Three-Dimensional Conformal Radiotherapy (3DCRT)

Treatment planning for external beam

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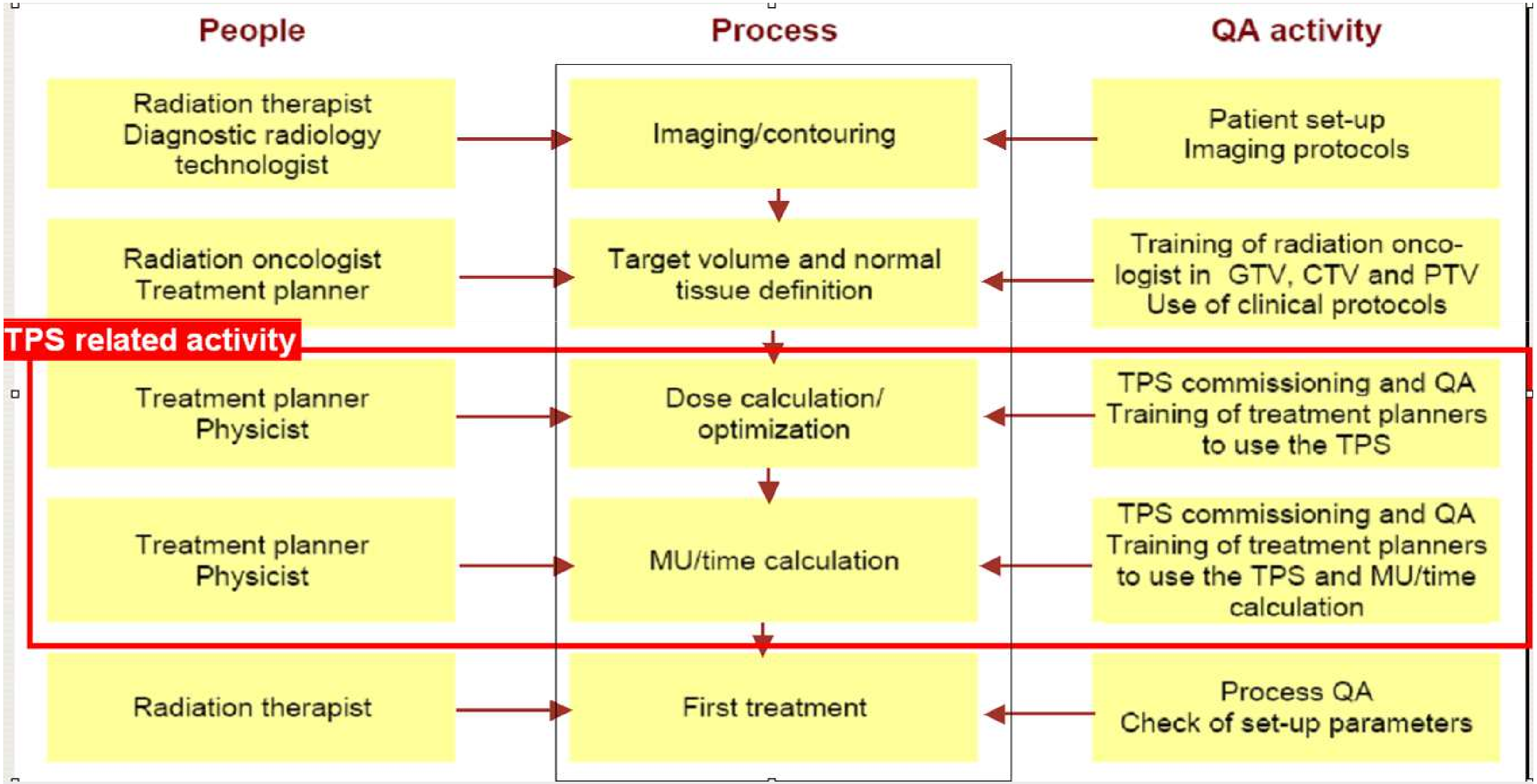
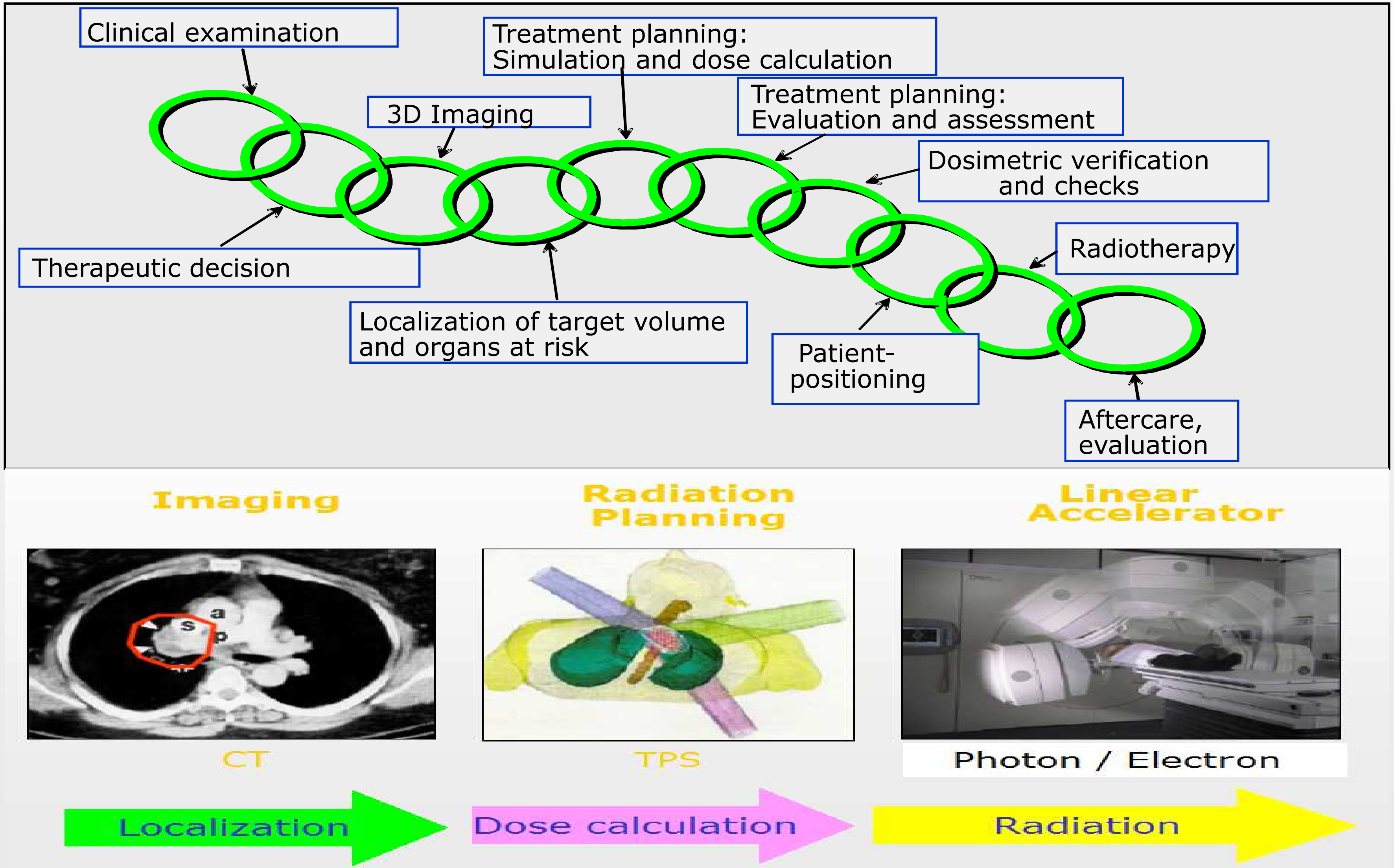
Professionals involved in the treatment planning process **(IAEA)**

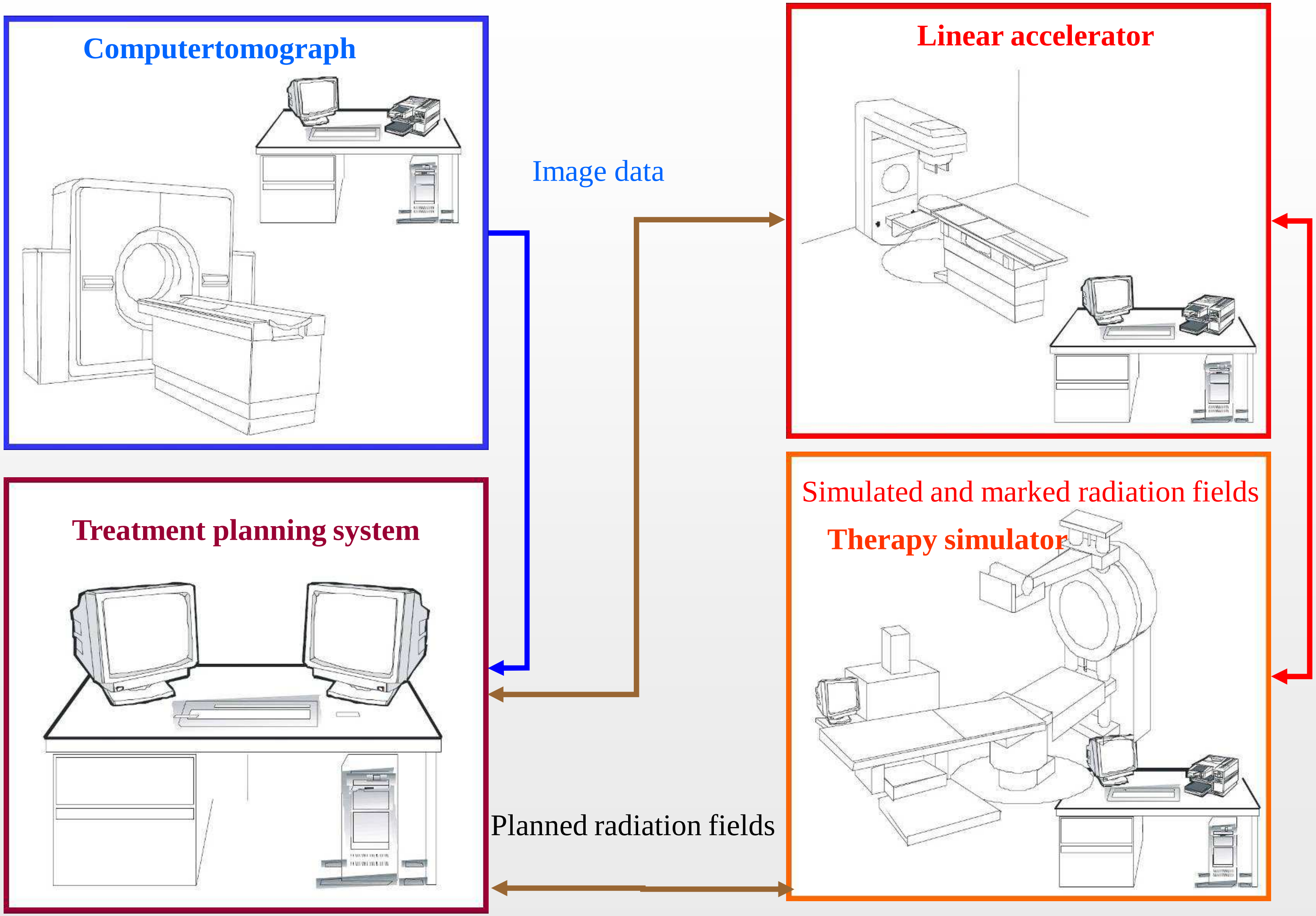


The radiotherapy chain

- A characteristic feature of modern radiotherapy is a **multi-disciplinary approach**, consisting of and usage of many complex devices and procedures.



The Radiotherapy Chain example:



Radiotherapy treatment goal

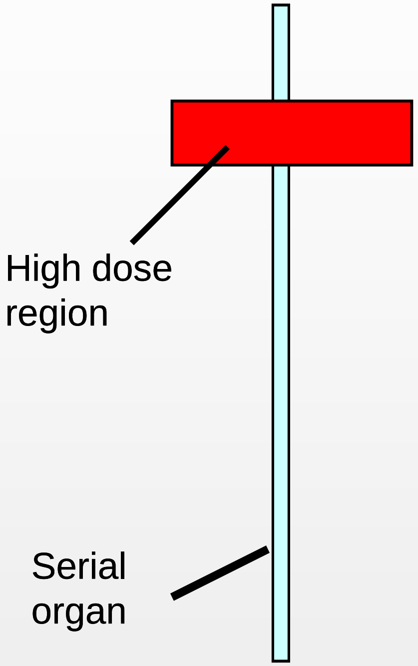
- The objective of radiotherapy is the destruction of local tumour without severe side effects
- Removal of the tumour
  - (Local tumour control / Regional tumour control)
- Avoidance of treatment effects
  - disfigurement
  - loss of function
  - restriction of quality of life
- Therapy optimization: maximum effect with minimal burden

Tolerance doses in Gy *(Emami et al).*

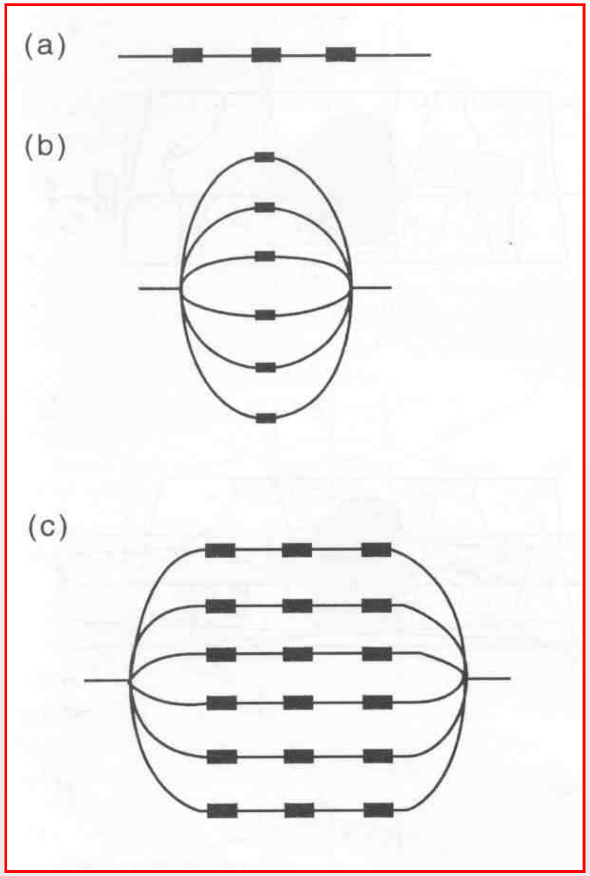
Organ Volume part	$TD_{5/5}$ 1/3	$TD_{5/5}$ 2/3	$TD_{5/5}$ 3/3	$TD_{50/5}$ 1/3	$TD_{50/5}$ 2/3	$TD_{50/5}$ 3/3	Radiation consequense
Arm nerve plexus	62	61	60	77	76	75	Manifeste Plexopathie
Lens			10			18	Katarakt
Bladder		80	65		85	80	Symptomatische Schrumpfblase
Cauda equina	no Volume effect		60	no Volume effect		75	Manifeste Neuropathie
Chiasma opticum	no Volume effect		50	no Volume effect		65	Blindness
Small intestine	50	-	40[a]	60	-	55	Stenose, Perforation, Fistel
Femurkopf (I+II)	-	-	52	-	-	65	Bone necrosis
Skin	10 cm^2: 50	30 cm^2: 60	100 cm^2: 55	10 cm^2: -	30 cm^2: -	100 cm^2: 70	Nekrose, Ulzeration
Heart	60	45	40	70	55	50	Perikarditis
Brain	60	50	45	75	65	60	Nekrose, Infarkt
Brainstem	60	53	50	-	-	65	Nekrose, Infarkt
TMJ	65	60	60	77	72	72	Trismus
Colon	55		45	60		55	Stenose, Perforation, Fistel, Ulkus
Larynx	79[a]	70[a]	70[a]	90[a]	80[a]	80[a]	Knorpelnekrose
Larynx	-	45	45[a]	-	-	80[a]	Larynxödem
Liver	50	35	30	55	45	40	Liver failure
Lung	45	30	17,5	65	40	24,5	Pneumonitis
Stomach	60	55	50	70	67	65	Ileus, Perforation
Middle Ear/Externa Ear	30	30	30[a]	40	40	40[a]	Akute seröse Otitis
Middle Ear/Externa Ear	55	55	55[a]	65	65	65[a]	Chronische seröse Otitis
Kindney (one)	50	30	23		40[a]	28	Klinisch manifeste Nephritis
osophagus	60	58	55	72	70	68	Striktur, Perforation
Parotiden		32[a]	32[a]		46[a]	46[a]	Xerostomie
Rectum	Volume: 100 cm^3		60	Volume: 100 cm^3		80	Proktitis, Stenose, Nekrose, Fistel
Retina (I+II)	no Volume effect		45	no Volume effect		65	Blindness
Rippen	50			65			Pathologische Fraktur
Spinal Chord	5 cm: 50	10 cm: 50	20 cm:47	5 cm: 70	10 cm:70	20 cm: -	Myelopathie, Nekrose
Optic Nerve, Retinae (I+II)	no Volume effect		50	no Volume effect		65	Blindness

Tolerance doses (Organ types)

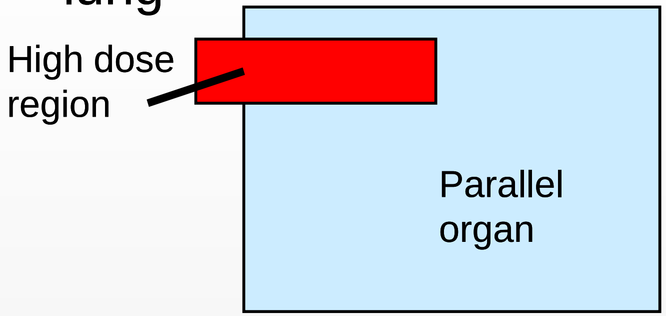
- Serial organs - *example* spinal cord



What difference in response would you expect?



