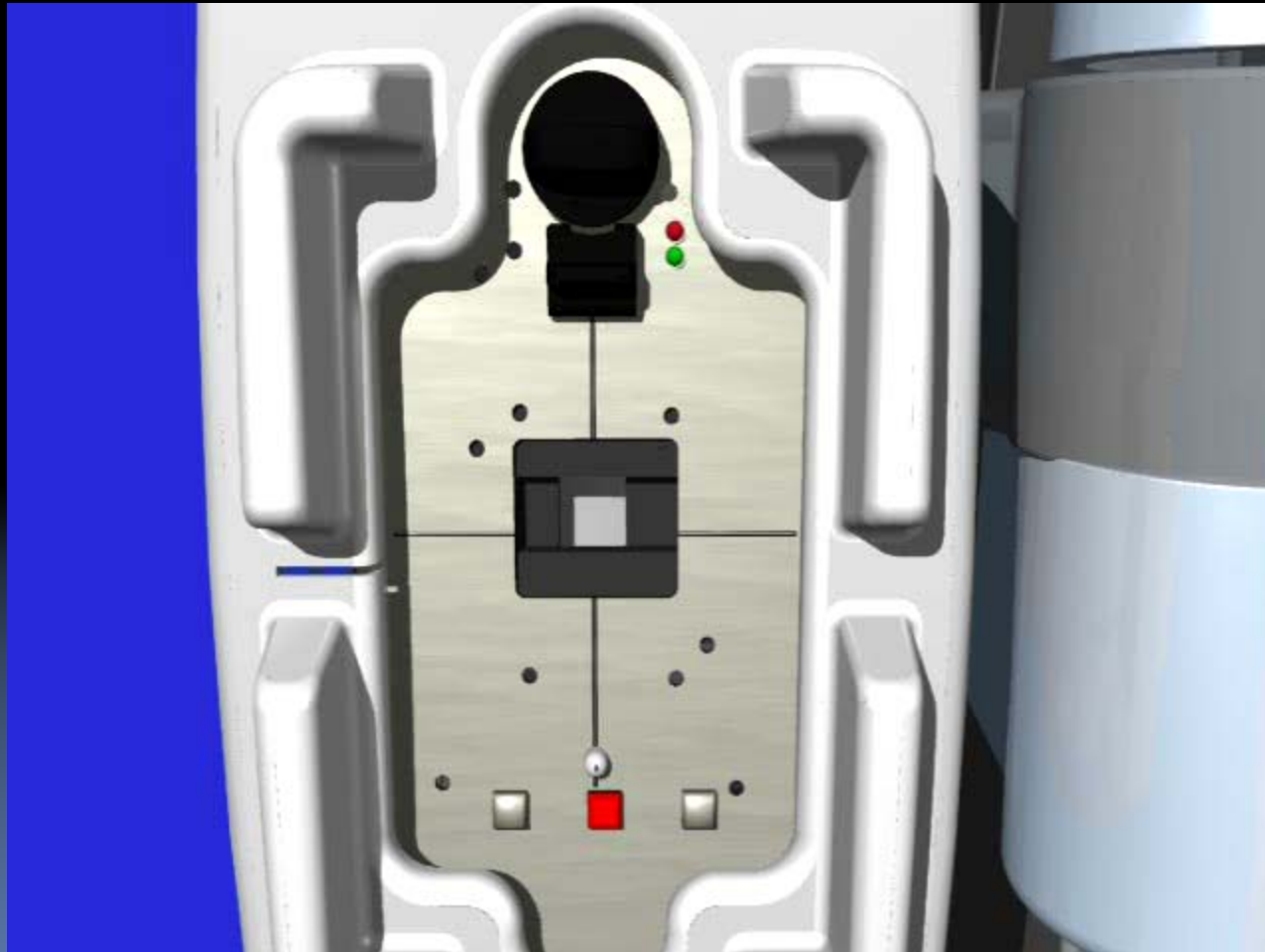
Volumetric CT dataset generated from a single revolution

