Radiotherapy Treatment Planning -An overview

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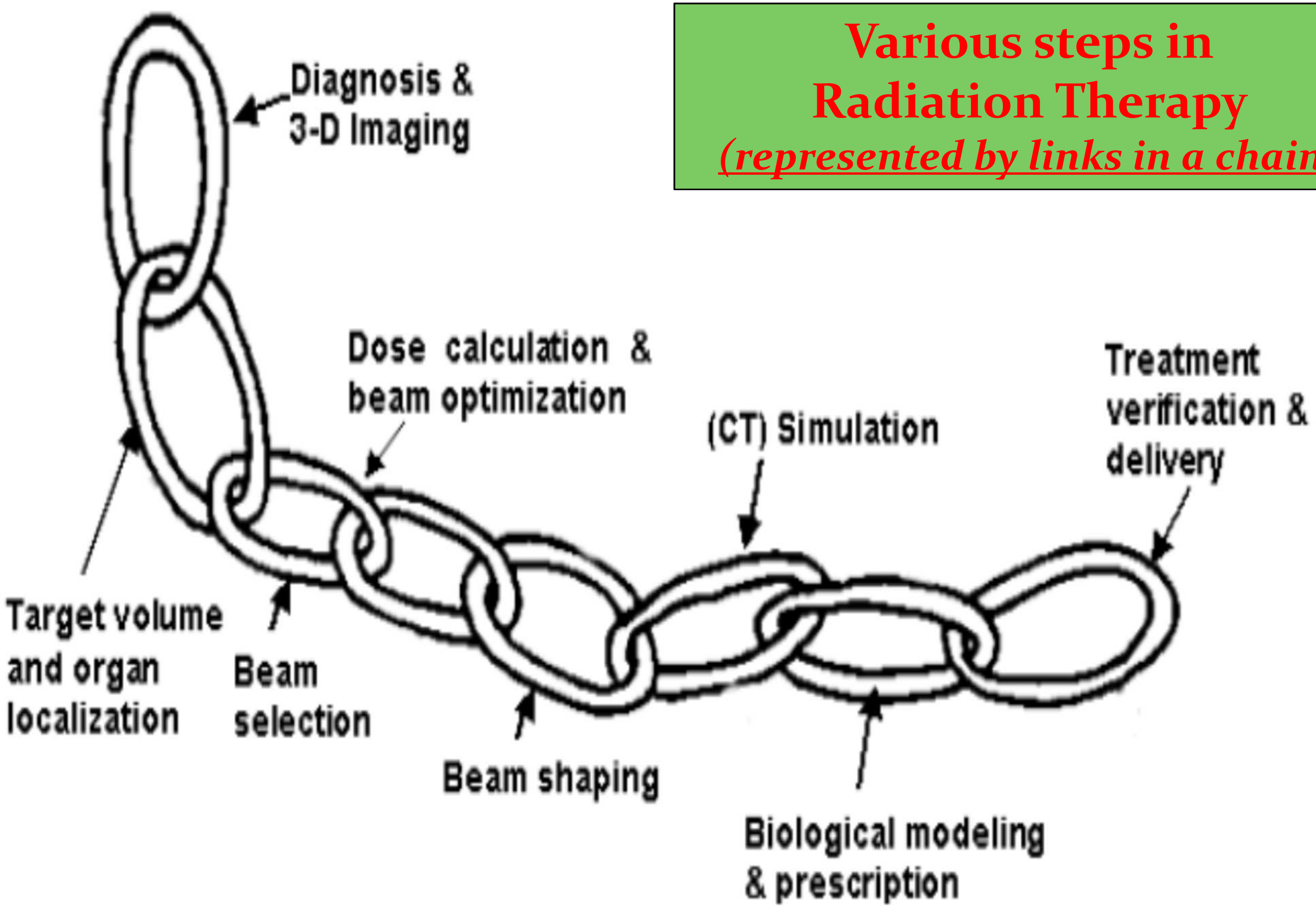
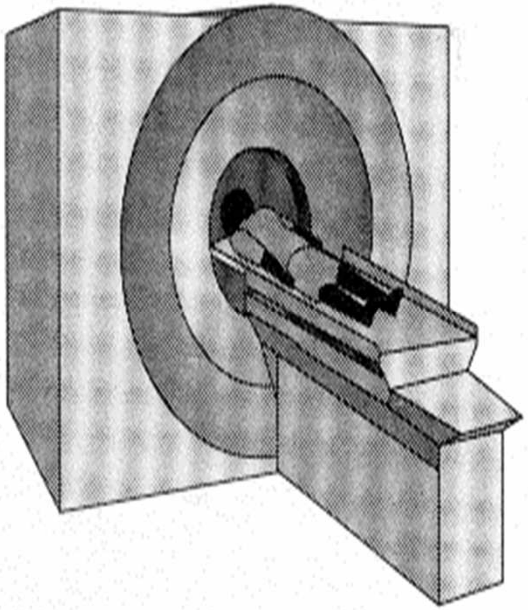
Various steps in Radiation Therapy

(represented by links in a chain)



CT—Standard of Care



- CT used for vast majority of RT simulations
- 3–5 mm slices common practice

Imaging Options

EACH WITH DISTINCT MERIT

CT: Highly effective tool for depicting anatomical references; unable to image metastasis

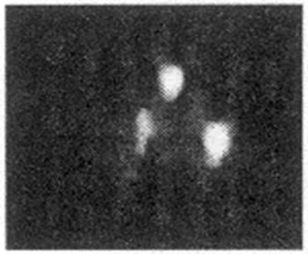
PET: Assesses metabolic activity rather than anatomic structure

MR: Ability to finely differentiate tissues

Fusion: CT + PET

CT Scan

- Anatomical reference
- Tells physician exactly where lesion is located
- Improves specificity



PET Scan

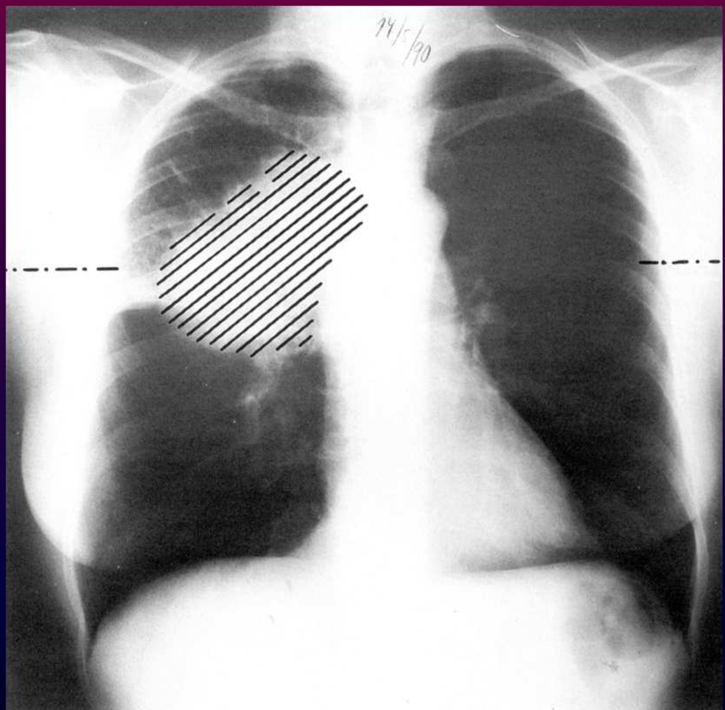
- Metabolic reference
- Helps physician determine whether lesions are malignant or benign and identifies areas of cancerous involvement
- Improves sensitivity in detecting small lesions

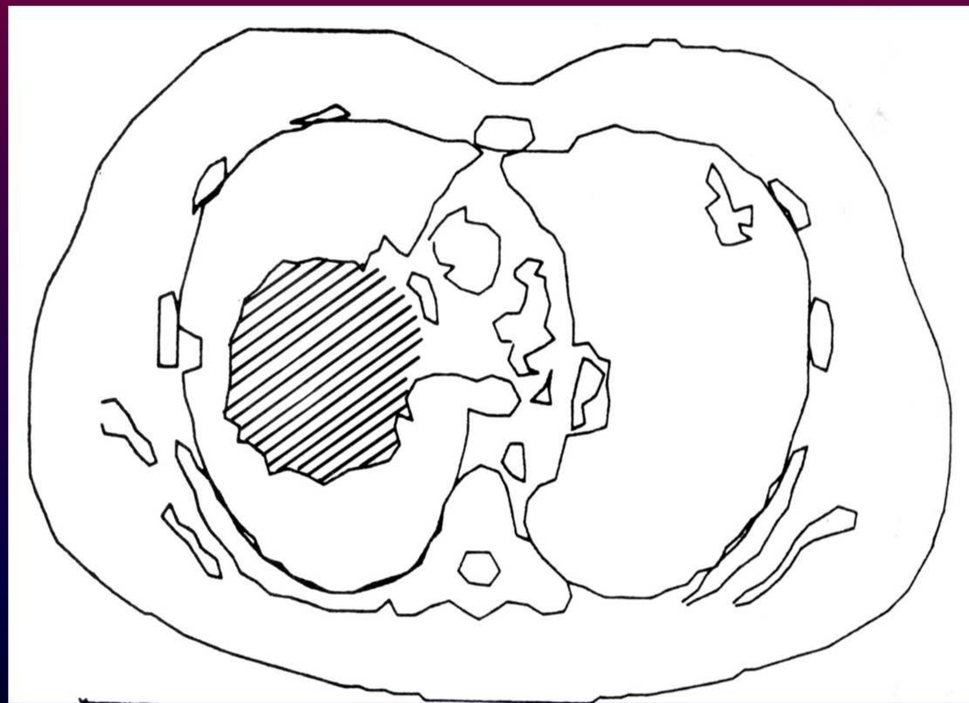
Fused Image

- Electronic fusion of CT and PET images
- Allows for direct visual comparison of two different data sets
- Image superposition/fusion allows for resizing and movement of data sets, as well as zooming and rotation to achieve optimal overlay of data

