Radiotherapy Treatment Planning

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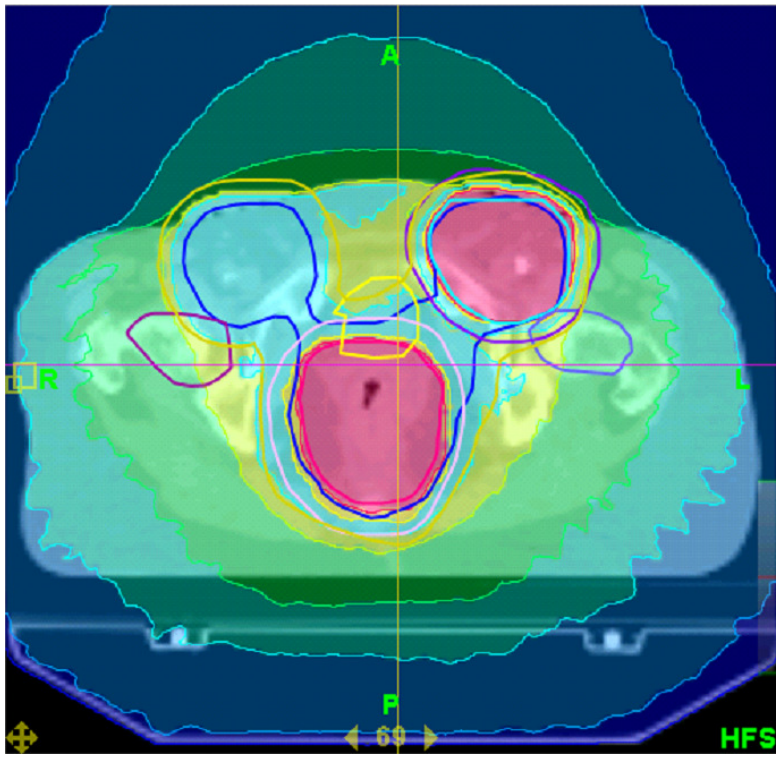
(Dr. Stacey Holloway)

Lecture 1: Autumn 2019



Course structure

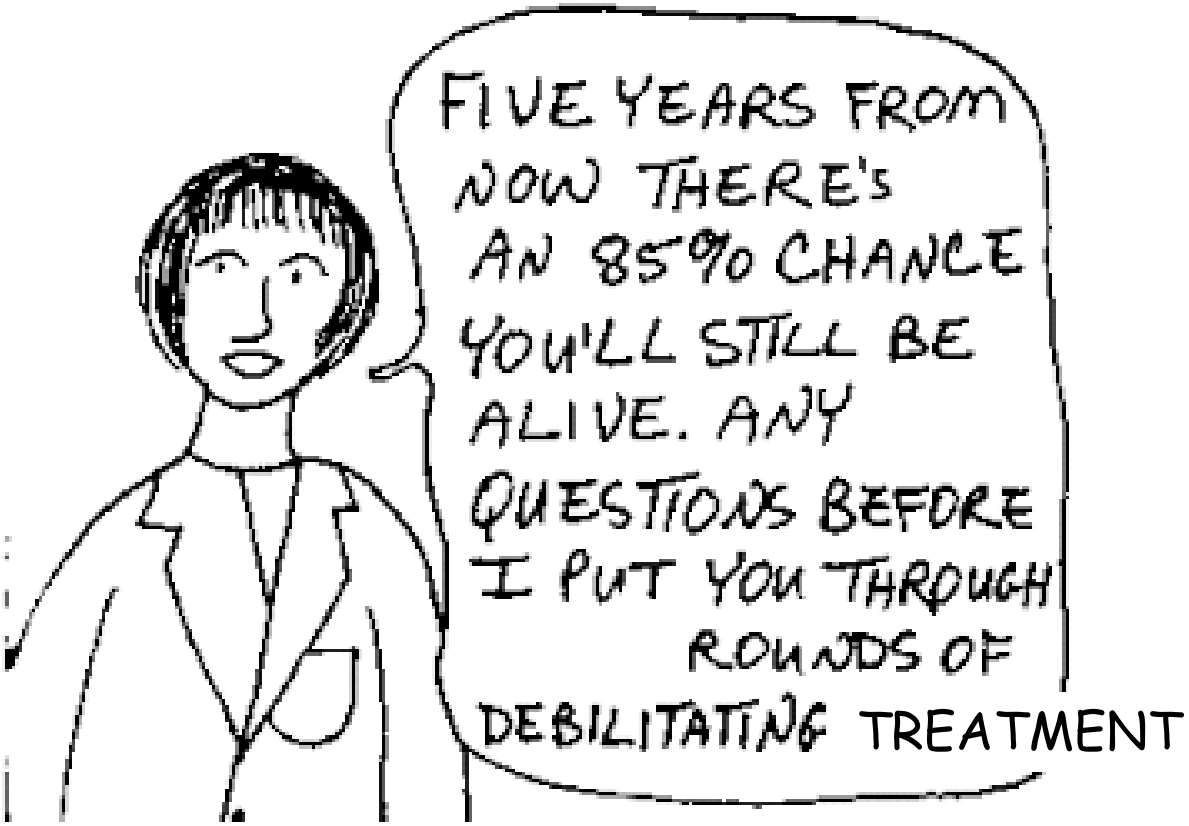
Hour 1&2. Treatment planning pathway – Precision and accuracy, margins, dose calculation, overview of IGRT, how a Linac works, adaptive planning.

Hour 3&4. Properties of MV beams band MU calculation.

Hour 5. Principles of Forward planning.

Hour 6. Principles of Inverse planning, optimisation, objectives vs constraints and modern treatment techniques, e.g. IMRT, VMAT.

Surviving = living



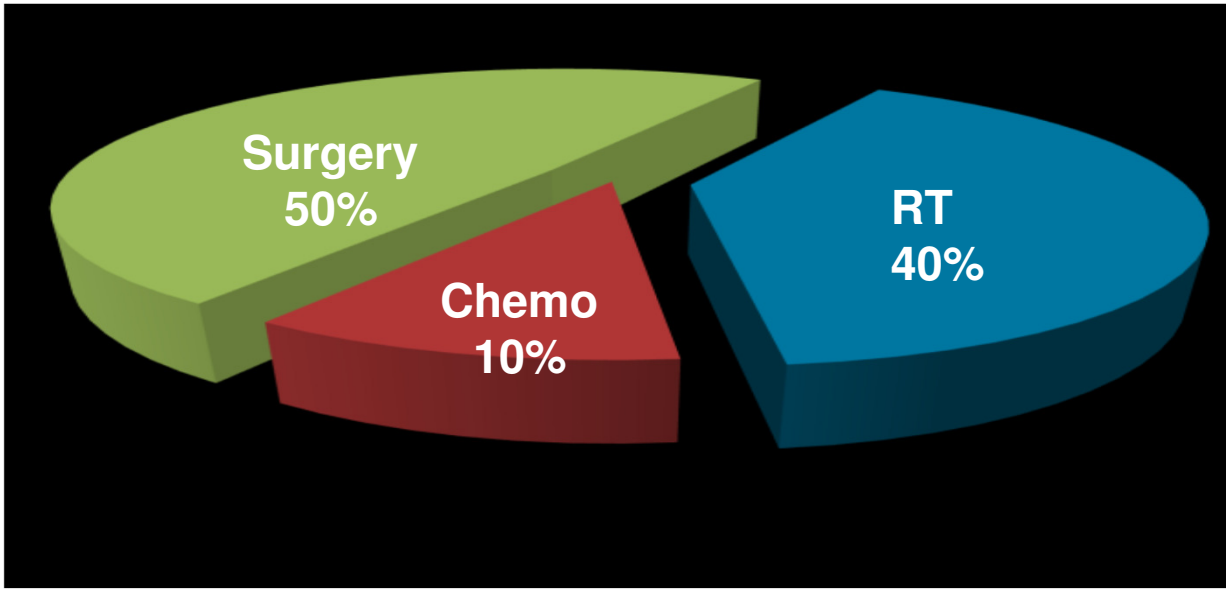
32.5 million people living with cancer

In UK 50% of patients survive cancer for 10 or more years

Aim of (Radio)therapy:
Cure without complication

- High Energy X-rays (mostly – electrons, protons…)
- External delivery (mostly – see brachytherapy)
- Higher dose = greater chance of cure
- BUT, limitation is healthy tissue damage (“toxicity”)

Cancer Treatments & Cure Rates ("RT works")

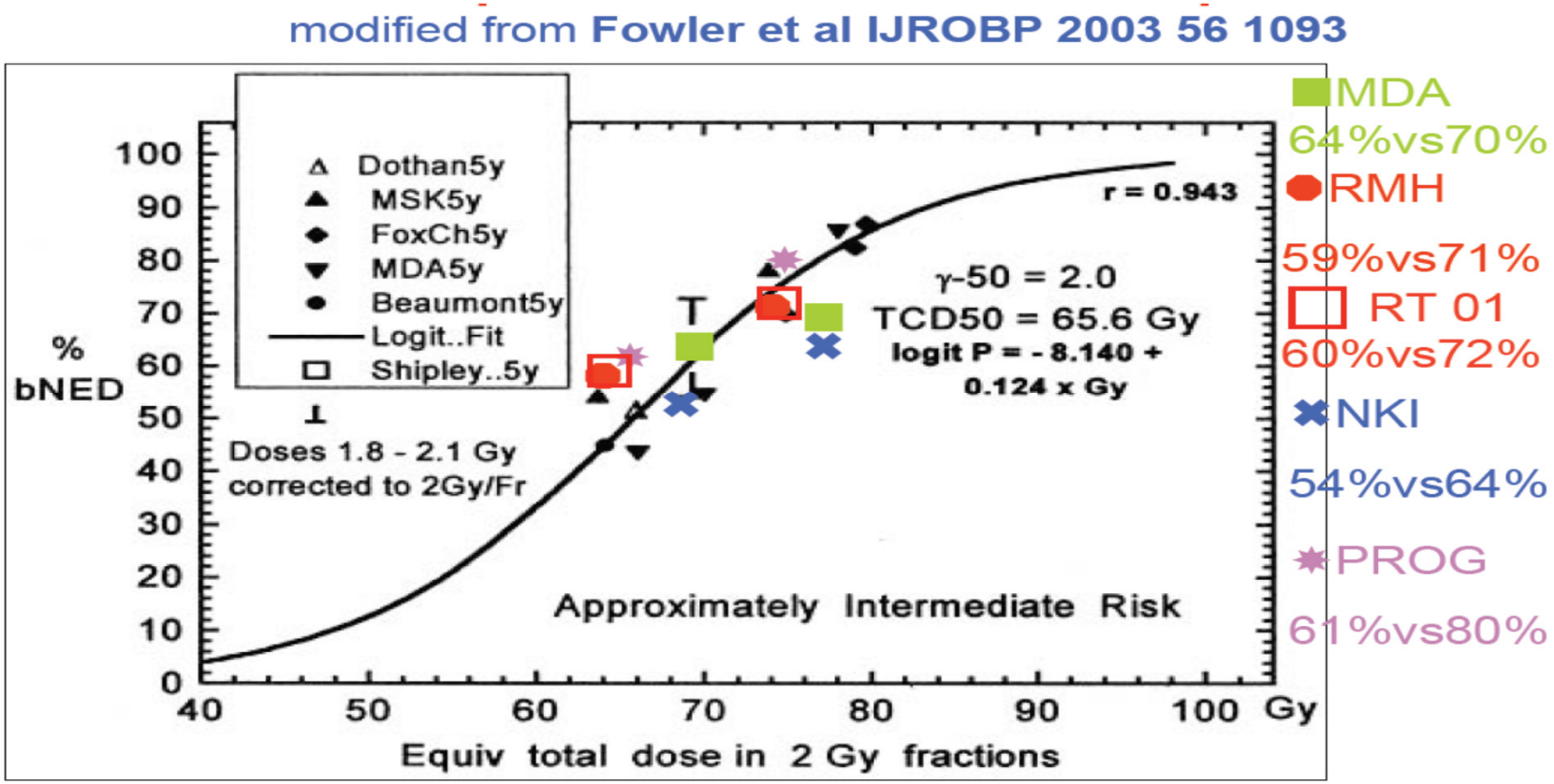


Professor Sir Mike Richards, NCRI cancer conference 2011

Treatment modality	Annual spend
Surgery	£2.1 billion
Chemotherapy	£1.7 billion
Radiotherapy	£0.5 billion

Neil Burnet, PBT Research Town Meeting, April 2015

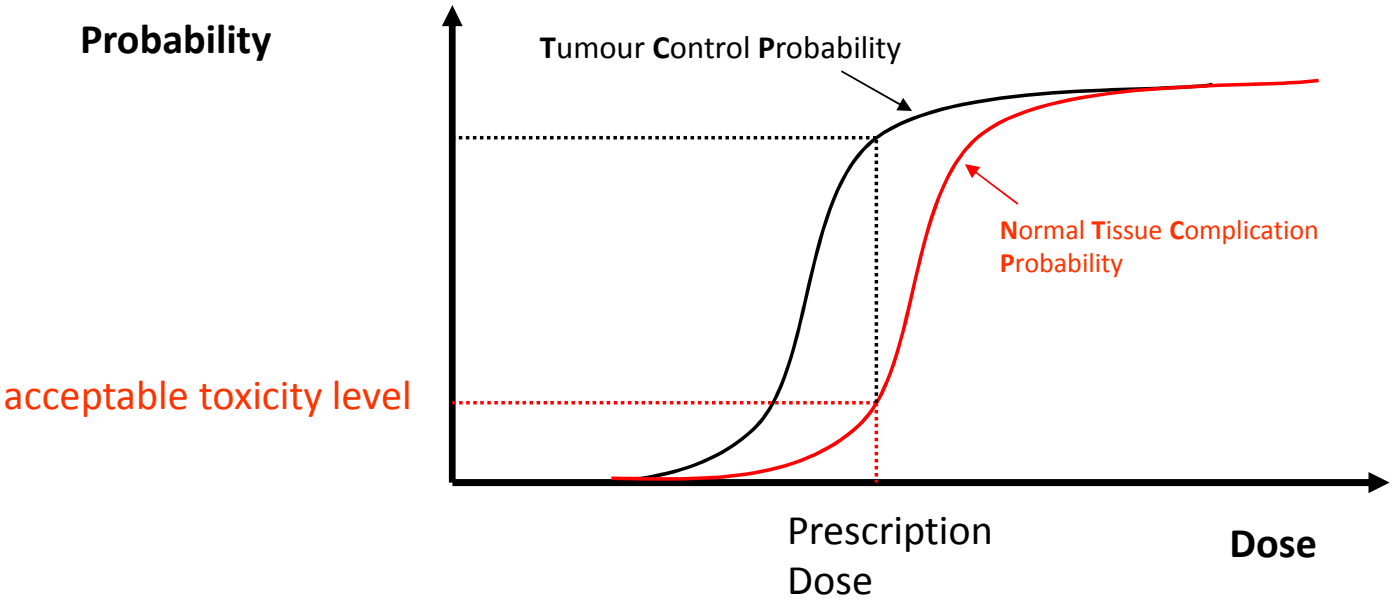
Radiotherapy “Dose-effect” relation in prostate Cancer