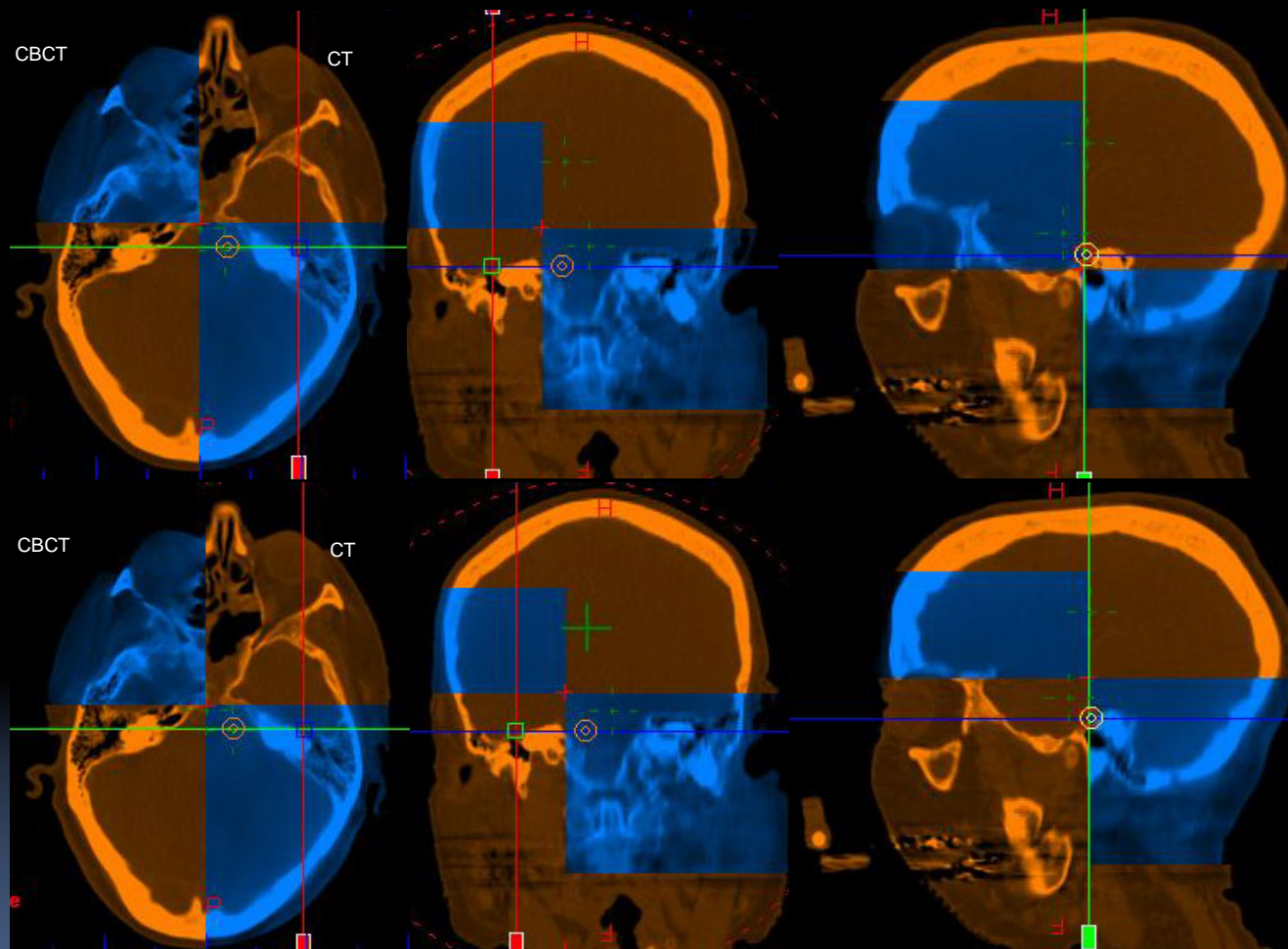


*Courtesy WBH*



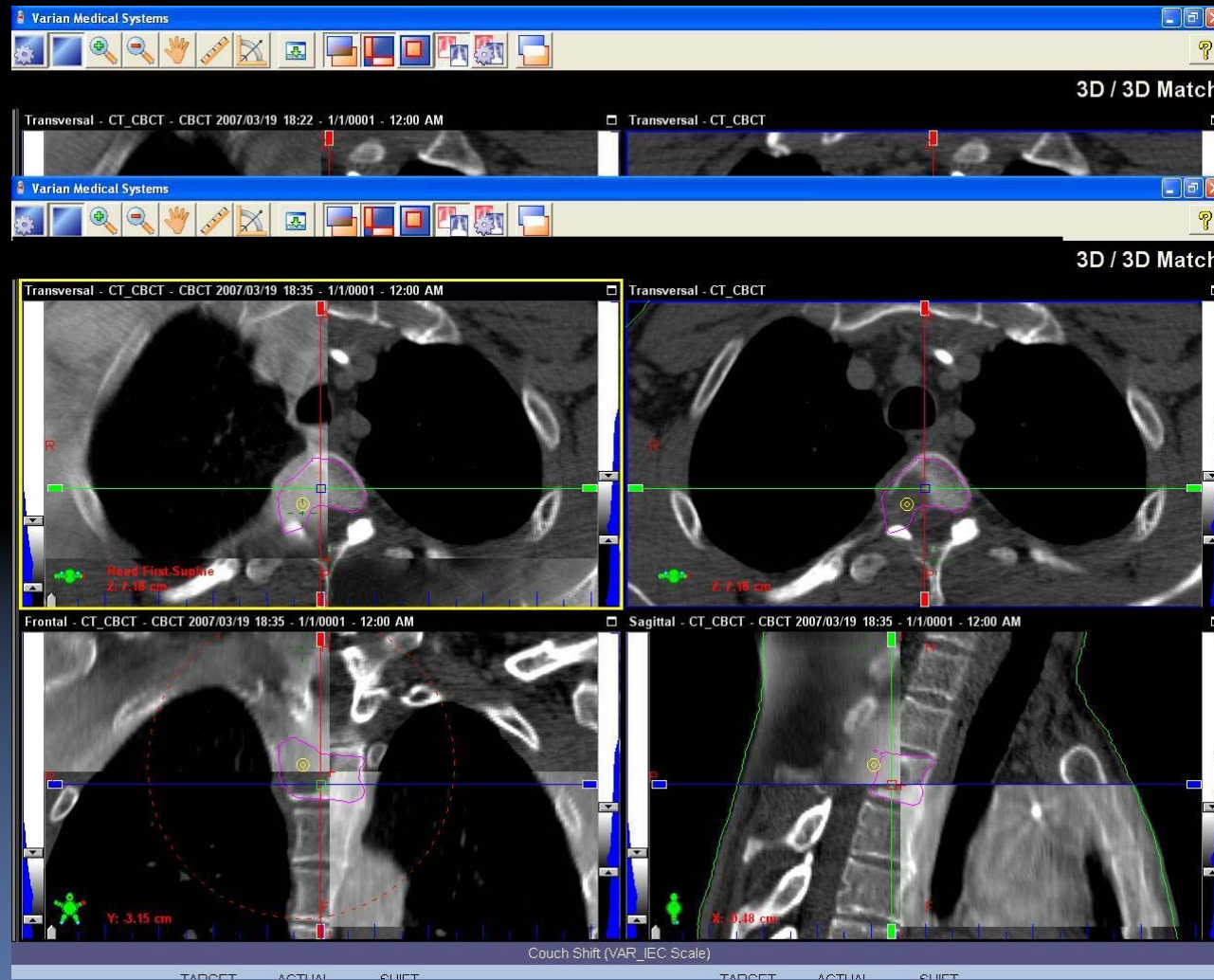
# Cone Beam CT for Online Setup Correction





(a) Only using optical positioning system  
(b) After CBCT-based 3D/3D match

# First SBRT (Spine) Patient (CBCT Based 3D/3D Match Before Treatment)



# First SBRT (Spine) Patient (CBCT Based 3D/3D Match After Treatment)

Varian Medical Systems

3D / 3D Match

Transversal - CT\_CBCT - CBCT 2007/03/19 18:22 - 1/1/0001 - 12:00 AM

Transversal - CT\_CBCT

Head Final Supine  
Z: 1.72 cm

Z: 1.72 cm

Frontal - CT\_CBCT - CBCT 2007/03/19 18:22 - 1/1/0001 - 12:00 AM

Sagittal - CT\_CBCT - CBCT 2007/03/19 18:22 - 1/1/0001 - 12:00 AM

Y: 3.45 cm

X: 8.05 cm

Couch Shift (VAR\_JEC Scale)

	TARGET	ACTUAL	SHIFT		TARGET	ACTUAL	SHIFT	
Couch Vrt	13.1	13.0	0.1	<input checked="" type="checkbox"/> Include	Couch Lat	2.0	+2.2	-0.2 <input checked="" type="checkbox"/> Include
Couch Lng	116.3	116.3	0.0	<input checked="" type="checkbox"/> Include	Couch Rtn	0.1	0.1	0.0 <input checked="" type="checkbox"/> Include

All units in cm and degrees

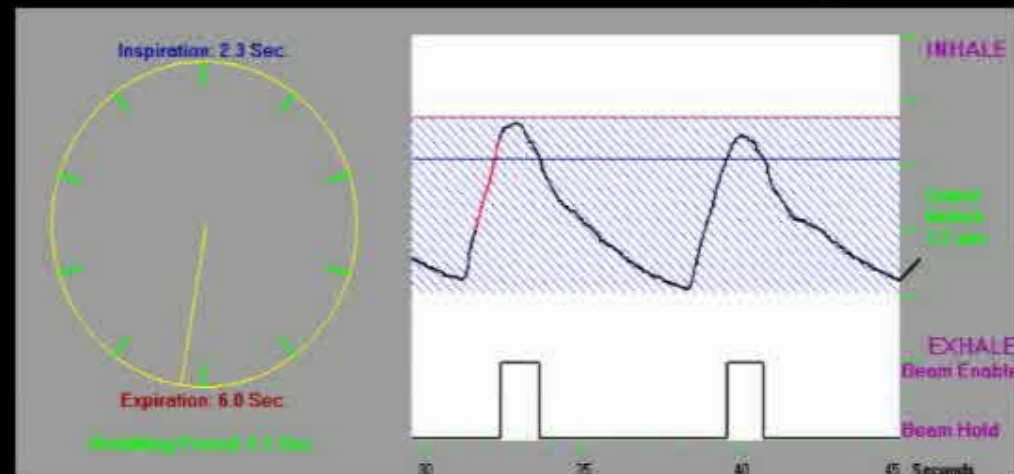
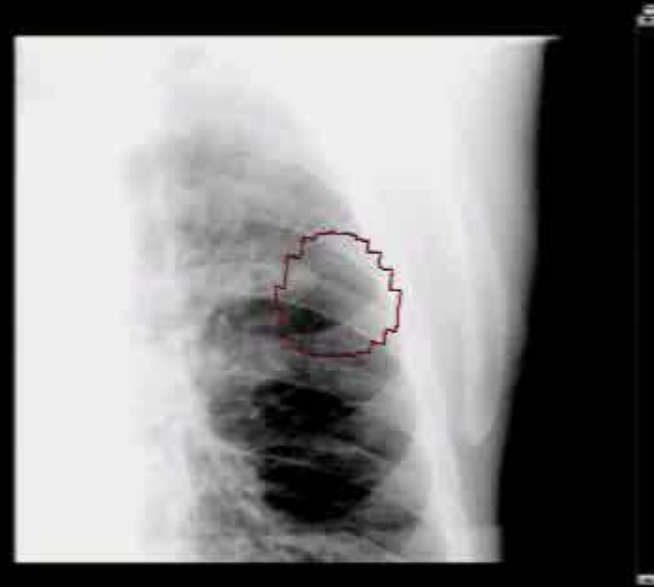
Perform the anatomy match

1. Acquire 2. Analyze Cancel

start Varian Medical Systems CBCT Match Before T... 6:34 PM

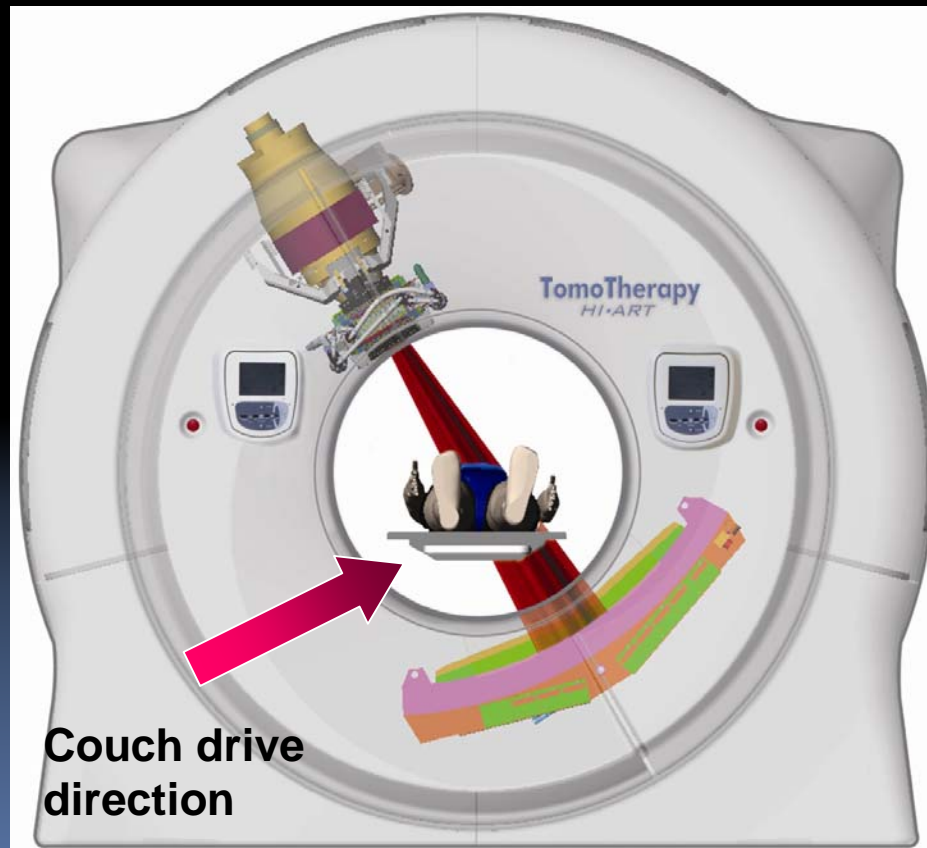
# Pretreatment Fluoroscopic Verification of Gating