Gross Tumor Volume (GTV)

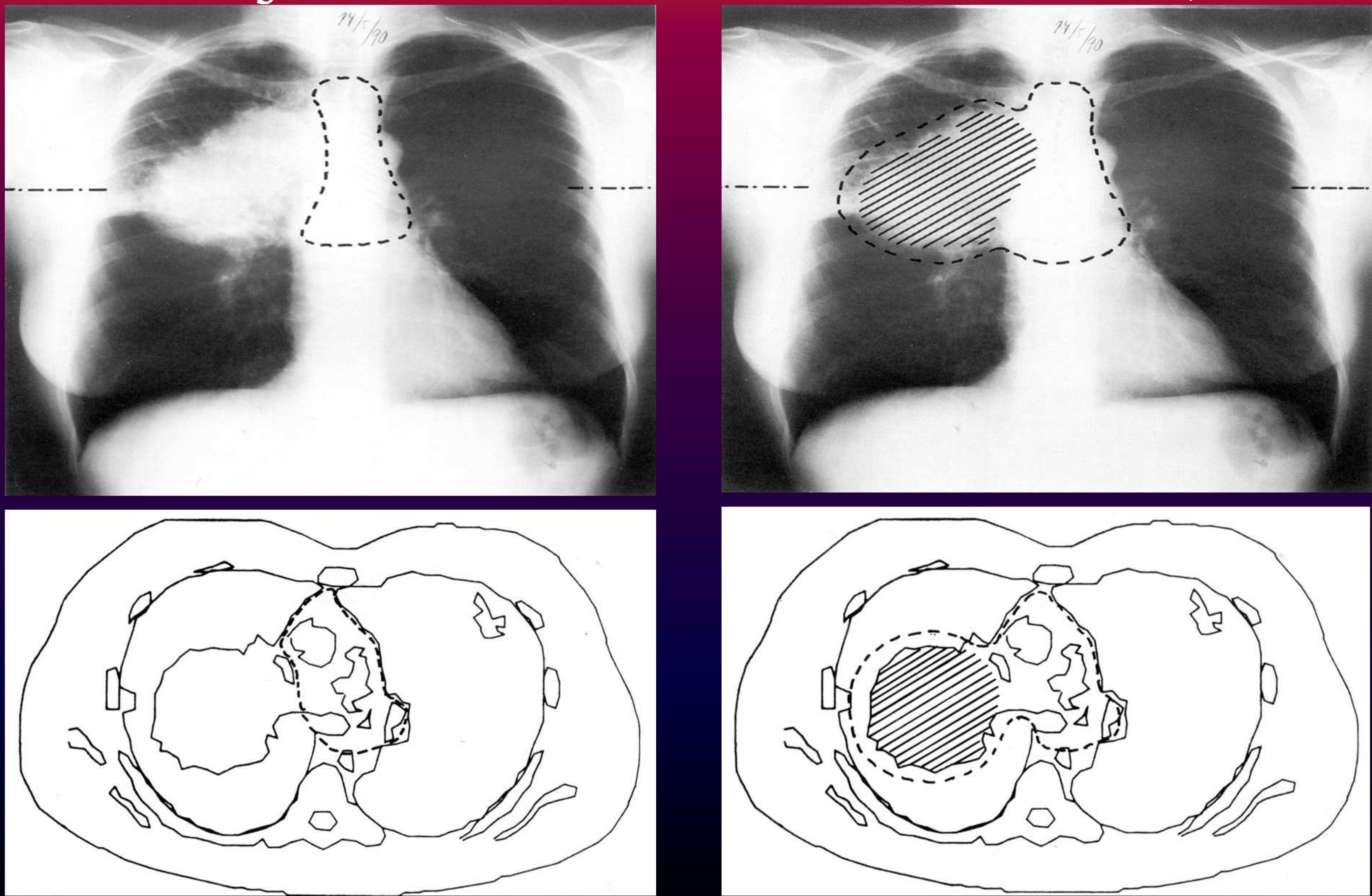
(*The gross palpable or visible/demonstrable extent and location of the malignant growth*)

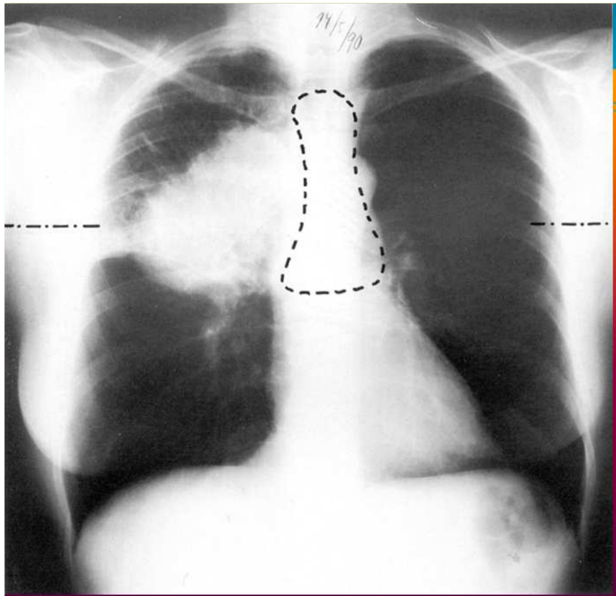


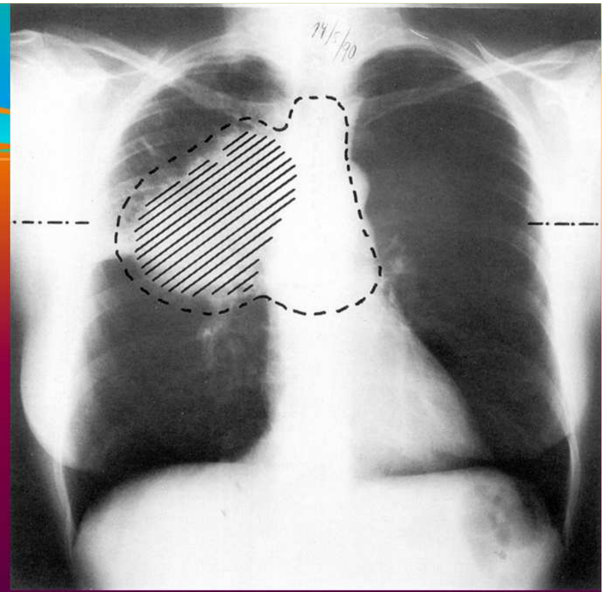


Clinical Target Volume (CTV)

(A tissue volume that contains a GTV and/or subclinical microscopic malignant disease, which has to be eliminated)



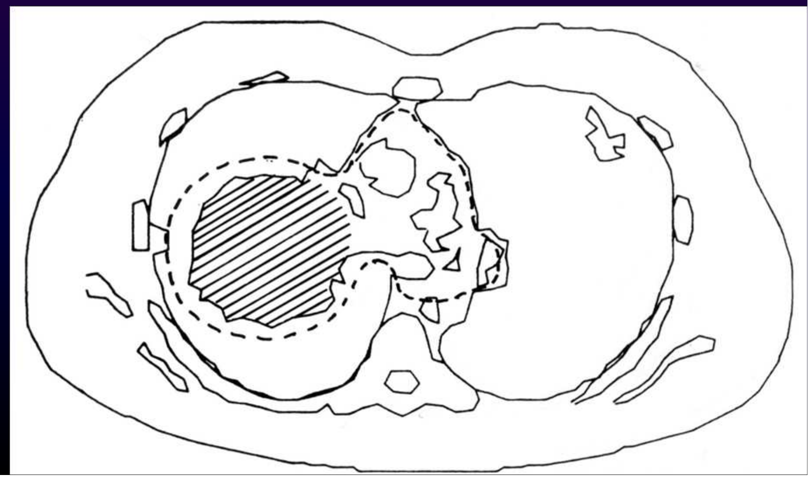




The GTV & CTV concept is clear,

but

not easy to draw/delineate.



Internal Target Volume (ITV)

It is the CTV plus an internal margin.

