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DOSIMETRY FOR RADIATION TREATMENT

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**MDAnderson
Cancer Center**

Making Cancer History®

TODAY'S TOPICS

1. Types of radiotherapy
2. Components of dose (*known verses unknown*)
3. Treatment process and records
4. Dosimetry for late effects studies
5. Managing data for epidemiological studies
6. *Dosimetry challenges for modern radiotherapy (time permitting).*

Types of Radiotherapy

External Radiotherapy

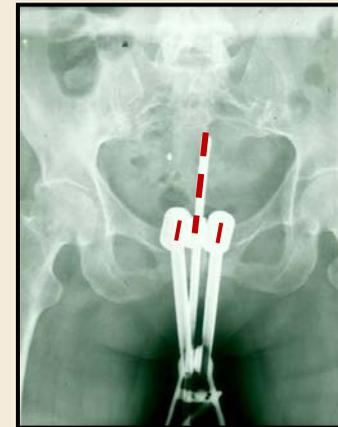
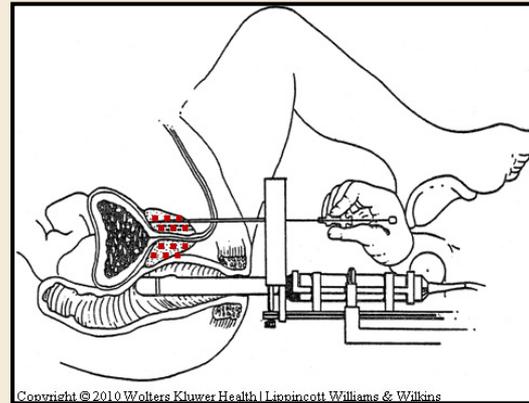
- External source of radiation aimed from outside body.
- Most common: MV photon beam therapy using linear accelerator.



External beam figure from:
<http://www.cancer.gov/cancertopics/factsheet/Therapy/radiation>

Internal Radiotherapy

- Internal source of radiation implanted inside the body.
- Most common: brachytherapy with implanted radioactive source.



Prostate figure from: FM Khan. Physics of Radiation Therapy
4th ed., ISBN: 978-0-7817-8856-4, 2010

Components of Dose

Therapeutic verses Stray Radiation

- Therapeutic radiation is specifically intended to treat the target volume, i.e. intended dose → **Known Dose.**
- Stray radiation is radiation outside the therapeutic beam, i.e. unwanted consequence → **Unknown Dose**

Components of Dose Therapeutic Radiation

- Therapeutic radiation is the radiation inside the defined therapeutic treatment field.
- High dose to intended target volume.
 - Organs in close proximity to the intended target may also receive high doses.

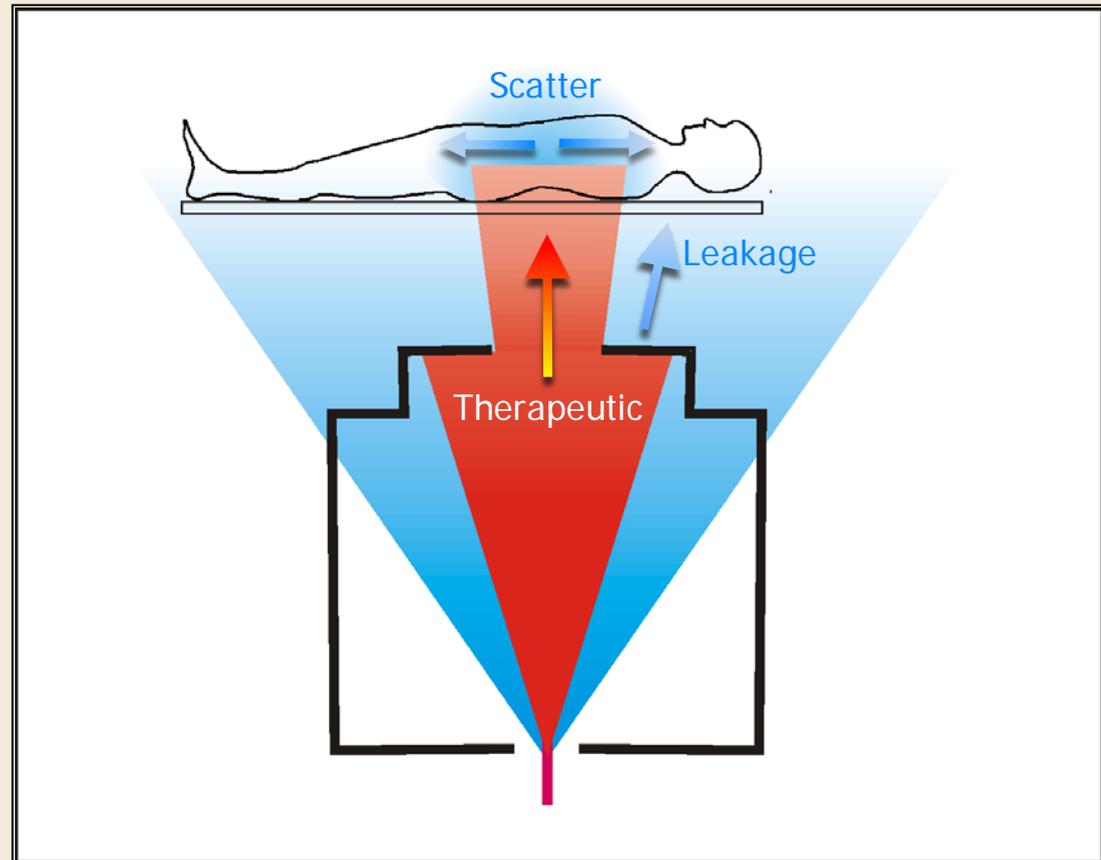
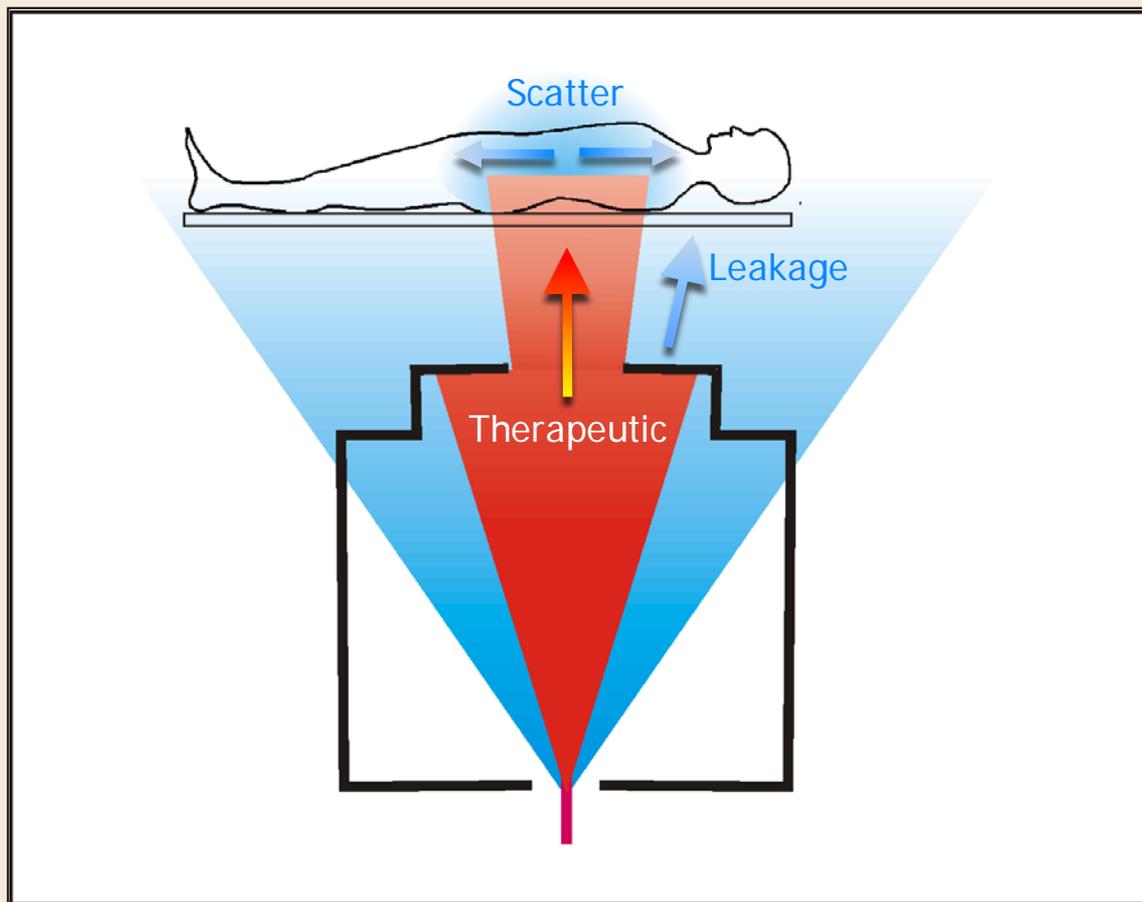


Figure from: WD Newhauser and M Durante, Nature Reviews Cancer, *at press*

Components of Dose

Therapeutic versus Stray Radiation

- Stray radiation is radiation outside the therapeutic beam.
 - Includes scatter and leakage radiation
- Results in low dose to organs throughout the body (even those far from target volume).