- Setup patient
- Extend arms
- Rotate gantry to first field
- Exit treatment room
- Remotely acquire fluoro
- MLC aperture turns green/red, indicating when the gate is open/closed
- Verify target remains within aperture
- Repeat for other fields
- Retract arms remotely
- Treat



# Intervention Strategy for Inter-fraction Variation (MV CT)

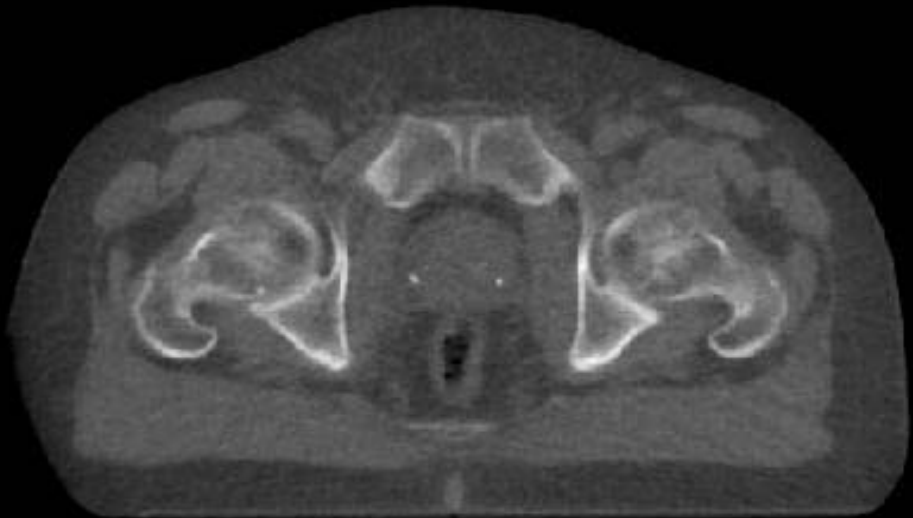
*“Helical Tomotherapy and Megavoltage CT Imaging is free from high Z artifacts”*



Courtesy: Rock Mackie

# MVCT Image Quality

**Hi-ART<sup>s</sup> MVCT**

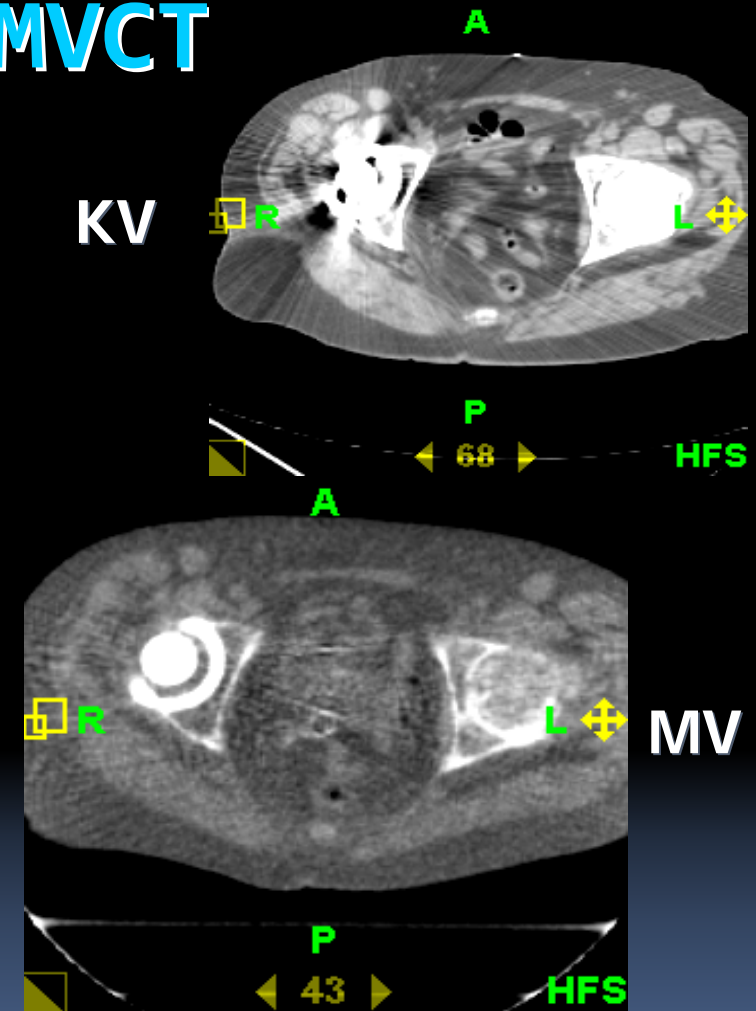
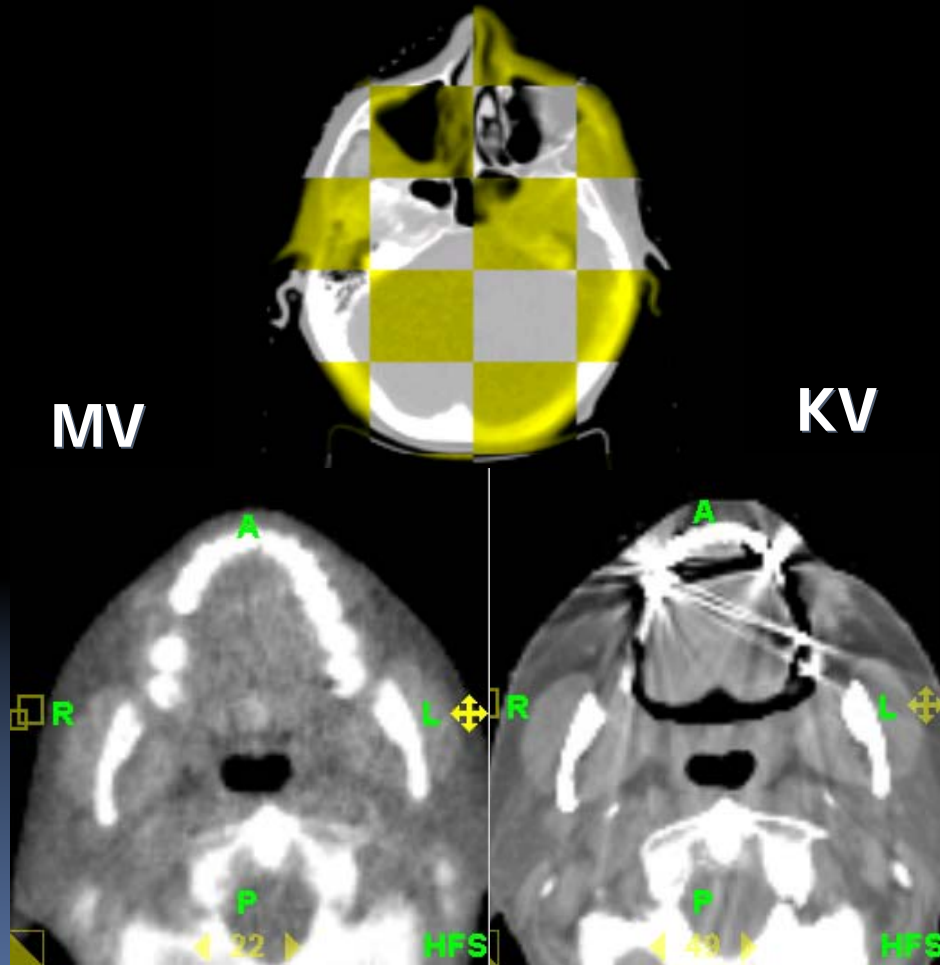