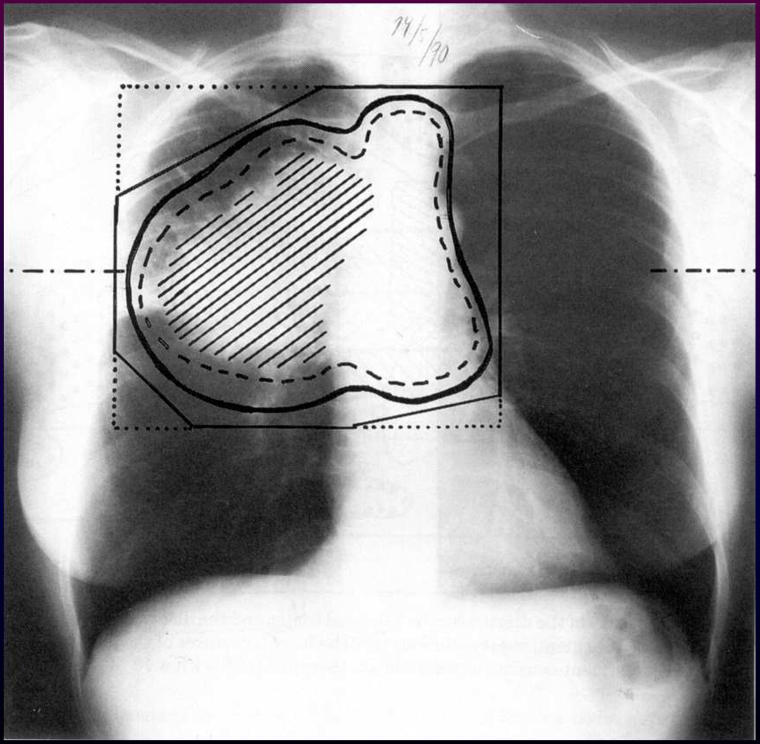
The internal margin is designed to take into account the variations in the size and position of the CTV relative to the patient’s reference frame (usually defined by the bony anatomy); that is, variations due to organ motions such as breathing and bladder or rectal contents.

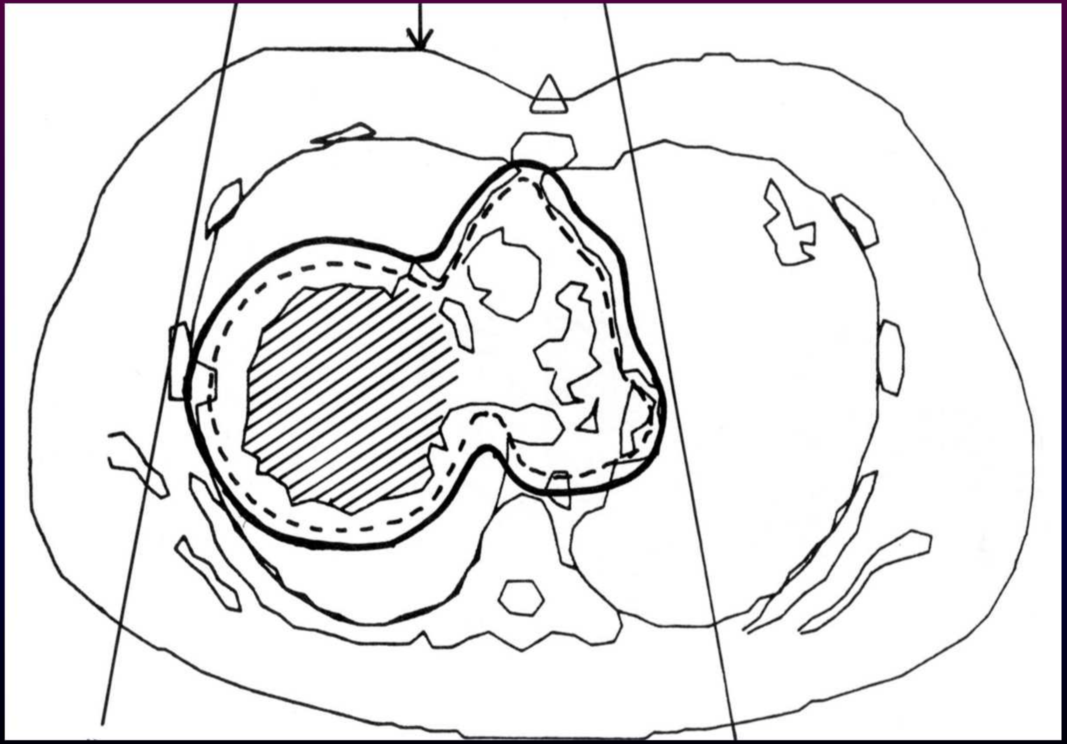
Organs at Risk

Normal tissues, whose radiation sensitivity may significantly influence treatment planning and/or prescribed dose.

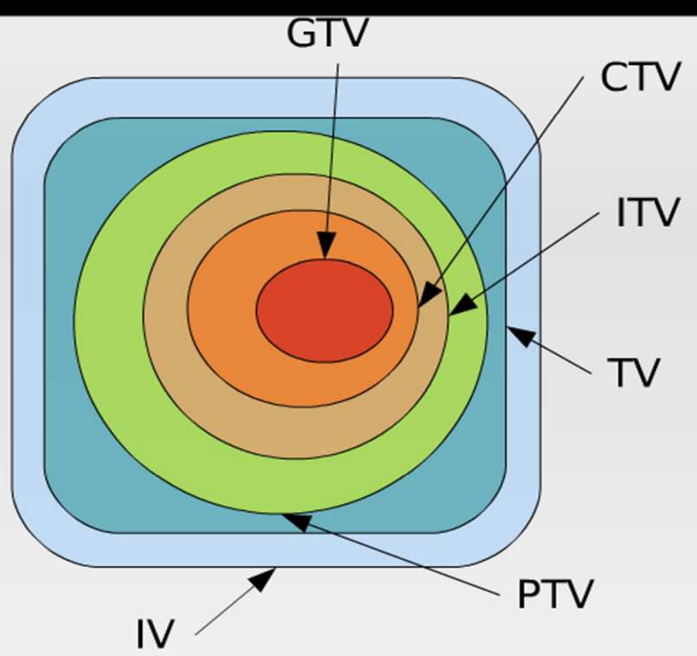
Planning Target Volume (PTV)

(A geometrical concept that is defined to selcet appropriate beam sizes and beam arrangements, taking into consideration the net effect of all the possible geometrical variations and inaccuracies in order to ensure that the prescribed dose is actually absorbed in the CTV)





Definitions: ICRU 50/62



- **Treated Volume**: Volume of the tumor and surrounding normal tissue that is included in the isodose surface representing the irradiation dose proposed for the treatment (V_{95})
- **Irradiated Volume**: Volume included in an isodose surface with a possible biological impact on the normal tissue encompassed in this volume. Choice of isodose depends on the biological end point in mind.

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Conformal Therapy

Treatment plans create a high dose volume closely conforming to the shape of the PTV in 3D, and minimize dose to normal structures.

Forward Planning

- Define PTV-dose, Treatment Beams and Specify each beam parameters (*beam directions, weights, wedges, blocks, margins, etc*.)
- Dose Calculation
- Assess dose distribution and adjust beam parameters until satisfactory plan is derived.

Intensity Modulated Radiation Therapy (IMRT)

Advanced image-guided 3D-CRT utilizing variable beam intensities determined via computerised optimization.

Inverse Planning

- *Clinical objectives (dose-volume constraints,* Beam directions & dose distribution*) specified in advance*.
- *Computerized optimization of pencil beam intensities (modulation) to best meet the desired dose constraints.*

Dynamic multileaf collimator (DMLC)

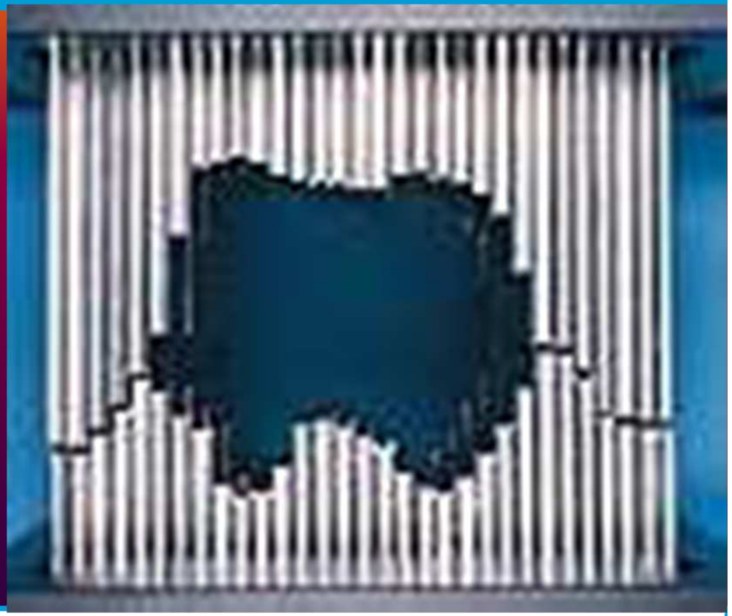
MLC is capable of dynamic leaf motion and sliding window.

Sliding-window

MLC leaves move continuously while the beam is on.

&

The gap and speed for each opposing leaf pair modulates the dose.



Step & shoot in IMRT

Variable fluence across the field is created by summation of multiple static fields defined by MLC.

For each static field, the MLC leaves are set (step), and a pre-calculated number of MU delivered (shoot).

The beam then halts, MLC shape changes, & the beam again comes on. The more steps, the finer gradation in fluence changes.

Objective Function

It is a *mathematical description of criteria for treatment plan optimization that may be specified in terms of dose-limits, dose-volume limits, and/or in terms of dose-response functions etc.*

Score

It is a numerical value of the objective function that represents a figure of merit, or quality of the treatment plan.

The best plan corresponds to the extremum-score.