- Parallel organ - *example* lung



In practice not always that clear cut

3-D-Treatment planning process (positioning)

Fixing of the treatment position
(positioning, immobilization)

<u>Example: HNO-Area</u> A technician places the mask on the patient.

Fixation aids and markers on the skin permit reproducibility of the settings by means of a stationary laser- coordinate system

3-D-Treatment planning process (positioning)

Various tools for the positioning and immobilization:

Areas: Skull, chest, abdomen, pelvis, upper and lower extremities.

3-D-Treatment planning process (3-D Imaging)

Fixing of the treatment position
(positioning, immobilization)

↓

CT

Example: HNO-Area planning CT

The patient is positioned according to skin markers or anatomical reference points by using mechanical or optical viewing aids, but actually stationary laser.

3-D-Treatment planning process (3D Imaging - Fusion)

Fixing of the treatment position (positioning, immobilization)

↓

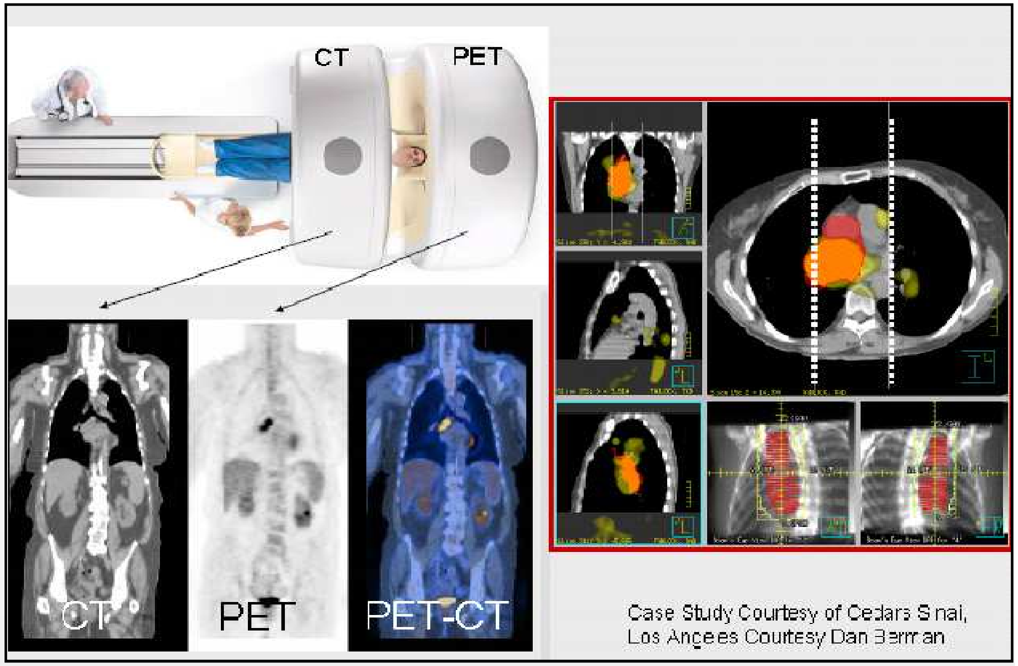
MRT | **CT** | **PET** | **SPECT**

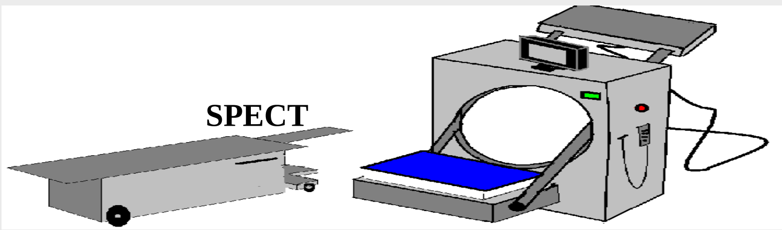
↓

Fusion

↓

3-D CT data or optional PET /MR images will be acquired. Image fusion serves for a better recognition of the target





3-D-Treatment planning process (Contouring)

Fixing of the treatment position (positioning, immobilization)

↓

MRT **CT** **PET** **SPECT**

↓

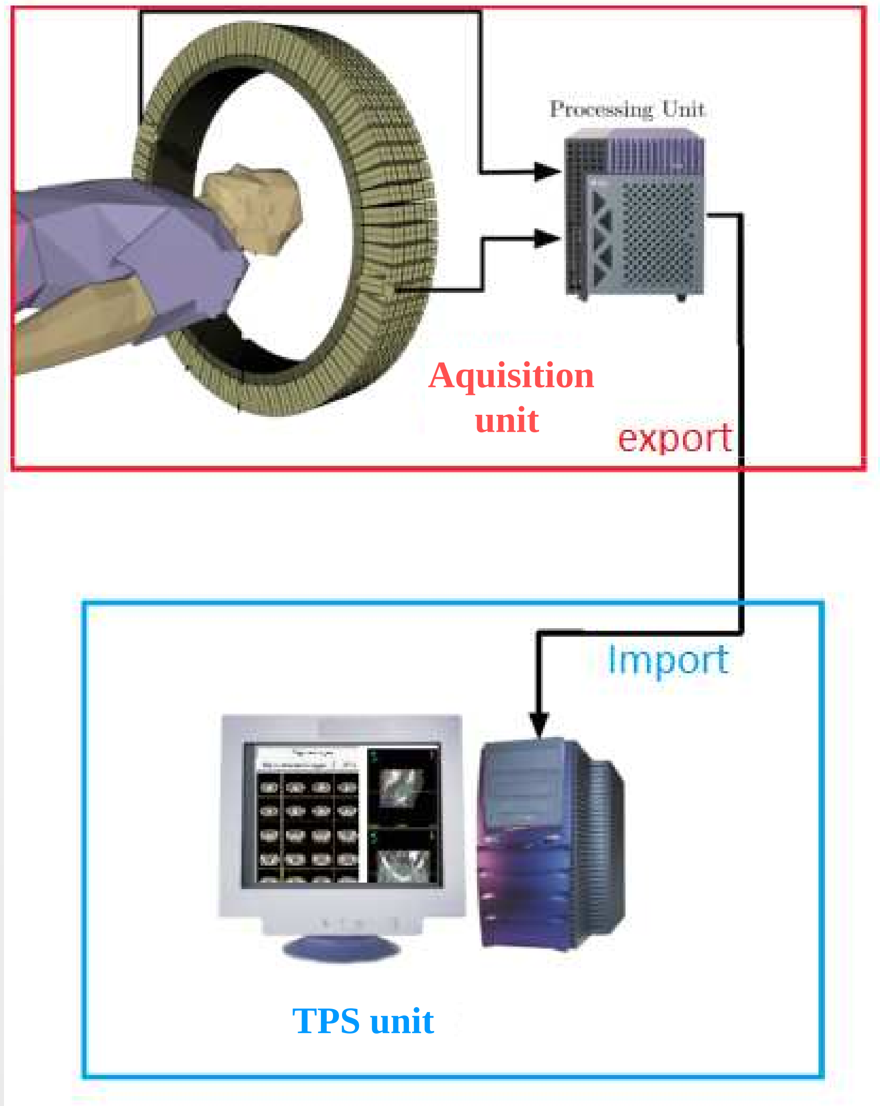
Fusion

↓

Contouring

↓

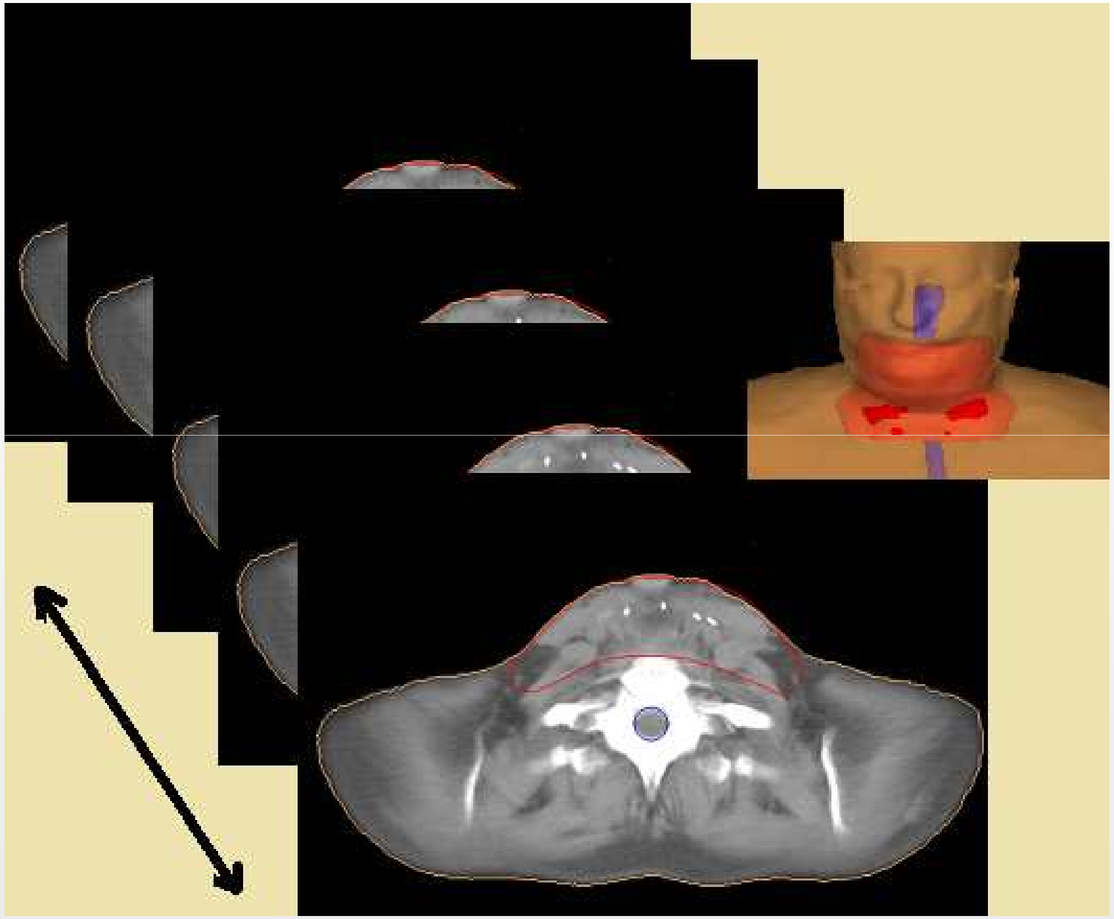
For the treatment planning, the images must be exported from the acquisition unit and imported to the TPS unit.



3-D-Treatment planning process (Contouring)

Contouring:

- On each slice of the CT (e.g.: Larynx Ca.) is drawn ...
- an **outer contour** which limits the body (**brown**)
- a **target volume** that encloses the planning target volume PTV (**red**)
- **organs at risk** (here the spinal cord) (**blue**)
- The radiation oncologist is responsible for defining and contouring the target volume.



Depending on tumour location, other organs at risk are taken into consideration during the irradiation

3-D-Treatment planning process (Contouring)

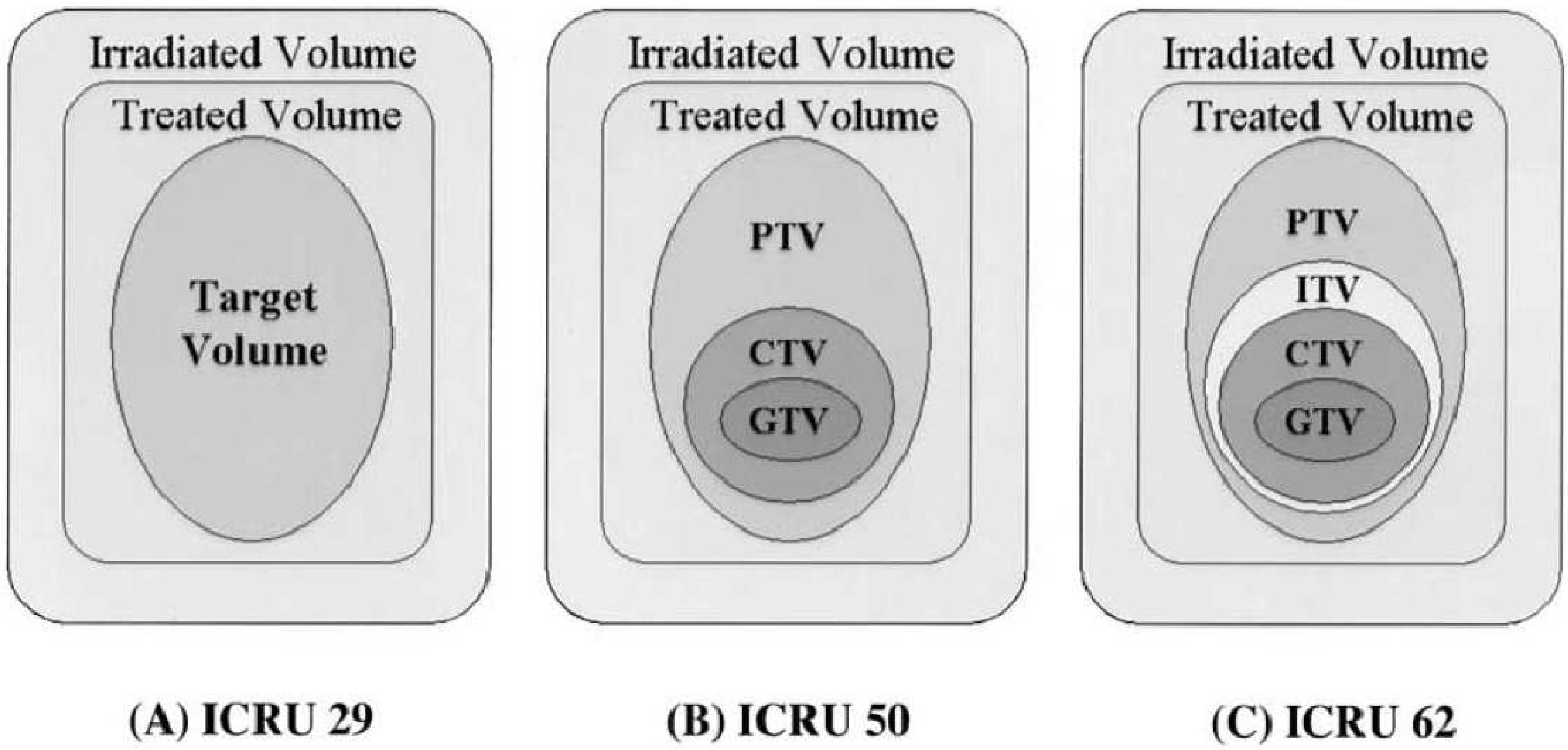
Strategy

- **tumour mass (X-Ray, CT, MRT)**
- **tumour localization (X-Ray, CT, MRT)**
- **tumour character (MR-Spectrom, SPECT, PET)**