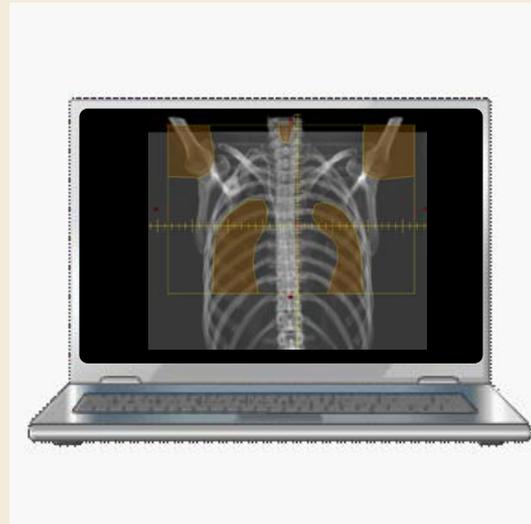
IMPORTANT !

All organs receive some dose from any radiation therapy treatment field.

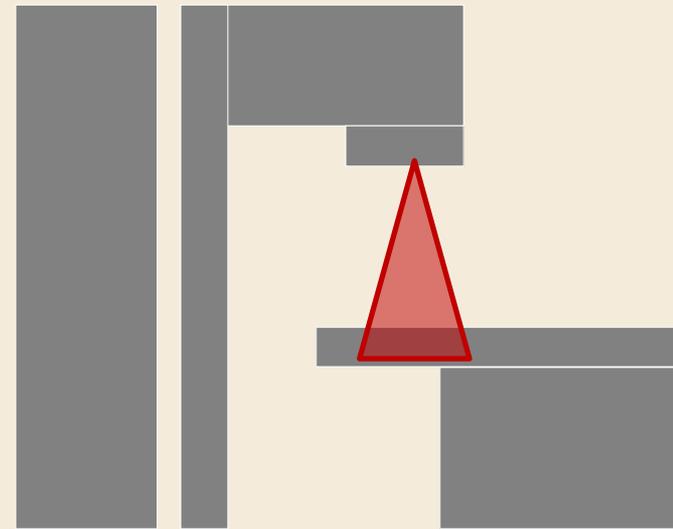
The Treatment Process



Imaging



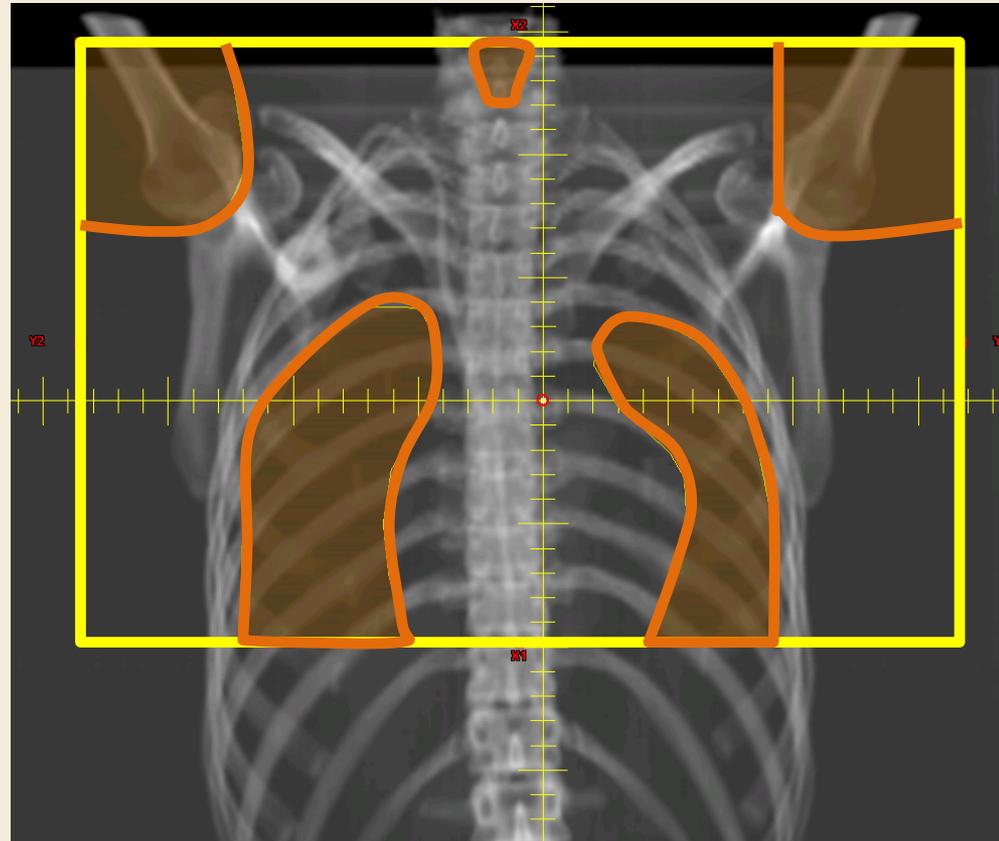
Planning



Treatment

The Treatment Record

- Type of radiotherapy
- Total therapeutic dose
- Dose per fraction
- Number of beams
- Beam orientation
- Beam energy
- Radiograph with field geometry(s)



- What's not in the treatment record? **Stray radiation dose.**

Commercial Treatment Planning Systems (TPS)

Current standard of care in radiotherapy:

TPS calculates dose to region of anatomy included in CT scan.

- Accurately calculate therapeutic dose.
 - Accurate up to ~ 3-5 cm beyond field edge.
- Do not accurately calculate stray dose.
 - **Dose is still reported, but is not accurate.**
 - Accuracy decreases with distance from the field edge.

Dosimetry for Late Effects Studies

Dosimetry

Late Effects Studies

Patient Data

Abstract radiotherapy records for individual patients.



Therapeutic dose is known from Rx record, stray dose is unknown. **Out of field dosimetry is required.**

Physics Data

Use abstracted data to measure and/or calculate organ doses for individual patients.

Out-of-Field Dosimetry for Late Effects Studies

Calculations

- Analytical dose model + mathematical phantom
frequently used can be customized for special projects