Leaf motion file (leaf sequence file)

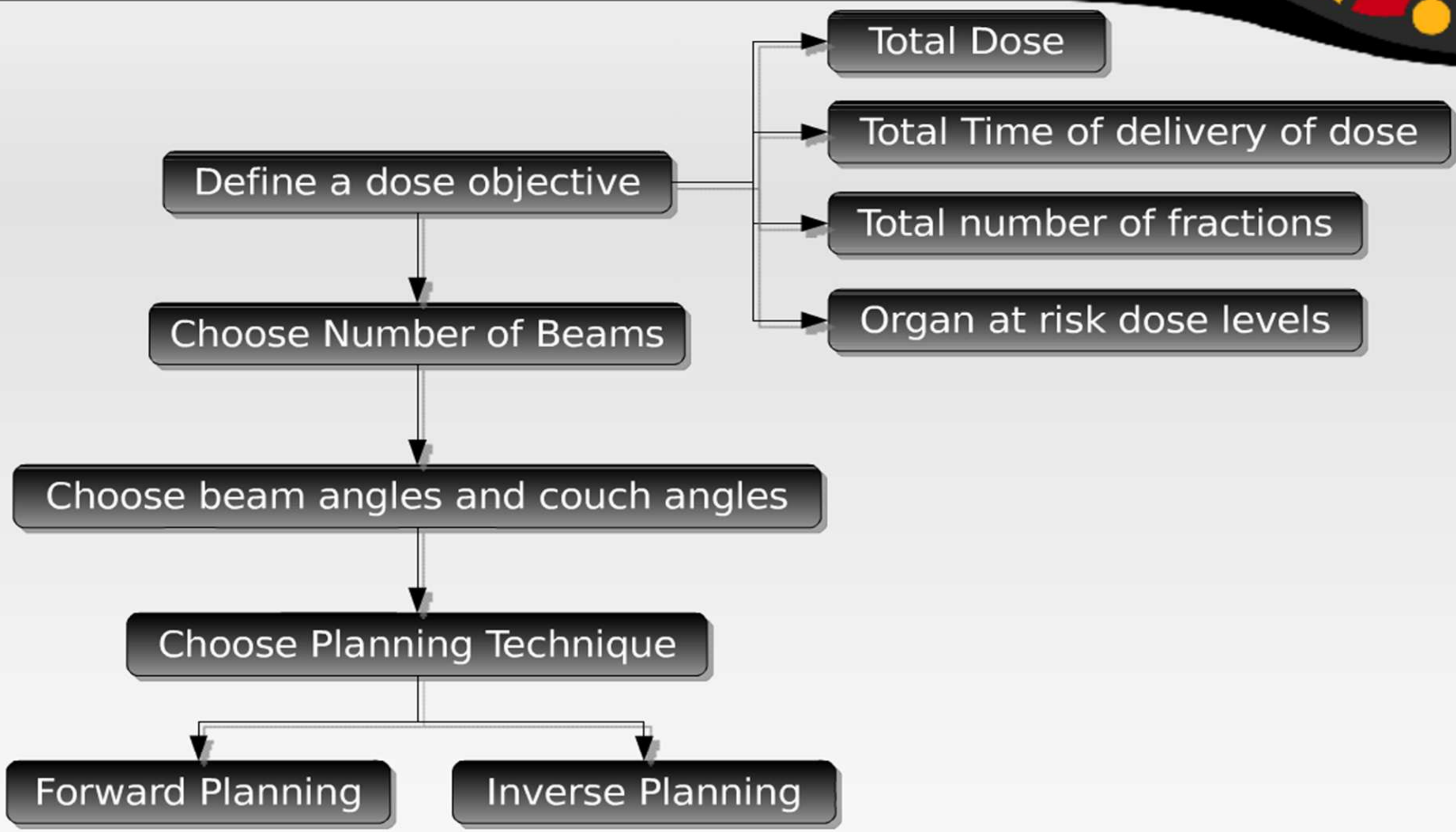
Data file generated by the TPS defines position of each MLC-leaf as a function of MU delivered.

It is then down-loaded to the MLC control computer on the accelerator for patient treatment.

Autosequencing

Accelerator control software that automatically sets up gantry, collimators, etc. for multi-field treatments. Particularly useful for `step and shoot' IMRT.

Planning workflow



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IMRT & Inverse Treatment Planning (ITP)

- **Objectives:**

  Dose escalation
  Normal tissue dose sparing

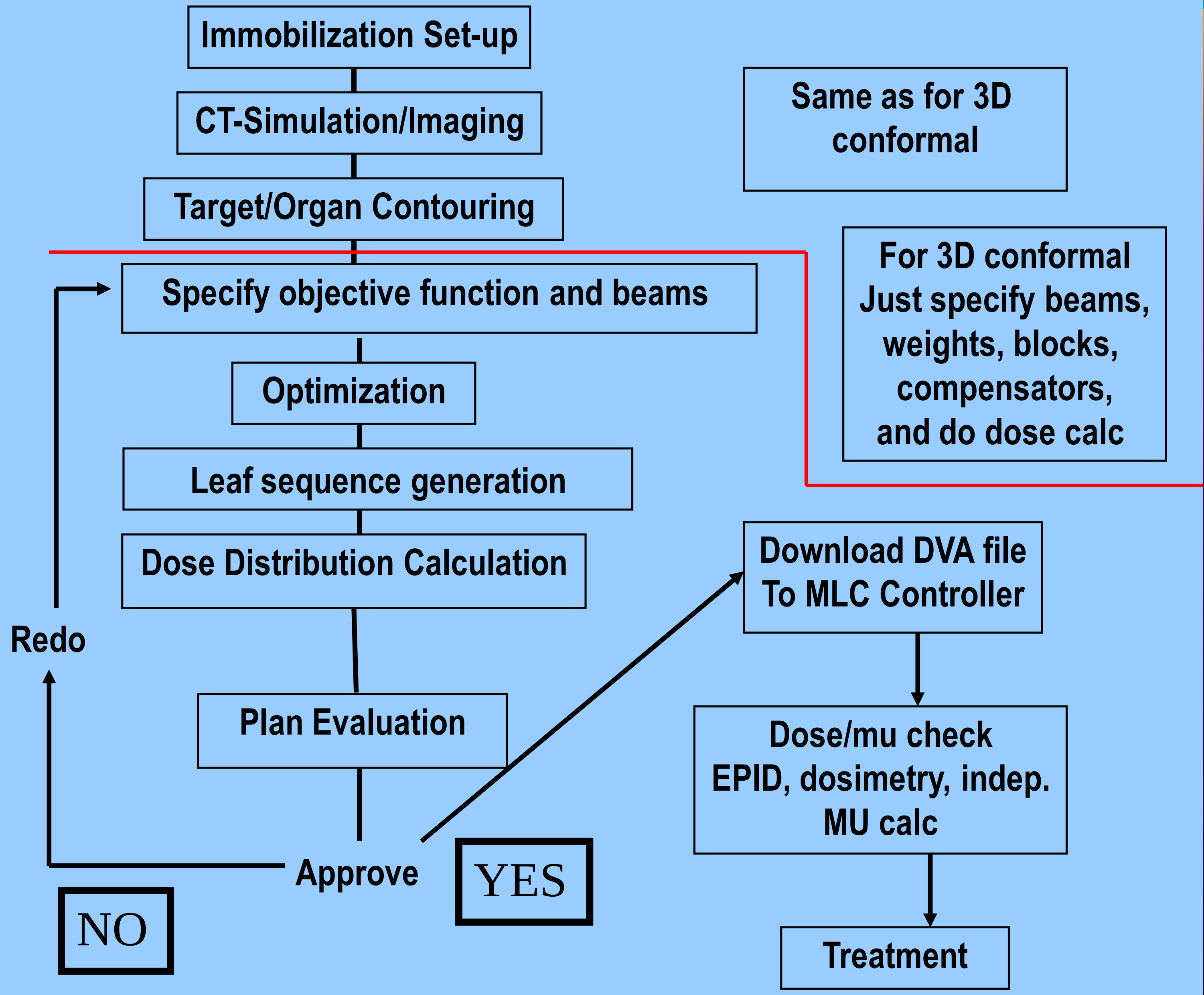
- **Equipment Requirements:**

  MLC - DMLC
  ITP Computer System
  3D-CT simulation
  Record and Verify system
  EPID
  Respiratory Gating System
  (for treatment and imaging)

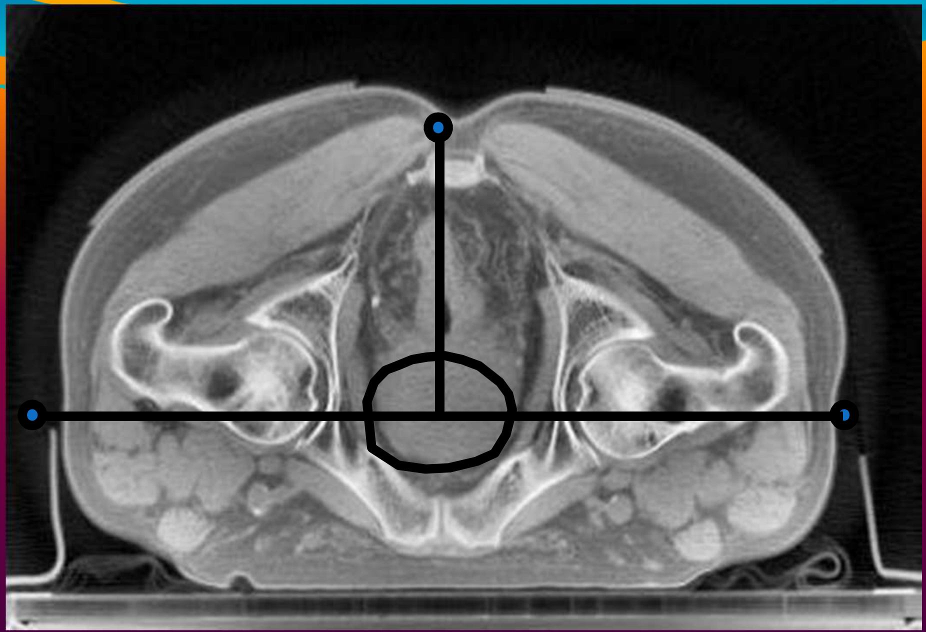
Sequence

for

Treatment Planning


Immobilization Set-up
CT-Simulation/Imaging
Target/Organ Contouring
Specify objective function and beams
Optimization
Leaf sequence generation
Dose Distribution Calculation
Plan Evaluation
Approve
YES
NO
Redo
Same as for 3D conformal
For 3D conformal Just specify beams, weights, blocks, compensators, and do dose calc
Download DVA file To MLC Controller
Dose/mu check EPID, dosimetry, indep. MU calc
Treatment