Prof. D. Dearnaley, IG-IMRT in clinical practice, RMH 2009

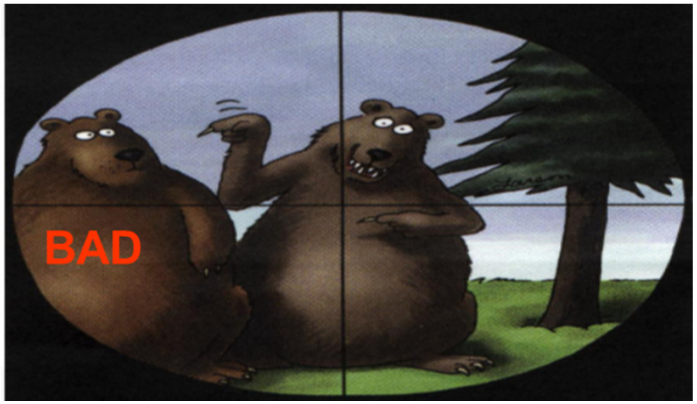
Radiotherapy's Rational & *modus operandi*

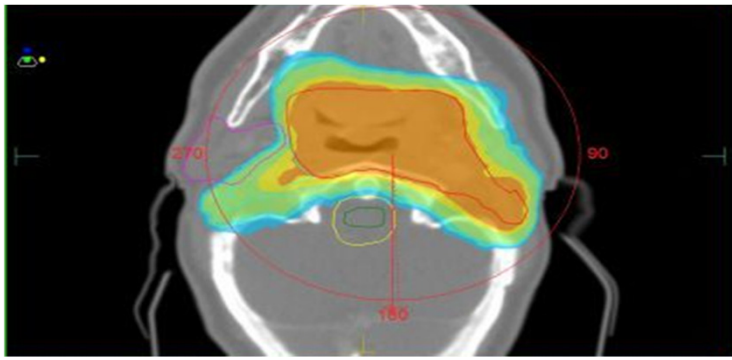
Cause – Effect

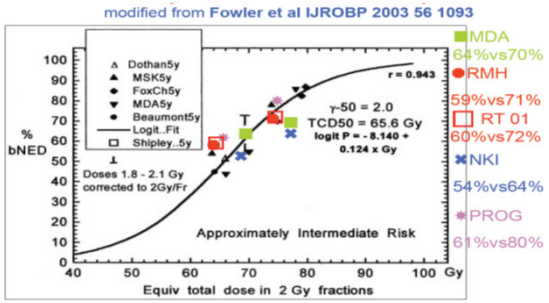


RT mantra

"Treat the bad, spare the good"







Dose to cancer = tumor control

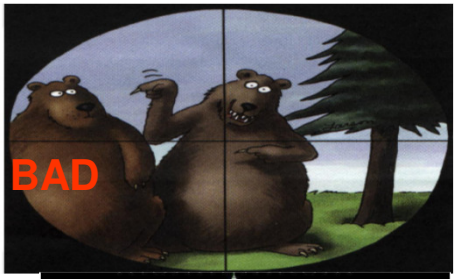
Dose to normal tissues = side effects

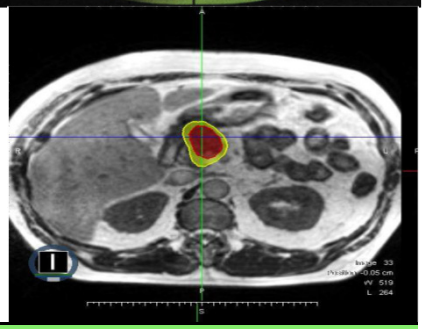
=> Treatment's efficacy is toxicity limited

The evolution of Radiotherapy

RT mantra

"Treat the bad, spare the good" or in technical terms optimise the radiation in order to deliver the prescribed dose with maximum sparing of the healthy tissue...





First Linac

Cerrobend blocks

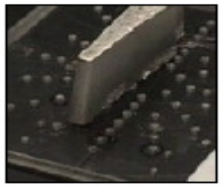
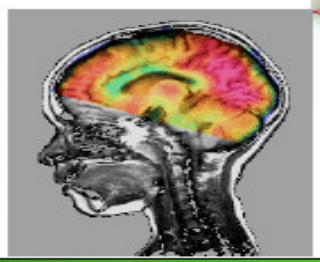
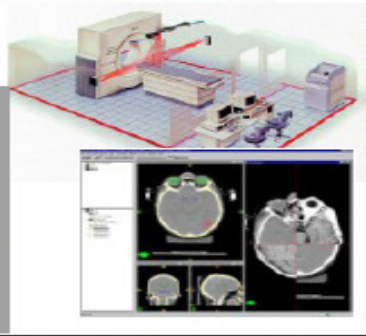


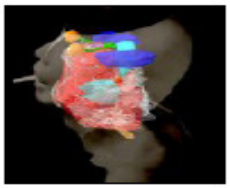
Image Fusion

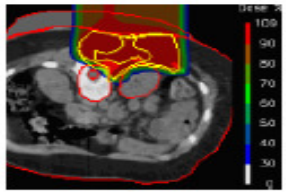


Computerized 3D CT treatment planning



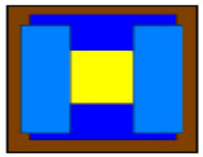
IMRT dose-painting



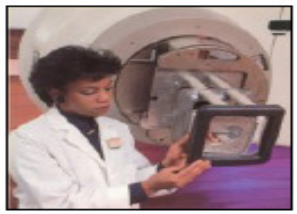


Particle Therapy

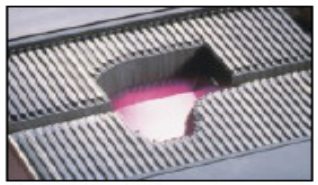
1960 1970 1980 1990 2000 2010 2018+



Standard collimator



Shaped electron fields



Multileaf collimator

High resolution IGRT

SABR

MR-linac

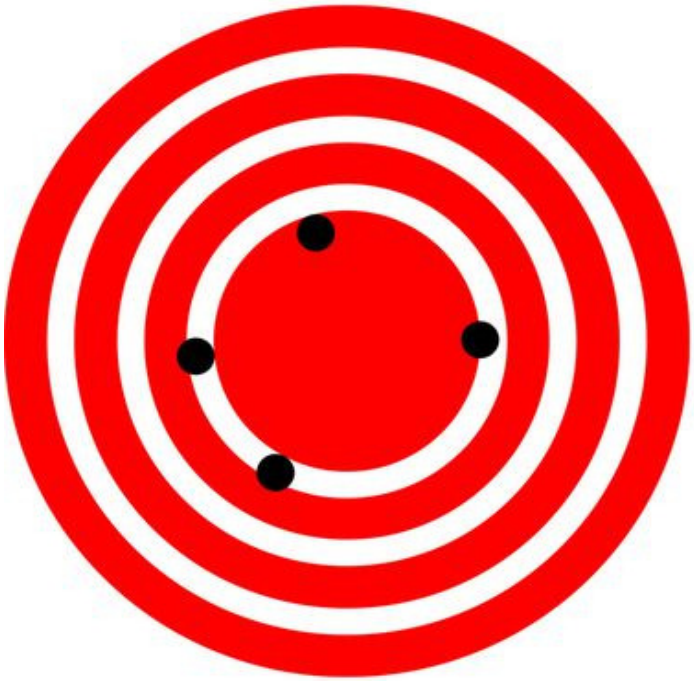
https://vimeo.com/78791415

Aims of today's lecture on RT Treatment Planning

1. Define uncertainties; precision and accuracy
2. Learn the Radiotherapy patient pathway
3. Learn about how CT imaging is used in Radiotherapy Treatment Planning
4. Understand how treatment uncertainties are accommodated; Margins
5. Understand treatment planning and dose calculation
6. Learn about image guidance in Radiotherapy
7. Learn about RT treatment delivery and the basics of how a Linac works

1. Uncertainties (“Errors”)

Accuracy



Random errors

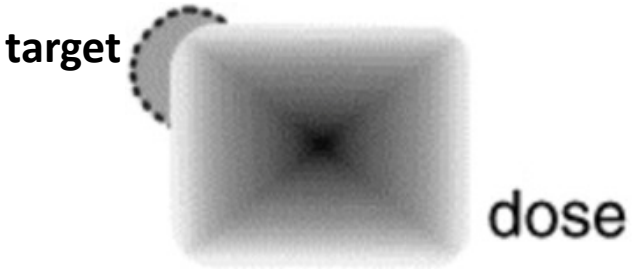
Precision

Systematic errors

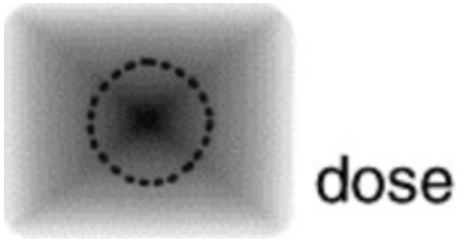
Radiotherapy treatment uncertainties

There are two aspects of accuracy and precision that need to be considered in radiotherapy.

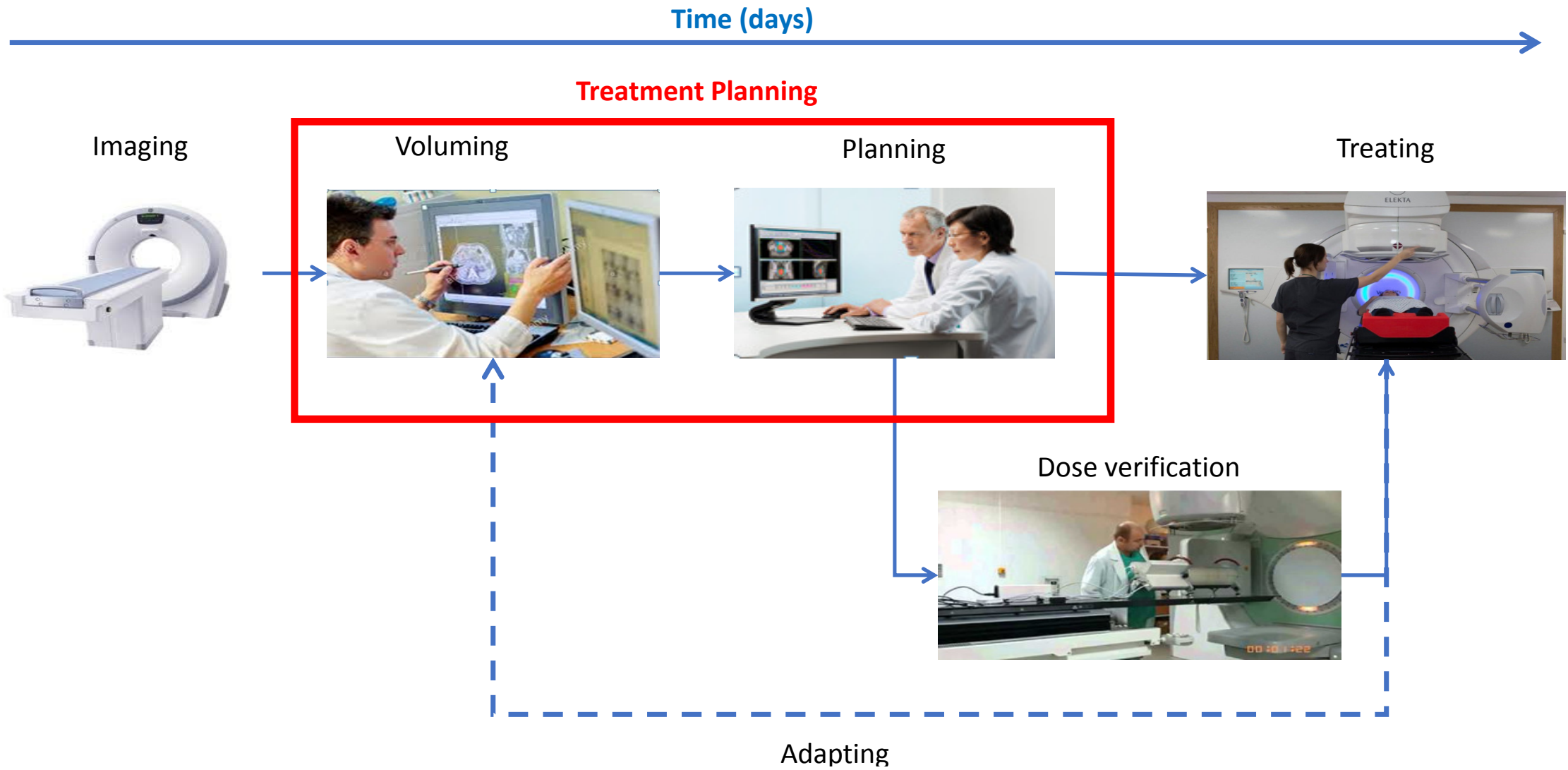
1. **The accuracy of the dose given to the tumour and the surrounding tissue.**