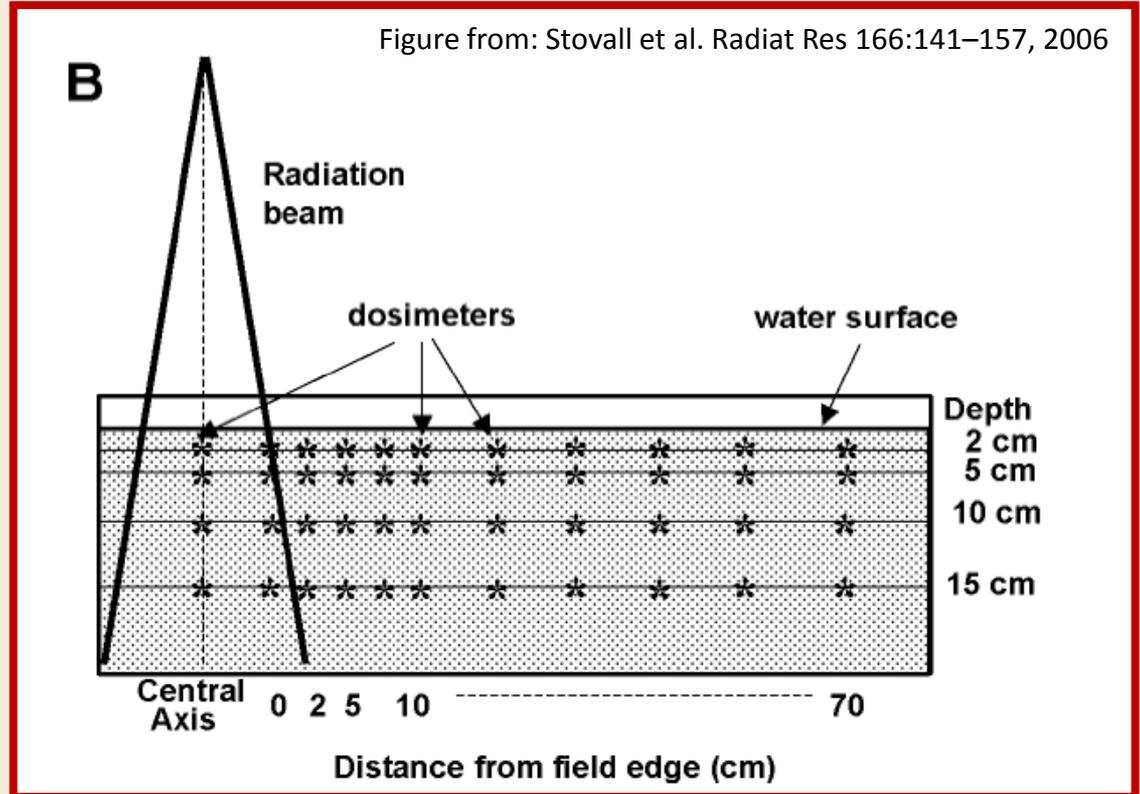
Measurements

- Anthropomorphic phantoms - frequently used
can be customized for special projects

- Treatment Planning Systems - not routinely used due to inaccuracy outside treatment field
- Monte Carlo simulations - not routinely used because computationally demanding.

Analytical Model of Out-of-Field Dose

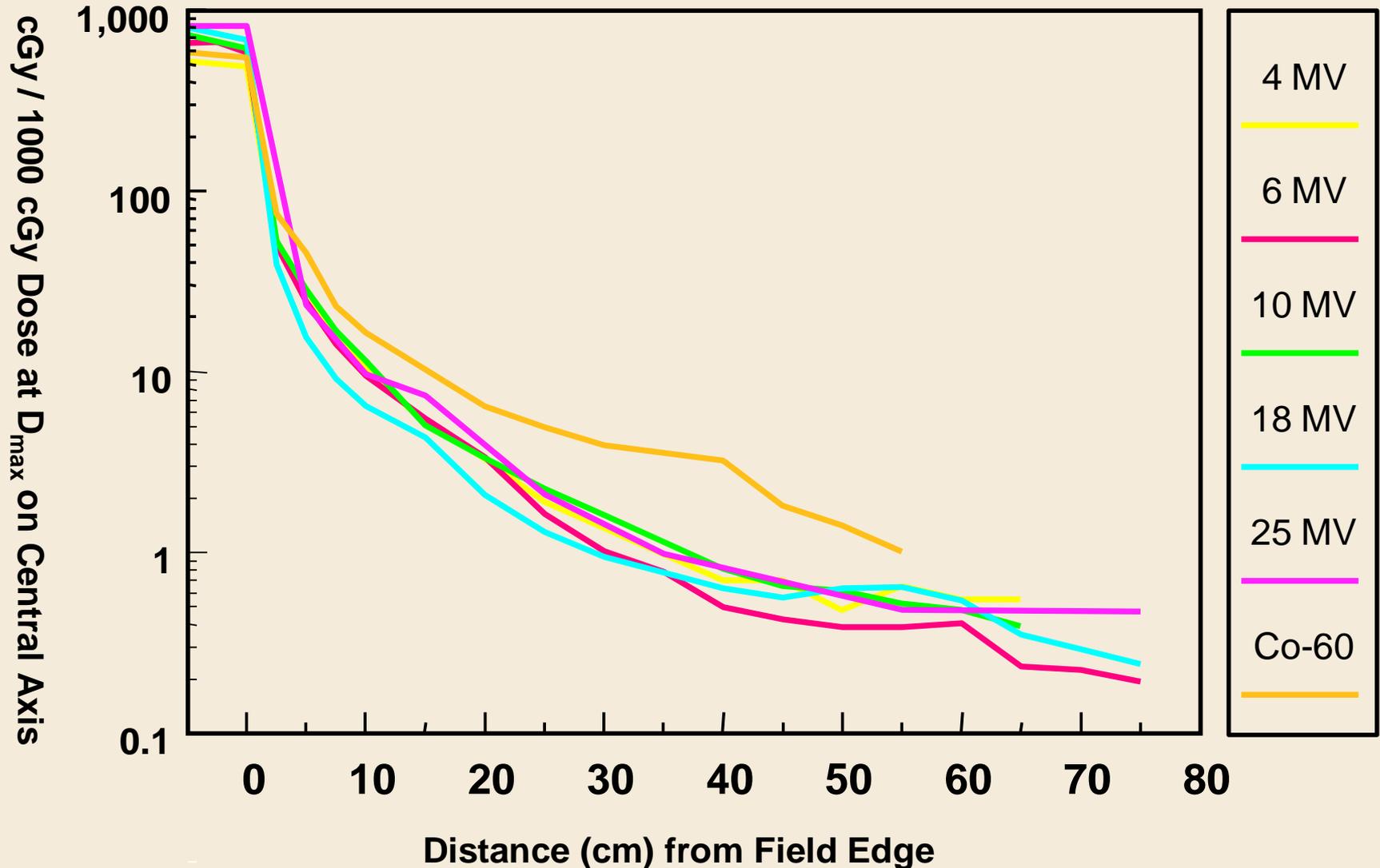
- Dose outside the treatment beam was measured in large water phantom
 - Various beam energies and field sizes.



Data were fit to analytical models to derive doses at specified distances from the field

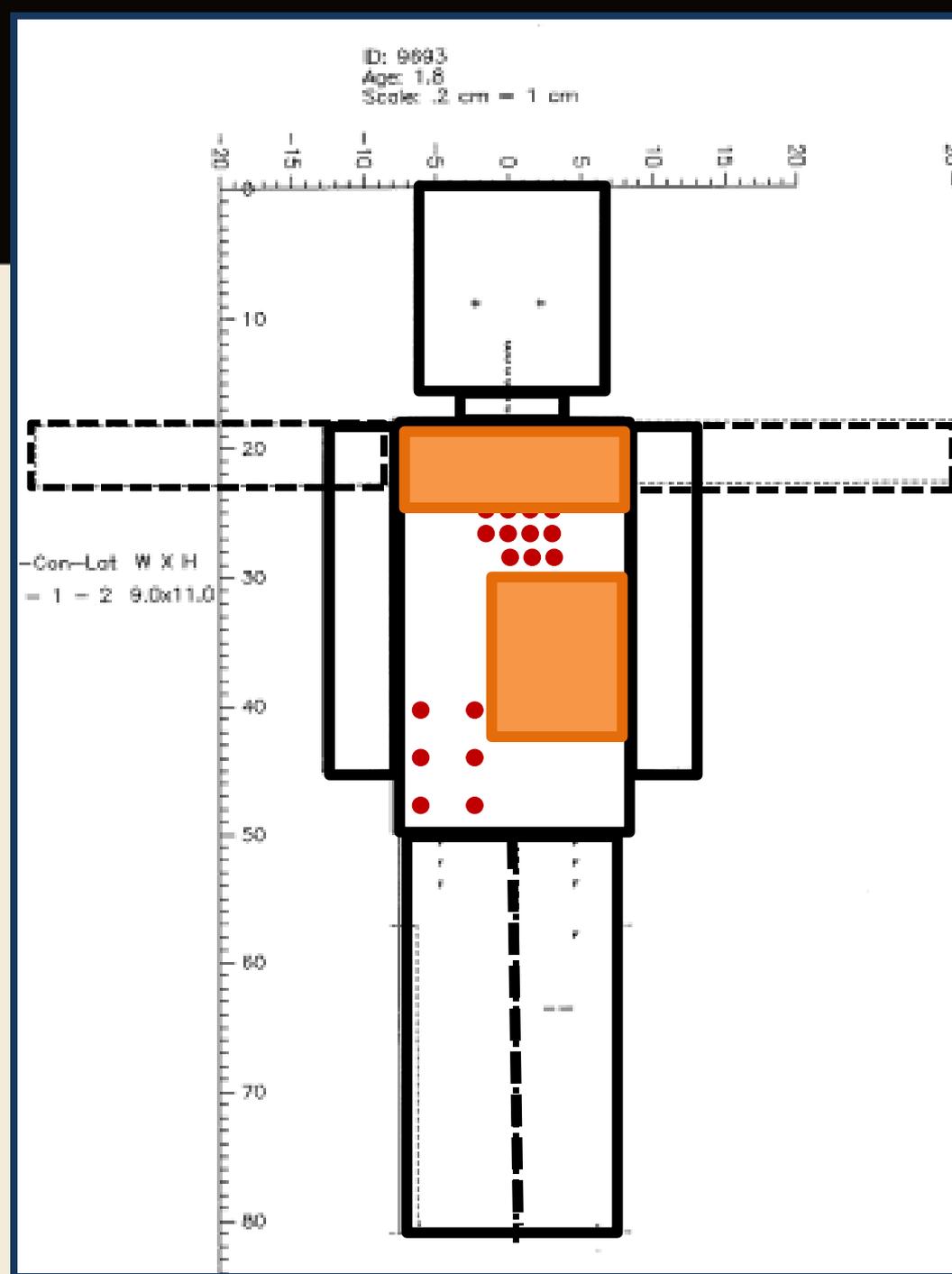
Total Absorbed Dose from Treatment Beams