Tumor and Tissue Contouring



1. Isocenter defined at CT-Simulation

2. In room laser, skin marks, tatoos, etc.

3. Implanted markers?

4. Contour one or more GTV's.

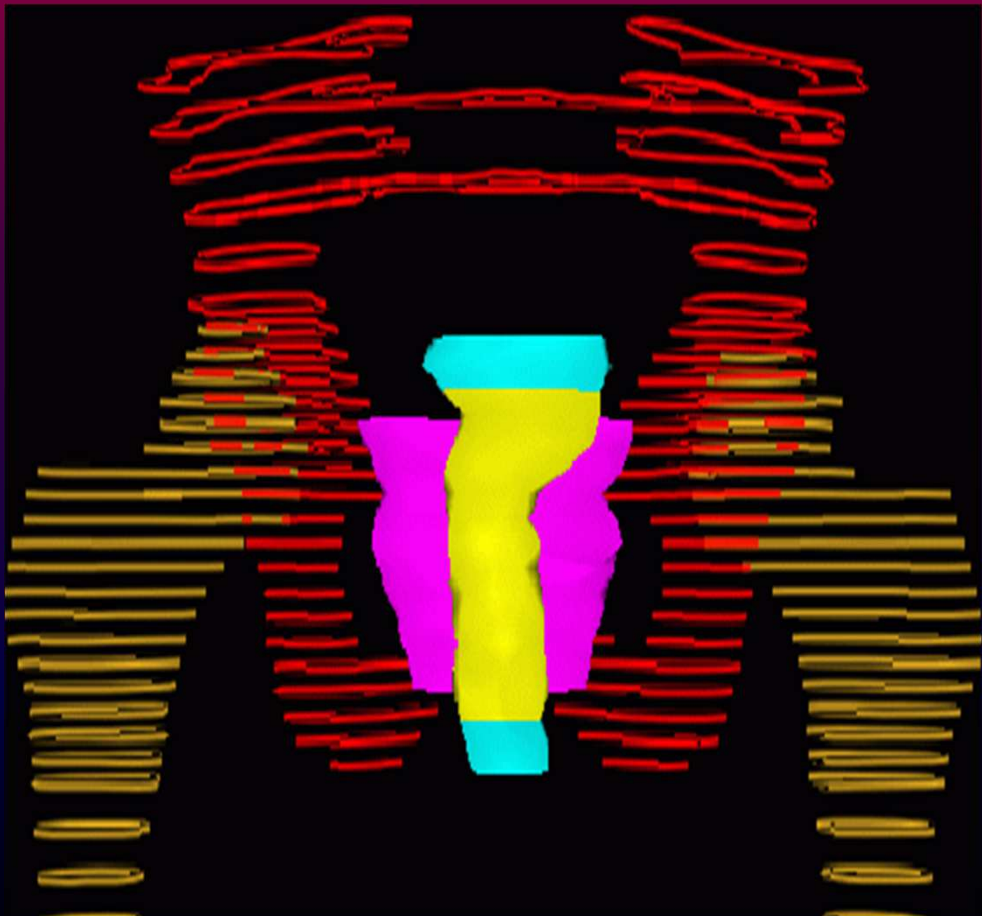
5. GTV, CTV, PTV

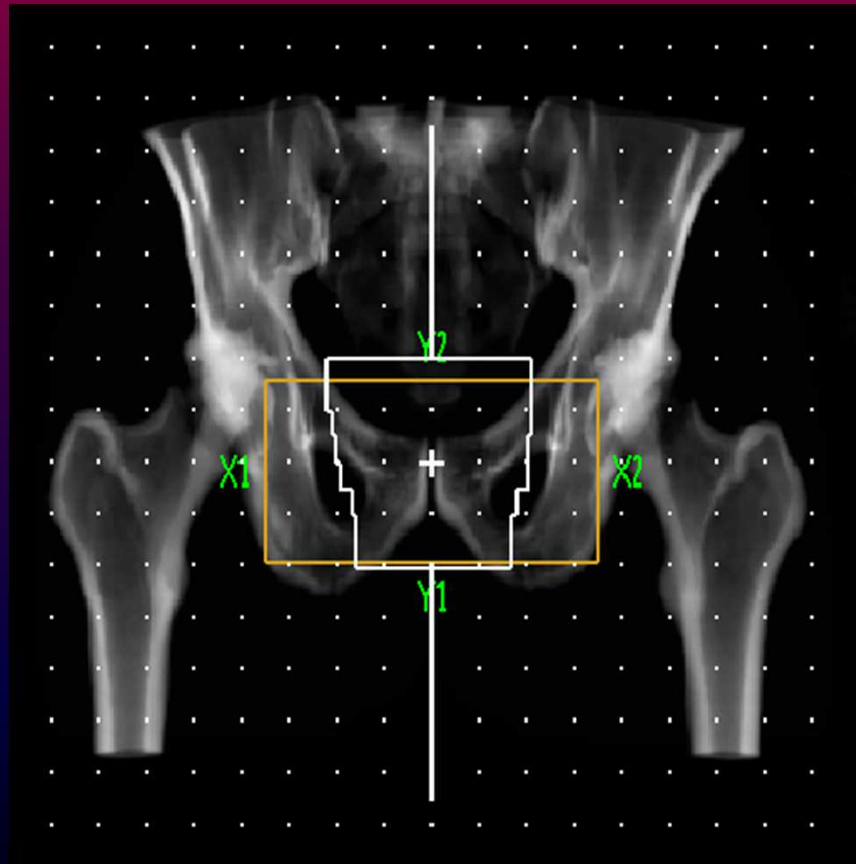
6. Contour all normal tissues requiring dose volume constraints.

Example of IMRT contouring for
Prostate + all relevant normal tissues

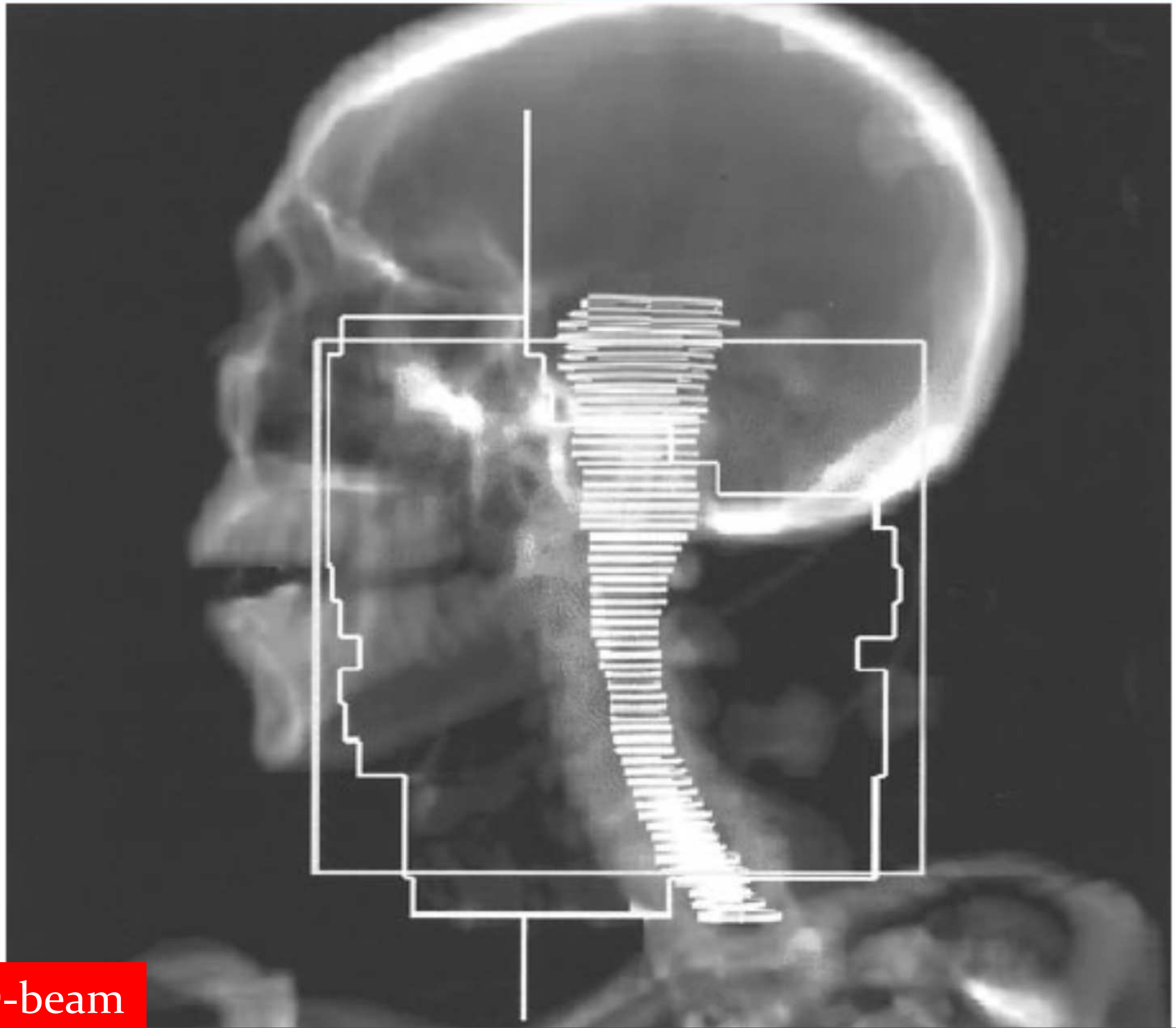
Length:

- **Clinical / Conventional :** *one CT slice above & below PTV*
- **Anatomic :** *anal verge to below sigmoid*





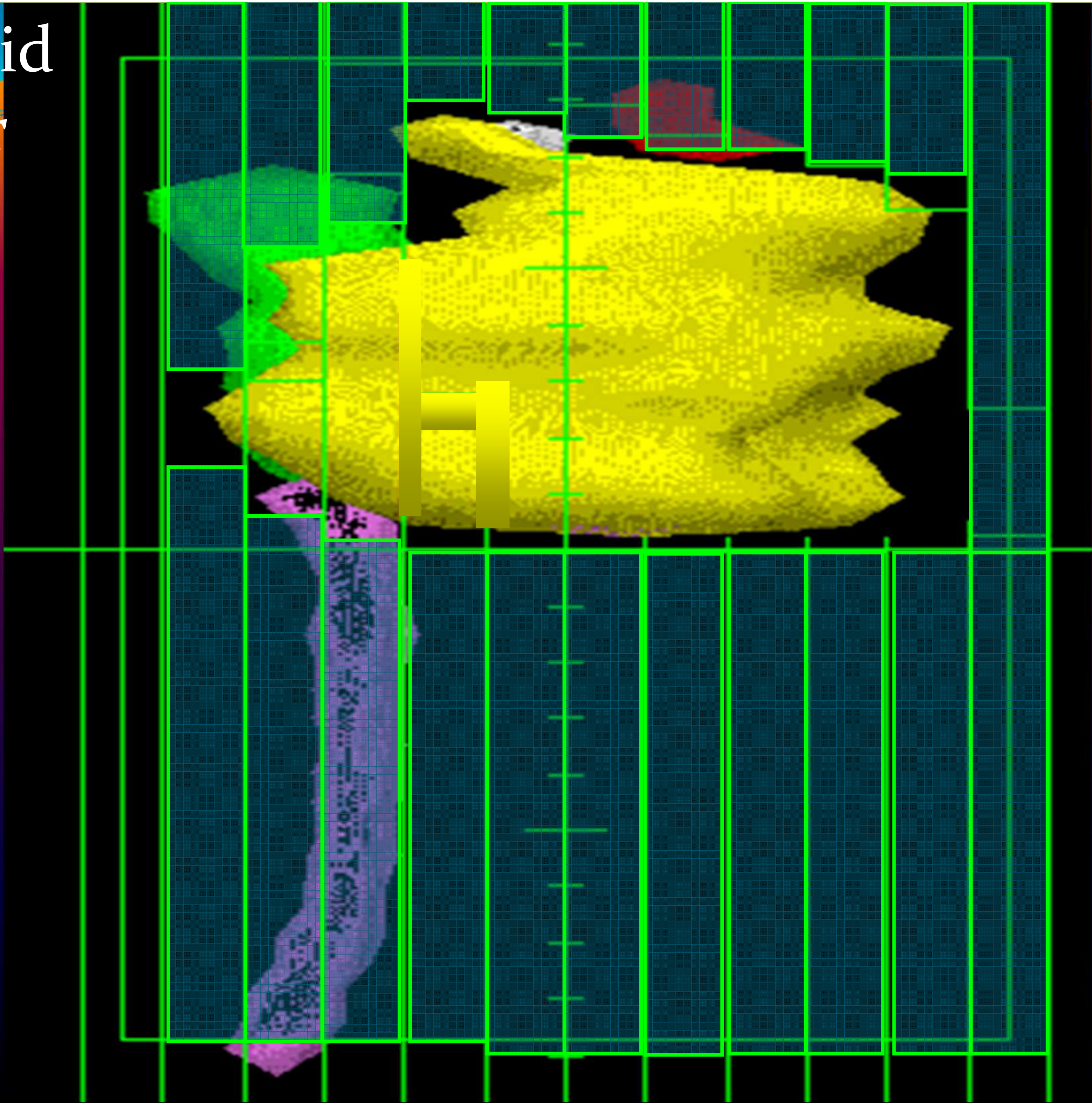
DRR for the PA field



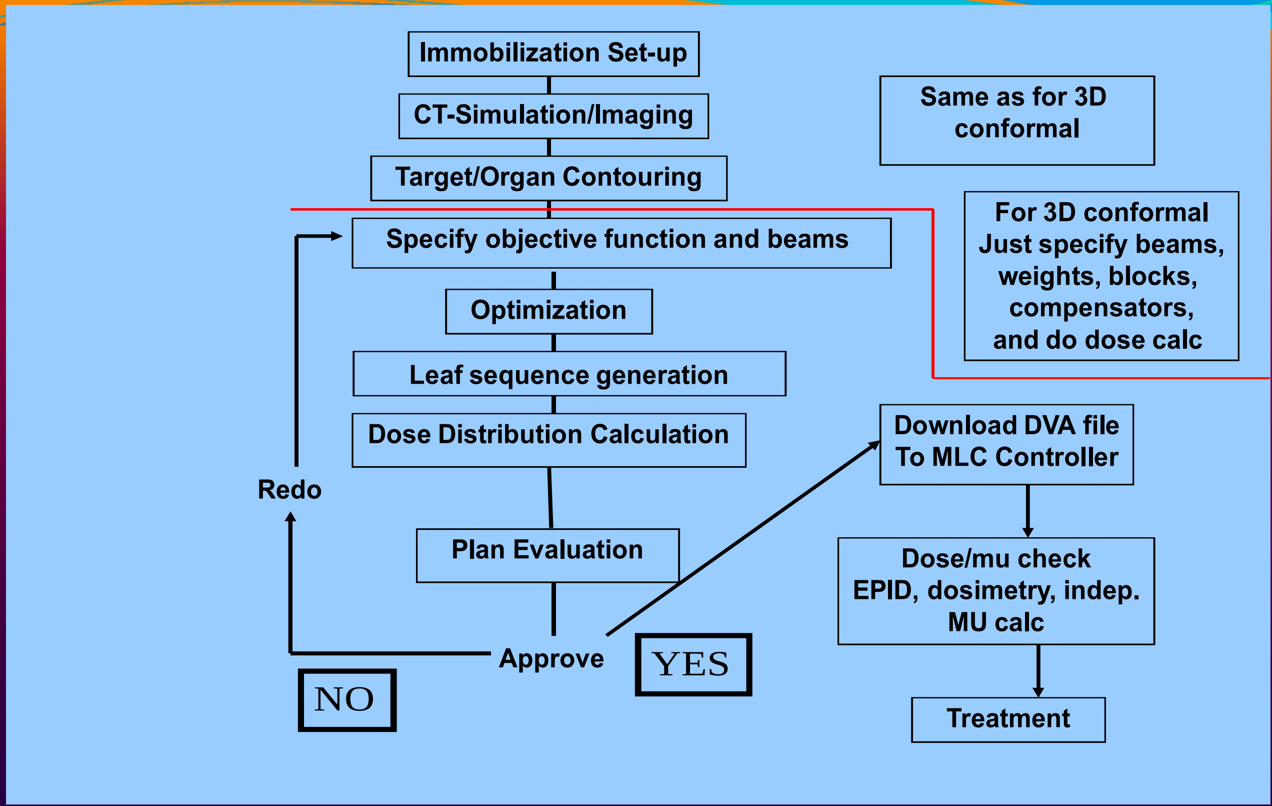
DRR for a LPO-beam

Initial wire-frame outlines
of the spinal cord & Brainstem
+
Final DMLC-aperture

Thyroid tumor



Differences between conventional 3D and IMRT planning:



- Planner does NOT design blocks, choose wedges, assign beam weights, etc.
- Instead: Assign dose-volume constraints and penalties
- Plan-evaluation relies more on DVH
- Experience/ intuition from conventional planning not applicable to IMRT

More differences

- Hard to know if optimization succeeded or failed:
  a) *was objective function reasonable?*
  b) *were dose-volume constraints achievable?*
  c) *stuck in local minimum?*
- Manual calculations to verify plans NOT POSSIBLE.
- *In-vivo* dosimetry, confirmation of beam delivery, and dose distributions more complicated.
- Only to trust your computers.
- Comprehensive QA-Program: Tailored to IMRT
- Factors usually inconsequential for conventional 3D-planning, become important with IMRT:
  a) *2-3 times more monitor units: MLC leakage and scatter.*
  b) *Room shielding design.*
  c) *Patient whole body dose, neutron dose increase.*
  d) *Longer treatment planning times (at least in the beginning).*
  e) *Enormous volume of data transferred between computers.*

How does the TPS find the optimum plan?

TPS doesn't really find the optimum plan.