=>

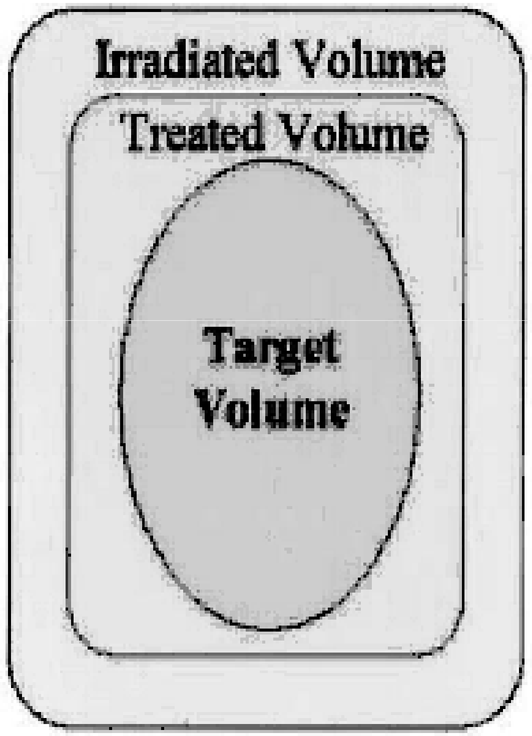
Target 1 (Tumour detected) → higher dose
Target 2 (Tumour suspected) → lower dose

ICRU: Changes Over Time



3-D-Treatment planning process (Contouring)

ICRU 29, 1978

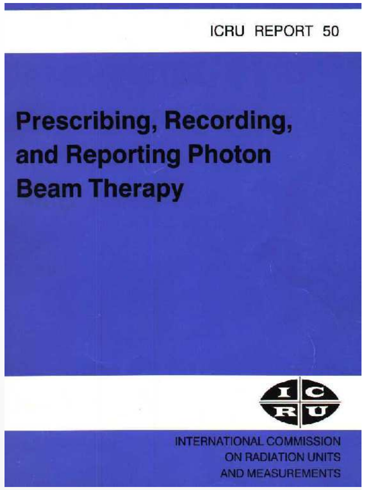


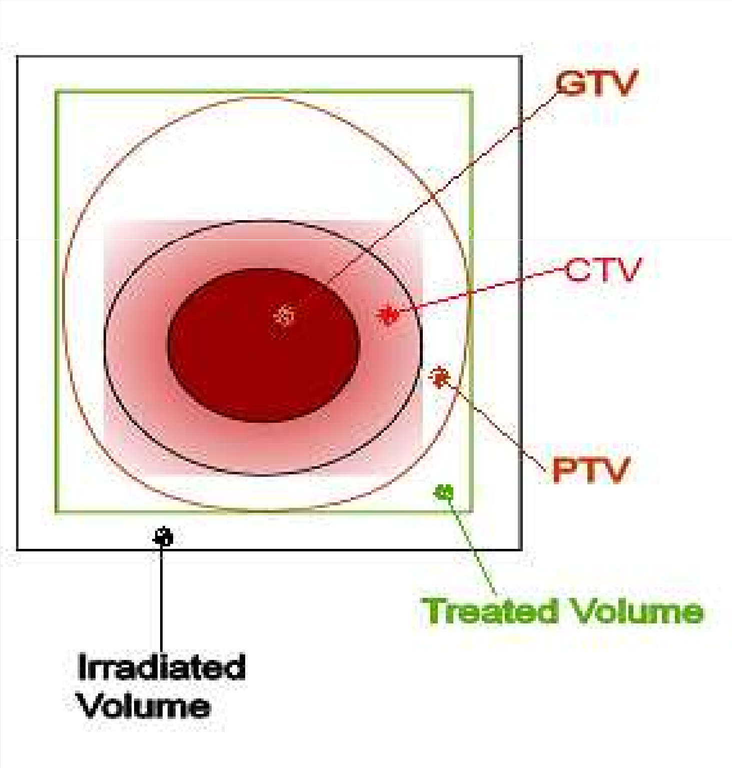
ICRU 29

- Single slice (or few)
- External contour
- Coplanar beams
- Simple calculations
- Dose prescription to “ICRU reference point”

3-D-Treatment planning process (Contouring)

Target volume definition (ICRU 50) 1993



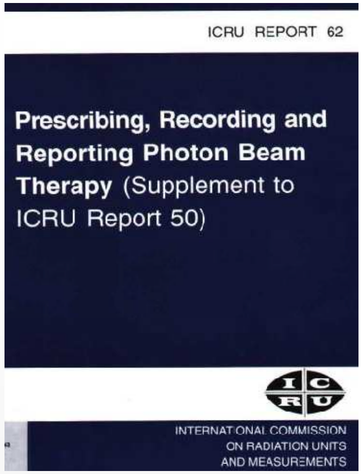


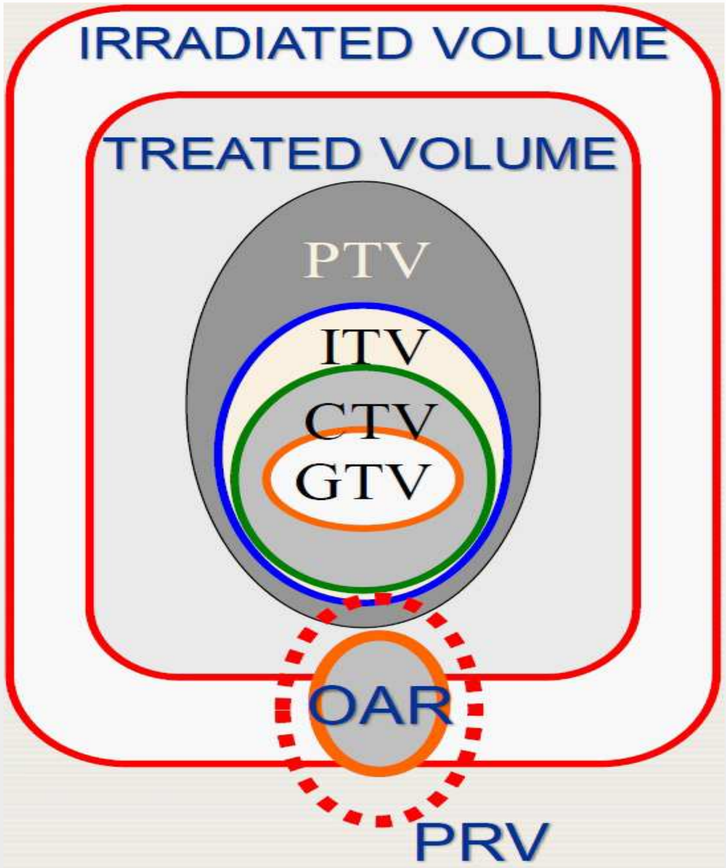
- **Gross Tumour Volume (GTV) = clinically demonstrated tumour**
- **Clinical Target Volume (CTV) = GTV + area at risk (*e.g.* potentially involved lymph nodes)**
- **Planning Target Volume (PTV) = volume planned to be treated = CTV + margin for set-up uncertainties and potential of organ movement**

3-D-Treatment planning process (Contouring)

Target volume definition (ICRU 62)

1999





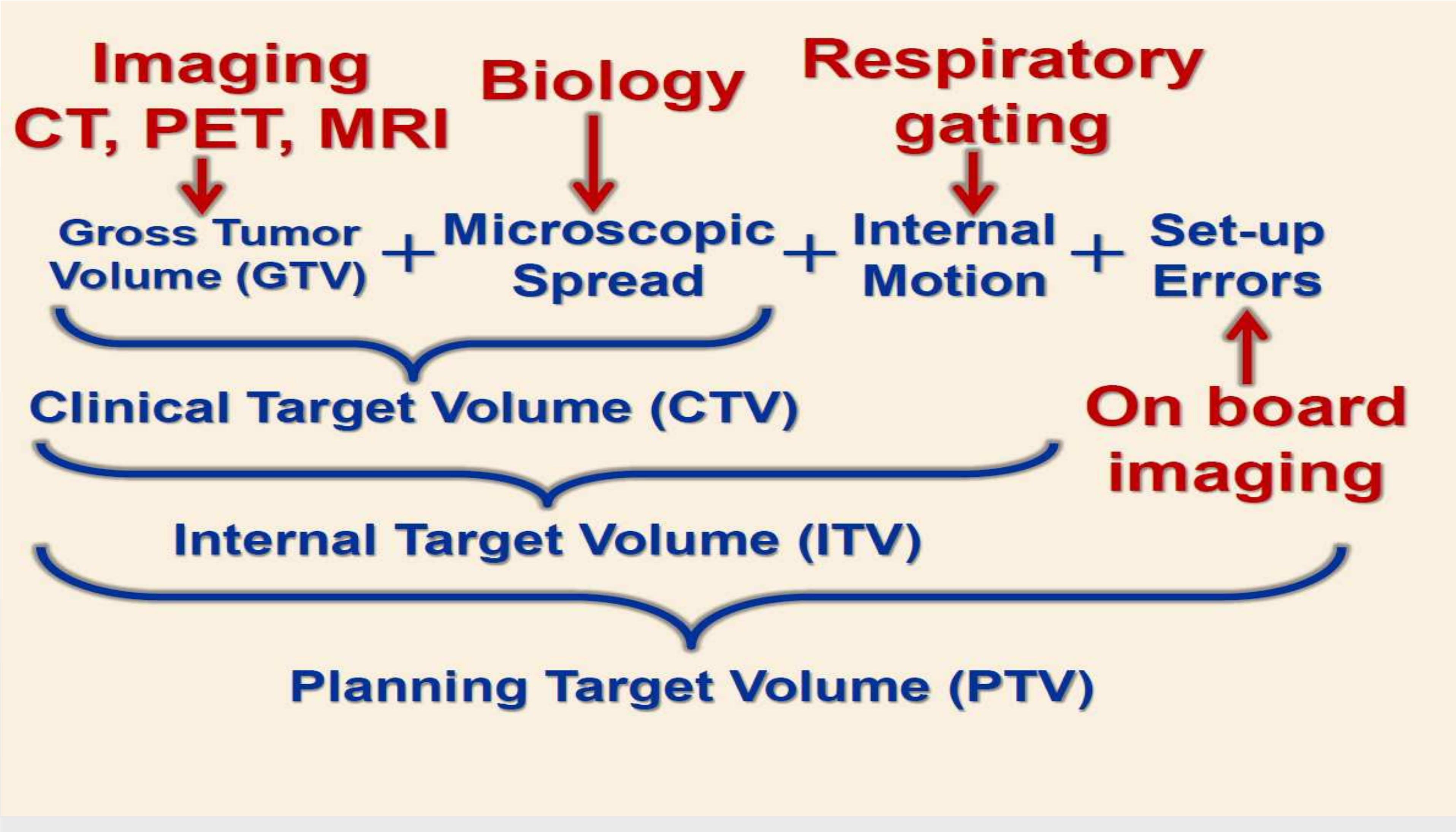
PRV: Includes margin around the OAR to compensate for changes in shape and internal motion and for set-up variation.

- **Irradiation techniques have advanced**

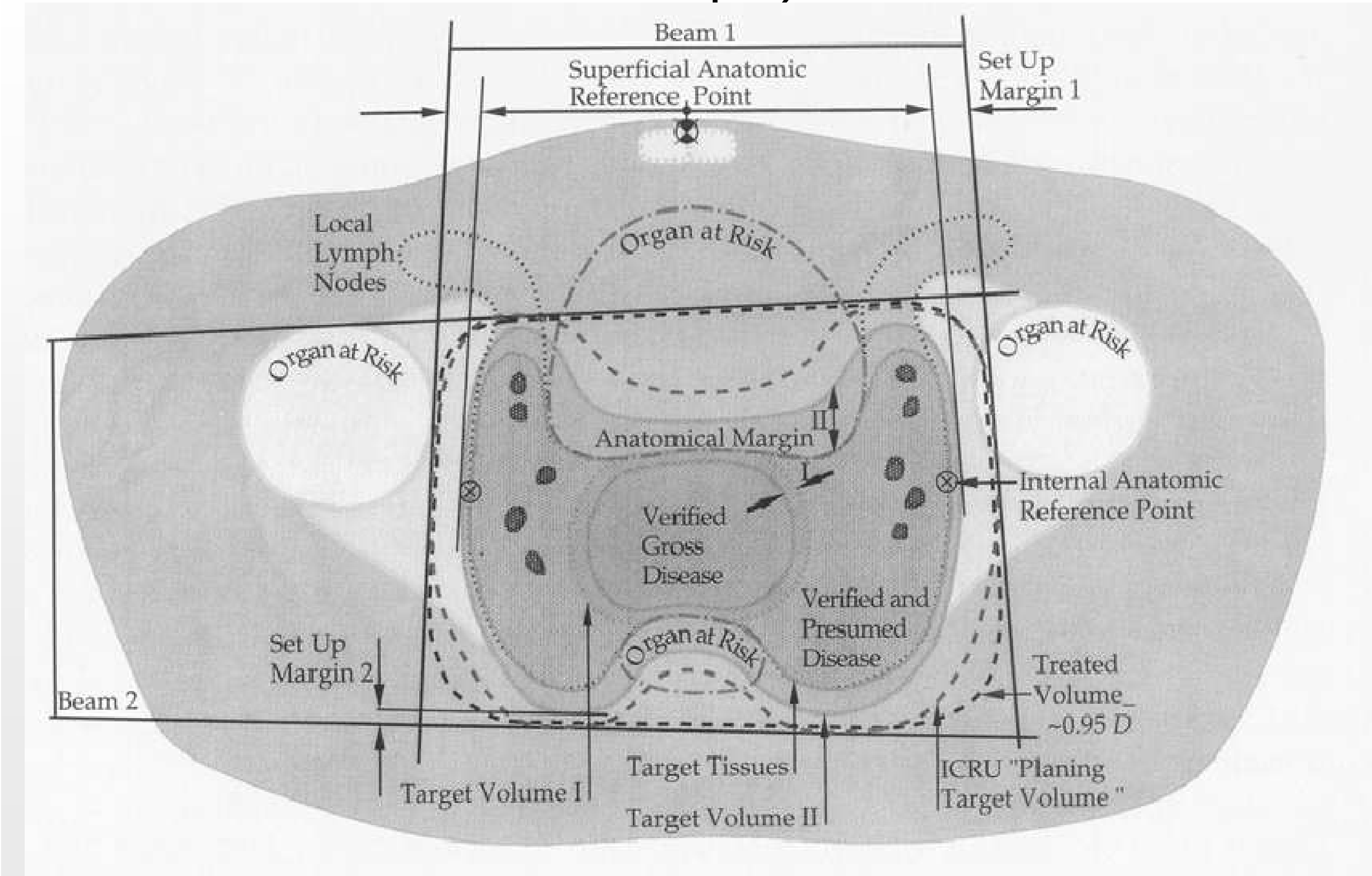
  =>
- **More accurately formulate definitions & concepts**
  - **Reference points and coordinate systems**
  - **Introduction of**
    - **Internal Margin (IM)**
    - **Setup Margin (SM)**
    - **Internal Target Volume (ITV)**
    - **Planning organ at Risk Volume (PRV)**
    - **Conformity Index (CI)**

3-D-Treatment planning process (Contouring)

<u>Planning Target Volume</u> (ICRU 62)



3-D-Treatment planning process (Contouring-example)



3-D-Treatment planning process (Beam Modelling)

Fixing of the treatment position (positioning, immobilization)