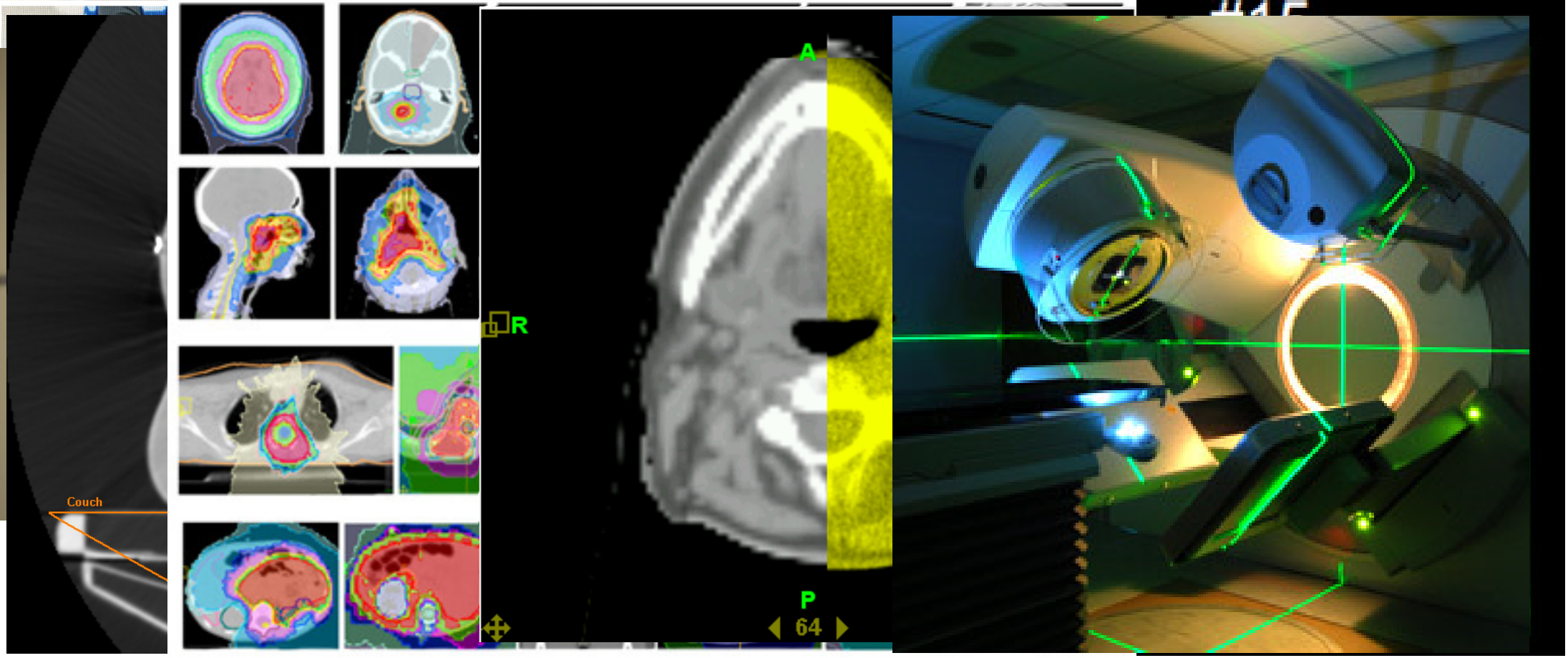
2. **The precision of the spatial geometry of the treatment delivery.**



2. Radiotherapy Treatment pathway

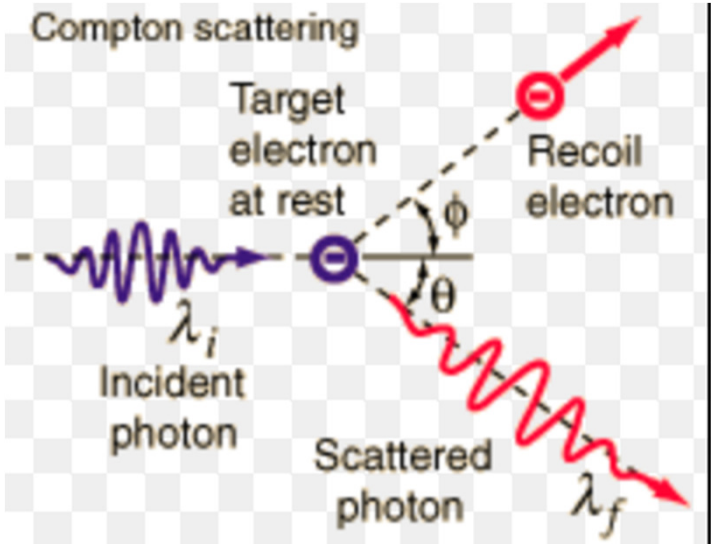


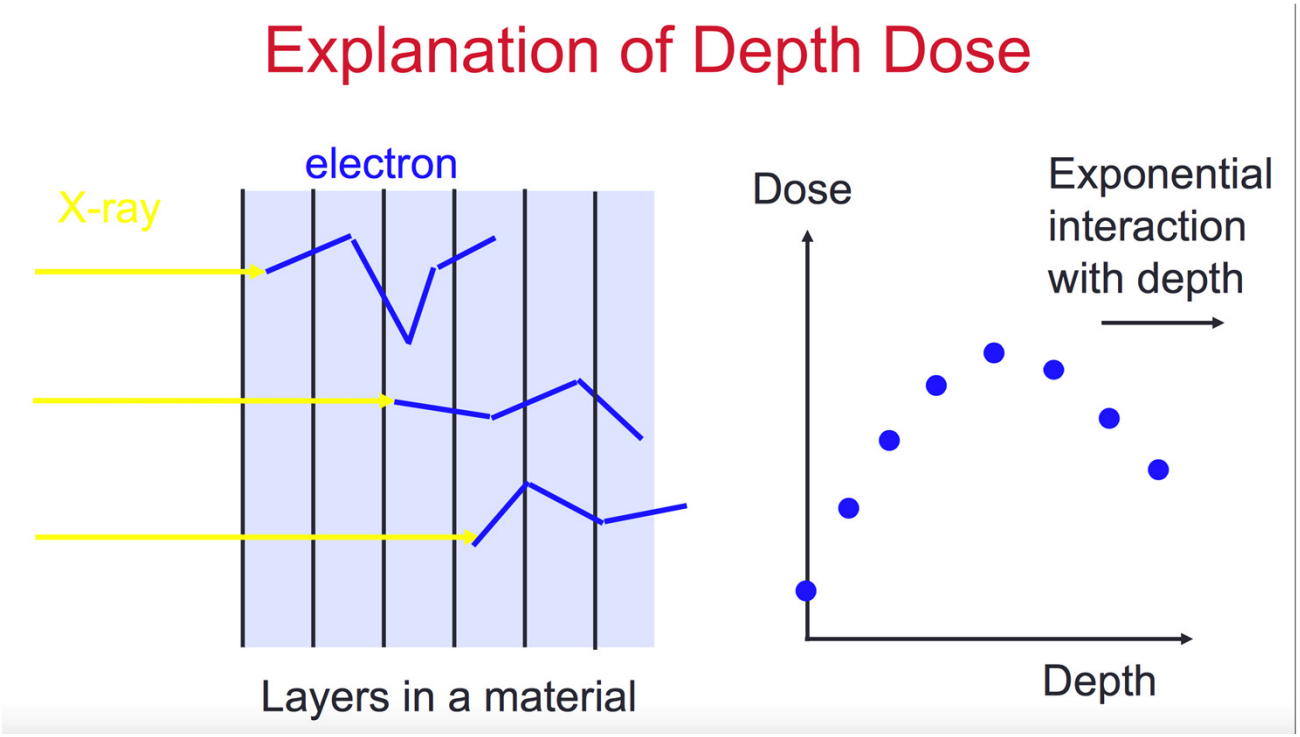
Radiotherapy Treatment pathway



(MV) Photon interactions

- Linear attenuation coefficient = probability of interaction occurring per distance
- Dose in patient deposited by **electrons** that MV photons interact with and liberate
- So we really care about no. electrons
- Specifically **electron density relative to water**





3. Imaging

Materials with different electron density attenuate X-rays by a different amount.

To calculate dose in a volume we need a 3D image with quantifiable information on the object's electron density, i.e. at each image pixel, that will allow to determine how the treatment x-rays will interact in the patient.

CT images do not display linear attenuation correction directly, instead display CT numbers (CTN) or Hounsfield Units (HU) :

$$HU = \left(\frac{\mu(\text{tissue}) - \mu(\text{water})}{\mu(\text{water})}\right) x\ 1000,$$

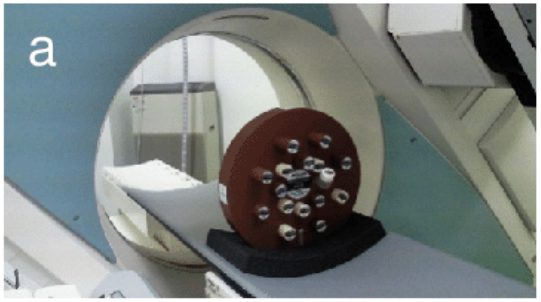
where, $\mu(\text{water}) = 1\ and\ \mu(\text{air}) = 0$ and ρ_e is electron density relative to water

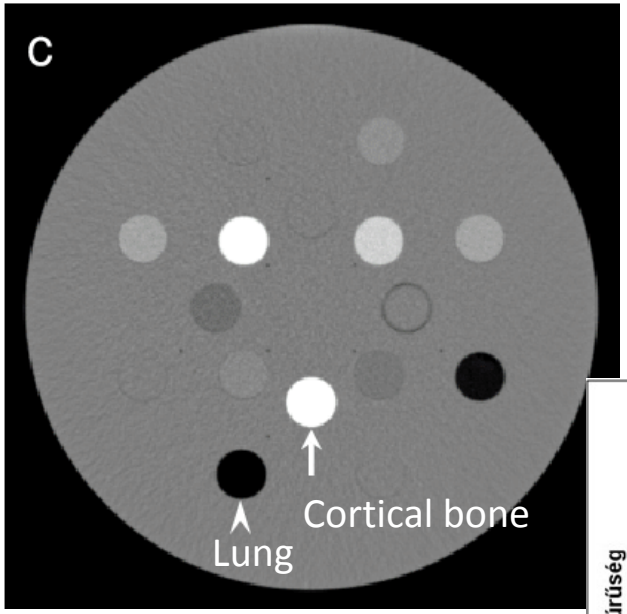
$$\rho_e = \frac{HU}{1000} + 1.00 \quad \text{For HU < 100}$$

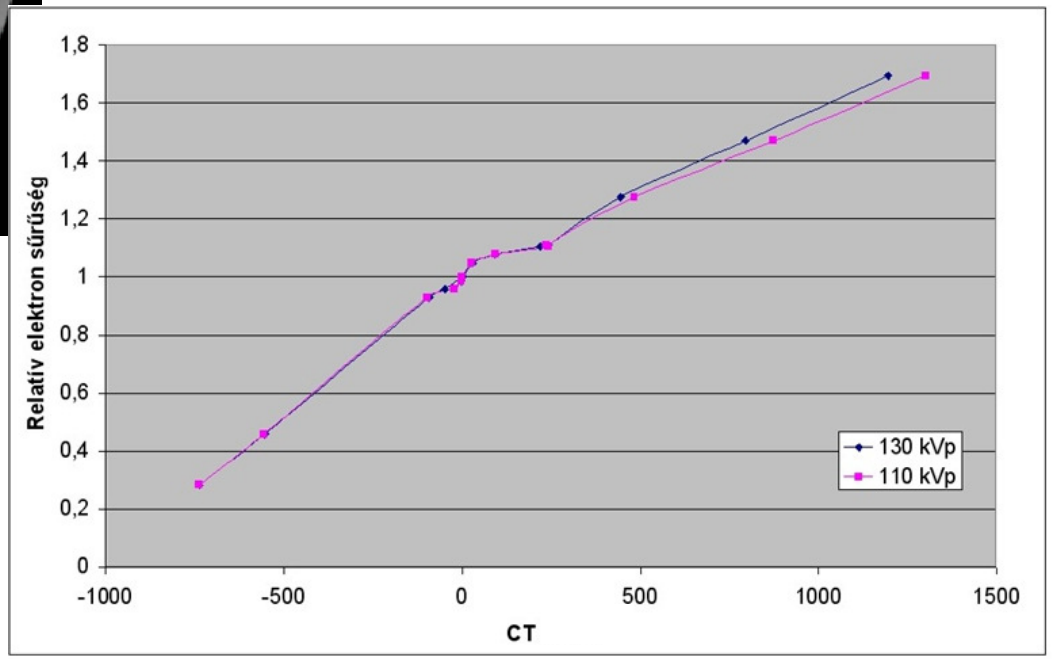
$$\rho_e = \frac{HU}{1950} + 1.00 \quad \text{For HU > 100}$$

HU(air) = -1000, HU(water) = 0

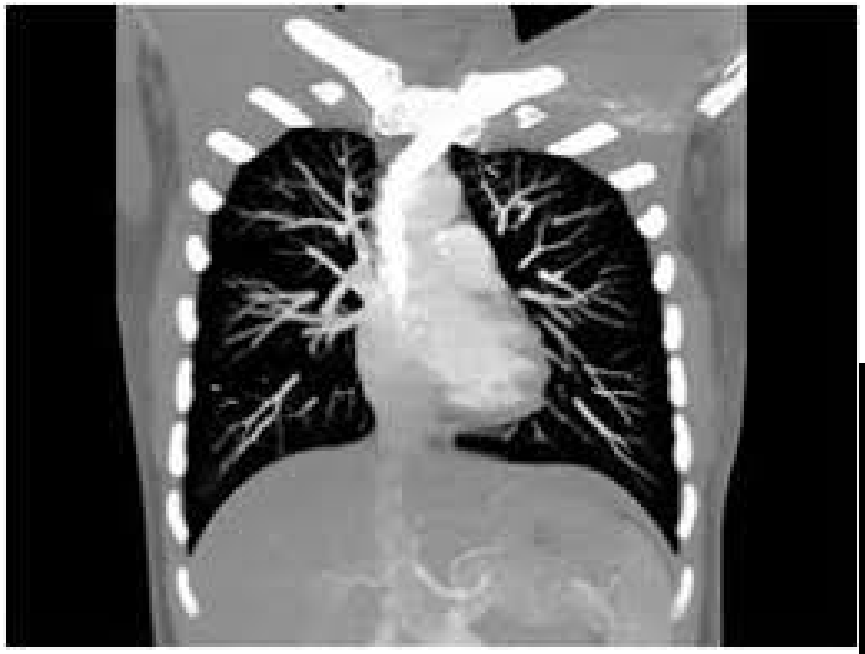
CT calibration (HU to ED)