6 MV Photon - 10x10 cm² Field Size - Various Energies



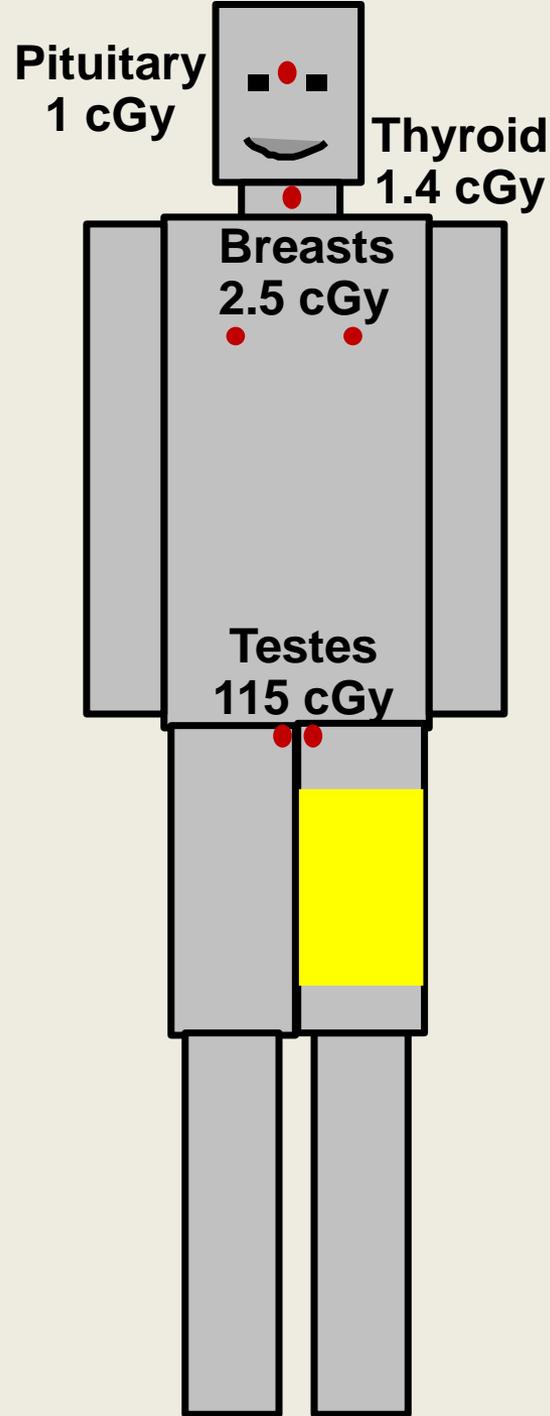
Mathematical Phantom

- Organs represented by a grid of points.
 - Grid can be moved.
 - Grid resolution can be \uparrow or \downarrow .
- Field can be placed in any position.
- Field geometry can be varied



Mathematical Phantom Example

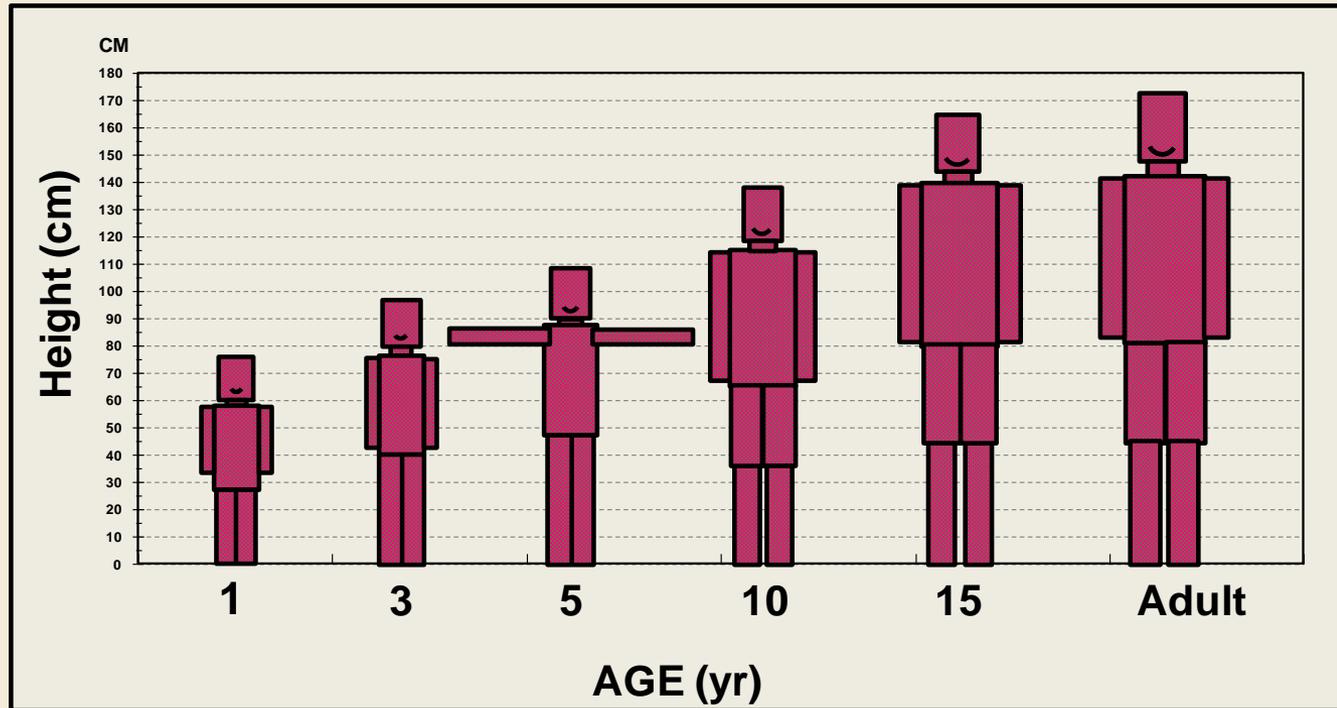
- **Details from RT record**
 - 16 year-old male treated for an osteosarcoma (bone cancer) in the left thigh.
 - Field size: 12x17 cm²
 - Field orientation: AP/PA
 - Target dose: 55 Gy
 - Beam type/energy: 6 MV photons
- Mathematical phantom + analytical model used to calculate dose to out-of-field organs.



Mathematical Phantom(s)

Advantages

- Phantom size can be modified to represent patient of any age.
- Models representing 7 age groups are shown in figure.



- Mathematical phantoms are also inexpensive to use.

Measurements with Anthropomorphic Phantoms

Advantages

- They most nearly simulate a real person.
- Commercially available from several manufacturers.