↓

MRT | CT | PET | SPECT

↓

Fusion

↓

Contouring

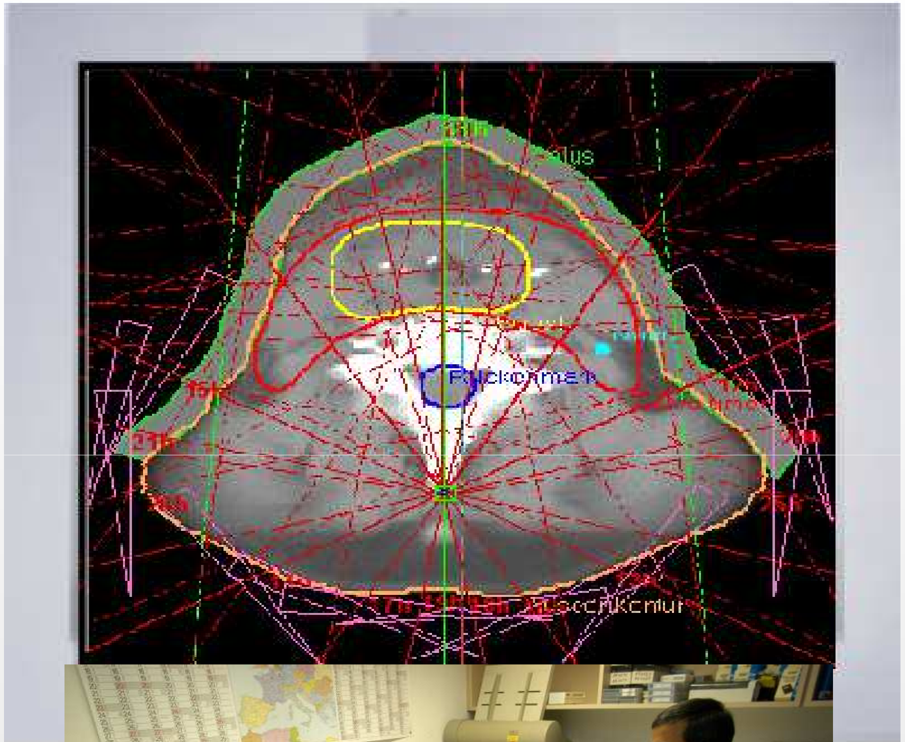
↓

Setting of the radiation fields virtual simulation

Optimization of the dose distribution

Evaluation

3-D-Treatment plan

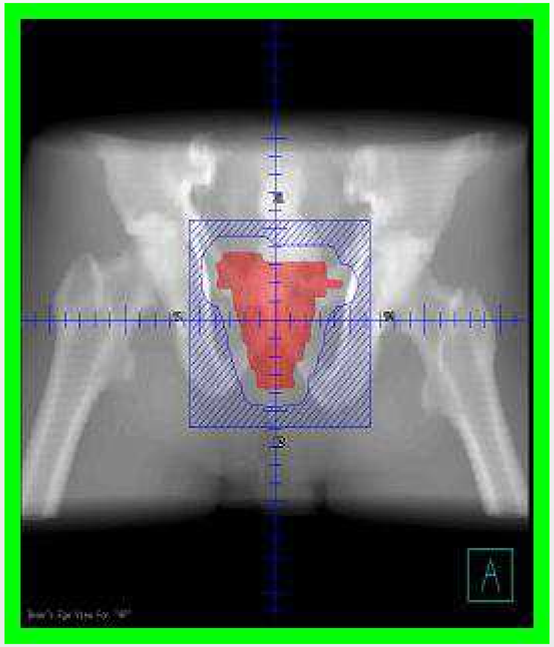


3-D-Treatment planning process (Beam Modelling)

Optimization criterion - field form

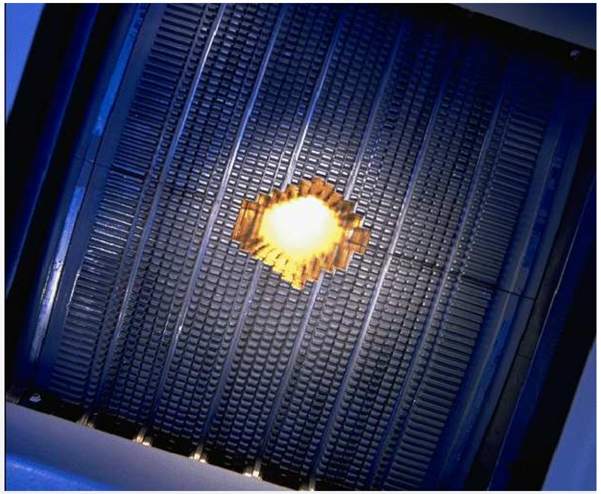
Satellites blocks

Adjustment of the fielf form to PTV



Beam eye view

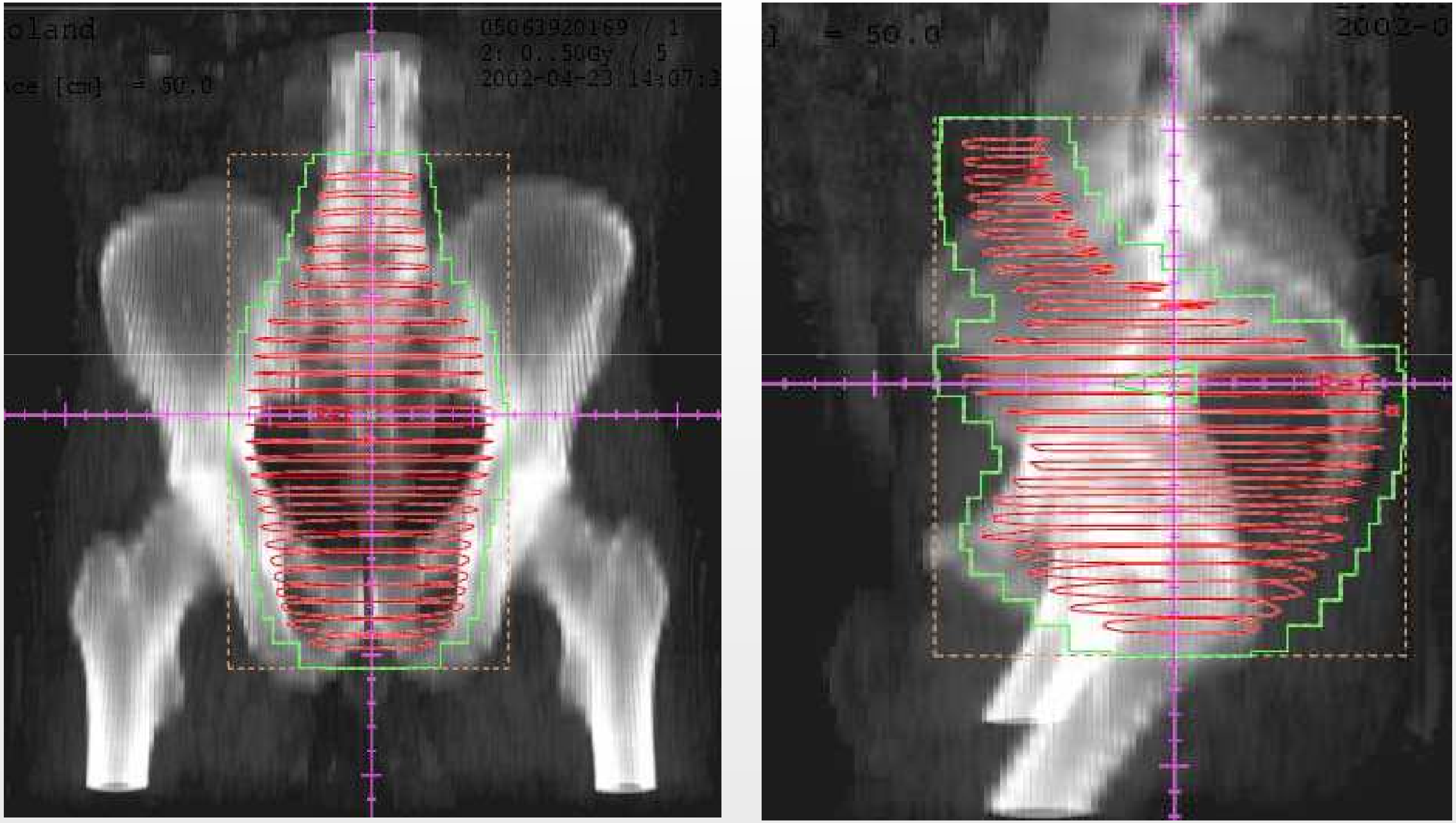
Multileaf Collimator (MLC)



Siemens factory Photo

3-D-Treatment planning process (Beam Modelling)

Optimization criterion - field form

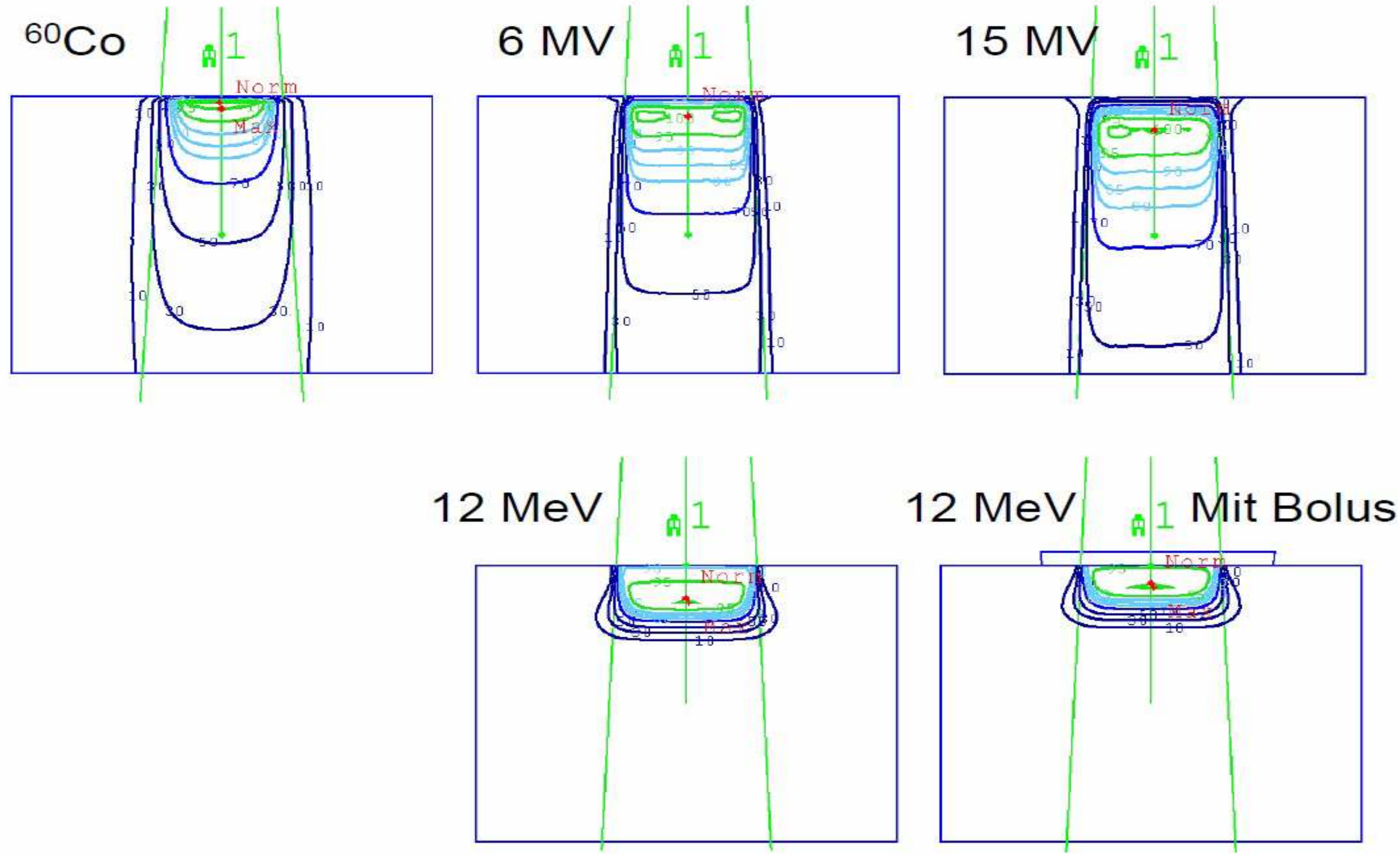


Field formation in the AP and lateral fields with a pelvic irradiation (4-field box) based on the Beam Eye View (BEV)

3-D-Treatment planning process (Beam Modelling)

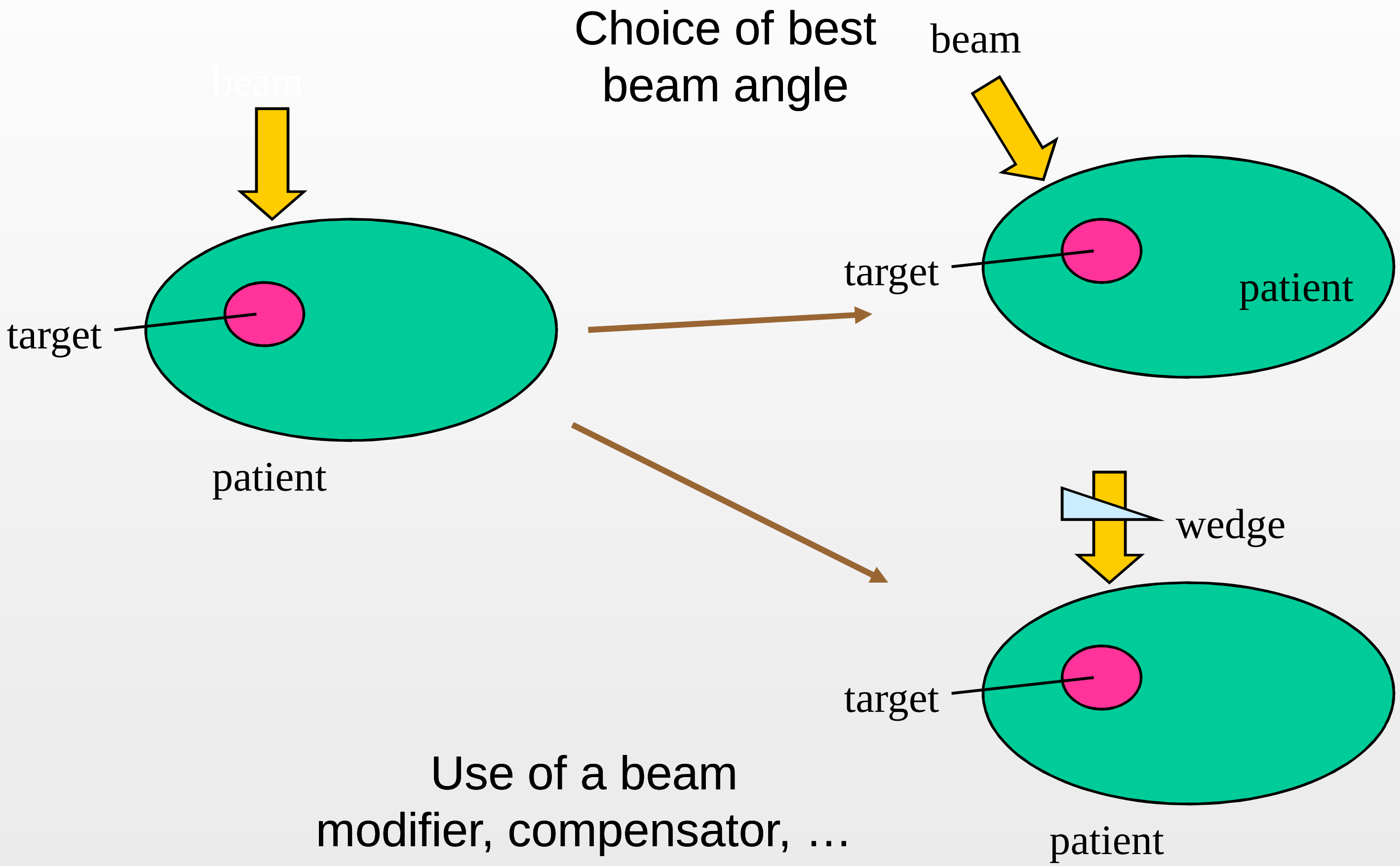
Optimization criterion - radiation type and energy

examples



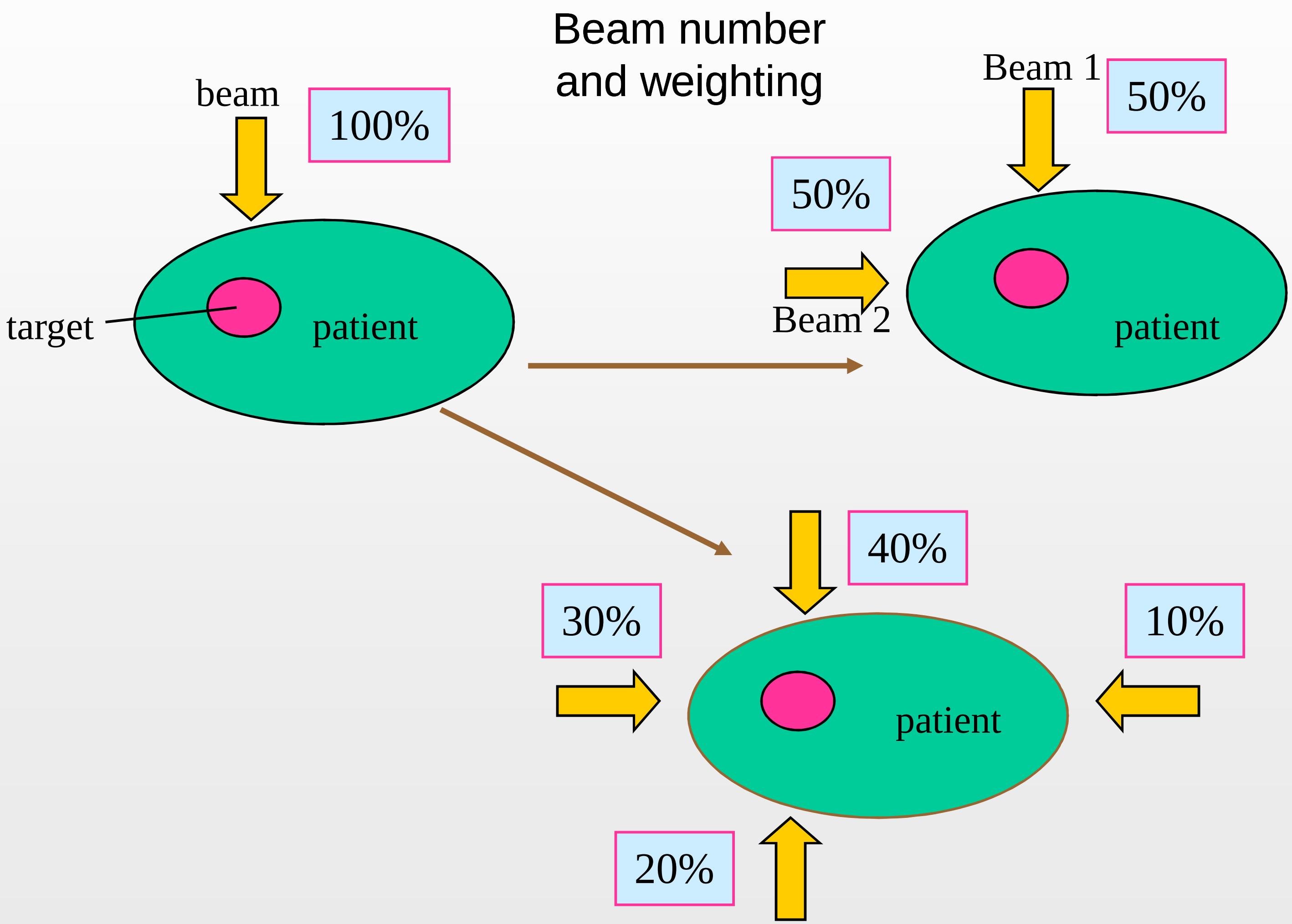
3-D-Treatment planning process (Beam Modelling)