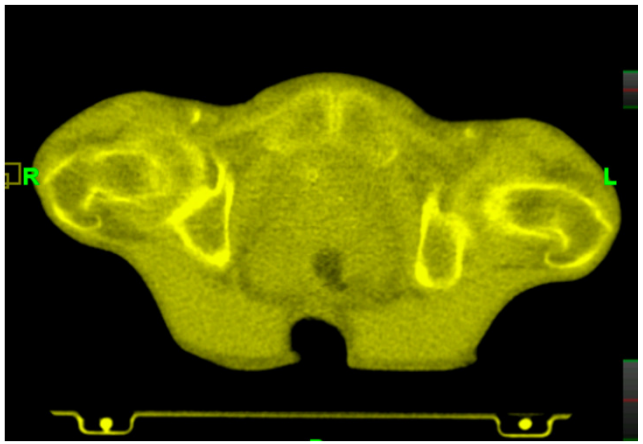


Patient treatments; position & motion

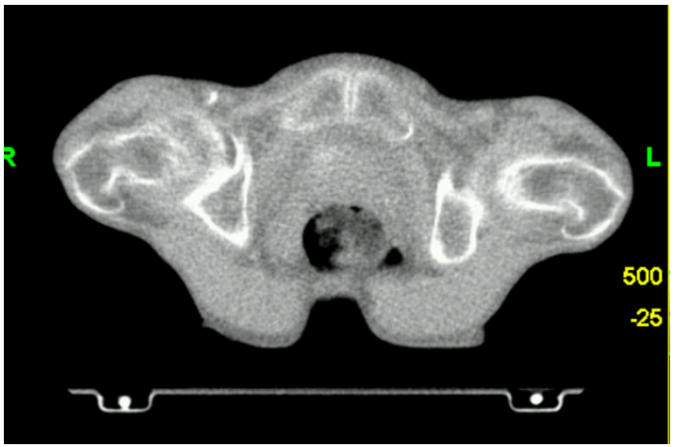


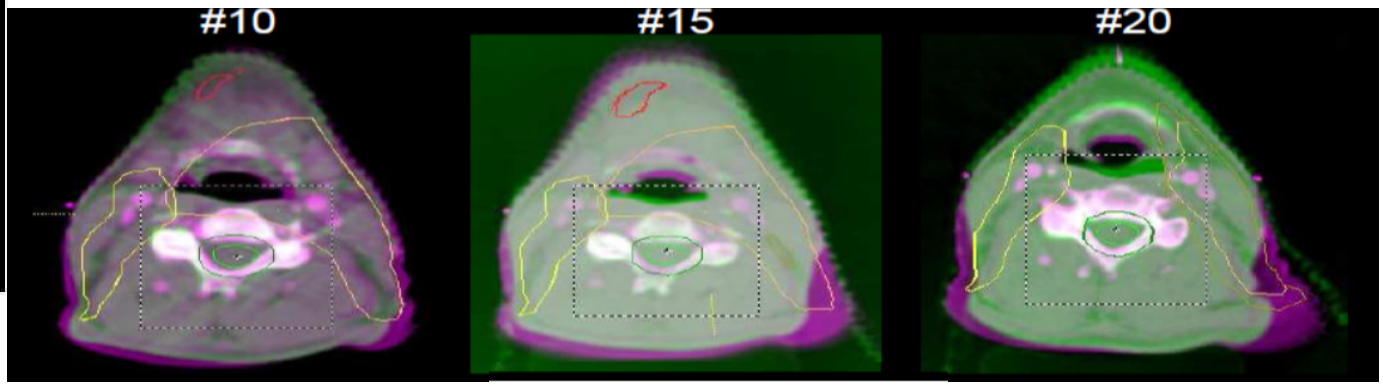
https://youtu.be/1uBkvOyp1b8

Day n



Day n+1

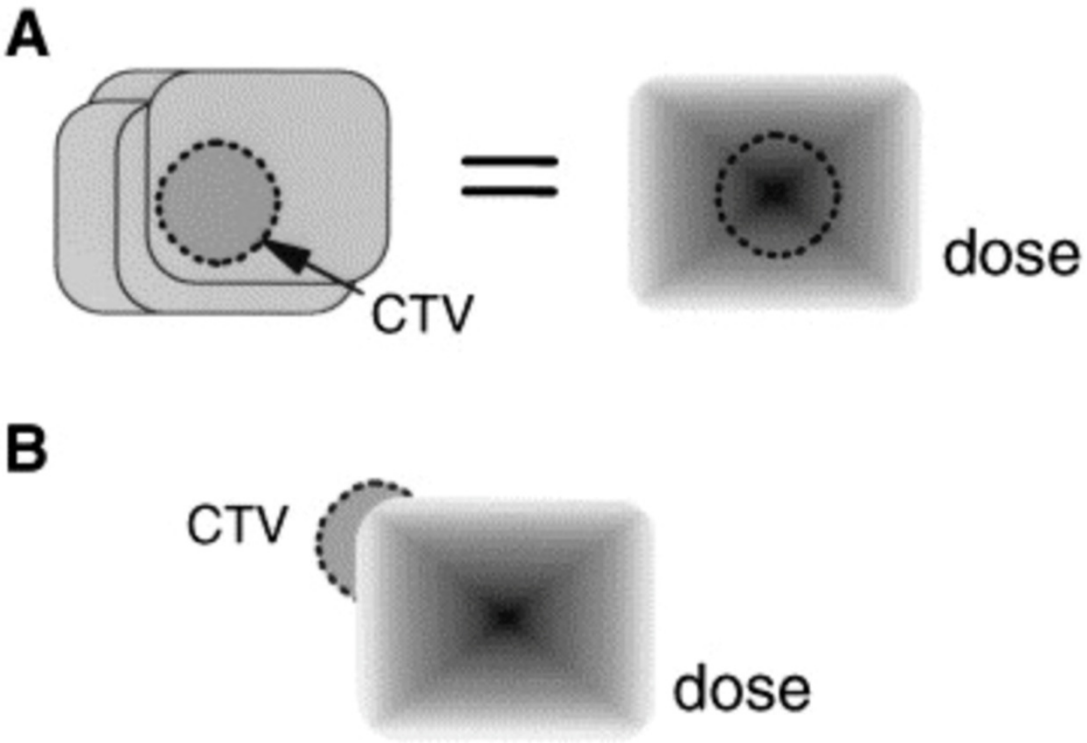




Purple = Planning CT

Green = CBCT (IGRT)

Treatment uncertainties

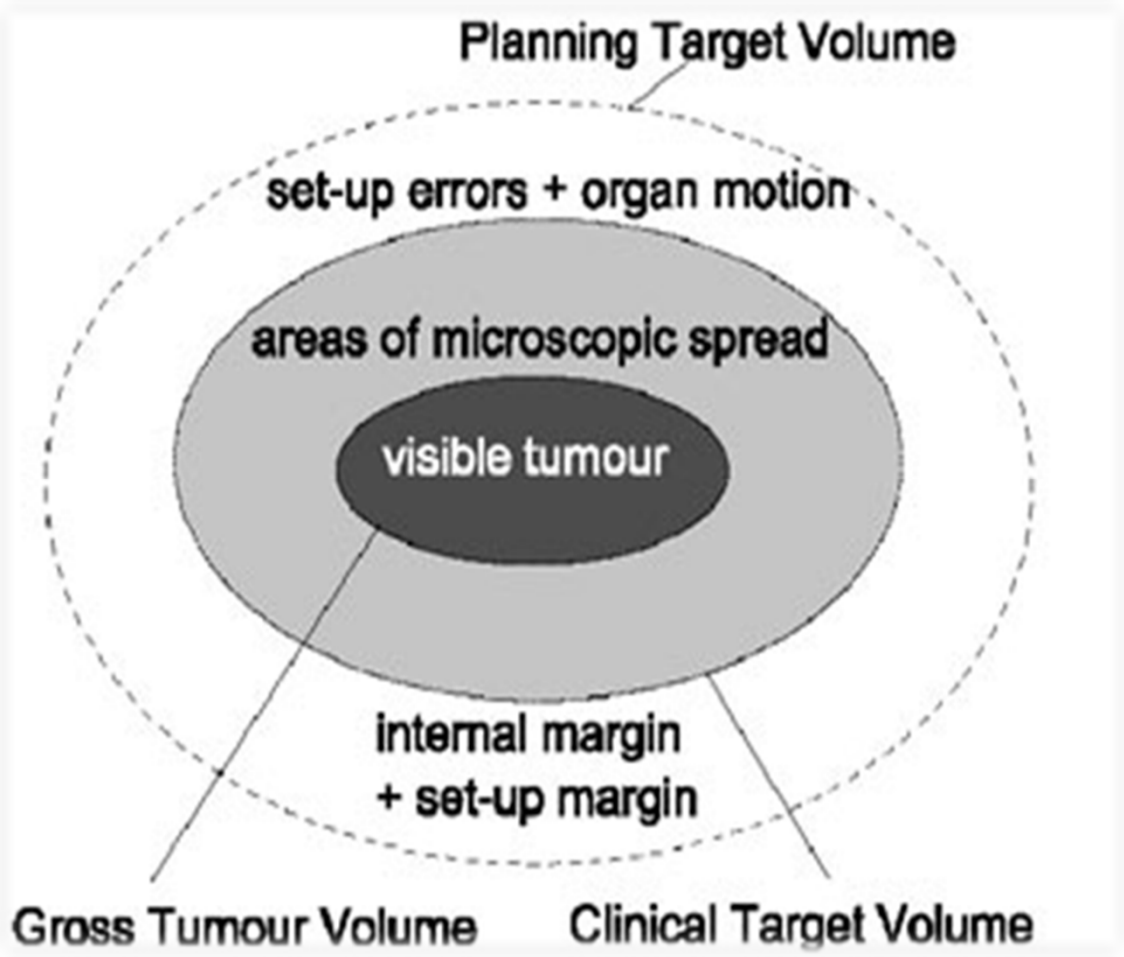


A. Random errors result in *blurring* of dose

B. Systematic errors result in a “geographical” *shift* of dose

4. Treatment uncertainties and Margins

- In external beam RT margins account for treatment uncertainties
- PTV margins are grown based on known random and systematic errors inserted into a recipe.
- Recipes designed to ensure CTV min dose is achieved for a predefined percentage of patients.
- Unlike CTV, PTV is not a “property” of the patient



[ICRU reports 50 & 62]

PTV Margin recipe

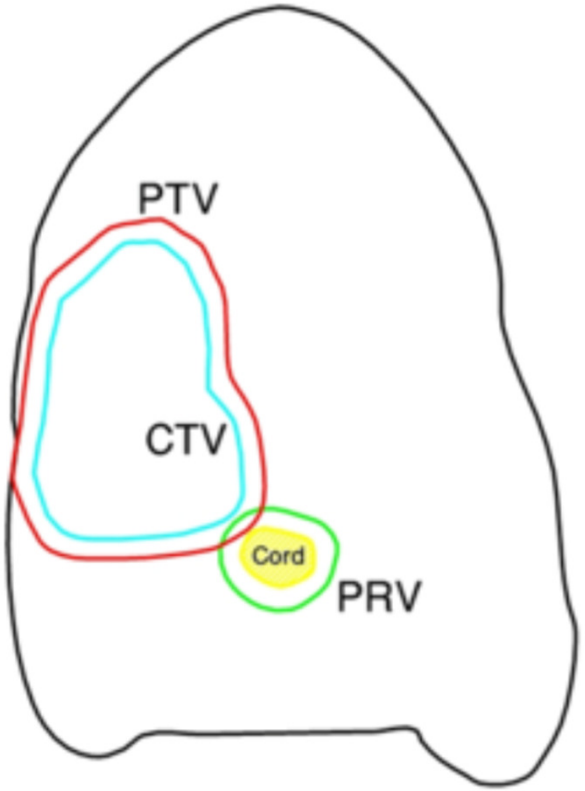
$$\text{PTV Margin} = 2.5\Sigma + 1.64\sqrt{(\sigma_p^2+\sigma^2)} - 1.64\sigma_{p\,=\ldots=}$$

$$\boxed{\textbf{PTV Margin} = \mathbf{2.5\Sigma + 0.7\sigma}}$$

- σ = quadratic sum of all **treatment** errors *(random = blur dose)*
- Σ = quadratic sum of all **preparation** errors *(systematic = shift dose)*
- σ_p = beam penumbra (*in photons often simplified to assume* σ_p = *3.2mm over a range of 0-5mm)*
- Ensures 90% of patients have CTV coverage of at least 95% of prescribed dose (Nb: this defines the choice of coefficients, as 2.5 and 0.7)

Limitations of the PTV

- Assume GTV/CTV are correctly defined/outlined
- Does not work if CTV is close to the skin
- Assume no target deformation
- Assume no target rotation
- Cannot use for very mobile tumours (lung)
- Confidence in quantifying and identifying specific uncertainties
- Assumes many fractions – central limit theorem
- Assume Homogenous dose coverage
- Modality specific
- Shift invariance assumption



5. Treatment planning and dose calculation

Prescribing

- Dose prescribed and normalised to a point or volume (PTV)
- Not in air or bone - in tissue
- Can be used as the isocenter.