**Planning CT (KVCT)**



Courtesy: Rock Mackie

# Reduced Artifacts on MVCT



Courtesy: Rock Mackie



# Intervention Strategy for Inter/Intra-fraction Variation (Calypso)

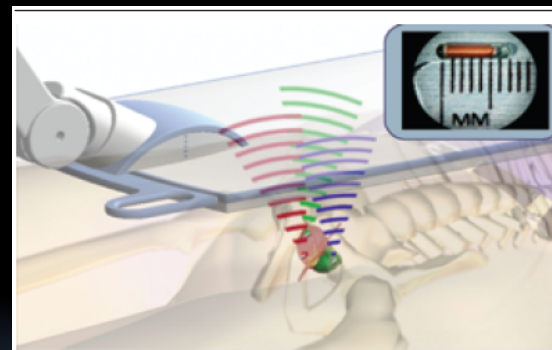
*Non-ionizing approach for accurate and continuous target localization for treatment setup and monitoring during radiation therapy delivery*



Transverse prostate with Beacon® transponders (AC electromagnetic markers )



The Calypso® 4D Localization System Console



← Three beacon transponders implanted in the prostate

Array over the patient →



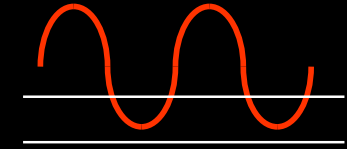


VARIAN  
Linear Accelerators

# Trilogy Technology Controlling for respiratory motion

TRILOGY

# Respiratory Gating

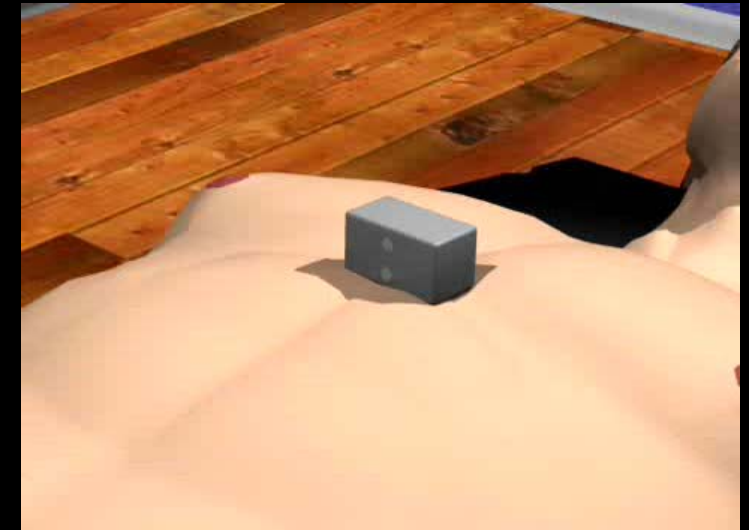


- **Trilogy includes the RPM Gating System**

- Infrared camera
- External marker block
- Gating workstation

- **Process**

- Place block on patient's abdomen
- Camera monitors block motion
- Respiratory waveform shows how the block moves up and down in time
- User sets upper and lower thresholds on block motion
- Whenever the block comes between the thresholds, the beam is on
- Whenever the block moves outside the thresholds, the beam is off
- Free-breathing and breath hold protocols are supported, as are gating at inhalation or exhalation or at any other point in the respiratory cycle



The Varian logo is positioned at the top center of the image. It consists of the word "VARIAN" in a serif font, with a small blue and red graphic element above the letter "I". Below "VARIAN" is the tagline "Caring for life" in a smaller, sans-serif font.

VARIAN  
Caring for life

# Trilogy Technology Optically-guided patient positioning

The Trilogy logo is located on a grey, rounded rectangular object at the bottom center of the image. The word "TRILOGY" is written in a white, spaced-out, sans-serif font.

TRILOGY

# Optically-guided Stereotactic Localization

- **Trilogy includes an Optical Guidance System**

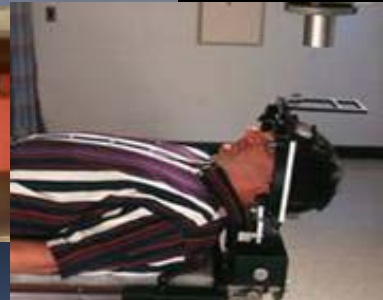
- 3D infrared camera
  - Tracking accuracy 0.3mm
- Optically-guided head ring
- Optically-guided bite tray
- Optical guidance workstation

- **Two modes of operation**

- Frame-based SRS and IMRS
  - Optically-guided head ring
- Frameless SRS, SRT, IMRS and IMRT
  - Optically-guided bite tray



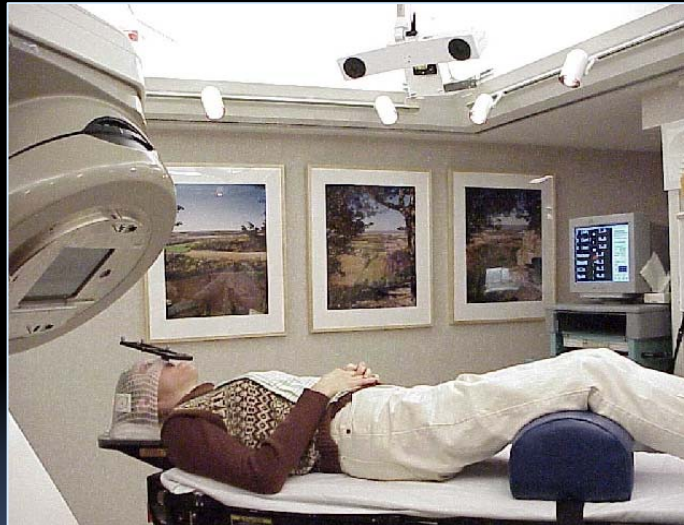
# Frame-based Intracranial Positioning



AP	-2.0	absolute
LAT	6.8	
AX	4.1	
Vector	8.2	
Couch	-2.6	
Tilt	1.1	
Spin	-4.3	

- Applications: Both cone-based and MLC-based SRS
- Clinical Uses: Functional, Benign and Malignant targets