Optimization approaches-Entry point



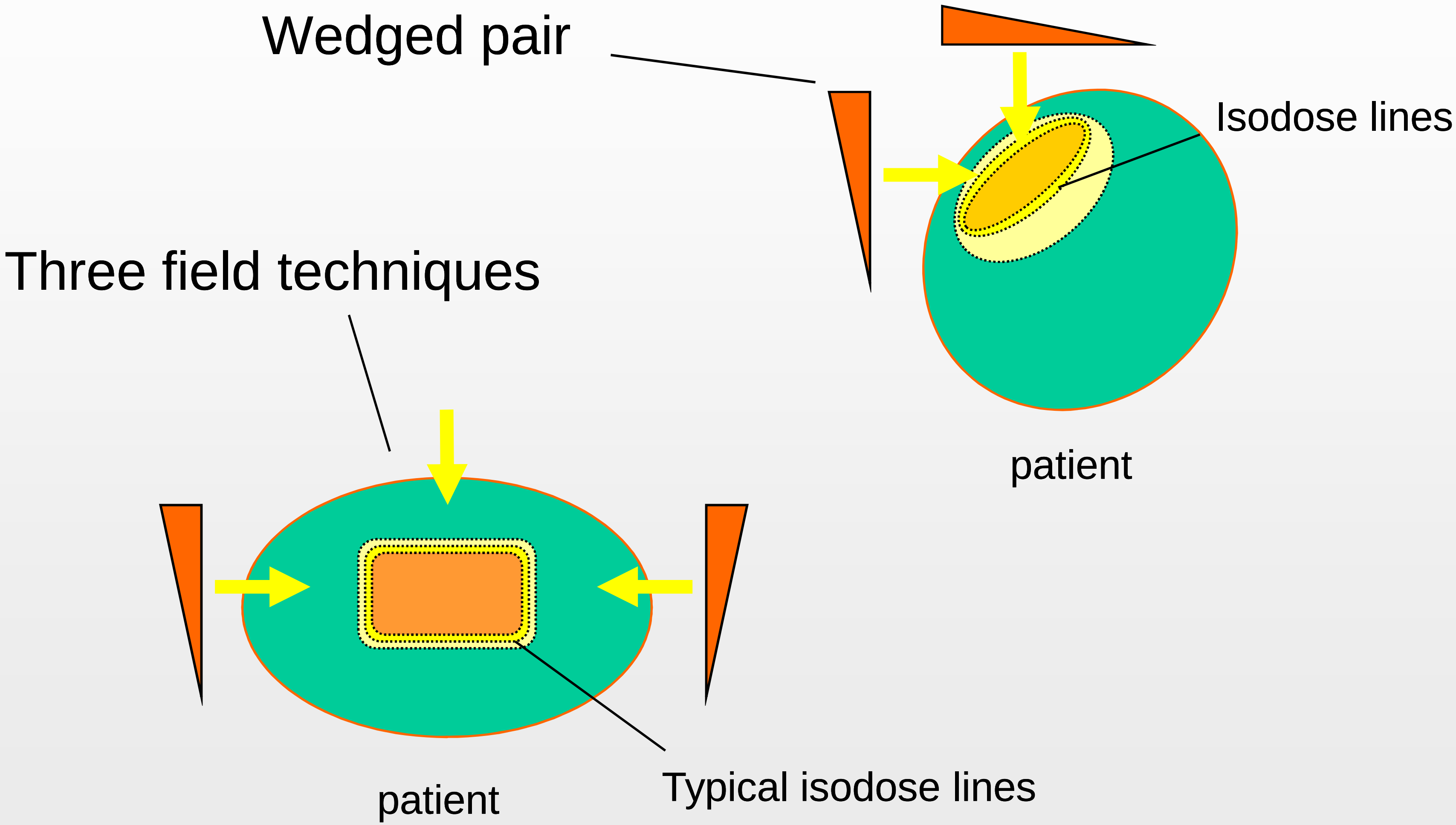
3-D-Treatment planning process (Beam Modelling)

<u>Optimization approaches: Beam number and weighting</u>



3-D-Treatment planning process (Beam Modelling)

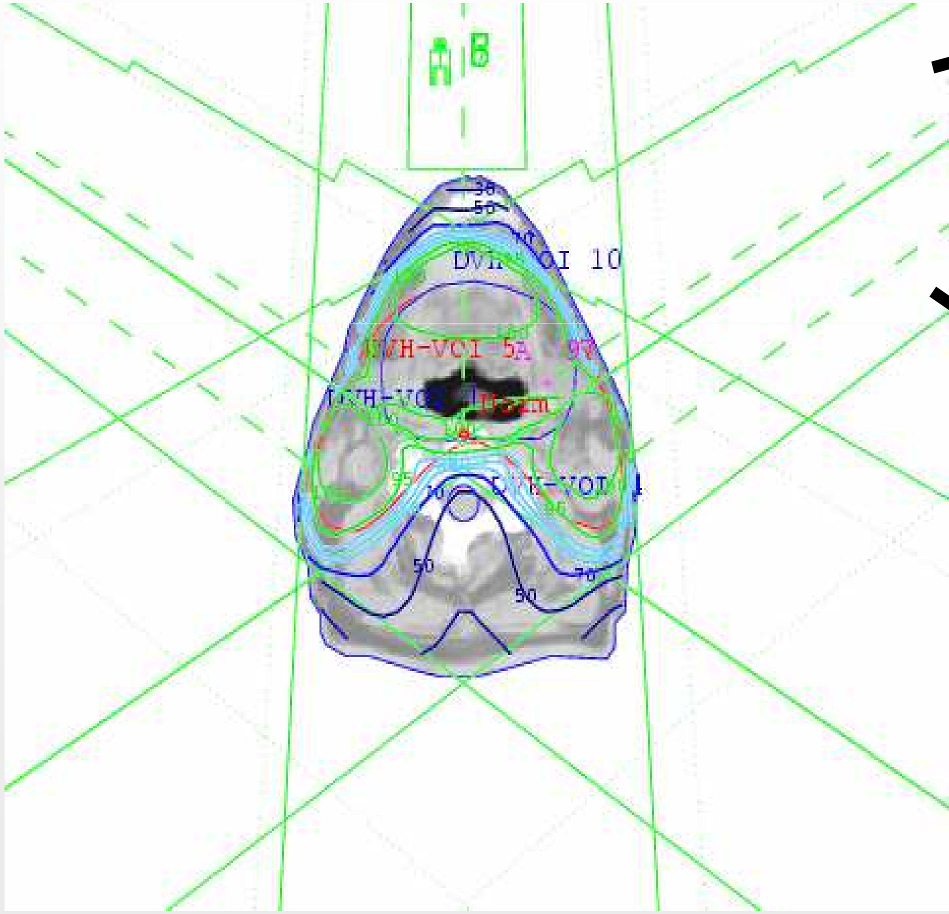
Optimization approaches- use of wedges



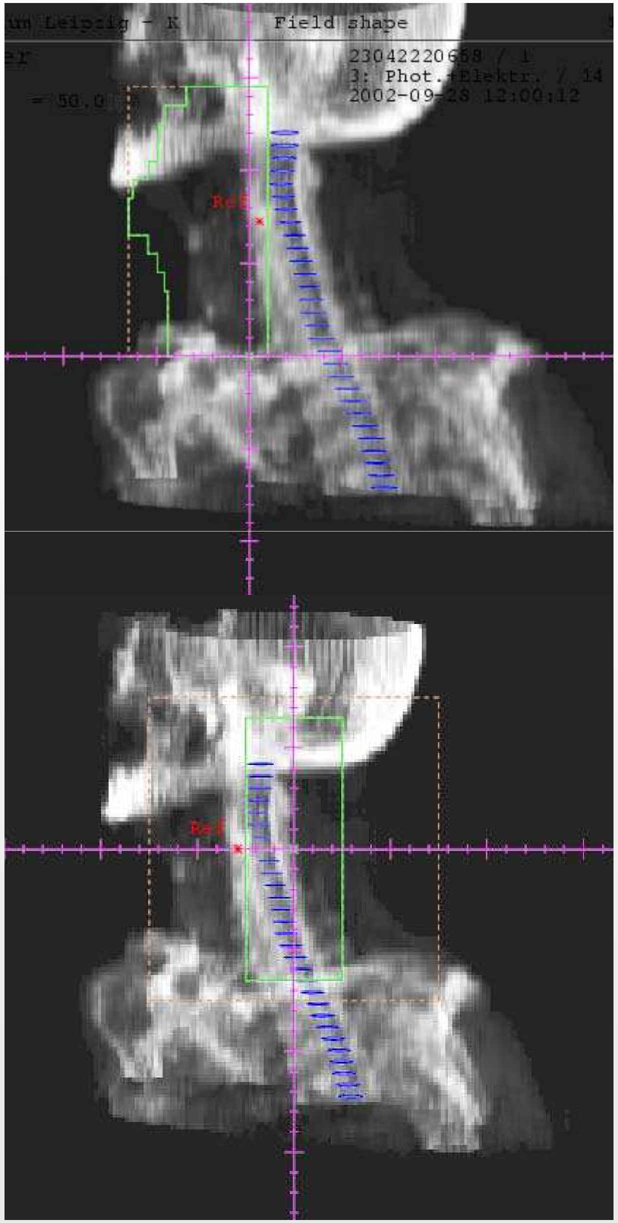
3-D-Treatment planning process (Beam Modelling)

Combination of photons and electrons

<u>Optimization criterion - Radiation type</u>



Head -Neck



BEV (DRR) photon field

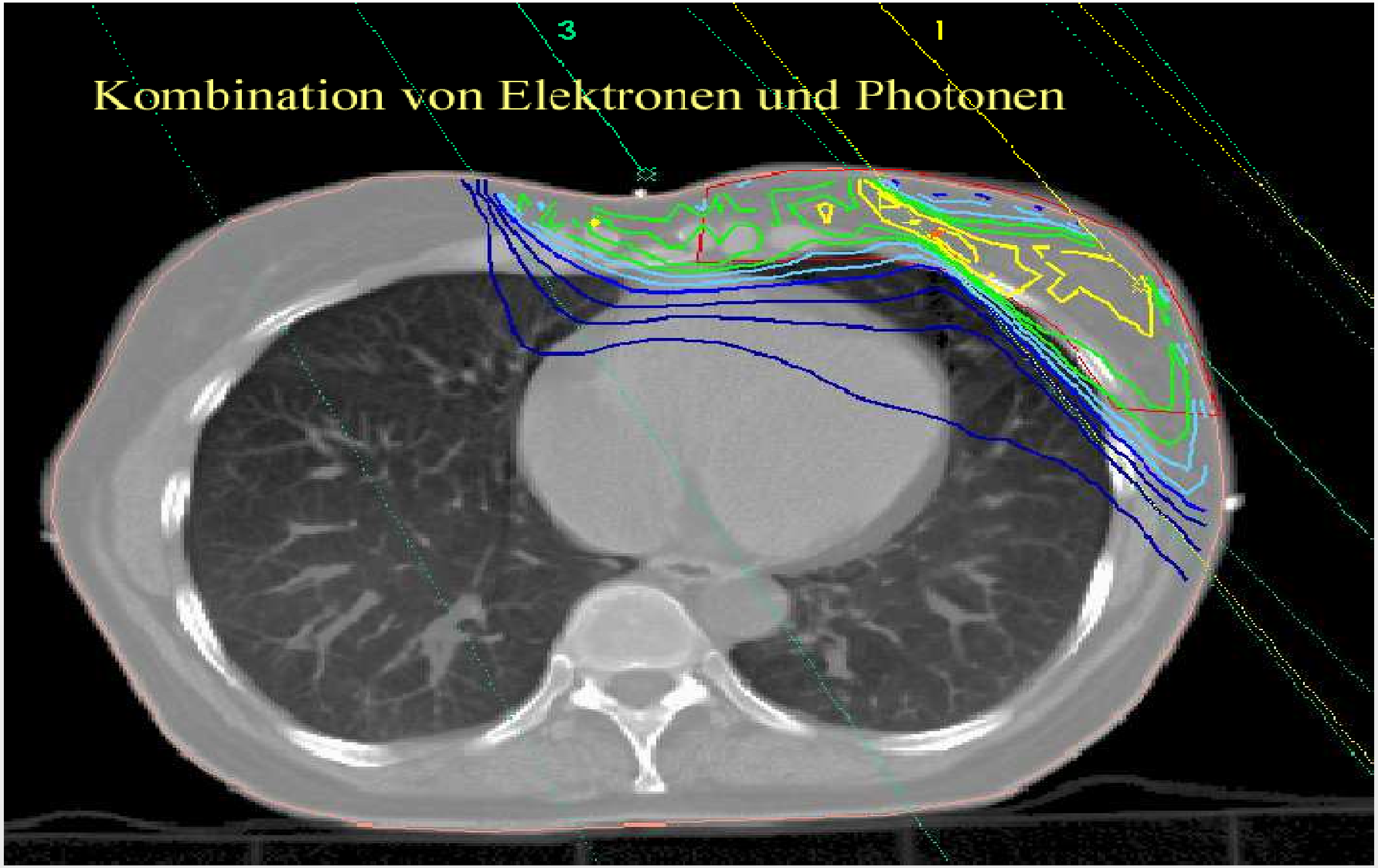
BEV (DRR) electron field

3-D-Treatment planning process (Beam Modelling)