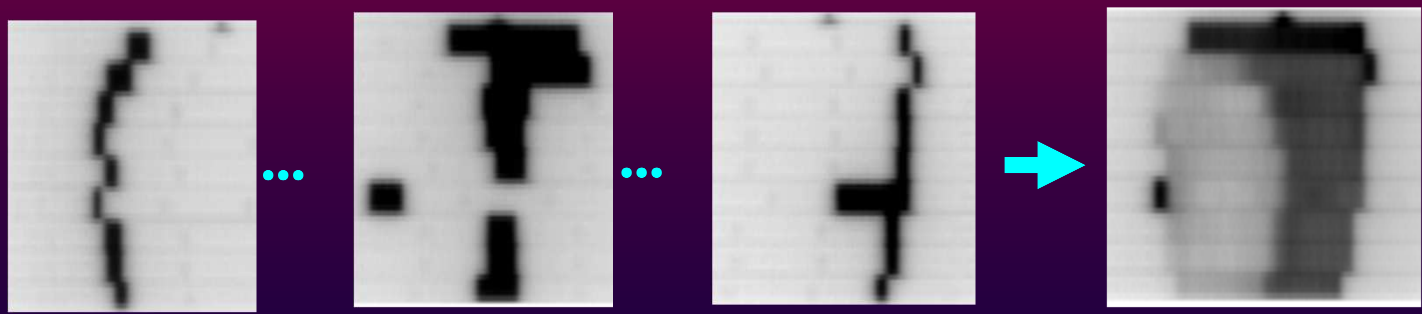
It finds a plan that best matches the dose volume constraints you specified.

So, if reasonably constraints are not provided to the TPS, we get a bad treatment plan.

Garbage in = Garbage out

Delivery of IMRT
with continuous leaf motion

- Each leaf pair forms a window which slides across the field.
- Dose given through the window as function of MU.



1 i

n 1+…+i+…+n

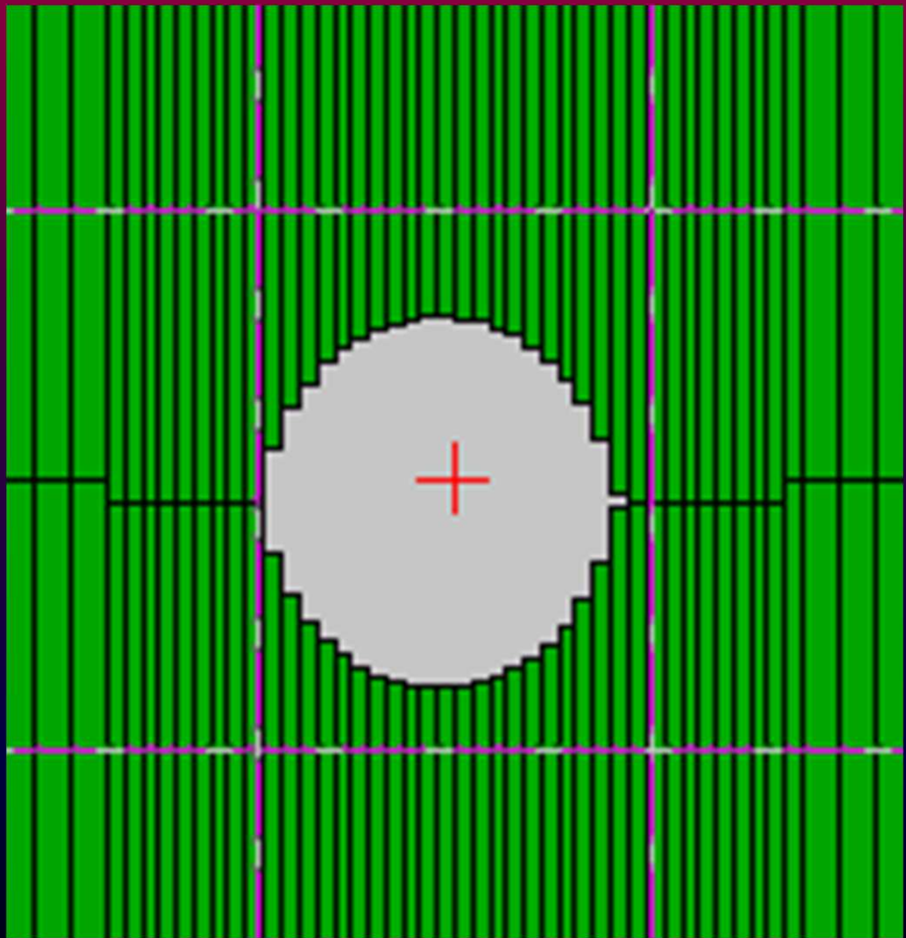
- The final dose distribution is the summation from all segments.

Treatment Delivery (Summary)

- IMRT fields can be delivered with dynamic (DMLC) or segmental (step-and-shoot) mode.
- It can be delivered (almost) any shaped intensity profile, subject to MLC limitations and beam properties.
- It needs account for leaf transmission, rounded leaf end and head scatter, leaf speed, etc.
- Large fields may have to be split into 2 or 3 sub-fields.
- Loss of beam-on time efficiency relative to conventional fields due to small field openings.

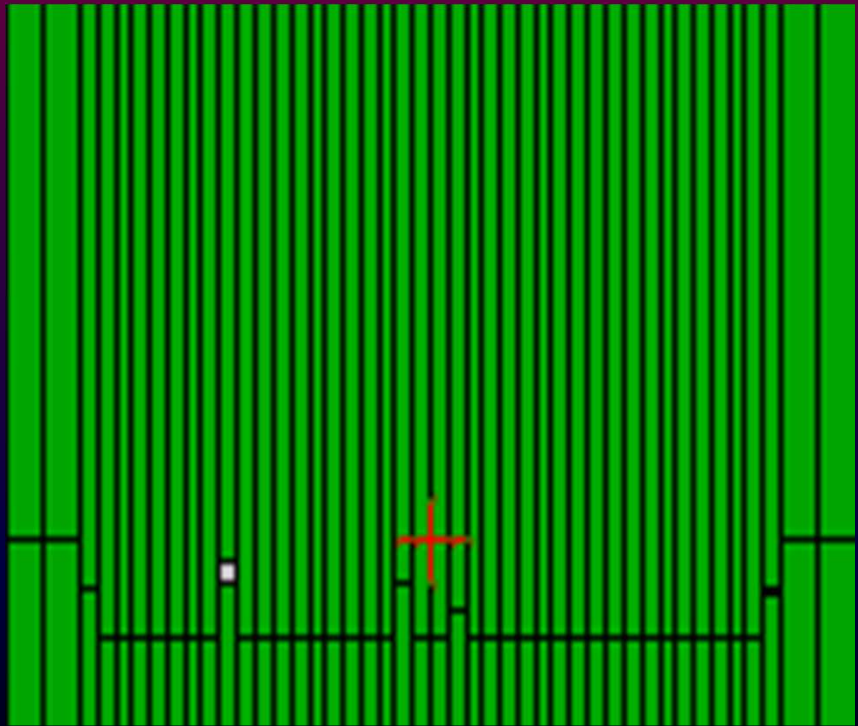
3D-CRT fields

Tracking a tumor moving with respiratory motion

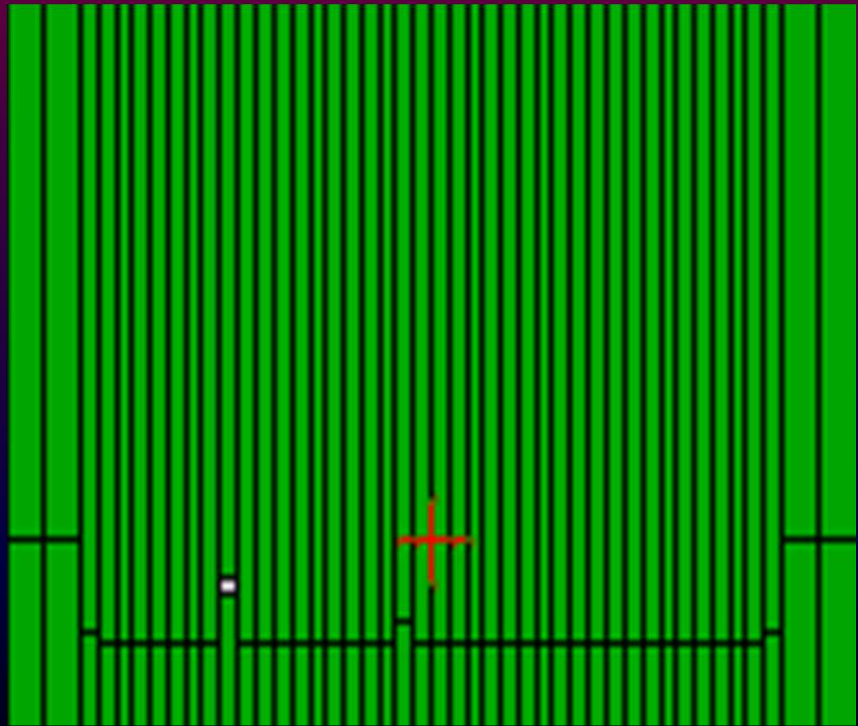


DMLC-IMRT fields

With NO-motion compensation



Tracking a tumor moving with respiratory motion



1	6	8	3
1	4	4	2
2	0	5	7
3	2	6	3

Desired Intensity Pattern

1	2	4	3
1	0	0	2
2	0	1	3
3	2	2	3

Remainder-1

1	0	2	1
1	0	0	2
0	0	1	3
1	0	0	1

Remainder-2

1	4	4	3
1	4	4	2
2	0	4	4
3	2	4	3

Shot-1

1	2	2	2
1	0	0	2
2	0	1	3
2	2	2	2

Shot-2

1	0	2	1
1	0	0	2
0	0	1	2
1	0	0	1

Shot-3

Step & shoot with 5 segments

Step & shoot with 5 segments

1	0	2	1
1	0	0	2
0	0	1	3
1	0	0	1

Remainder-2

1	0	0	1
1	0	0	0
0	0	1	1
1	0	0	1

Remainder-3

1	0	2	1
1	0	0	2
0	0	1	2
1	0	0	1

Shot-3

1	0	0	1
1	0	0	0
0	0	1	1
1	0	0	1

Shot-4

0	0	0	1
0	0	0	0
0	0	0	0
0	0	0	1

Remainder-4
& Shot-5

How to fix an IMRT plan
<u>that doesn't meet constraints</u>

Integral dose = $\int d_v \, dV$ is a constant,

dependents only
on patient shape,
prescription dose, and
number of beams selected

Think of it as a balloon.
Squeeze in some place
and it pops out some place else..