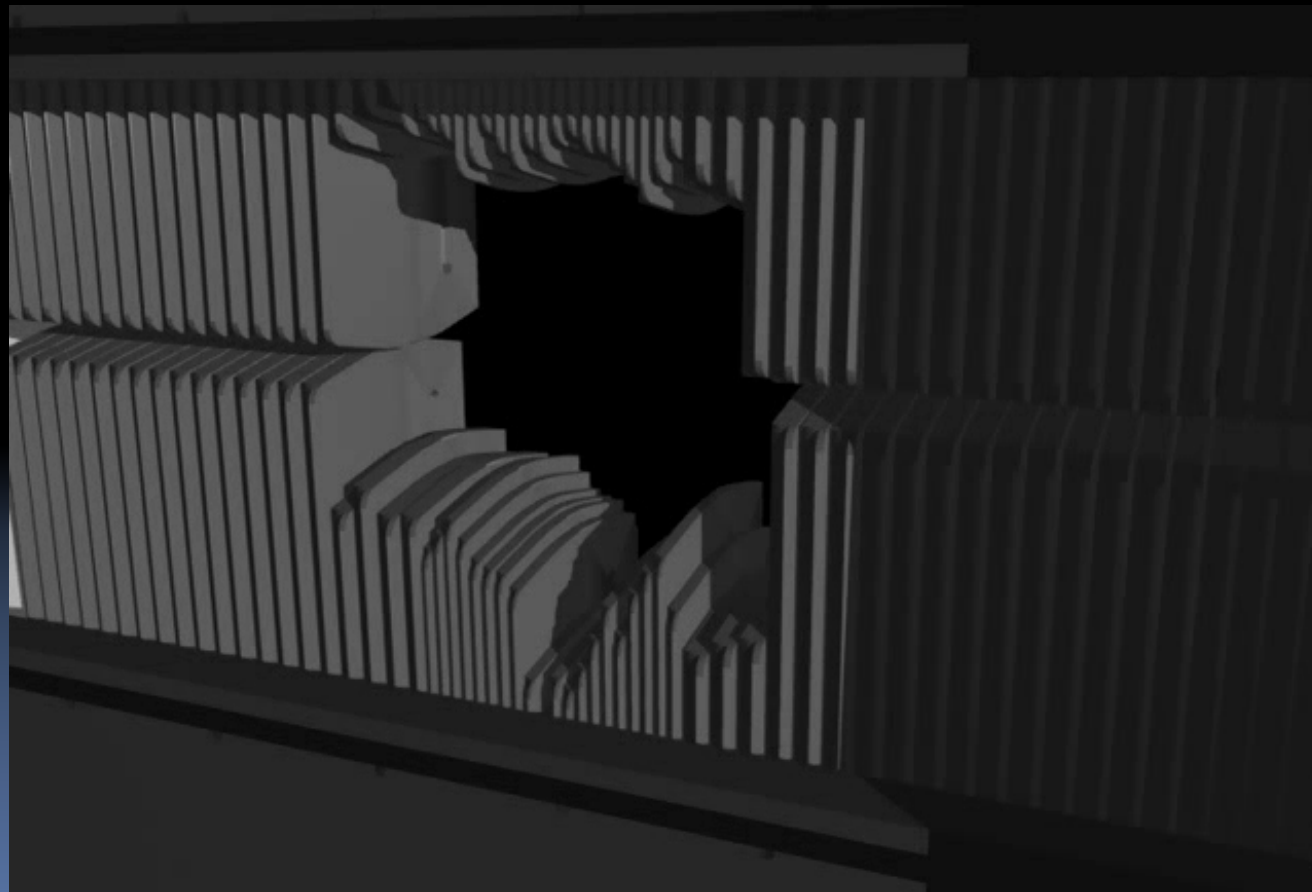
# Frameless Intracranial Positioning



- Applications: SRS, IMRS, SRT, IMRT, 3DCRT
- Clinical Uses: Metastatic tumors, Intracranial SRS/SRT, H&N

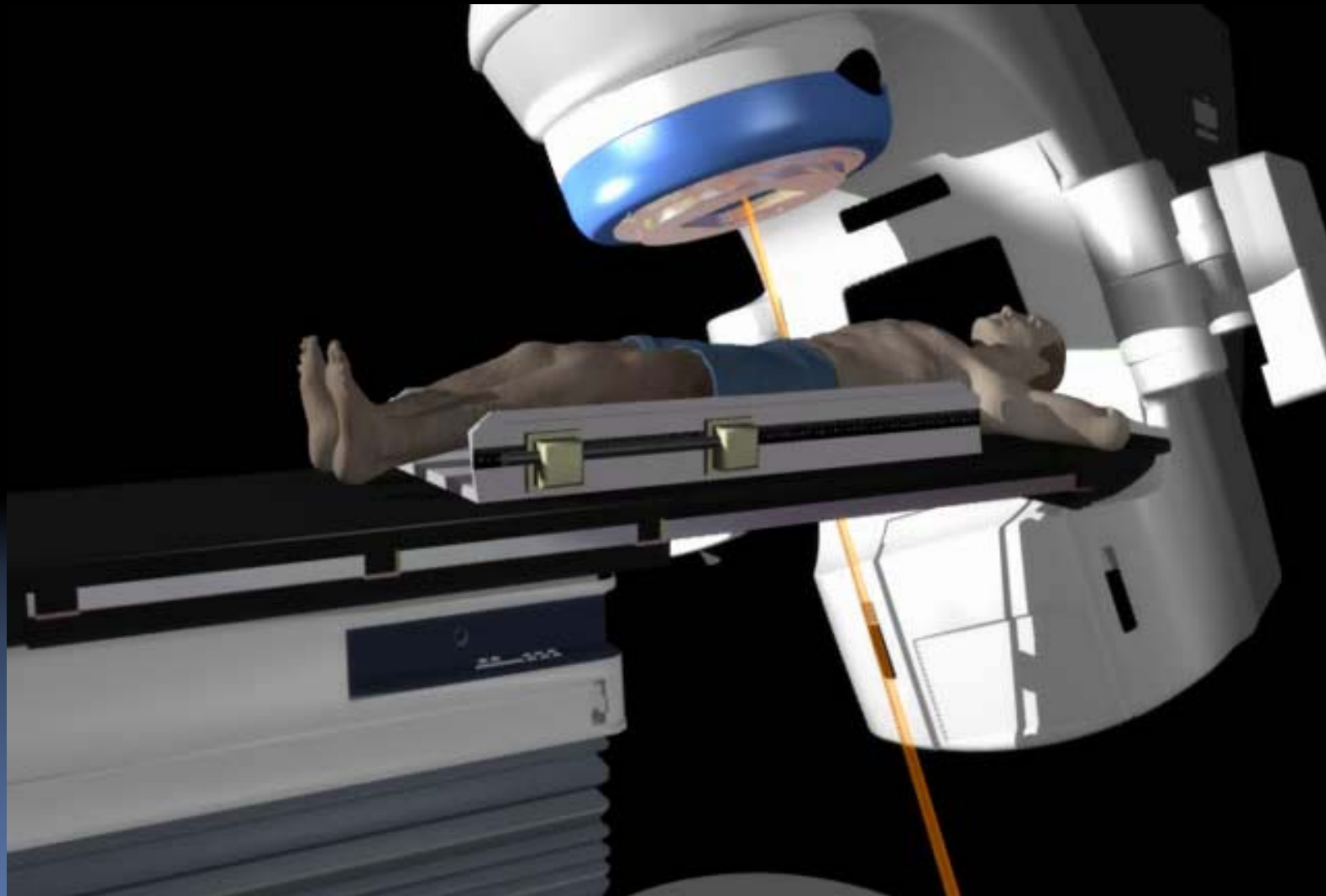
AP	-2.0	absolute
LAT	6.8	
AX	4.1	
Vector	8.2	
Couch	-2.6	
Tilt	1.1	
Spin	-4.3	