Disadvantages

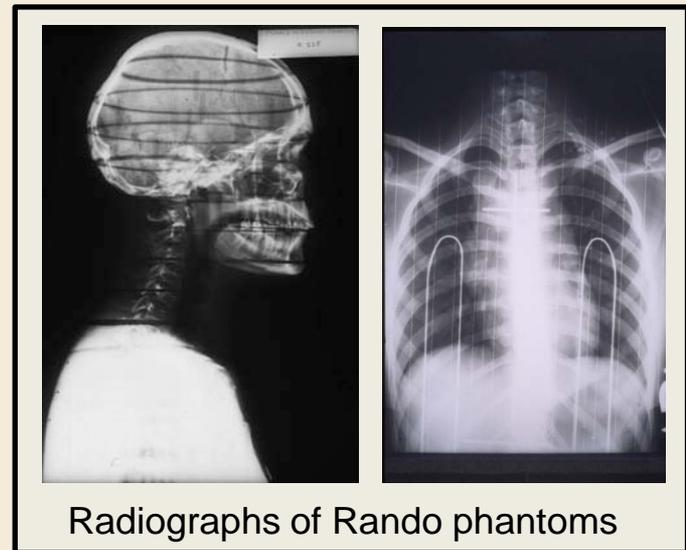
- Only available limited sizes.
- Expensive to buy and use.
- Internal organs are in a fixed position.

Anthropomorphic Phantoms

- Available sizes: 6-yr old child, adult male, and adult female



- They are made of 3 materials:
 - Natural human skeletons
 - Tissue-equivalent lungs
 - Tissue-equivalent soft tissue



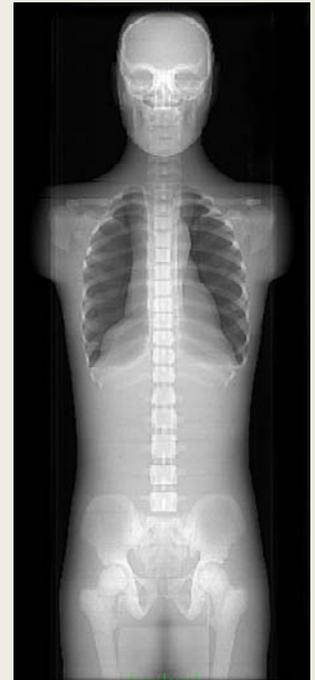
Anthropomorphic Phantoms

- Available sizes: newborn, 1-year old, 5-year old, 10-year old, adult male, adult female.
- The size of each model is based on ICRP 23, ICRU 48



- **Tissue equivalent materials:**
 - Soft tissue, bone, cartilage, spinal cord, spinal disks, lung, brain, sinus, trachea and bronchial cavities (ICRP-23).
- Simulated bone tissue for pediatric models matches age related density.

http://www.cirsinc.com/700_ct_xray.html



Procedure for Measurements with Anthropomorphic Phantoms

1.



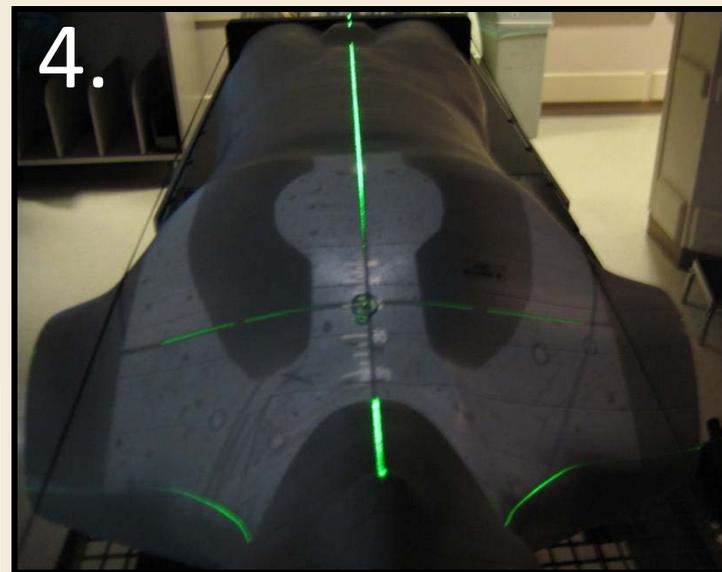
2.



3.



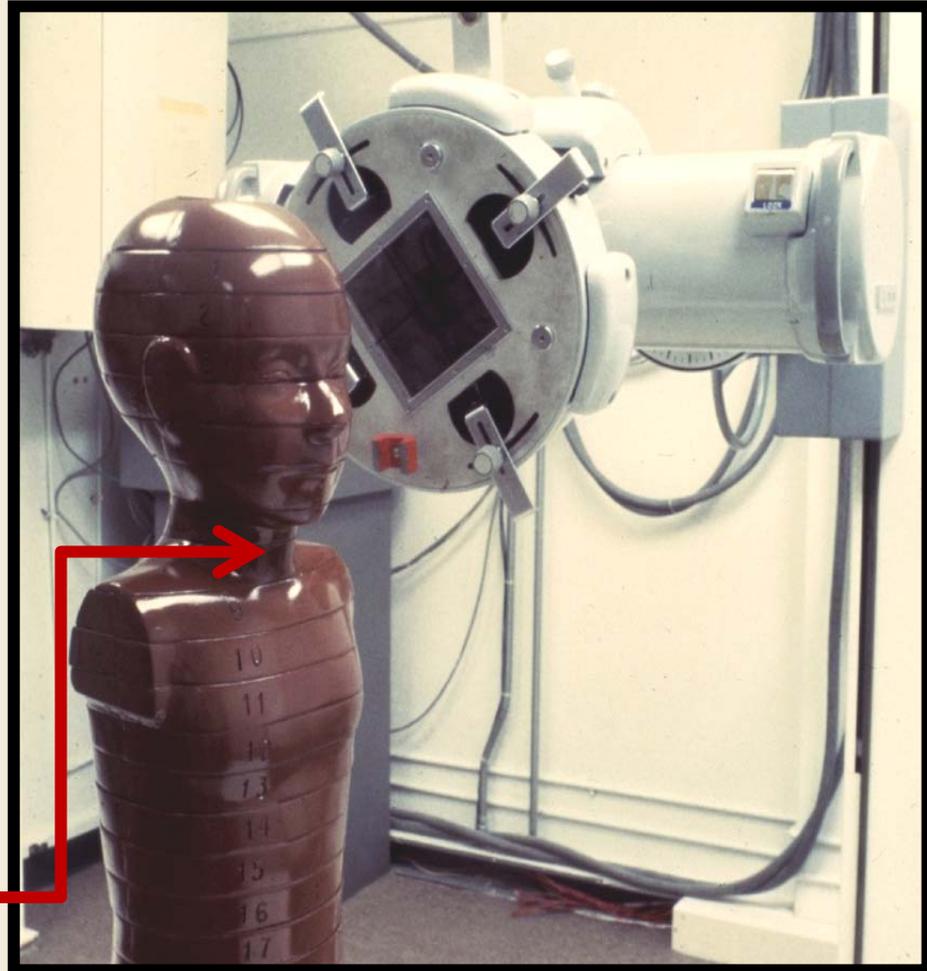
4.



Example of “6-year old” Phantom for Pediatric Study

- Planned radiation fields for treatment of benign tonsil lesion were delivered.
- Measure dose in the phantom at positions corresponding to location of thyroid.

Dosimeters placed in this region of phantom.

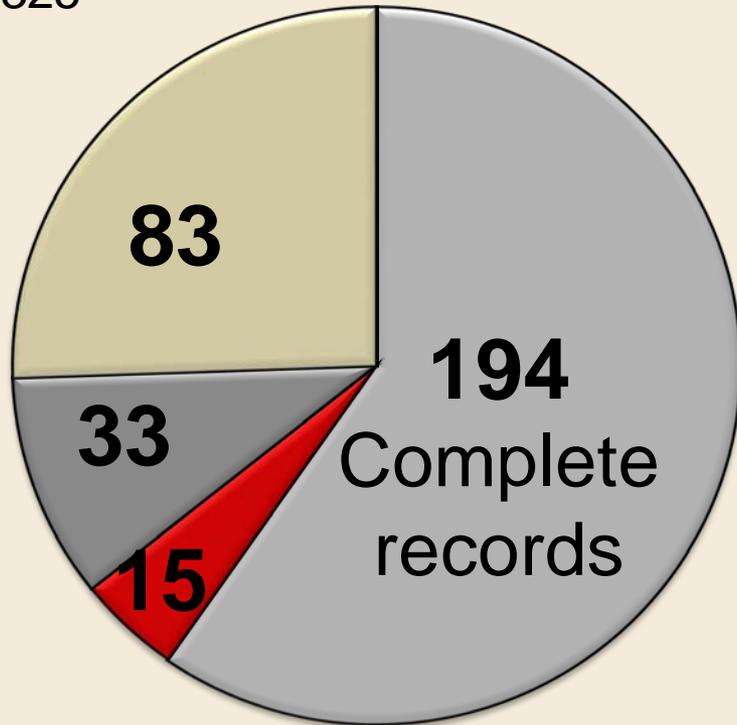


What is the relationship between the quality of the radiotherapy record and adequate dosimetry for epidemiologic studies?