Organ	Objective dose (i.e. soft limit, goal)		Absolute dose constraint	
PTV1 / PTV2 / PTV3	97% - 105% to cover		95% - 107% to cover	
Spinal Cord PRV	46Gy		50Gy	
Brainstem PRV	48Gy		52Gy	
Hypothalamus	44Gy		-	
Pituitary	45Gy		-	
Optic chiasm PRV	50Gy		55Gy	
Larynx	44Gy		-	
Pharyngeal Constrictors	50Gy (Mean Dose)		-	
Mandible	No hot spots (102%)		-	
	Right	**Left**	**Right**	**Left**
Parotid	20Gy (Mean Dc	ignore	-	-
Submandibular Gland	35Gy (Mean Dc	ignore	-	-
Lens	6Gy	6Gy	-	-
Cornea	30Gy	30Gy	-	-
Retina	50Gy	50Gy	-	-
Globe	40Gy	40Gy	45Gy	45Gy
Lacrimal Gland	26Gy	26Gy	-	-
Optic Nerve PRV	50Gy	50Gy	55Gy	55Gy
Cochlea	35Gy	35Gy	45Gy	45Gy

[ICRU report 83]

Forward planning

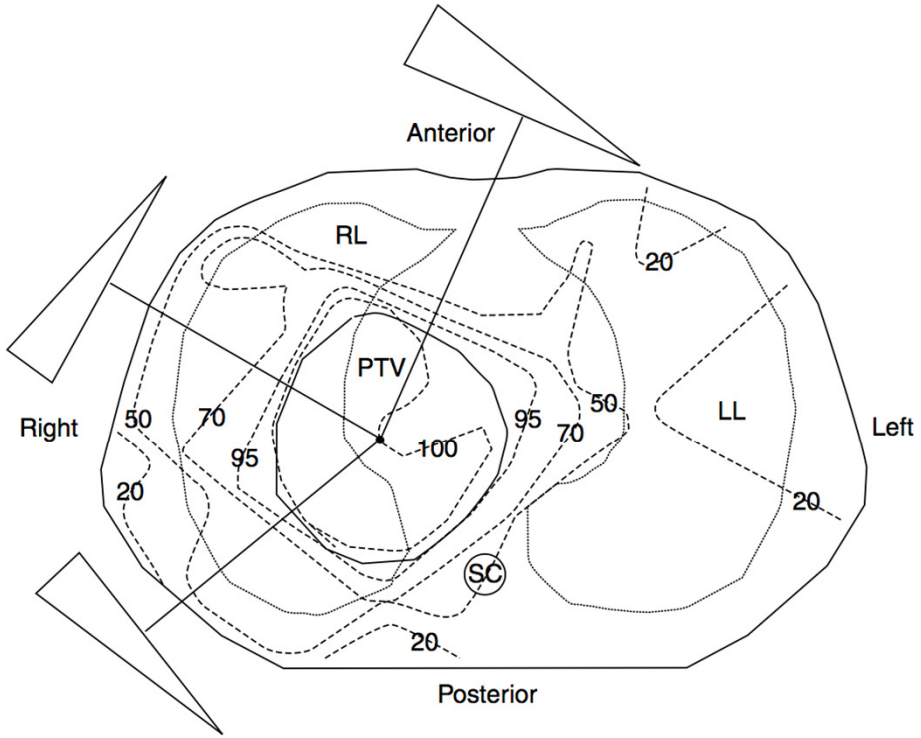
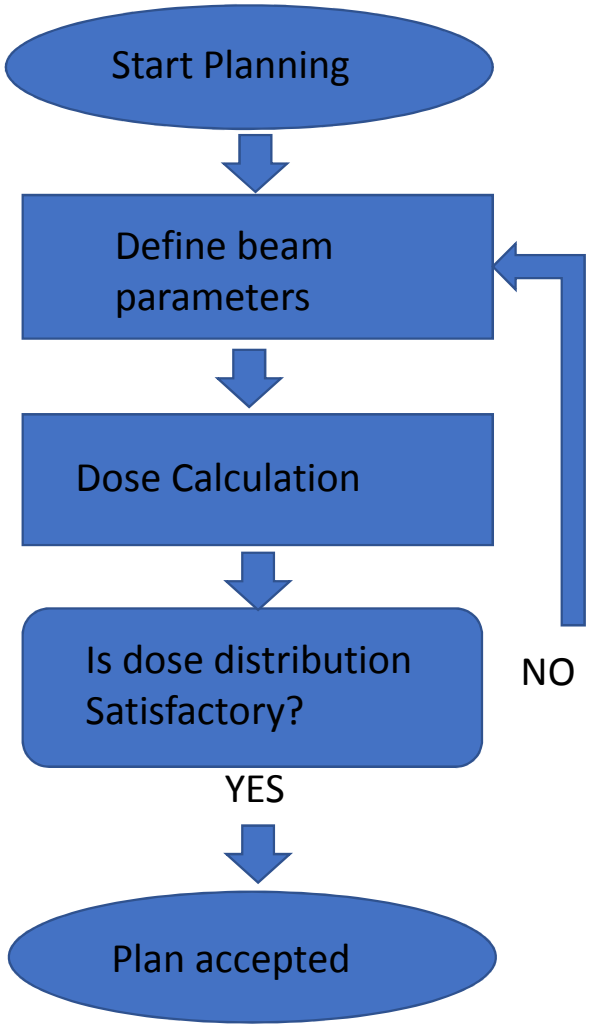


FIGURE 33.6
6 MV three-beam dose distribution normalised to 100 at the isocentre, for the treatment of a right bronchial tumour (PTV). The beams are arranged to avoid the contra-lateral lung and to keep dose to the spinal cord (SC) below tolerance. RL indicates the right lung and LL the left lung.



Plan type: 3 field brick with wedged pair

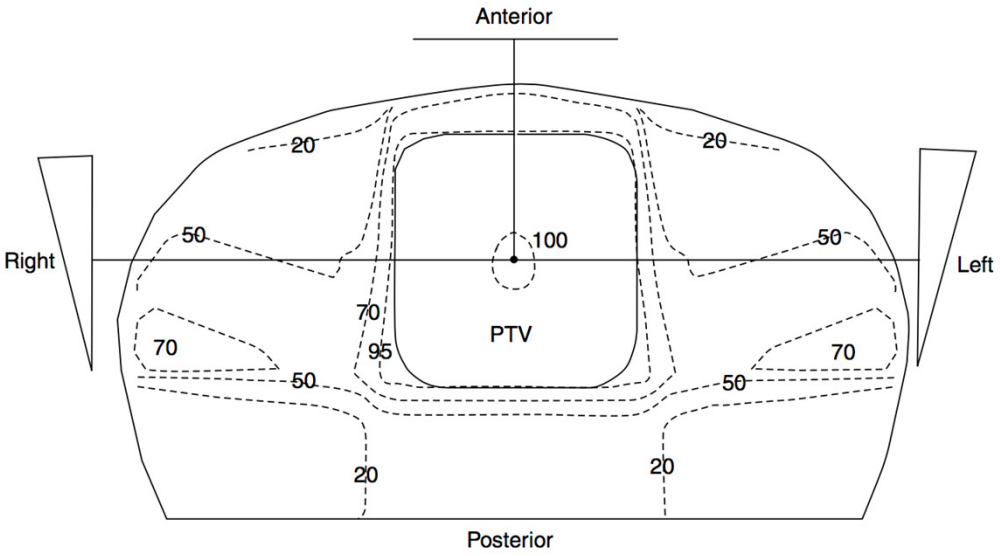
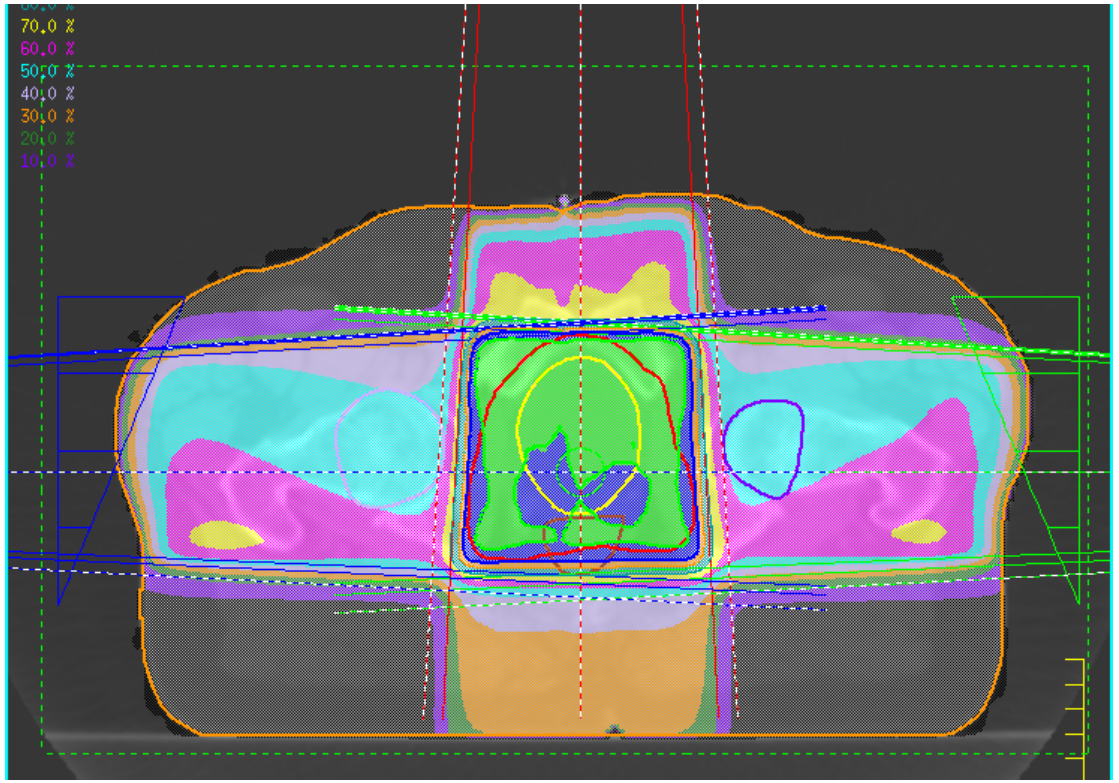
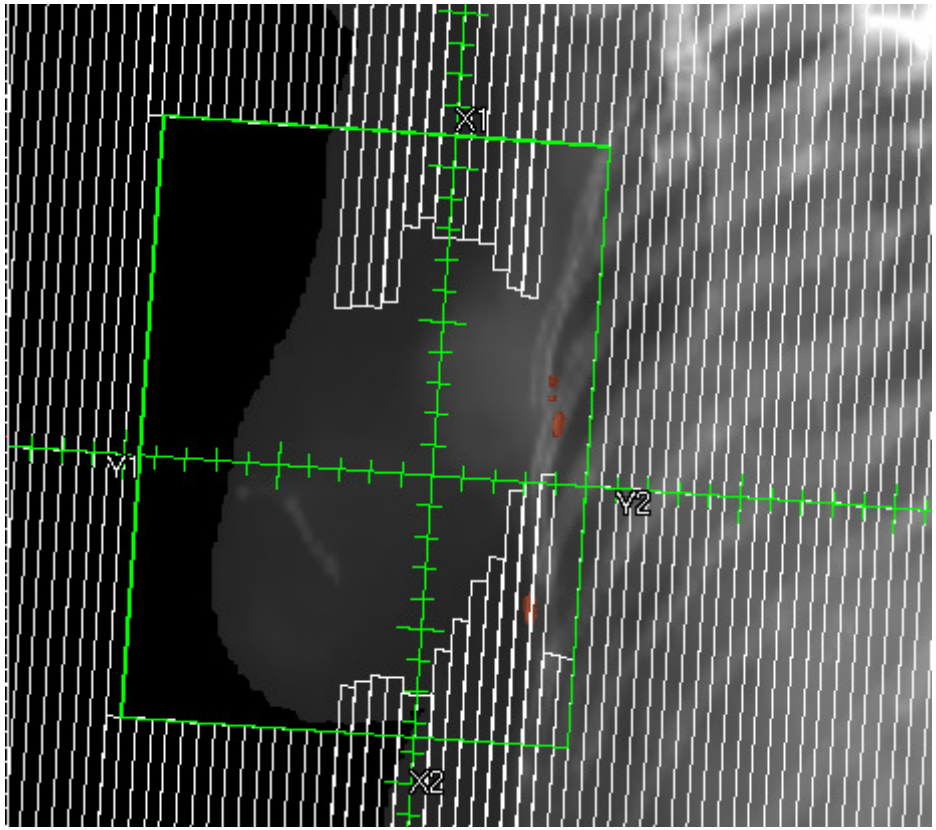
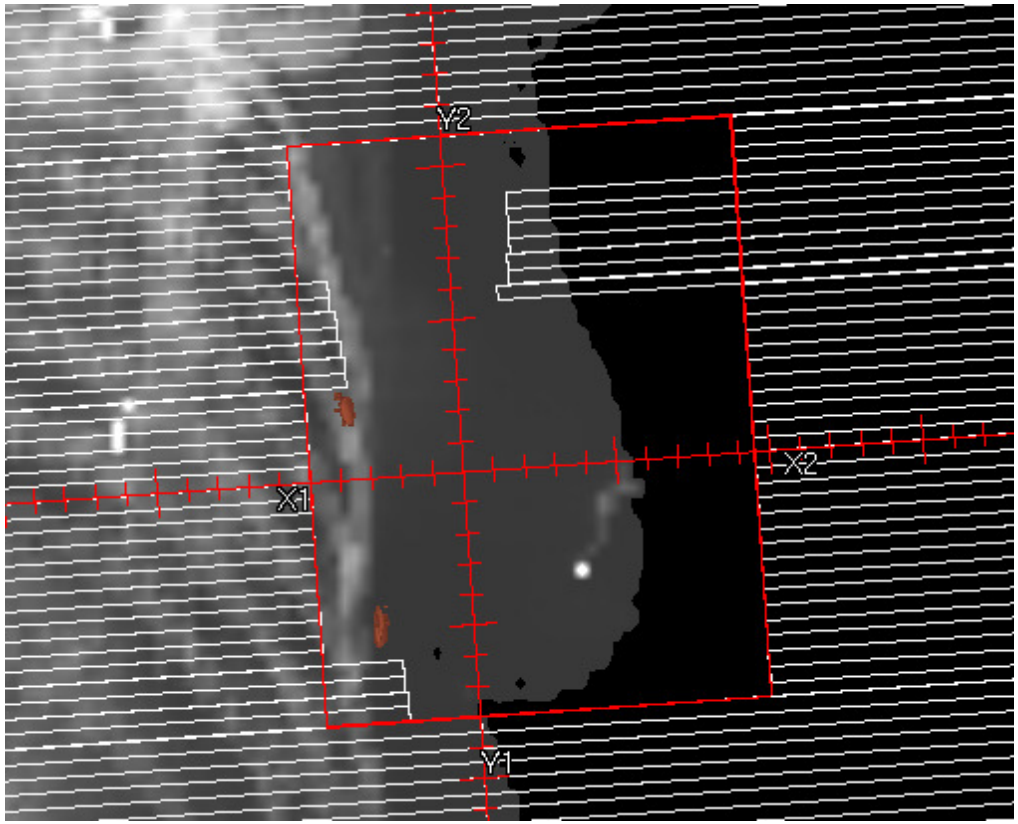


FIGURE 33.5
6 MV three-beam dose distribution normalised to 100 at the isocentre to treat the bladder (PTV).