Combination of photons and electrons

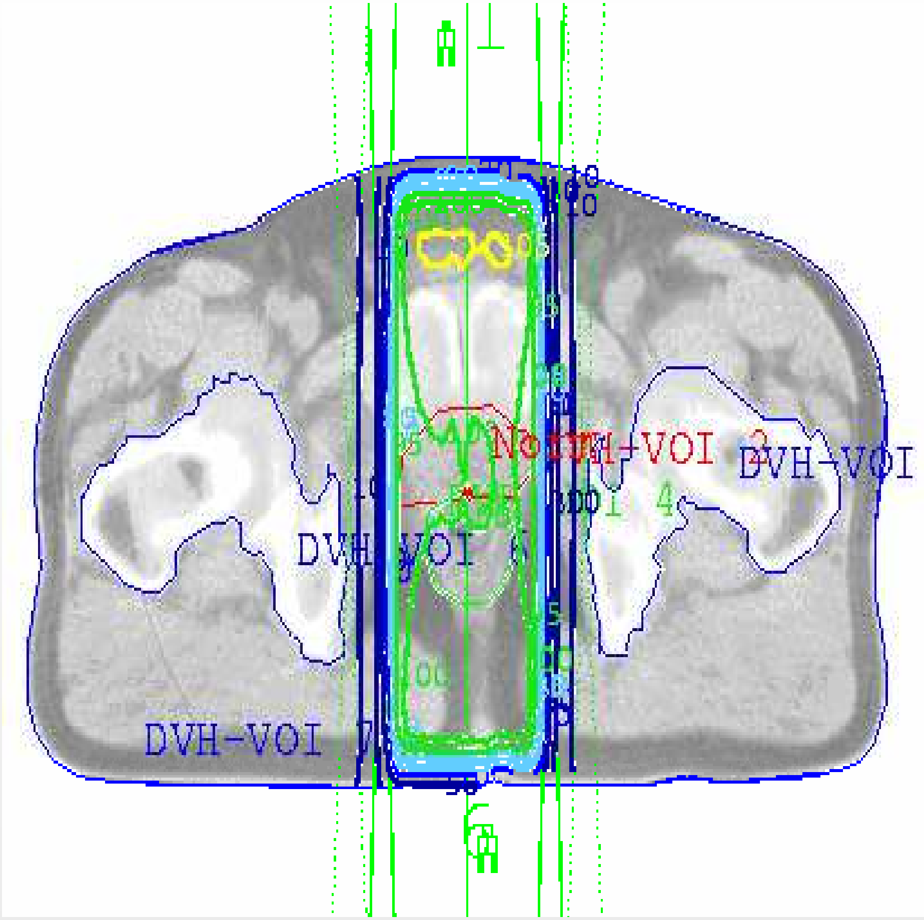
Optimization criterion - Radiation type

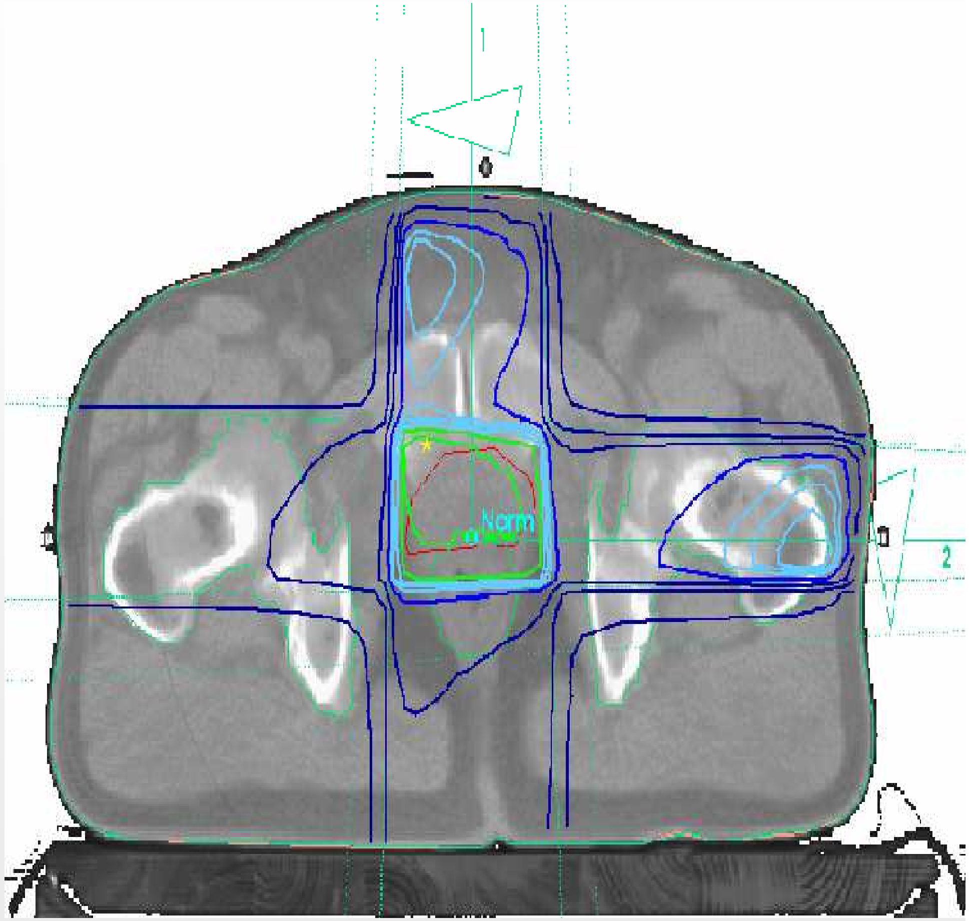
Breast



3-D-Treatment planning process (Beam Modelling)

<u>Optimization criterion - field number</u>



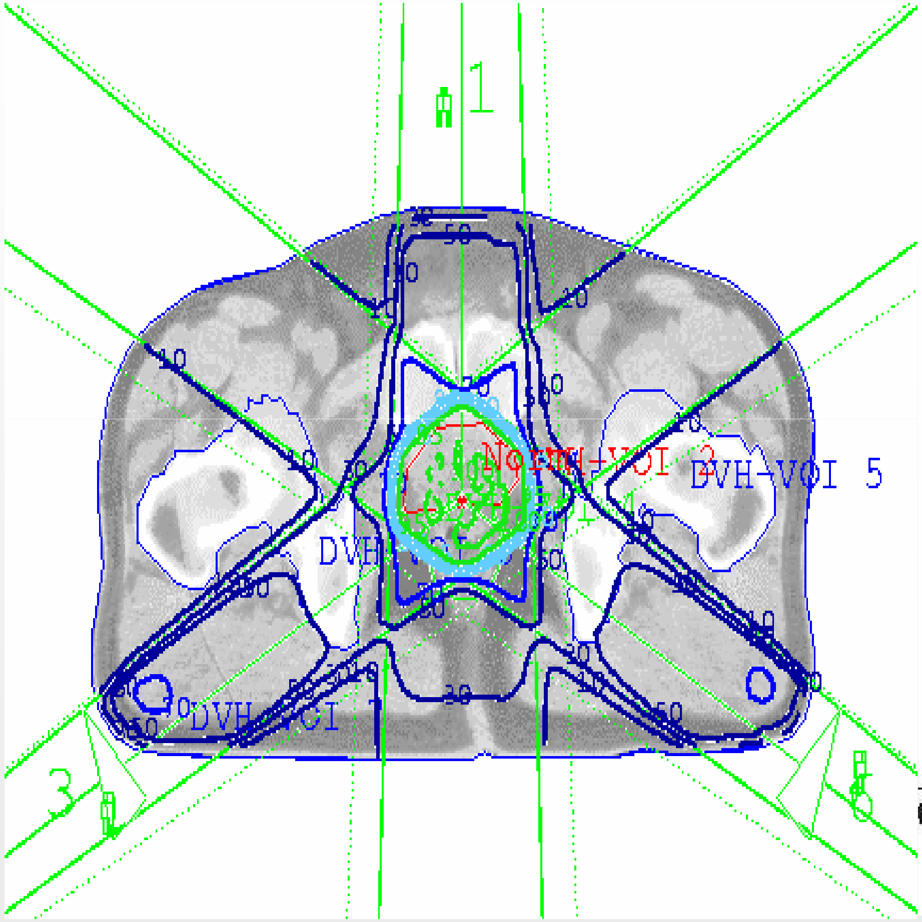


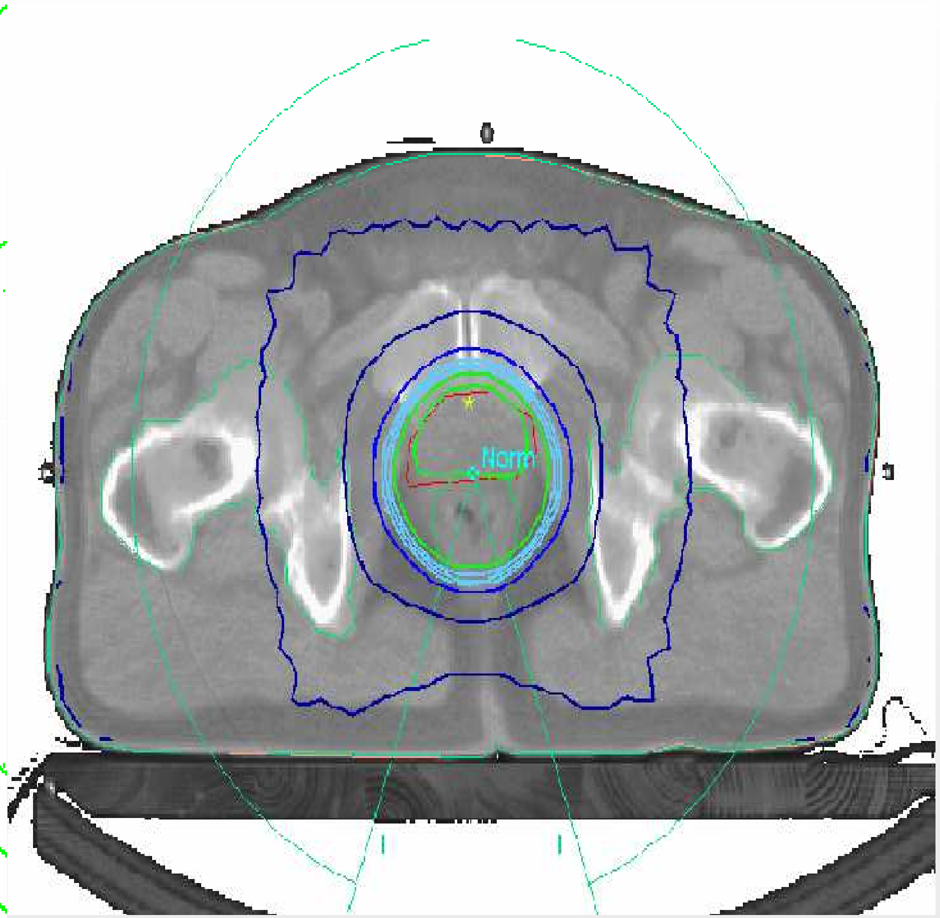
2 opposite fields

2 wedged fields

3-D-Treatment planning process (Beam Modelling)

Optimization criterion - field number

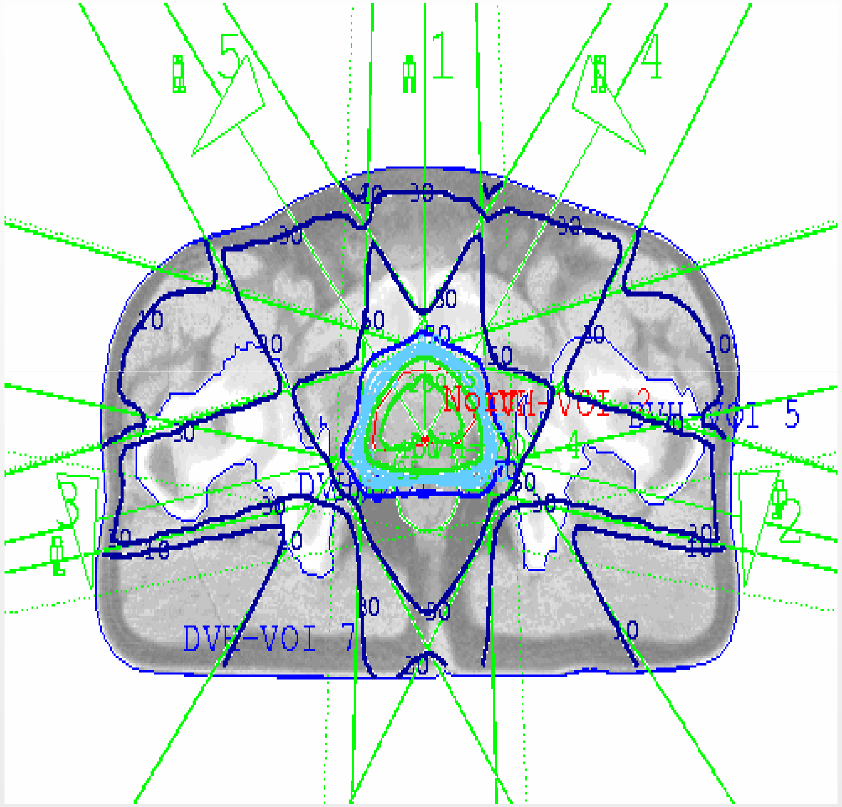




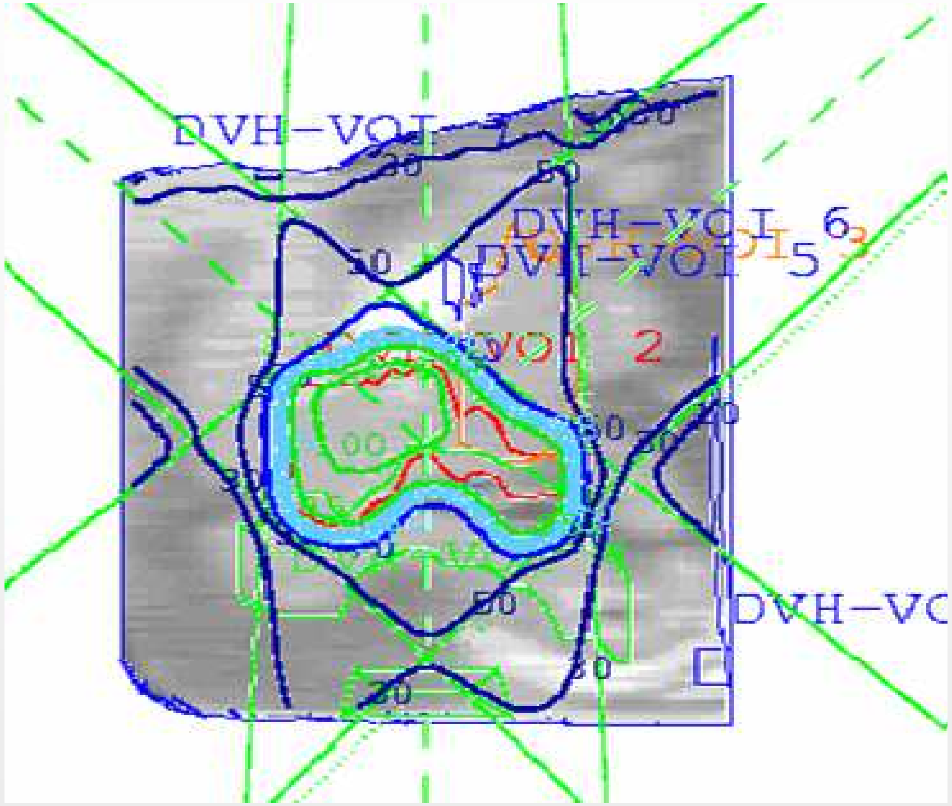
3 fields **Rotational irradiation**

3-D-Treatment planning process (Beam Modelling)

5 Felder non-coplanar



transversal



sagital

3-D-Treatment planning process (Dose Distribution criteria)

Radiotherapy - Spatial dose distribution

Criteria of a uniform dose distribution within the target

- Recommendations regarding dose uniformity, prescribing, recording, and reporting photon beam therapy are set forth by the International Commission on Radiation Units and Measurements (ICRU).
- The ICRU report 50 recommends a target dose uniformity within +7% and –5% relative to the dose delivered to a well defined prescription point within the target.
- The limits of the tolerance doses for the organs at risks are given in the next slide.

Tolerance doses in Gy (Emami et al).