Radiation Therapy Data Received

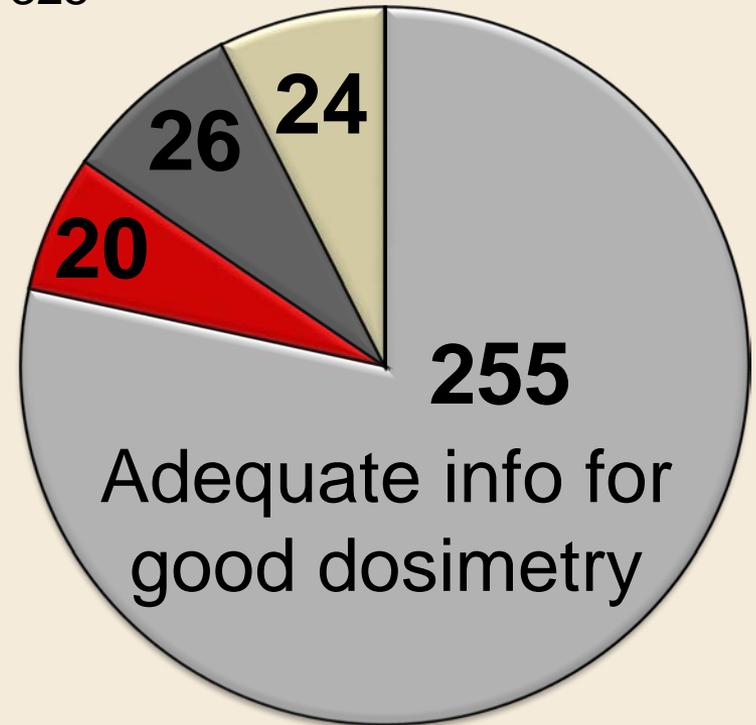
Radiation Therapy Information Quality

n=325



- Unsupported data
- Notes or summary only
- Partial Record

n=325



- Not adequate for dosimetry
- Missing information important
- Missing info not important

Uncertainties Out-of-Beam Dosimetry

Source

Organ near field

Treatment record incomplete

Patient age surrogate for size

Measurement system

Magnitude

Large

Variable

Small

Very Small

Consistency is Essential

- **Within a Study**

- No systematic differences between cases and controls or you may bias a study.
- Maintain same quality of documentation for cases and controls.

- **Across Studies**

- Important to be able to compare data, pool patients, etc. in studies many years apart.
- **If you change dosimetry method**, do it deliberately, with full understanding of the impact on results.

Organ Doses from Typical Pediatric Radiation Therapy

Disease Treated	Age (yrs) at XRT	Regions Treated	Tumor Dose Range (cGy)	Average Dose Range (cGy)		
				Heart	Lungs	Kidneys
Cranio-spinal Tumors	7	Brain only	4500 - 5500	15 – 55	15 - 65	5 – 30
Leukemia	4	Brain only	1800 - 2500	9 – 35	10 – 40	4 – 20
Hodgkin Lymphoma	15	Chest only	3500 - 4500	2800 – 3650	620 – 900	40 – 100
		Chest and Abdomen	3500 - 4500	3500 – 4500	1000 – 1500	950 – 1600
Wilms (Kidney)	4	Abdomen only	1500 - 2500	145 – 330	105 – 265	85 – 210 untreated side
		Abdomen & Chest	1500 - 2500 1200 - 2000	1300 – 2240	1200 – 2100	115 – 300
Neuroblastoma	2	Chest (right)	1200 - 2500	800 – 1850	600 – 1300	15 – 90

Dosimetry for Late Effects Studies

Challenges of Modern Radiation Therapy

Late effects studies require a fairly long latent periods and for that reason they have focused on older conventional radiation techniques.

However, in a few years late effects studies will also include contemporary radiation techniques.

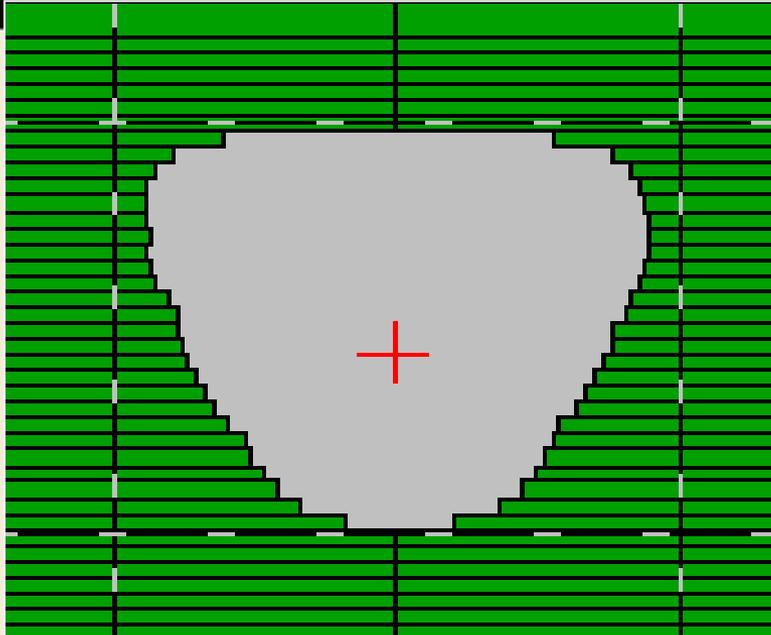
Contemporary Radiotherapy

- Intensity modulated radiation therapy, IMRT

Uses dynamically moving shielding to vary beam intensity based on individual patient anatomy (defined on CT).

- No standardized field borders
- More beams are used
- Beam-on time to deliver specified dose is much longer.

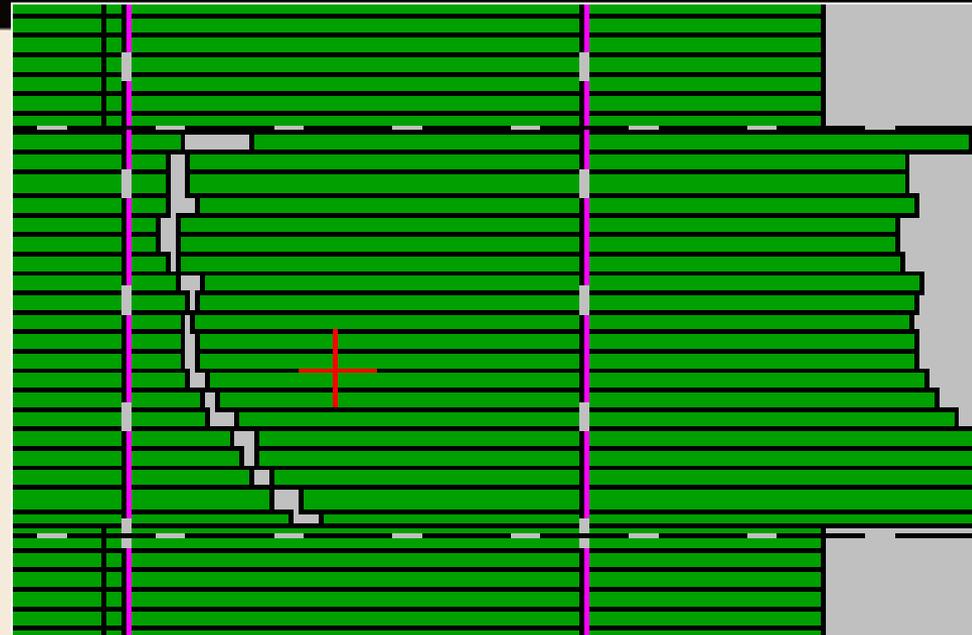
Conventional Radiation Therapy



Static - MLC does not change shape during a radiation beam-on session.

- Deliver one large field all at once.