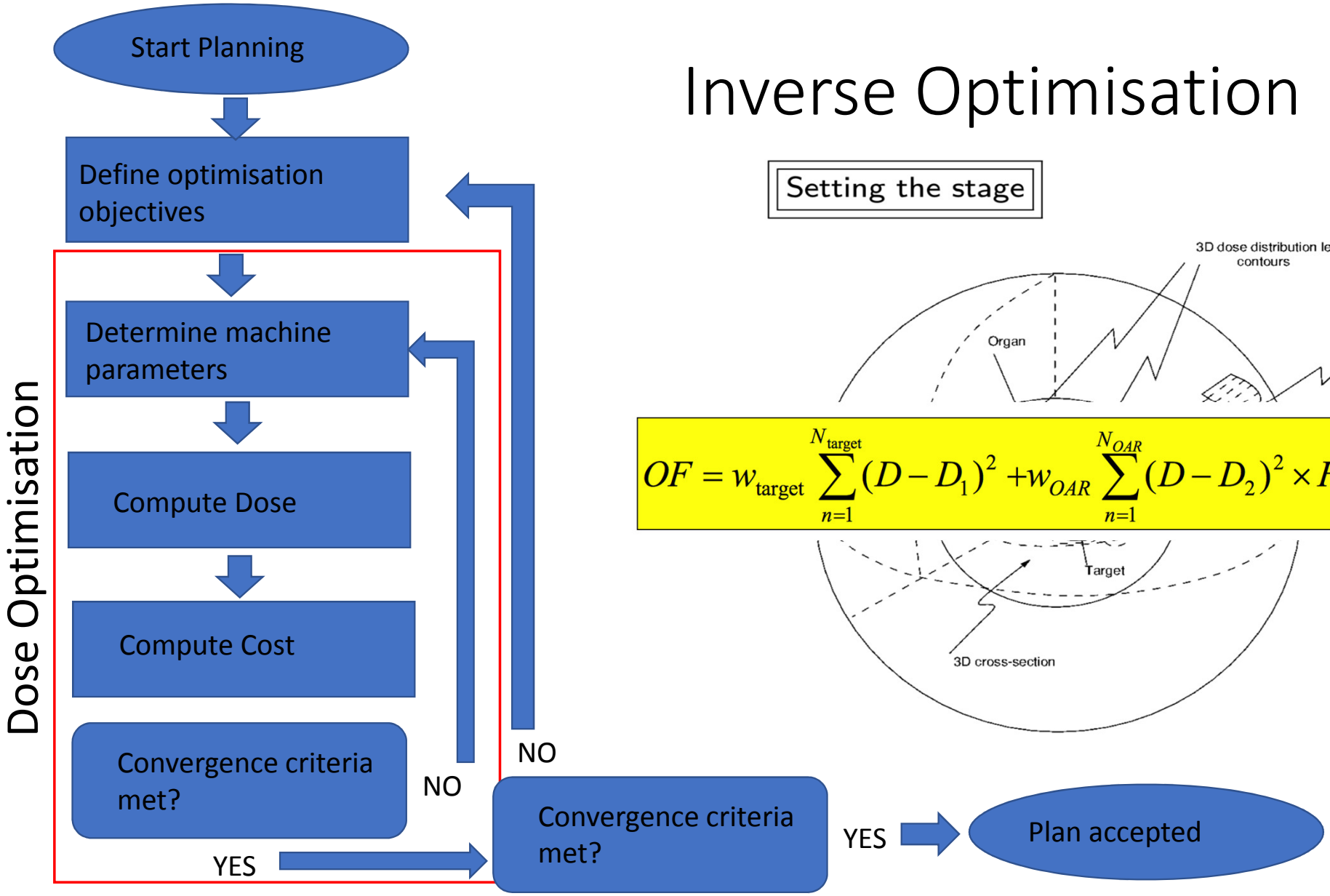


Multi-leaf Collimators





Inverse Optimisation

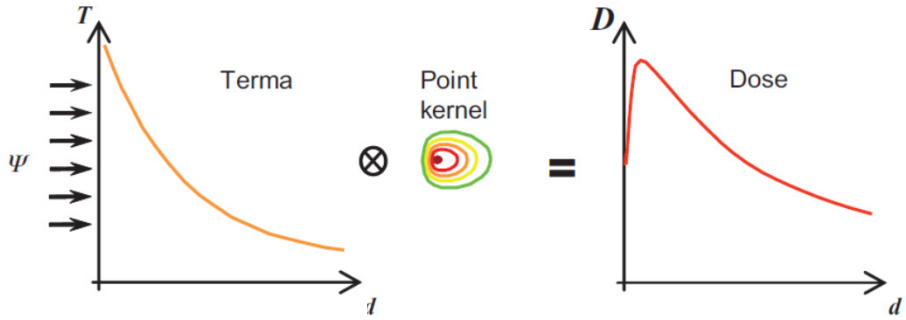


Setting the stage

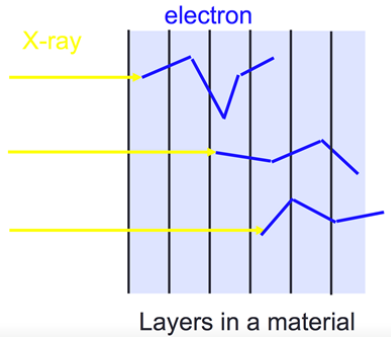
$$OF = w_{\text{target}} \sum_{n=1}^{N_{\text{target}}} (D - D_1)^2 + w_{OAR} \sum_{n=1}^{N_{OAR}} (D - D_2)^2 \times H(D - D_2)$$

Dose calculation algorithms

1. Input data (Beam, patient)
2. Dose Calculation equation

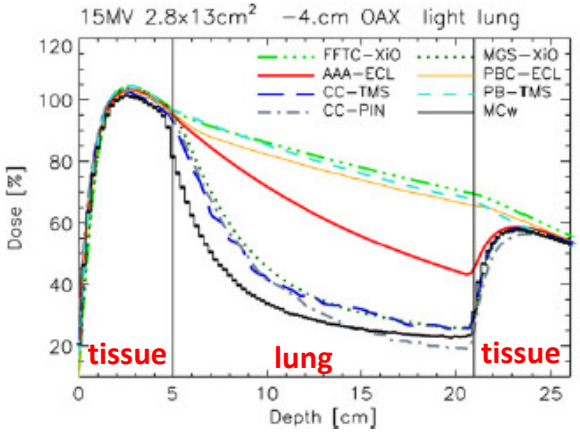


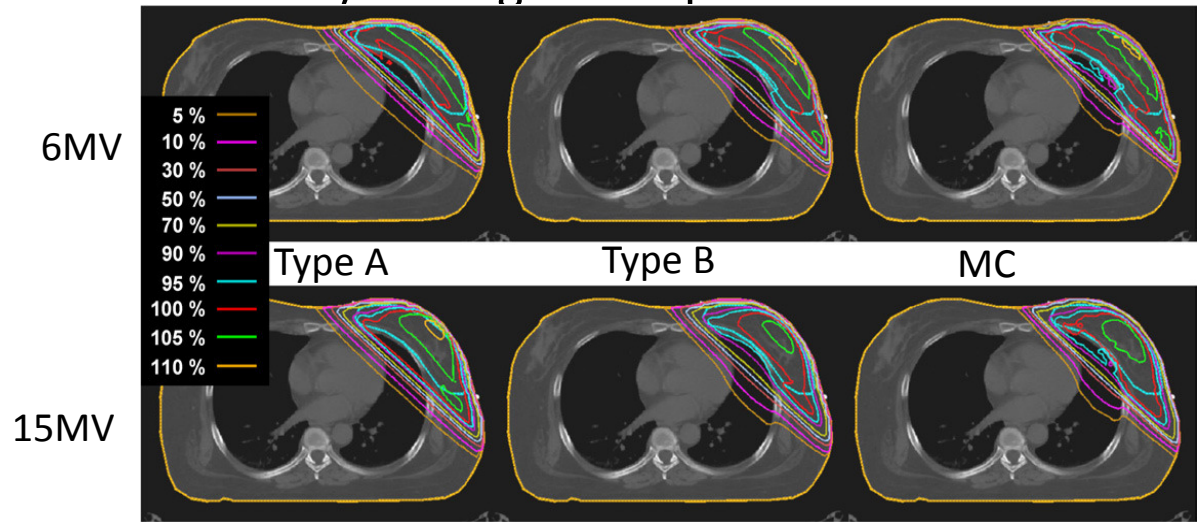
$$D(\bar{r}) = \int_E \int \int \int_{\text{volume}} T_E(\bar{s}) h_{\rho_{\text{water}}}(E, \bar{r} - \bar{s})\, \mathrm{d}^3 s\, \mathrm{d}E$$



Types of dose calculation algorithms in <u>modern</u> commercial TPS

- **"Type A",** e.g. (FFT) Convolution - homogenous spatially invariant objects.
- **"Type B",** e.g. Superposition – inhomogeneities
- **Monte Carlo** – individual particle (photons **and** electrons) tracing inside patient and dose calculation.





6. Image Guided RT (IGRT)

Why?

To eliminate setup error and reduce random error we need to detect the position of our treatment volume (or some surrogate), quantify the difference from the intended position, and then correct by adjusting the Linac couch position (x,y,z and roll).

How?

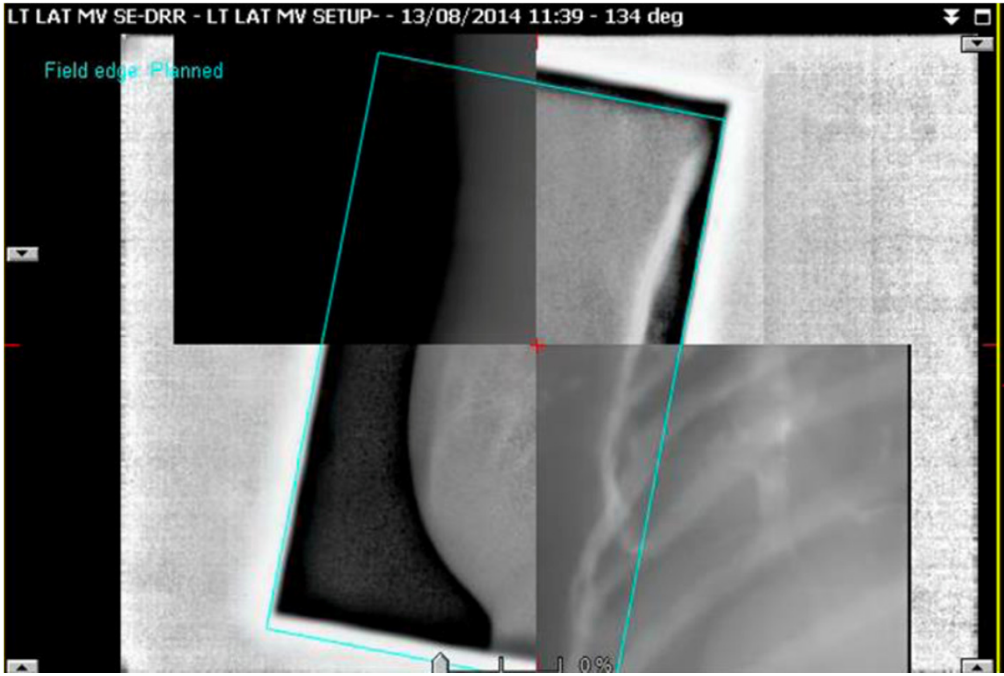
1. On-line treatment verification: The use of images acquired immediately before treatment delivery
2. Off-line treatment verification: The use of images after treatment has been delivered.

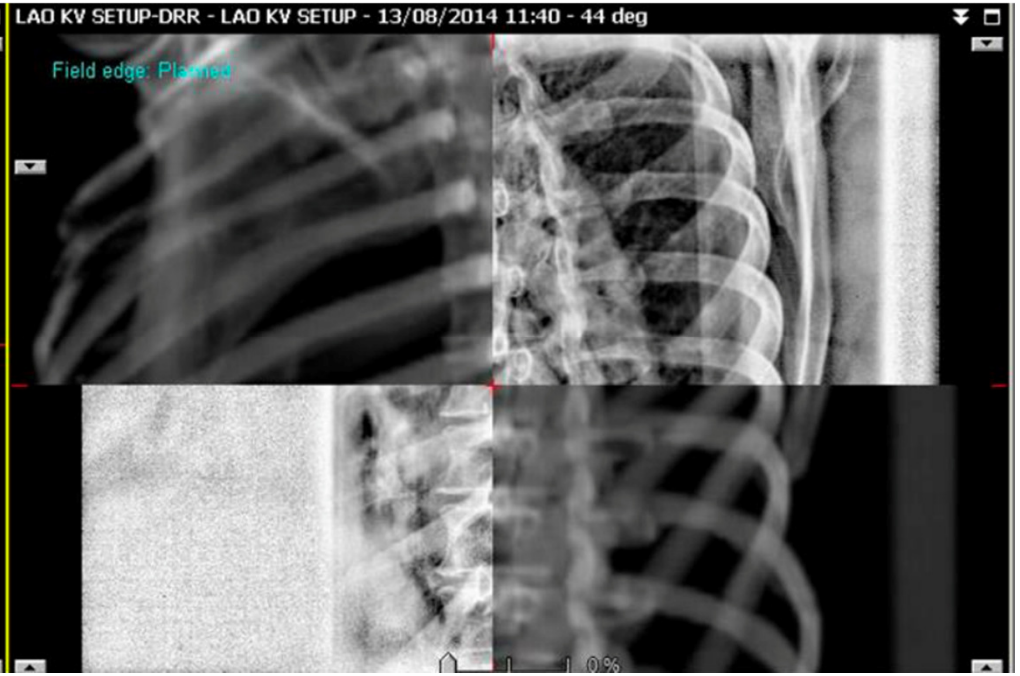
2D example - Breast

•MV tangent portal image
- – Align chest wall
- – Allows visualisation of breast contour and arm position

•kV orthogonal (anterior-oblique) image
- – Align chest wall and spine
- – Allows visualisation of rotation