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Brain	60	50	45	75	65	60	Nekrose, Infarkt
Brainstem	60	53	50	-	-	65	Nekrose, Infarkt
TMJ	65	60	60	77	72	72	Trismus
Colon	55		45	60		55	Stenose, Perforation, Fistel, Ulkus
Larynx	79[a]	70[a]	70[a]	90[a]	80[a]	80[a]	Knorpelnekrose
Larynx	-	45	45[a]	-	-	80[a]	Larynxödem
Liver	50	35	30	55	45	40	Liver failure
Lung	45	30	17,5	65	40	24,5	Pneumonitis
Stomach	60	55	50	70	67	65	Ileus, Perforation
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Optic Nerve, Retinae (I+II)	no Volume effect		50	no Volume effect		65	Blindness

3-D-Treatment planning process (Optimized dose Distribution)

Fixing of the treatment position (positioning, immobilization)

MRT **CT** **PET** **SPECT**

Fusion

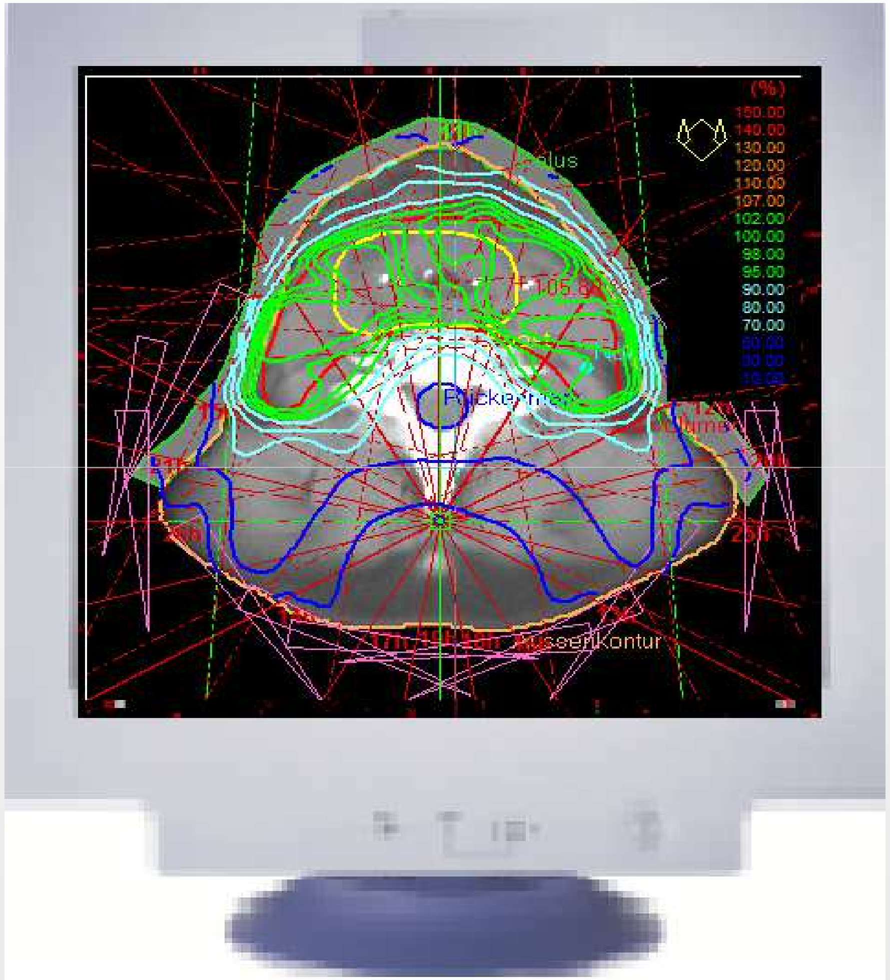
Contouring

Setting of the radiation fields virtual simulation

Optimization of the dose distribution

Evaluation

3-D-Treatment plan



Example: Optimized dose distribution in larynx Ca.

3-D-Treatment planning process (Dose Volume Histogram)

Fixing of the treatment position (positioning, immobilization)

MRT | **CT** | **PET** | **SPECT**

Fusion

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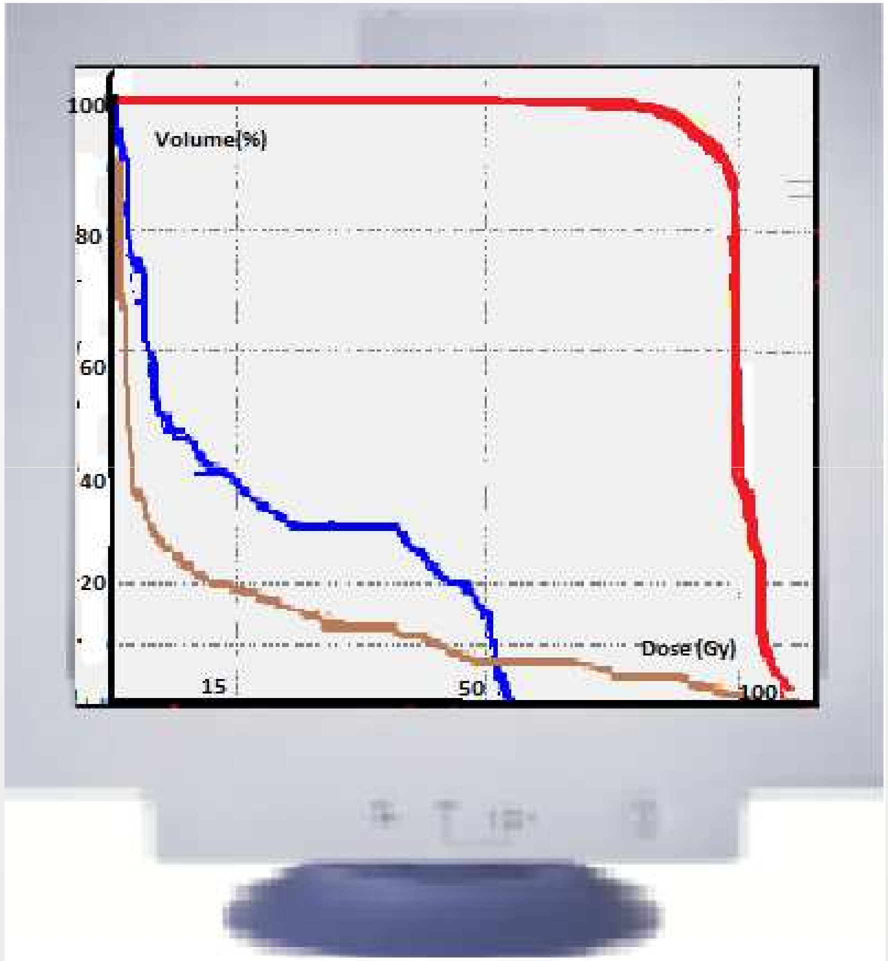
3-D-Treatment plan



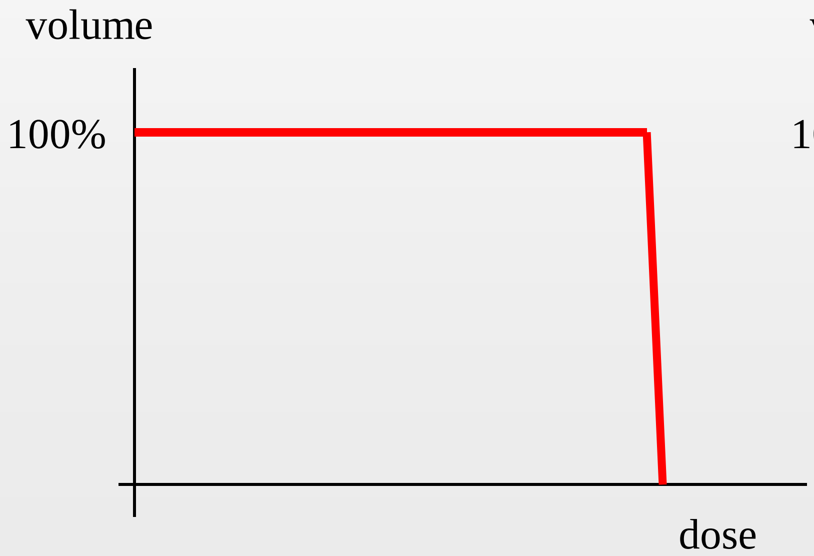
Example: Evaluation (DVH) in Larynx Ca

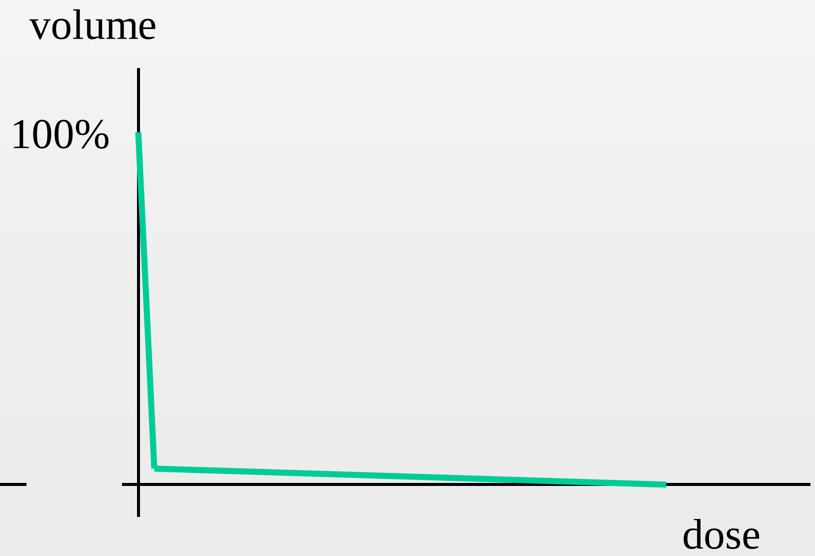
3-D-Treatment planning process (Dose Volume Histogram)

The ideal DVH

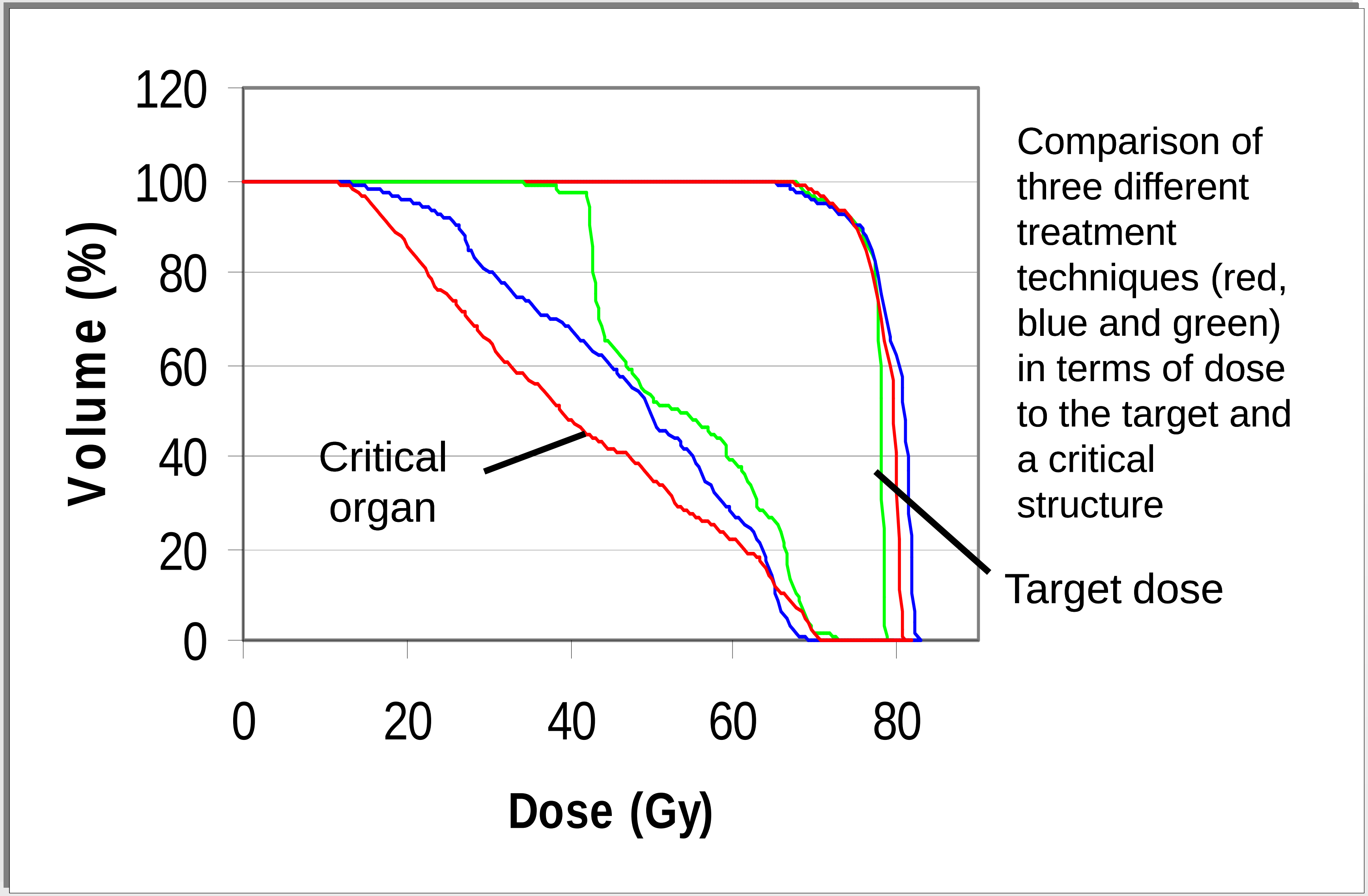
- Tumour:
  - High dose to all
  - Homogenous dose

- Critical organ
  - Low dose to most of the structure



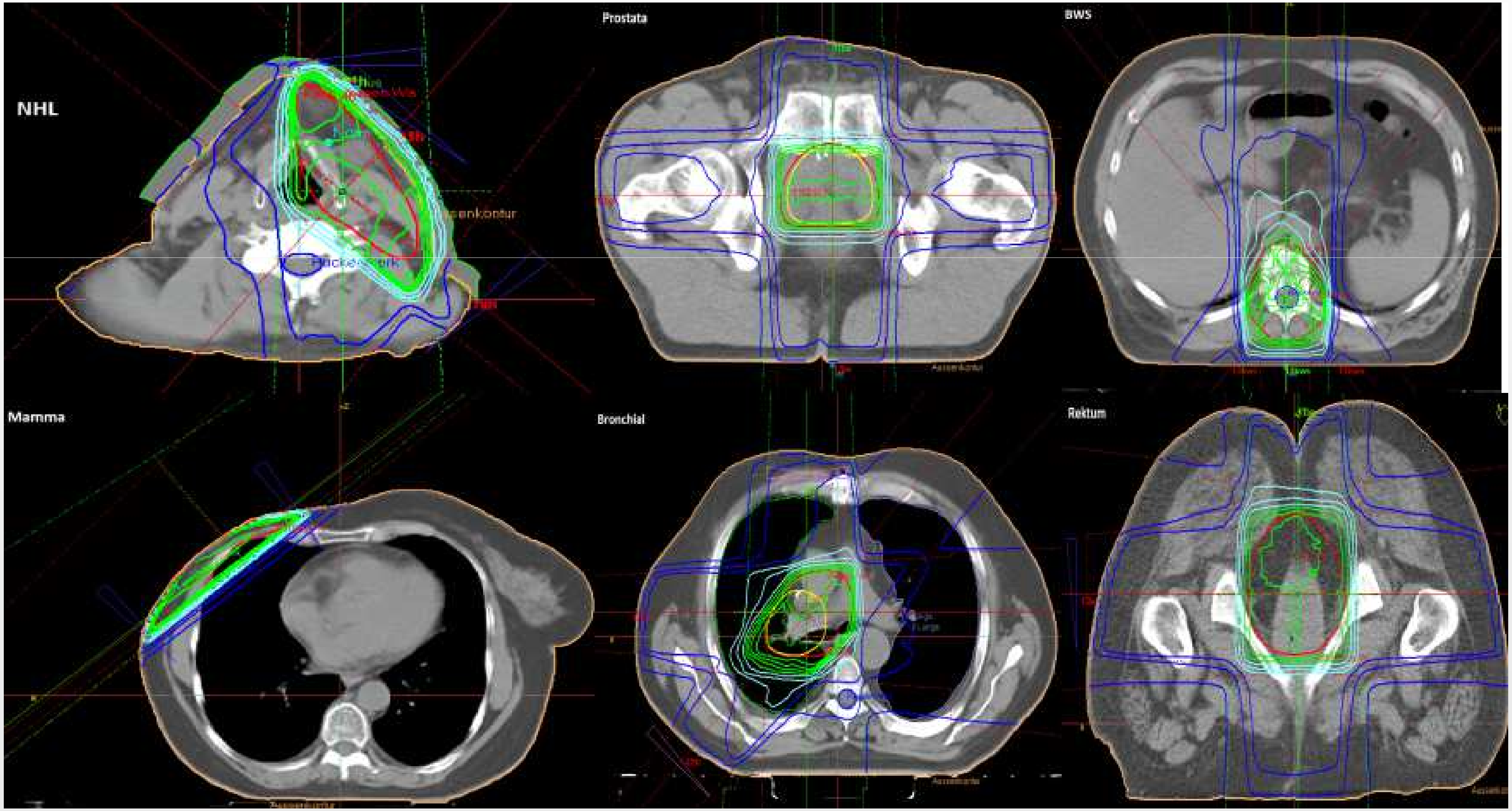


3-D-Treatment planning process (Dose Volume Histogram)



3-D-Treatment planning process (Dose Distribution examples)

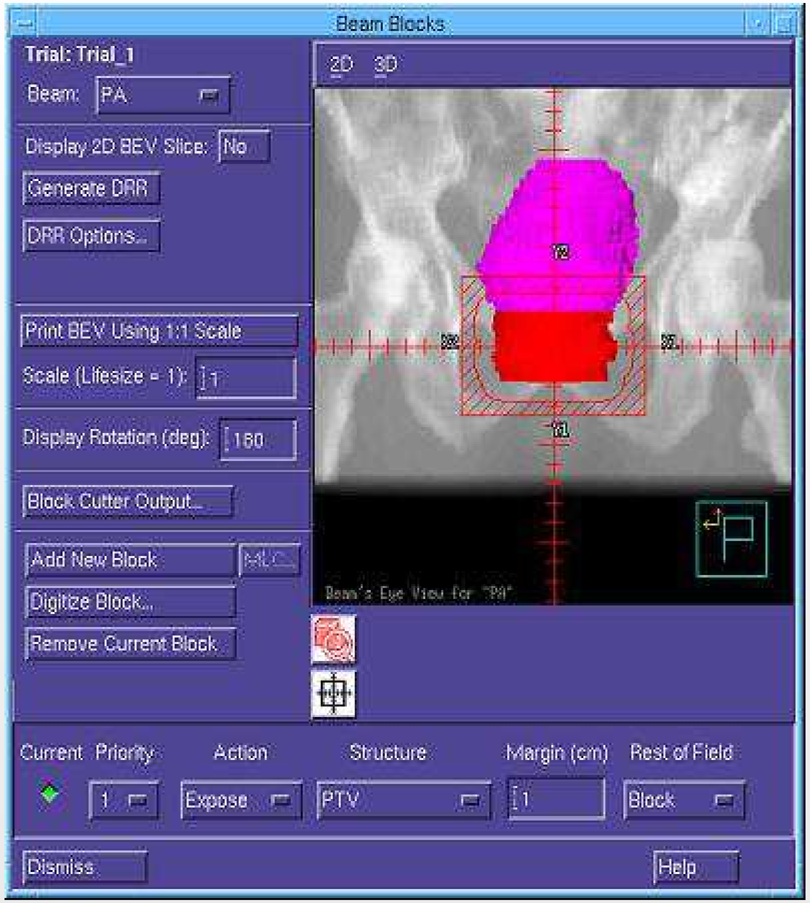
<u>Examples:</u> Malignant tumors such as: Mamma ca., Bronchial ca., Prostate ca., Rectum ca., Larynx ca., Metastasis, Sarcomas, lymphomas, ...