Intensity Modulated Radiation Therapy



Dynamic - MLC move while radiation is on to custom tailor the intensity of a radiation field

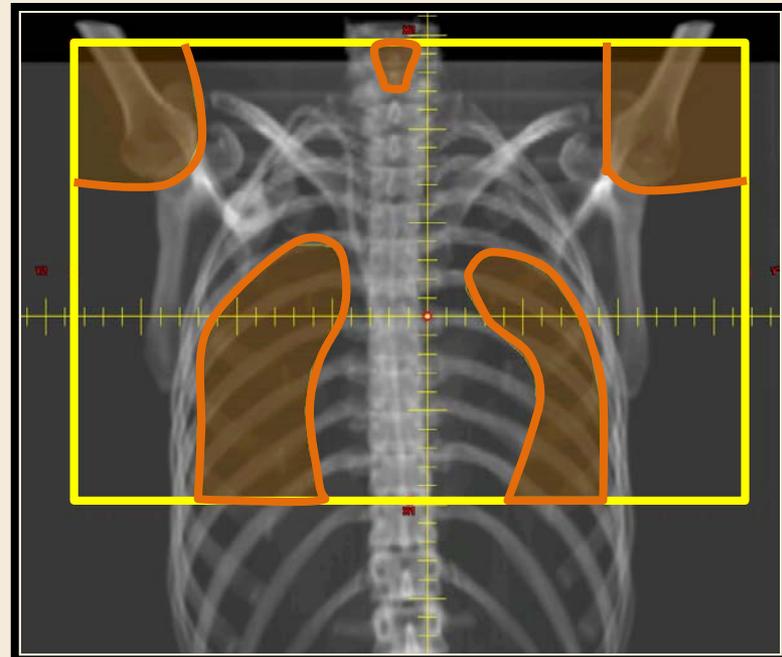
- Deliver small segments at a time.
- Beam on longer to cover entire field size.

**Let's compare an example
of dose reconstruction for
conventional RT and IMRT.**

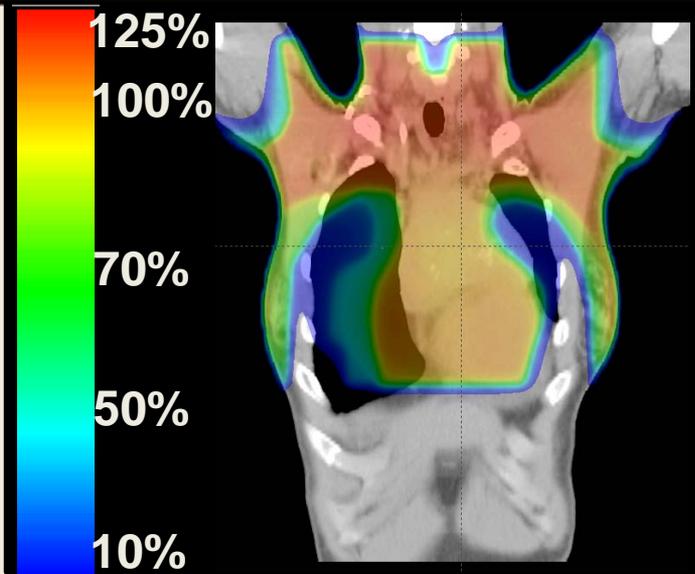
Conventional Radiotherapy

- Conventional beam therapy - Static beam with shielding blocks.
 - Standardized field borders based on anatomical borders
- Example: Hodgkin lymphoma.
 - Superior field border: chin
 - Inferior field border: T10
 - Lateral borders - cover ribcage

Anatomical field borders (from individual RT records) can be used to reconstruct organ doses in phantom.



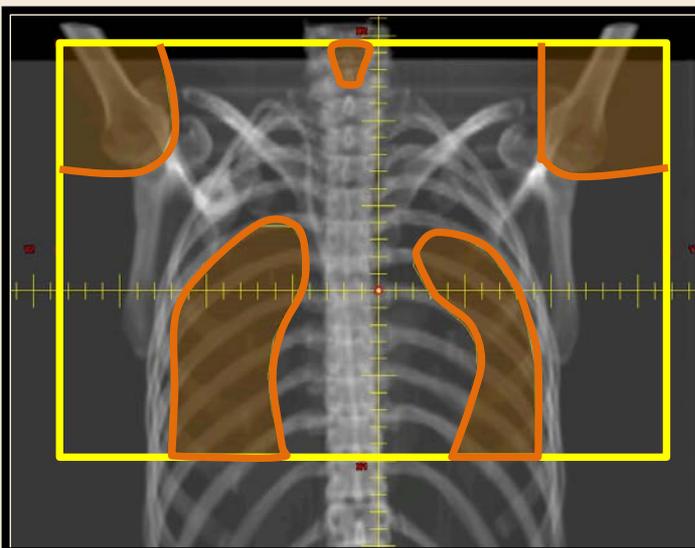
Conventional RT Dose Reconstruction



- Dose distribution for patient treated with conventional mantle field.

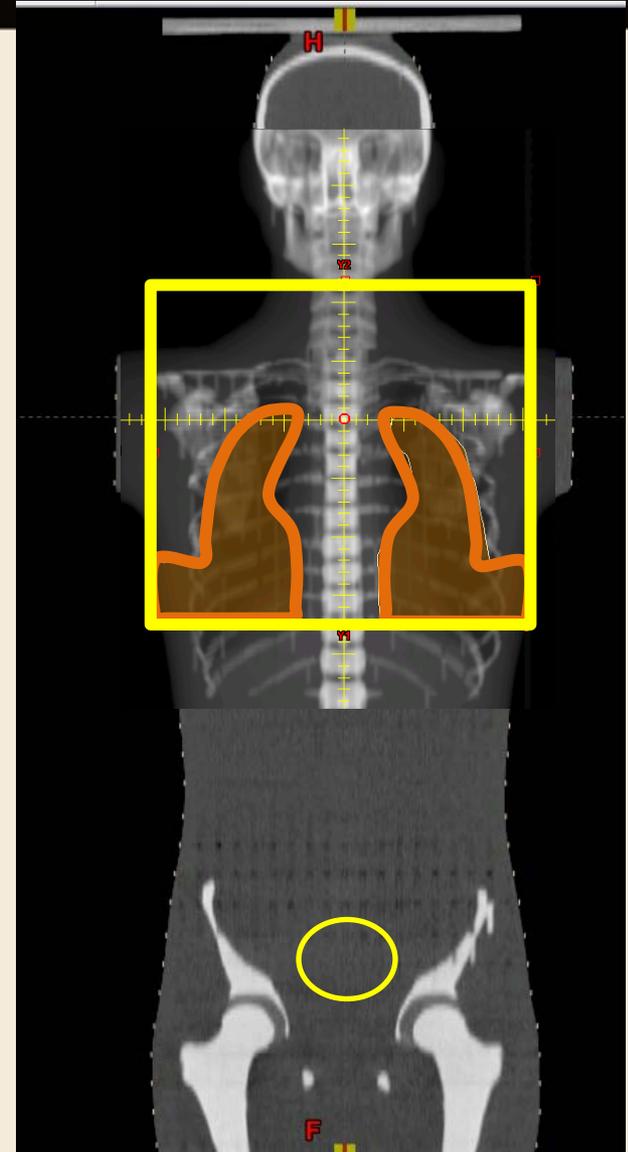


- Treatment field dimensions from treatment record.