# Intracranial SRS Using Millennium 120MLC

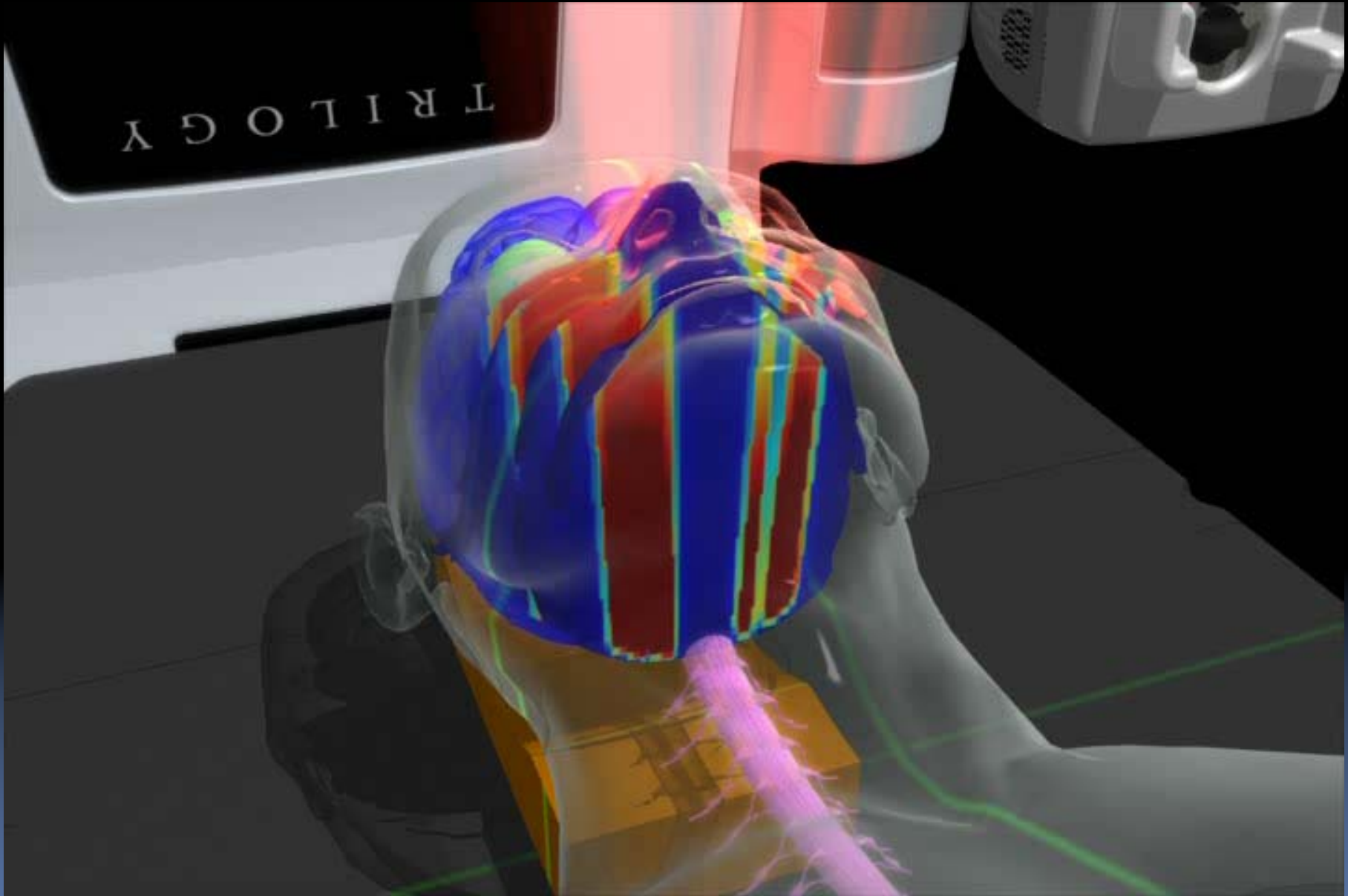


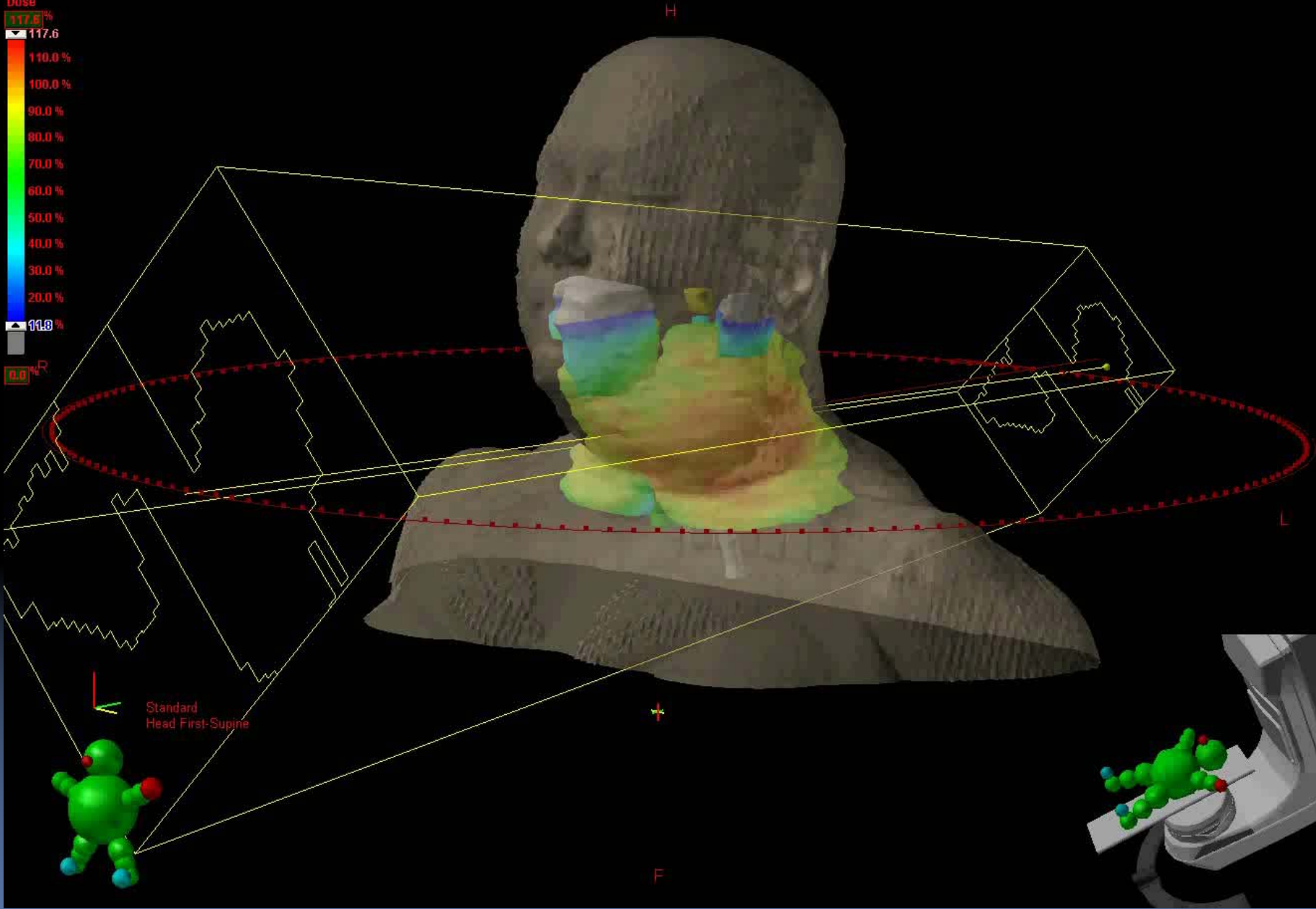


# Extra-cranial Radiosurgery



# Rapid Arc





# Elekta Synergy S





X-ray Sources

Linear Accelerator

**ROBOTIC DELIVERY SYSTEM**

**IMAGING SYSTEM**

**TARGETING SOFTWARE**

Manipulator

Image Detectors

The screenshot displays a complex software interface for image-guided radiotherapy. It features a grid of image windows: 'Synthetic Image A', 'Camera Image A', 'Overlay of Images A', 'Synthetic Image B', 'Camera Image B', and 'Overlay of Images B'. To the right, there are 'Crush Corrections' parameters (LFT: 3.1 mm, ANI: 4.2 mm, SUP: 2.2 mm, ROT: 1.2 deg, IL-DWNS: 0.2 deg, CCW: 1.0 deg) and a 'Correlation Error' section. Below these are 'Tracking Mode' and 'Lung (G)' options. The bottom section contains 'Imaging Parameters' with 'Patient Alignment' and 'View Parameters' buttons. At the very bottom, there are 'Show Mode' (Image, Wire, 3D), 'Zoom' (Auto), 'Marker On', 'Enable Object', and 'Go to 3D/2D View' controls. The interface is densely packed with technical data and interactive elements.

# Robot

- New robot integrated
- 6 Degrees of Freedom
- 210 kg pay load
- 0.2 mm repeatability
- 3 m reach
- Integrated cable management system



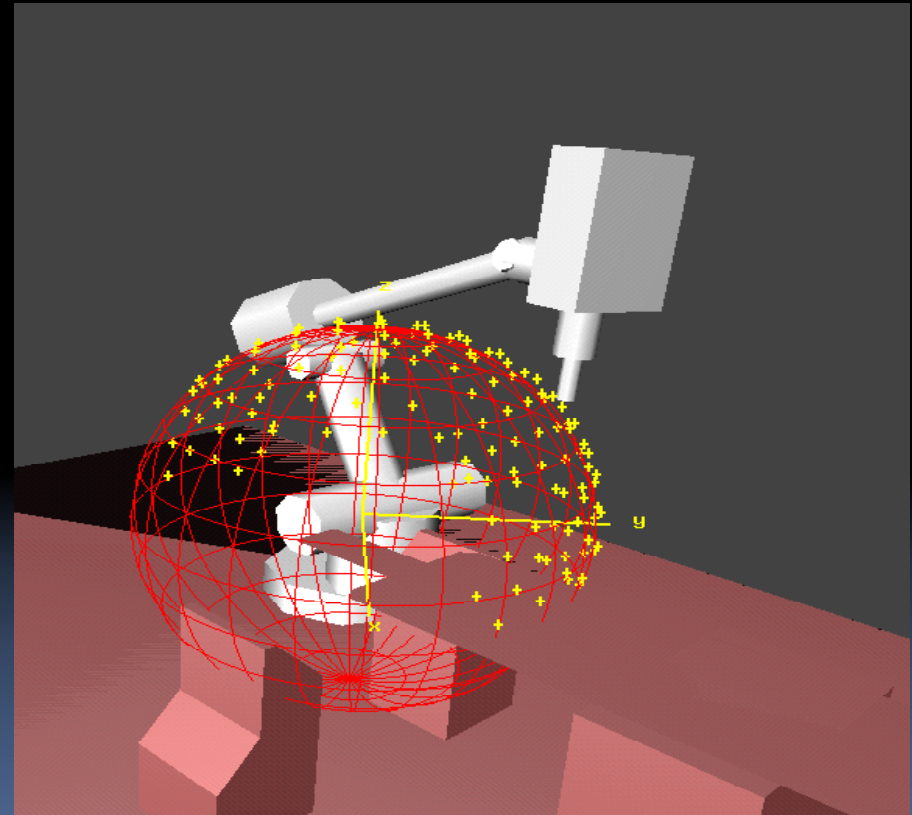
CyberKnife robot has six degrees of freedom