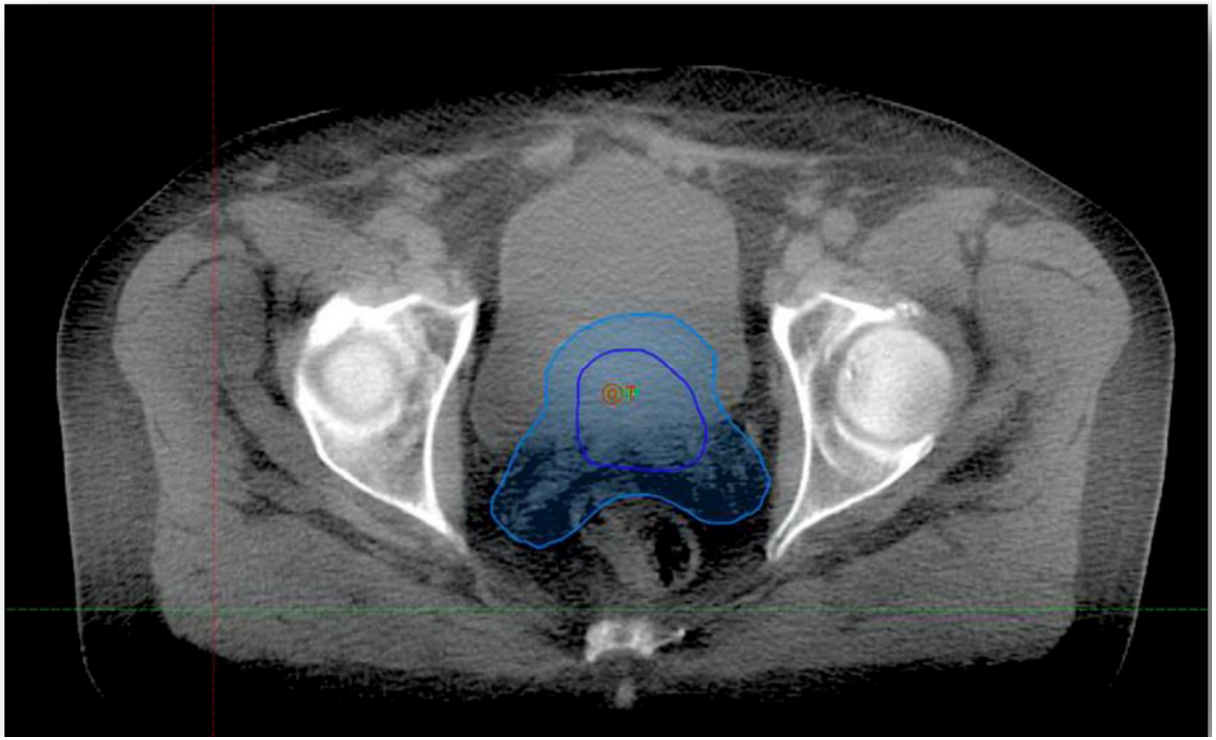
•Once bony alignment is complete, check coverage of breast tissue (flash, coverage to the inferior) and compromise if necessary



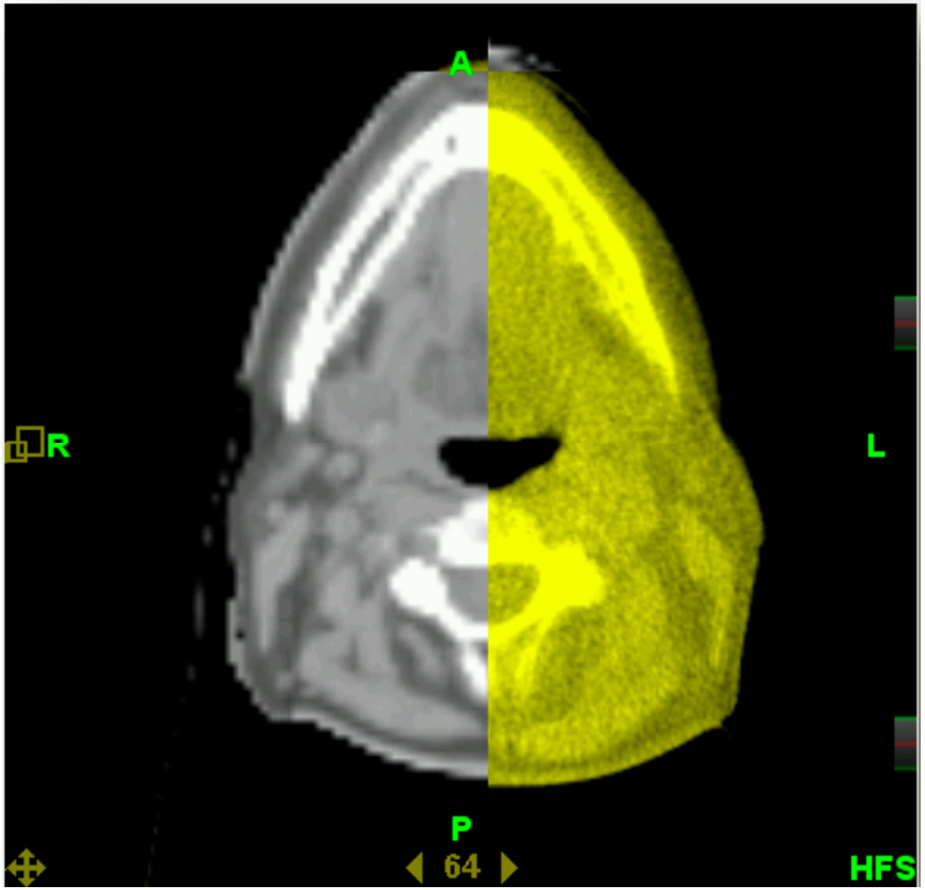


3D example – Prostate and HN

Prostate - Soft tissue matching

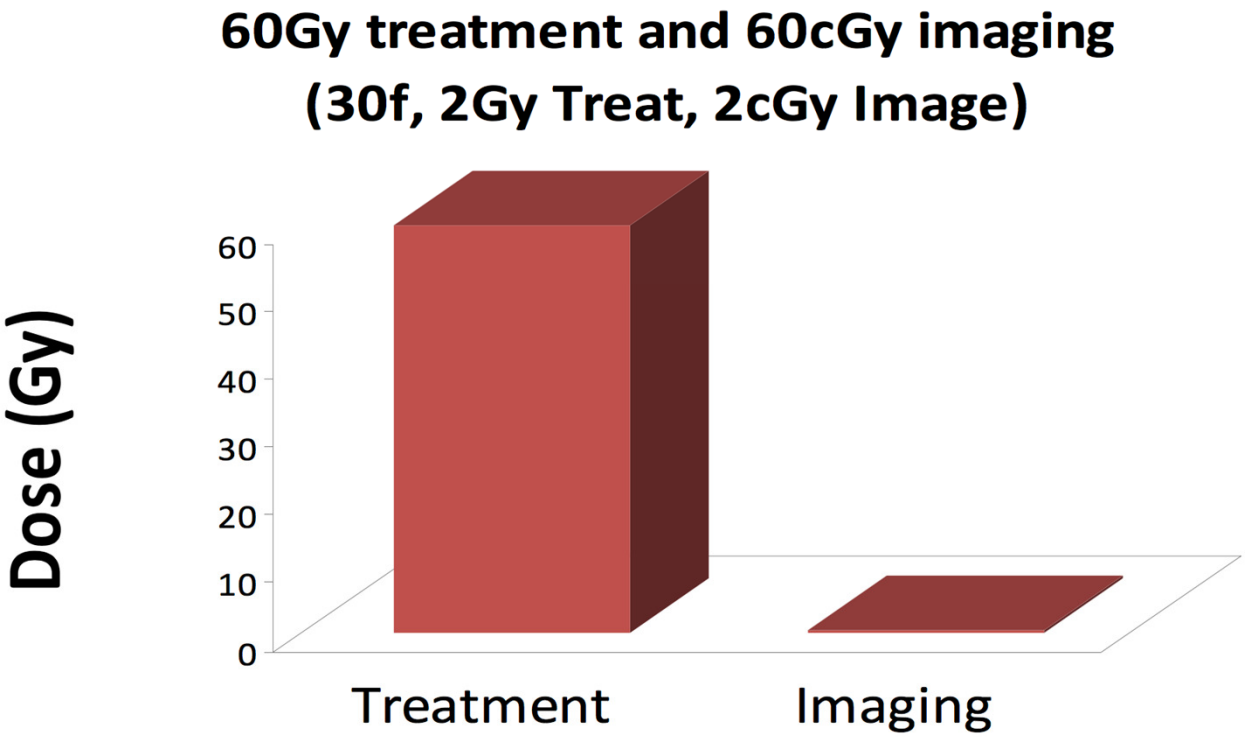


Head and neck – boney alignment as surrogate for target



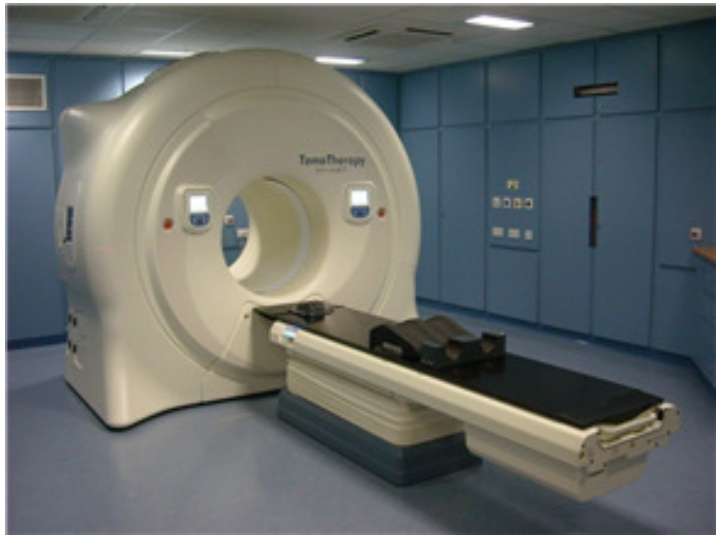
Concomitant Imaging Dose

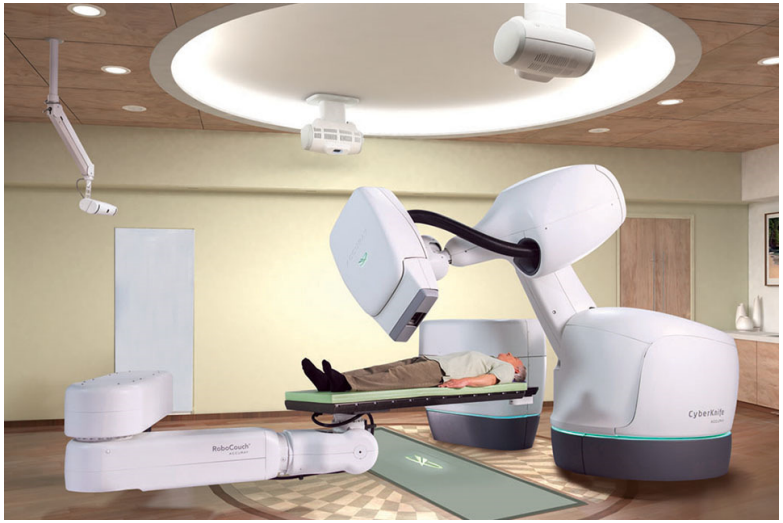
- Say each of our IGRT imaging sessions gives a dose of ~2cGy (0.02Gy)
- Quantified in this way, IGRT contributes a dose of ~1% of the prescription



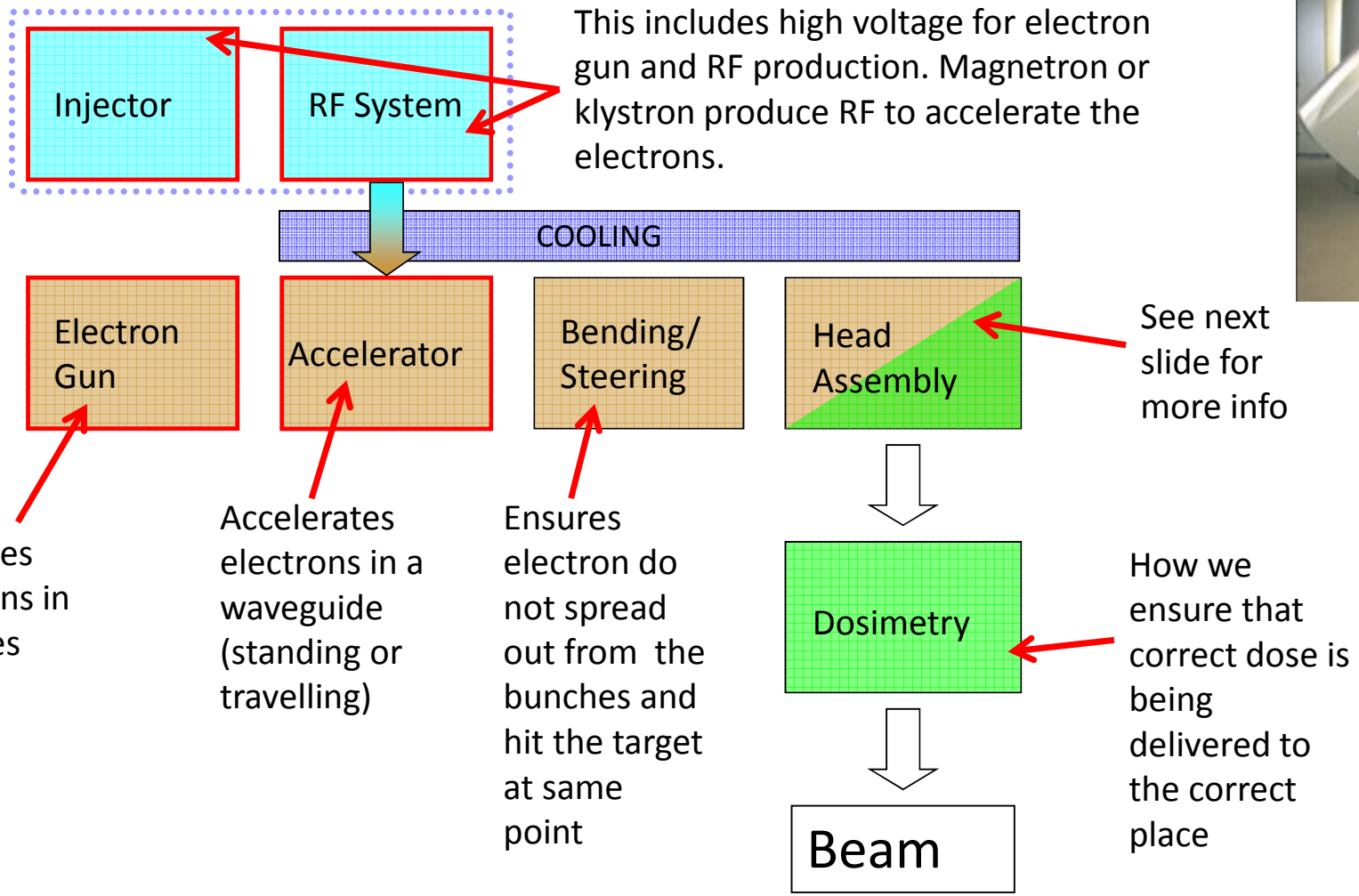
- Imaging dose from IGRT is much less than treatment dose
- Any dose could have a biological effect, e.g. secondary carcinogenesis
- Dose to patient needs to justified according to the law (IRMER)