Ask for more than you want?

- *Solutions are a “compromise”*
- *Objectives are “penalty” based (no rewards)*
- *Lenient constraints may lead to miss a better solution*

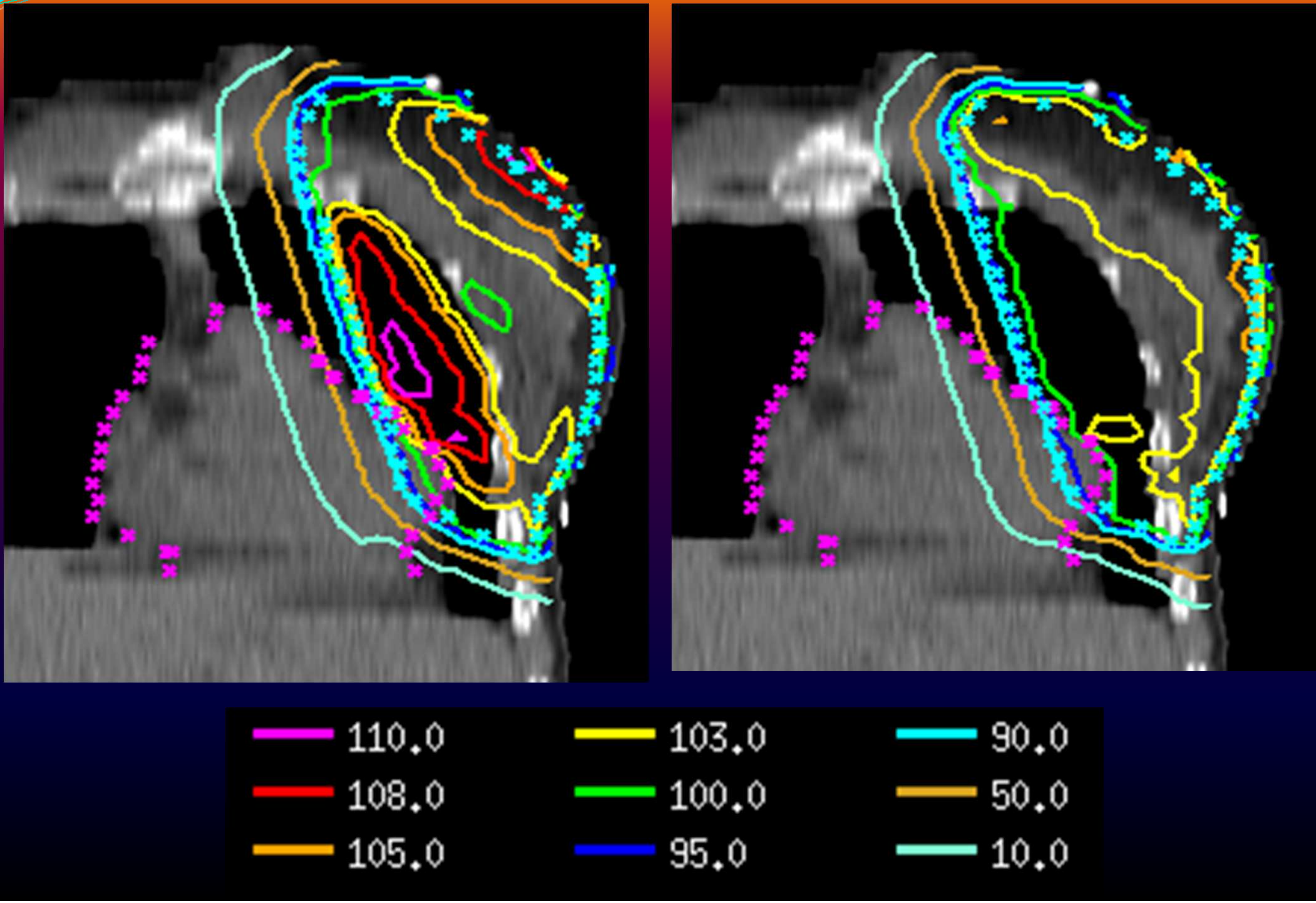
IMRT for Breast
<u>instead of Wedges</u>

IMRT tangents can

- *Improve target dose homogeneity*
- *Modestly reduce dose to ipsi-lateral lung and heart*
- *Reduce dose to contra-lateral breast*

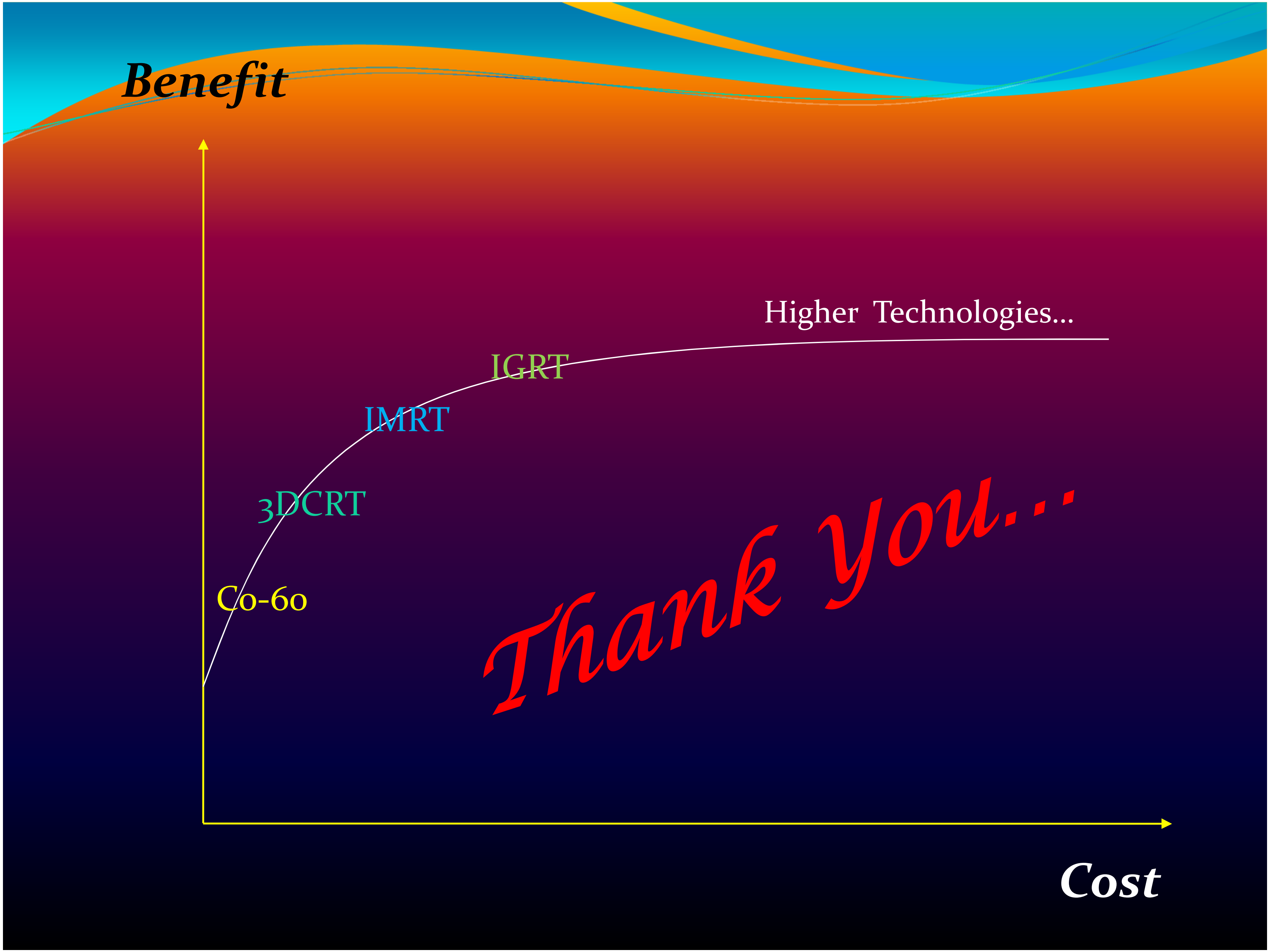
Standard Wedges

IMRT Tangents



Treatment Planning Issues for Lung

- GTVs and especially CTVs difficult to define without CT+PET
- Normal lung surrounds PTV (Radiation Pneumonitis)
- Setup uncertainties
- Respiratory motion
- Methods to reduce breathing motion:
  - *Respiratory gating*
  - *Breath-hold: voluntary/ forced*


Benefit
Higher Technologies…
IGRT
IMRT
3DCRT
Co-60
Thank you…
Cost