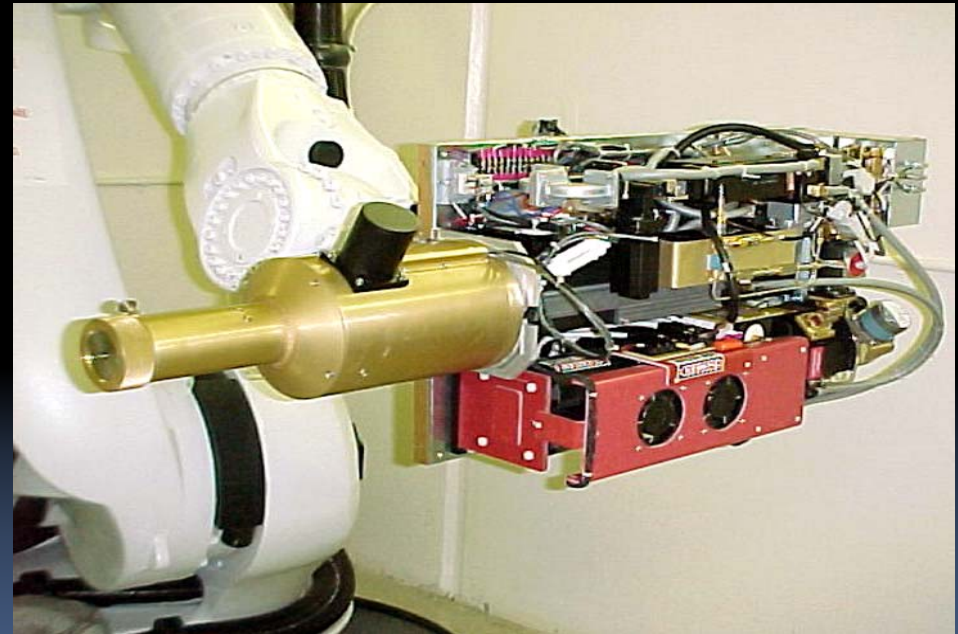
## Robot (contd)

- Robot calibration
- 0.12 mm mechanical accuracy
- Arbitrary beams
- Around 100 nodes
- Around 1200 beams

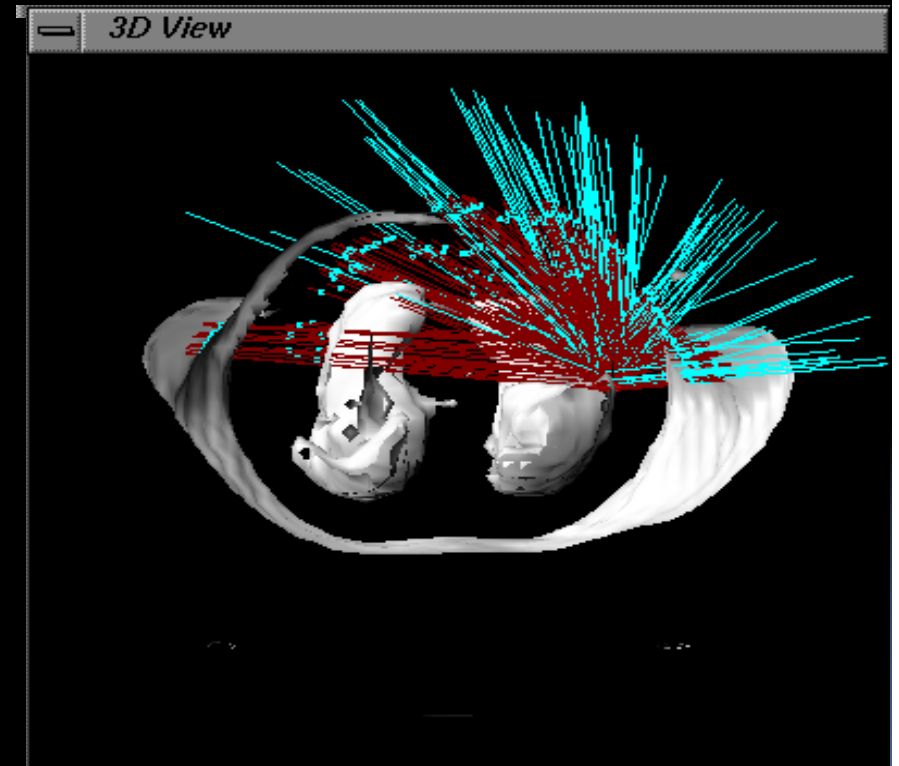
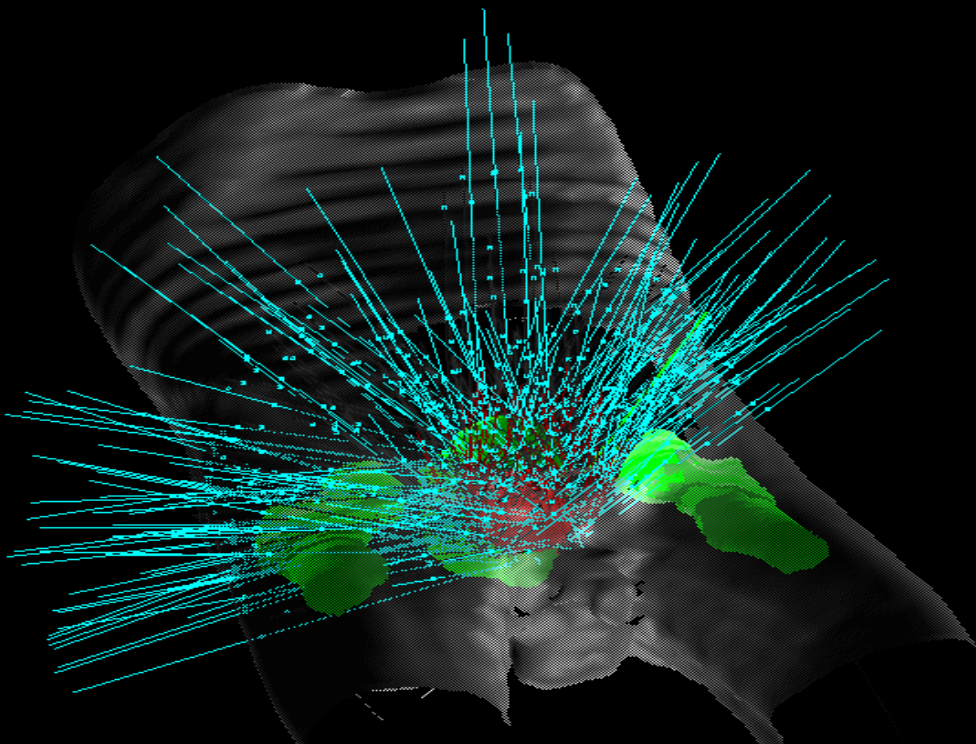


# Linear Accelerator

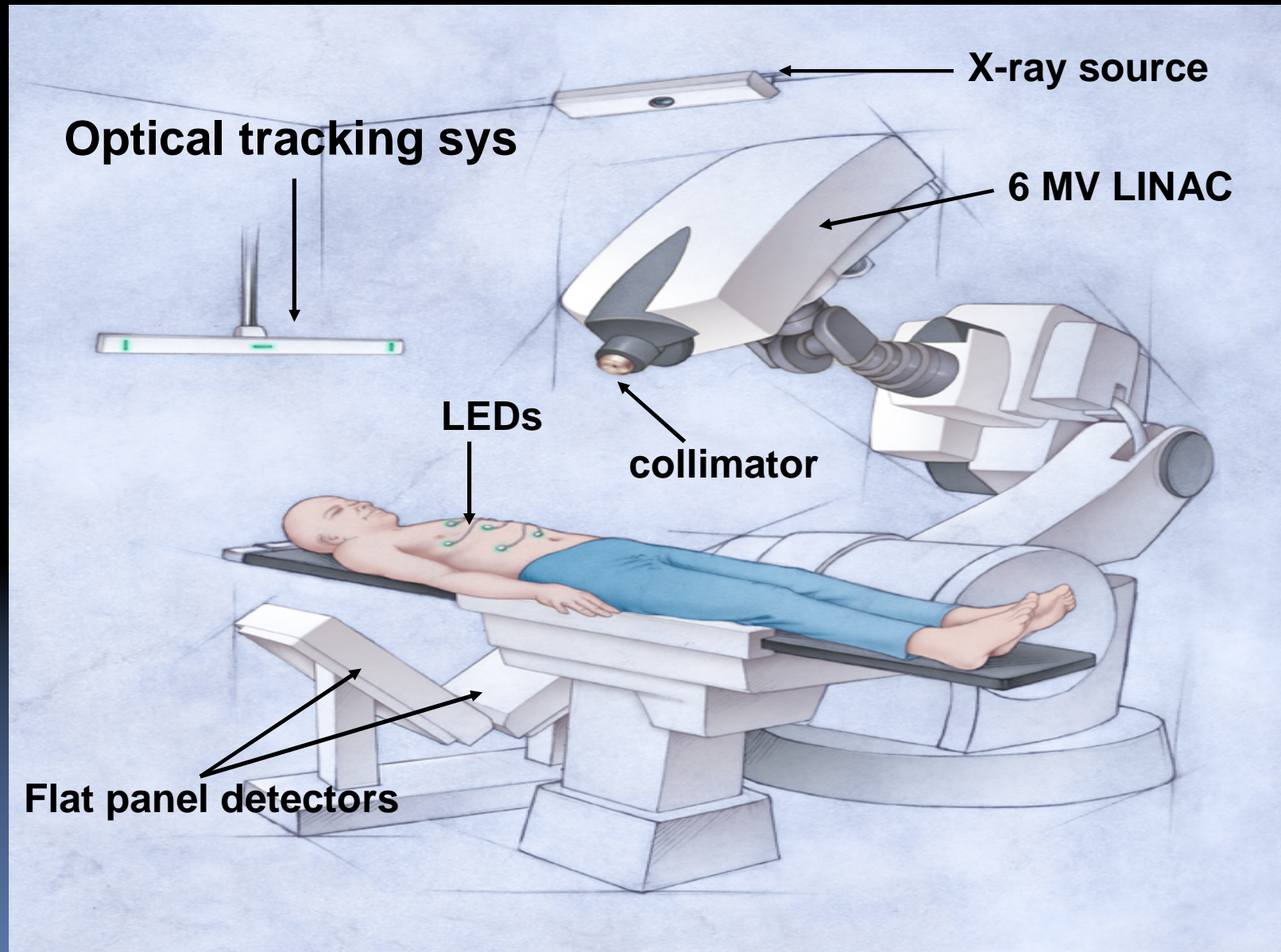
- 330 lbs.
- X-band
- 6 MV
- 800 MU/min\*
- 5 – 60 mm circular collimators (5, 7.5, 10, 12.5, 15, 20, 25, 30, 35, 40, 50, 60 mm)
- Maximum tumor size of about 250 cc