7. Treatment Delivery





How a Linac Works - Overview



Treatment Head

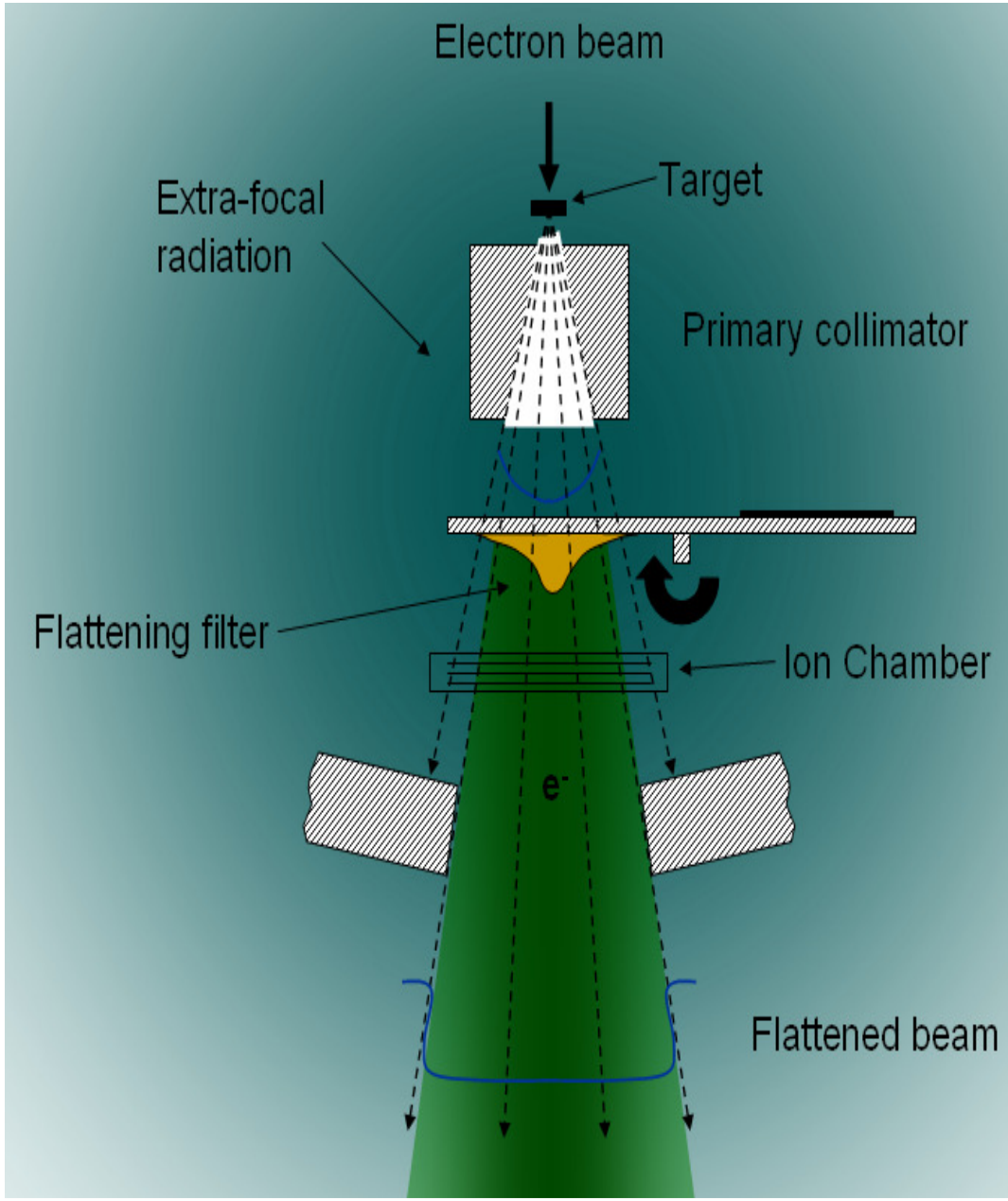
Target – Produces photons via electron interactions with Tungsten target

Primary Colls – define max field size

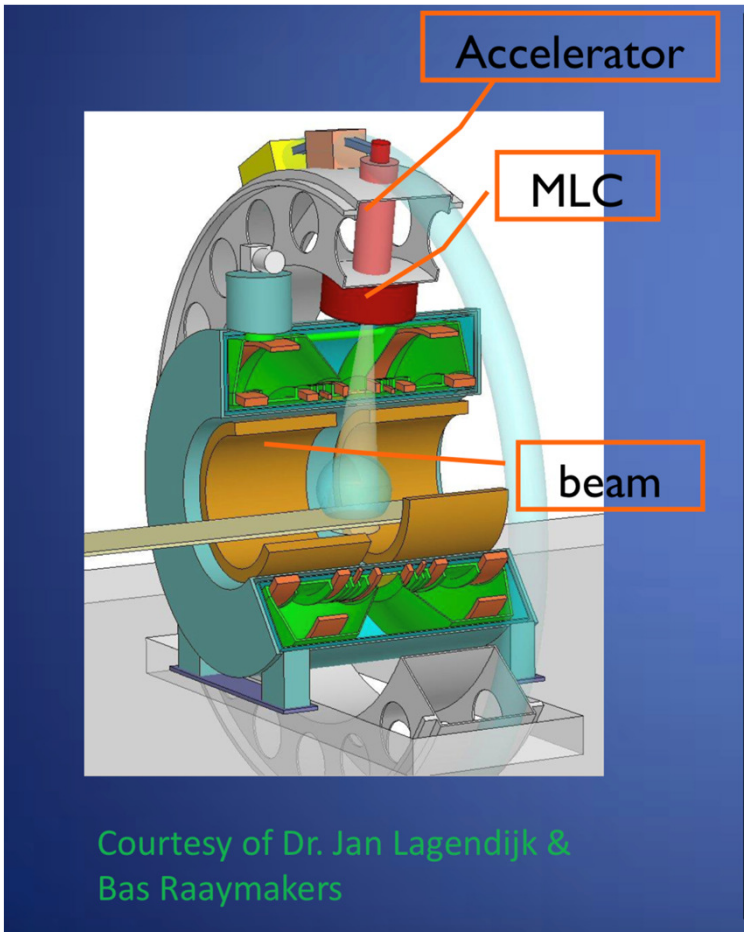
Flattening filter – produces a flattened beam

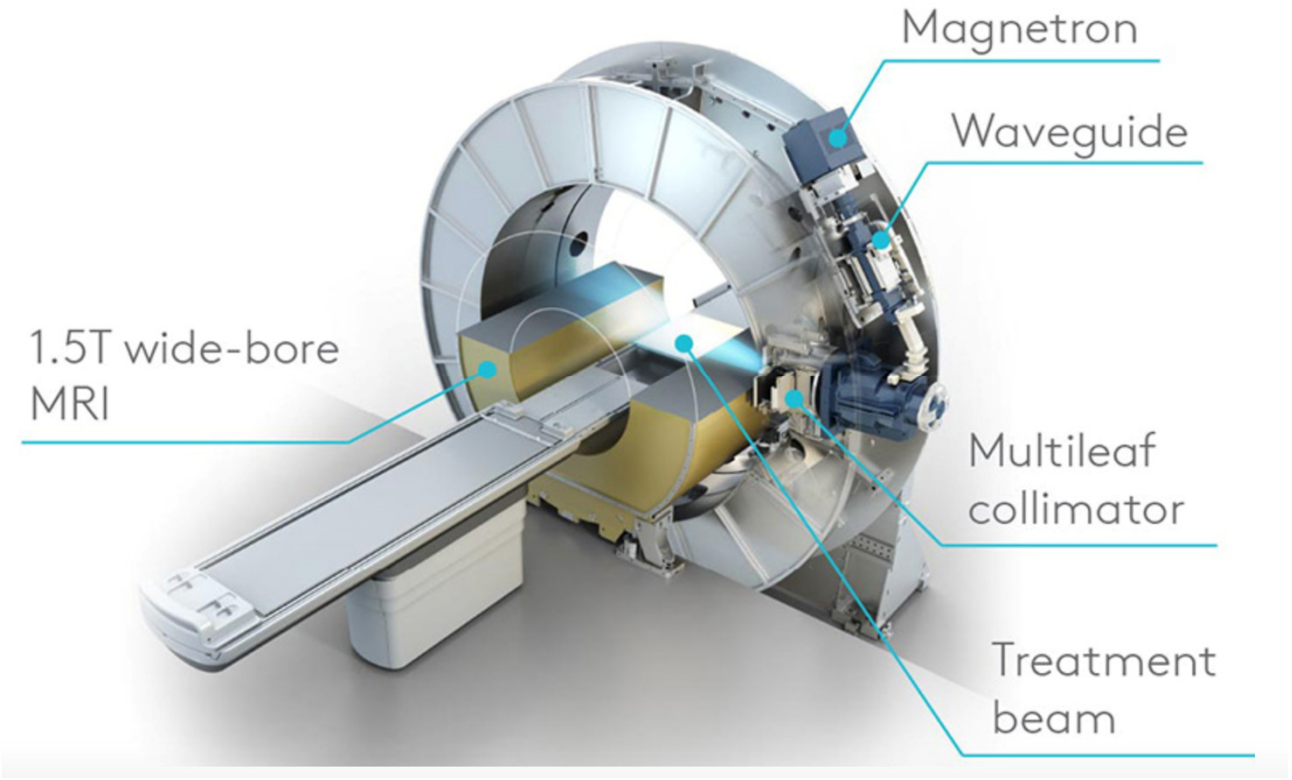
Ion chamber – monitors dose, this is main safety interlock

Secondary colls and MLCs – define field size and shape

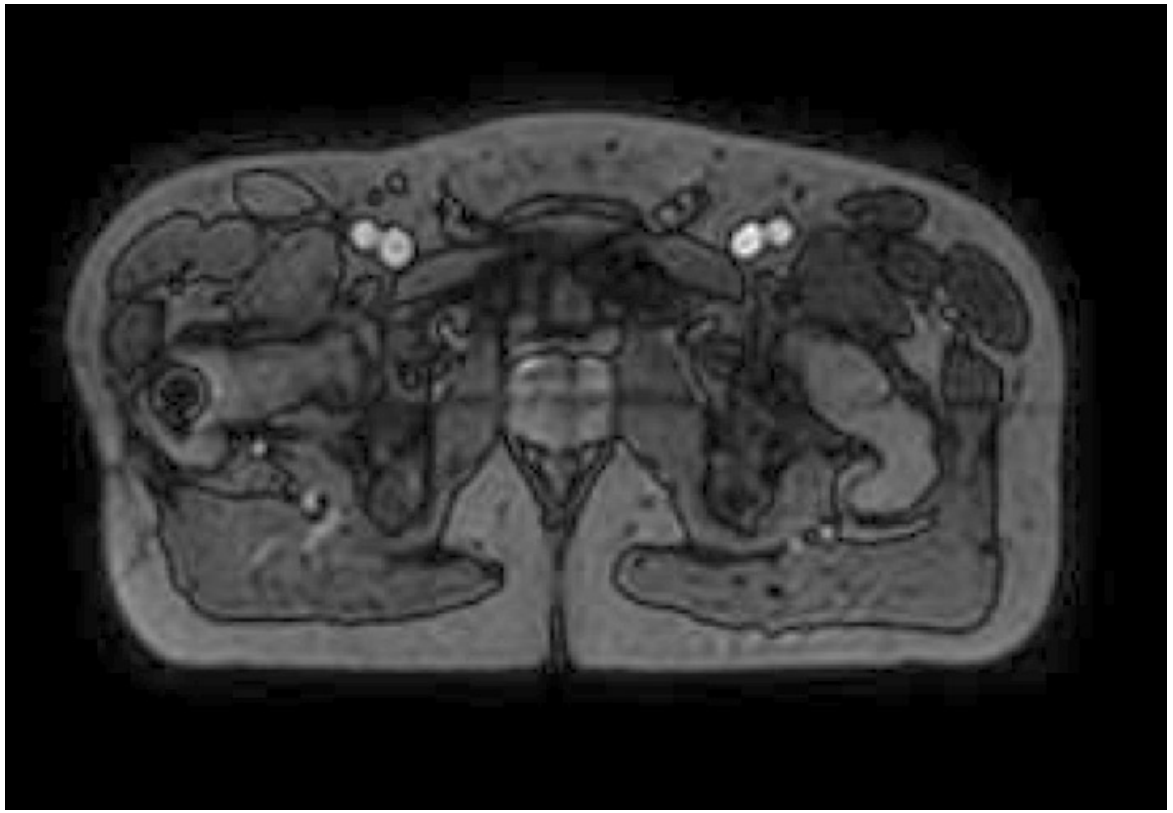


MR-linac


Accelerator
MLC
beam
Courtesy of Dr. Jan Lagendijk &
Bas Raaymakers


Magnetron
Waveguide
1.5T wide-bore
MRI
Multileaf
collimator
Treatment
beam

MR-Linac; Superior soft tissue contrast and real time imaging



http://mindsofmedicineinaction.henryford.com/videos/viewray-mr-linac-first-in-world-at-henry-ford-cancer-institute-hfci

Thank you