Conventional RT Dose Reconstruction

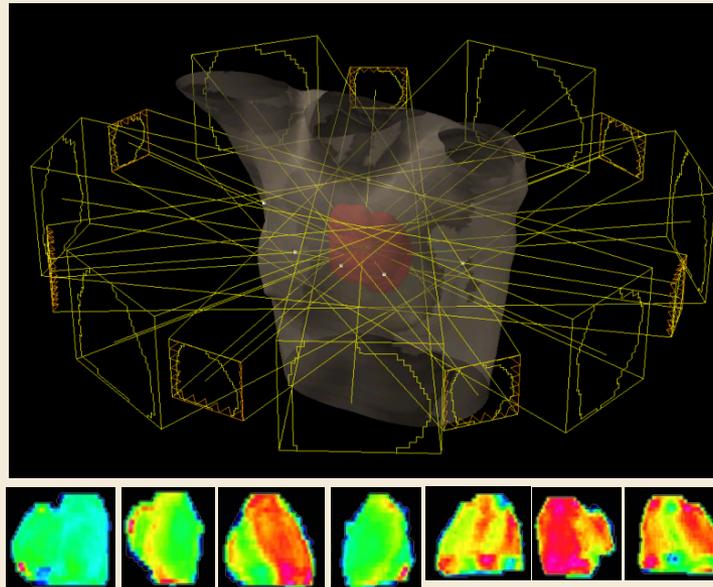
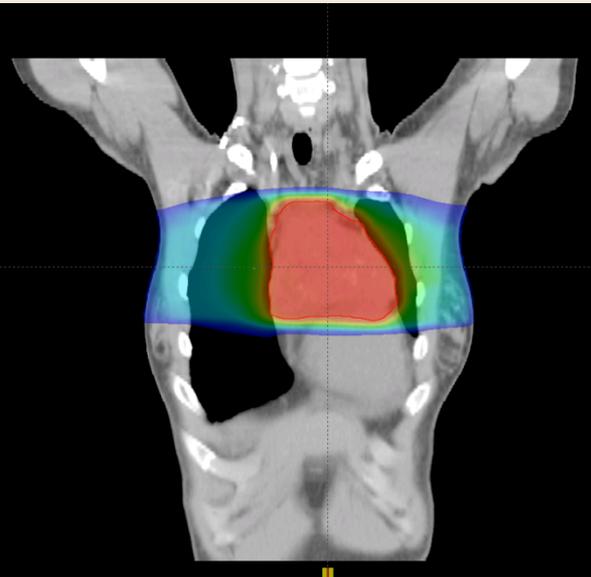
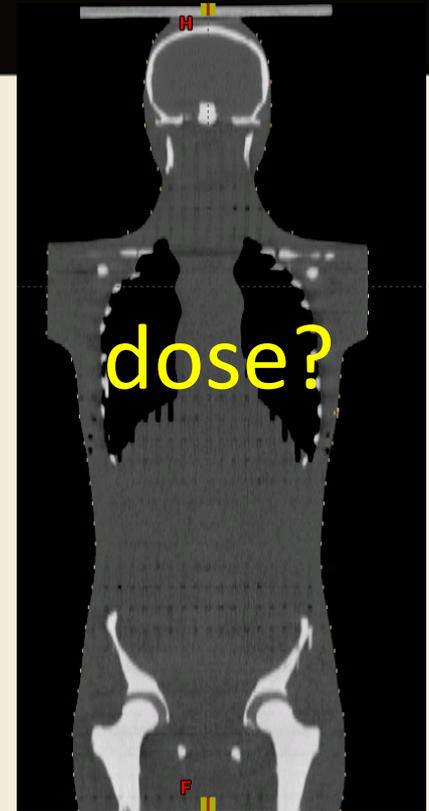
- Treatment field of same dimensions superimposed on phantom (approximately same size/age as patient).
- Dose measured or calculated in phantom (mathematical or anthropomorphic).
- Organ doses can be obtained at defined locations.



IMRT Dose Reconstruction

Typical information in IMRT record:

- PTV dose(s), # fx, isodose distributions in various planes, dose volume histograms, number of fields (and maybe intensity maps).



- From these data, difficult to reconstruct dose in phantom to obtain organ doses outside the field(s).

Monte Carlo Techniques

Monte Carlo Techniques

- The Monte Carlo (MC) technique can accurately determine stray dose to organs outside the treatment field because it relies on first principles of radiation transport physics.

Limitations:

- Different models are required for different radiation treatment machines (external beam) or sources (brachytherapy).
- Models must be benchmarked for both in-field and out-of-field dosimetry with measured data.
- Computationally demanding.
- Patient/treatment specific specific geometries must be defined in MC format.

Looking Forward to Future Epidemiological Studies

- Calculating organ doses from stray radiation for modern advanced-technology radiation therapy techniques is more difficult compared to simple conventional techniques.
 - Monte Carlo is valid method.
 - **Currently, it is not practical for calculations for thousands of patients.**
- In the late 1990s the first cohort of patients was treated with IMRT.
- By the late 2000s IMRT was standard of care for many types of cancer.

Overcoming Limitations of Patient Specific Monte Carlo

Computationally Demanding

- Variance reduction must be incorporated into the MC model.
- High performance computing with large clusters.

MDA HPC Cluster:
1072 processor
computer cluster



Defining Patient/Treatment Specific Geometries

- Code to automatically convert radiation field parameters and CT data defined in commercial TPS in DICOM format to the Monte Carlo input format.

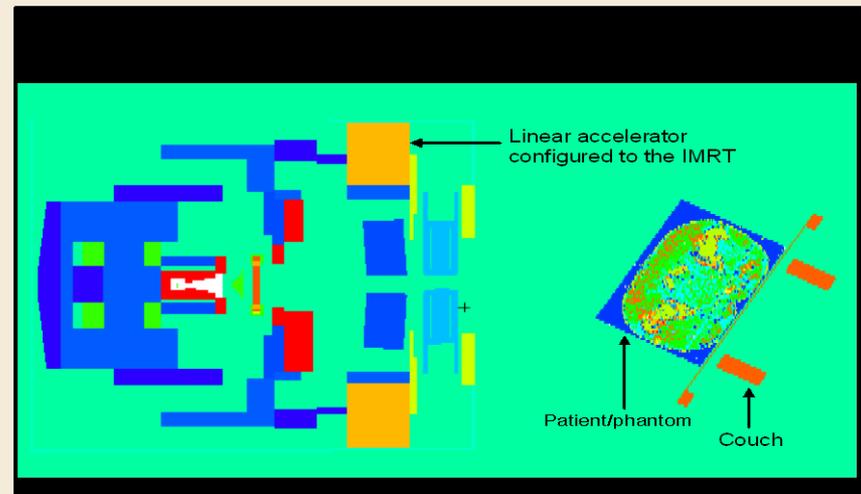
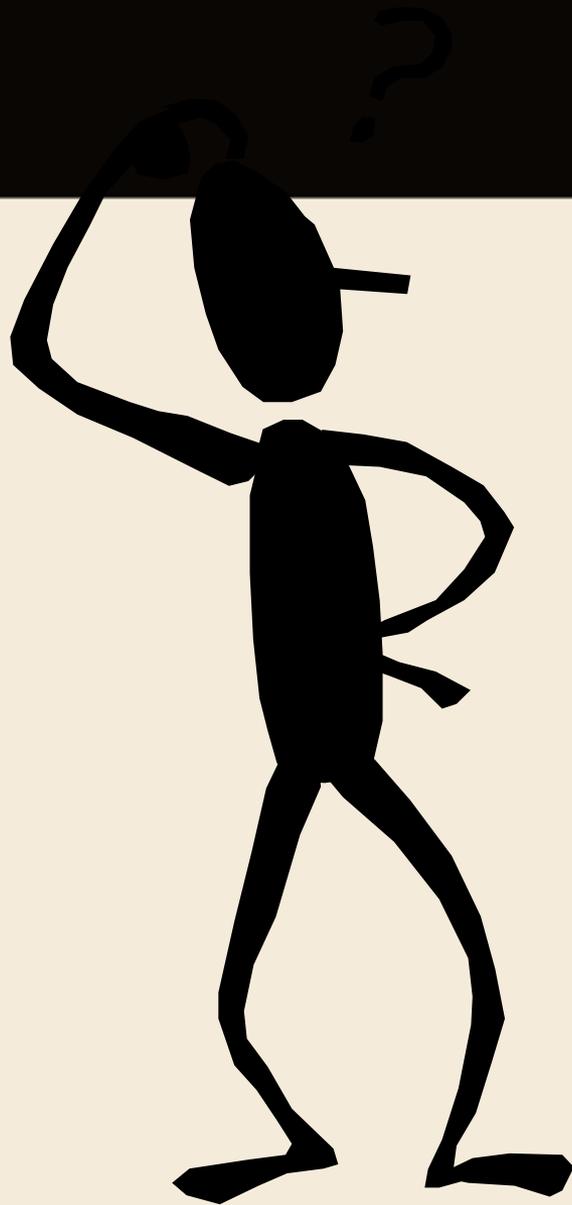


Figure from: Randeniya et al. *in review*

References

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- SD Randeniy, D Mirkovic, SF Kry, U Titt, WD Newhauser, and RM. Howell, Patient-specific Monte Carlo dose calculations for IMRT treatments based on DICOM-RT plan and CT data, Phys Med Biol, *in review*



QUESTIONS