# Beam Orientations for a 110 Beams Synchrony Plan

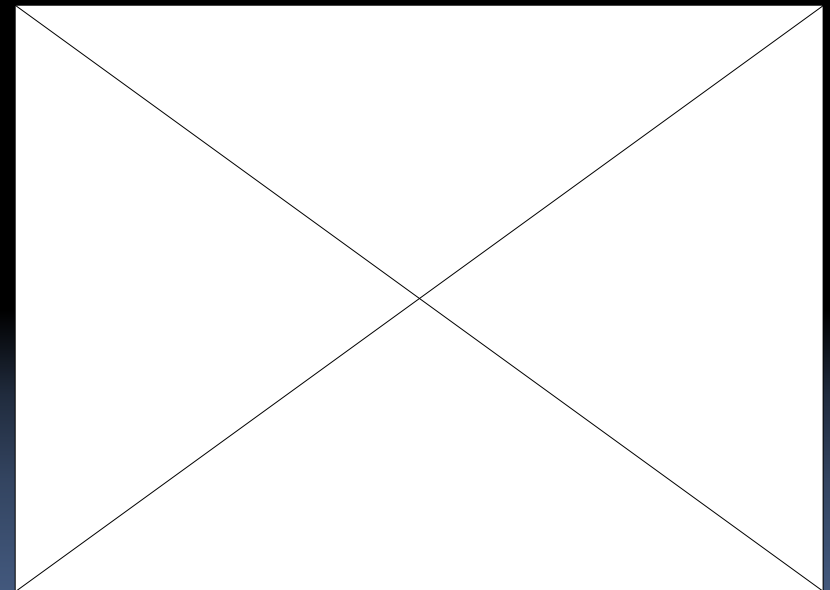


# Respiratory Compensation on the CyberKnife



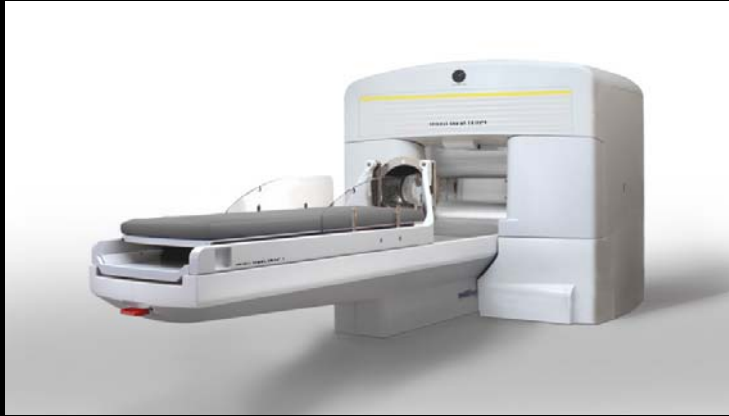
# Synchrony<sup>®</sup> Respiratory Tracking System

- Tightly contoured beams following tumor motion in real-time
- Delivers radiation throughout the respiratory cycle without gating or breath-holding
- Continually adapts to variations in breathing patterns
- Maximizes healthy tissue sparing relative to IMRT / IGRT





# Leksell Gamma Knife® 4B, 4C & Perfexion™



Leksell Gamma Knife® 4B



Leksell Gamma Knife 4C



Leksell Gamma Knife® Perfexion™

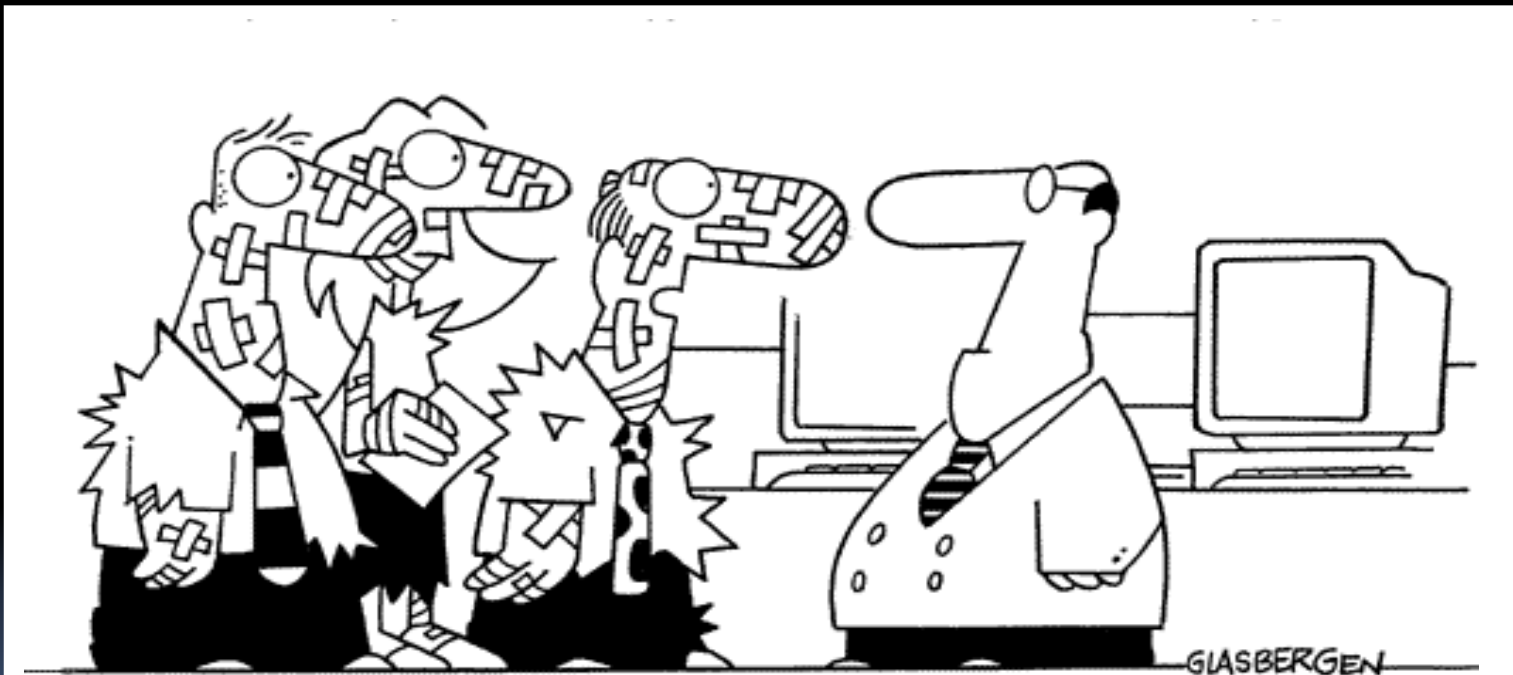
# Leksel1 Gamma Knife PERFEXION



# Collimator Body of **PERFEXION™**



# Thanks for Your Attention



**“Frankly sir, we’re tired of being  
on the cutting edge of technology.”**