3-D-Treatment planning process (DRRs)

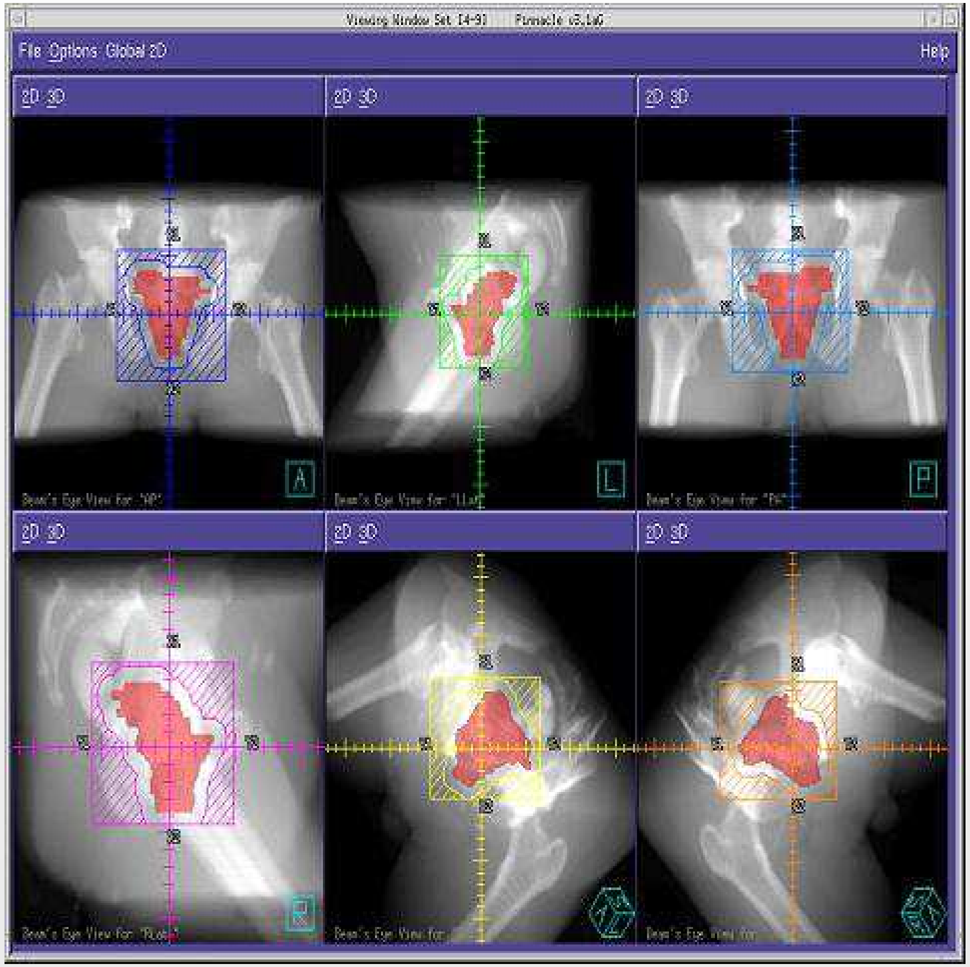
Digitally reconstructed radiographs (DRRs)

- Computer generated virtual images
- Requires patient CT dataset
- Choice of image quality - diagnostic or therapy type image
- Depends significantly on the number of CT slices available
- Important to compare with the verification



3-D-Treatment planning process (DRRs)

DRRs can mimic any geometry



- **Divergent beams**
- **3D**
- **Dose images**

Here :<u>Case Prostate</u>

3-D-Treatment planning process (Simulation)

Fixing of the treatment position
(positioning, immobilization)

MRT | CT | PET | SPECT

Fusion

Contouring

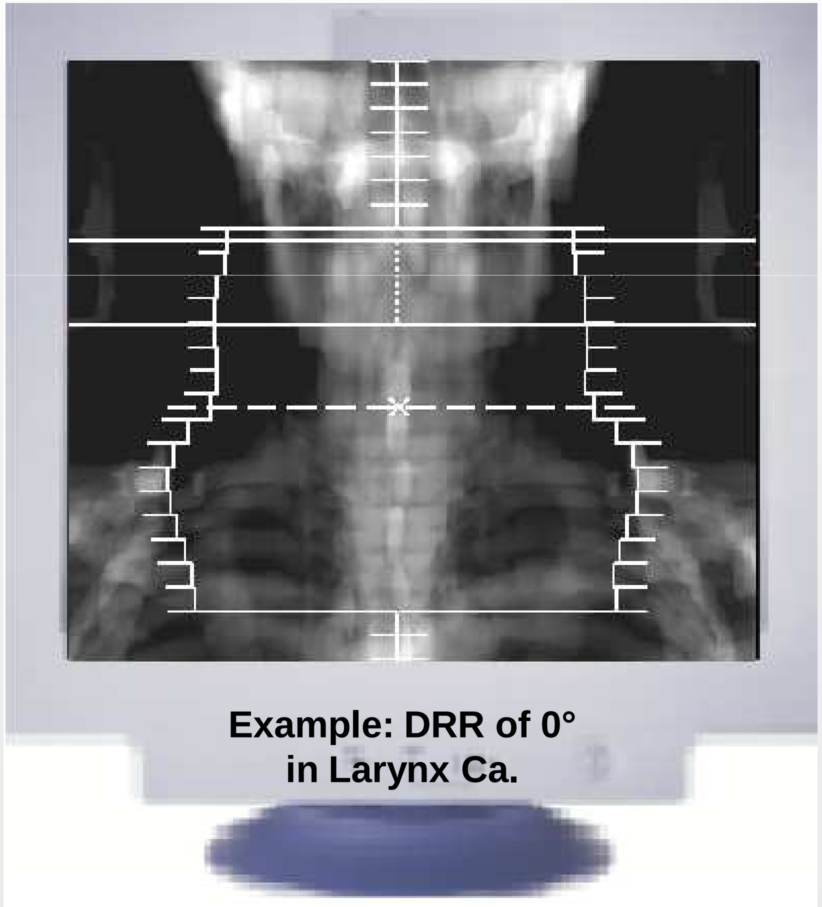
Setting of the radiation fields
virtual simulation

Optimization of the
dose distribution

Evaluation

3-D-Treatment plan

Simulation



Example: DRR of 0°
in Larynx Ca.

3-D-Treatment planning process (Verification System)

Fixing of the treatment position
(positioning, immobilization)

MRT **CT** **PET** **SPECT**

Fusion

Contouring

Setting of the radiation fields virtual simulation

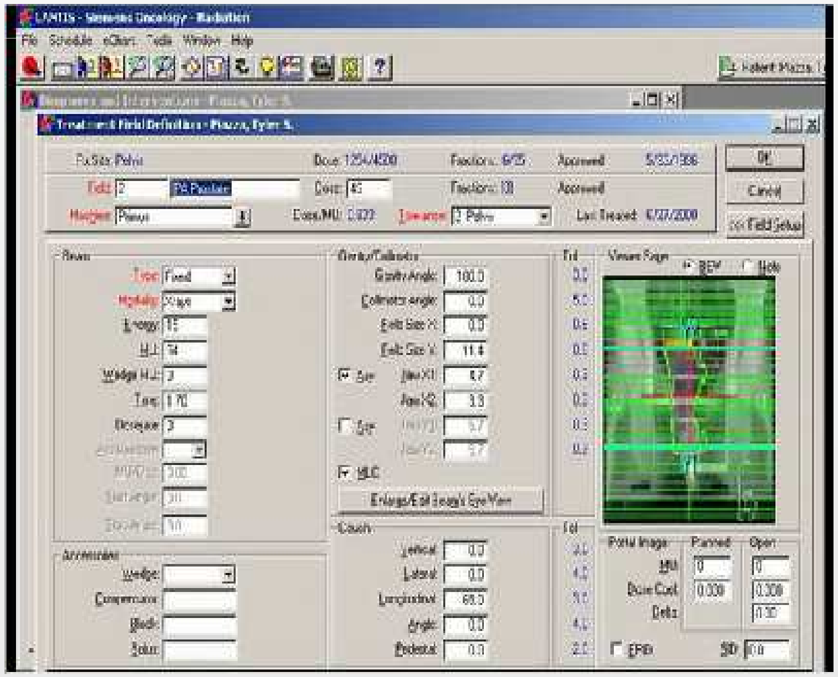
Optimization of the dose distribution

Evaluation

3-D-Treatment plan

Simulation

Radiotherapy information system



3-D-Treatment planning process (Positionning on LINAC table)

Fixing of the treatment position (positioning, immobilization)

MRT | CT | PET | SPECT

Fusion

Contouring

Setting of the radiation fields virtual simulation

Optimization of the dose distribution

Evaluation

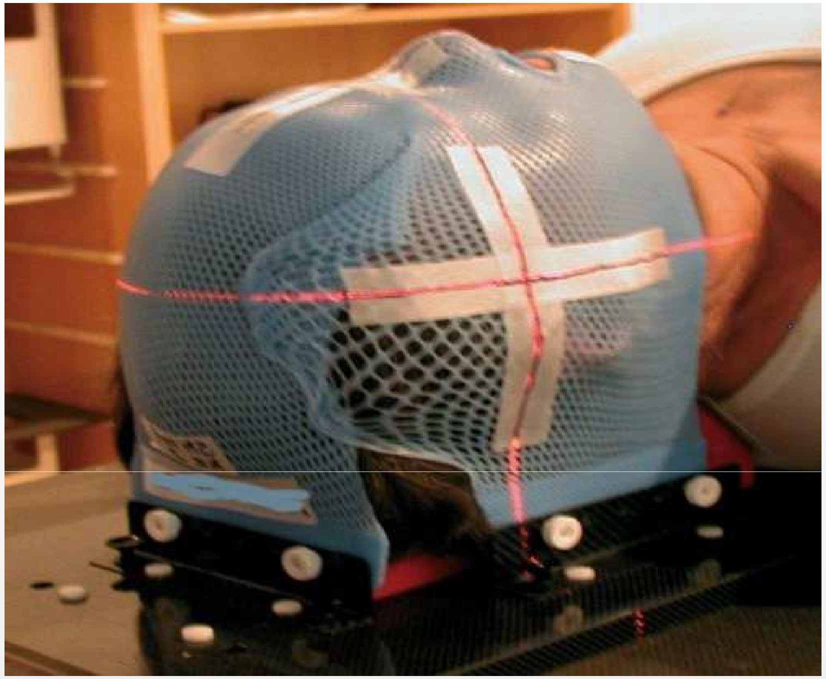
3-D-Treatment plan

Simulation

Radiotherapy information system

Reproducibility of positioning and settings on the linear accelerator from fraction to fraction

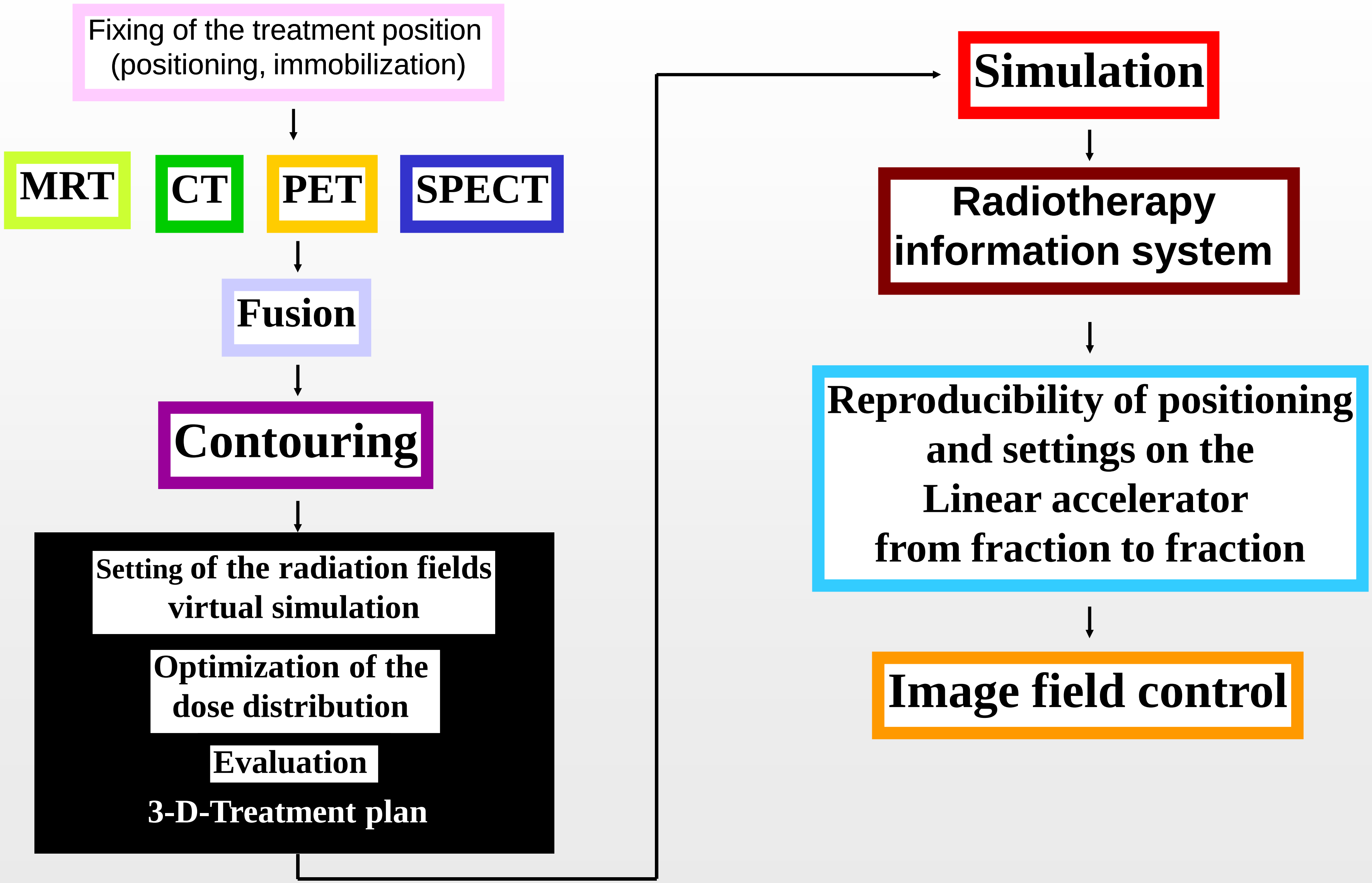
3-D-Treatment planning process (Positionning on LINAC table)



- The patient is usually positioned on skin markers or on anatomical reference points.
- With stationary lasers, the positioning of the head and neck is easier and more often reproducible than in the pelvic area or by obese patients.

- A stable and reproducible patient positioning is necessarily required.
  - Use of thermoplastic masks or other positioning aids.

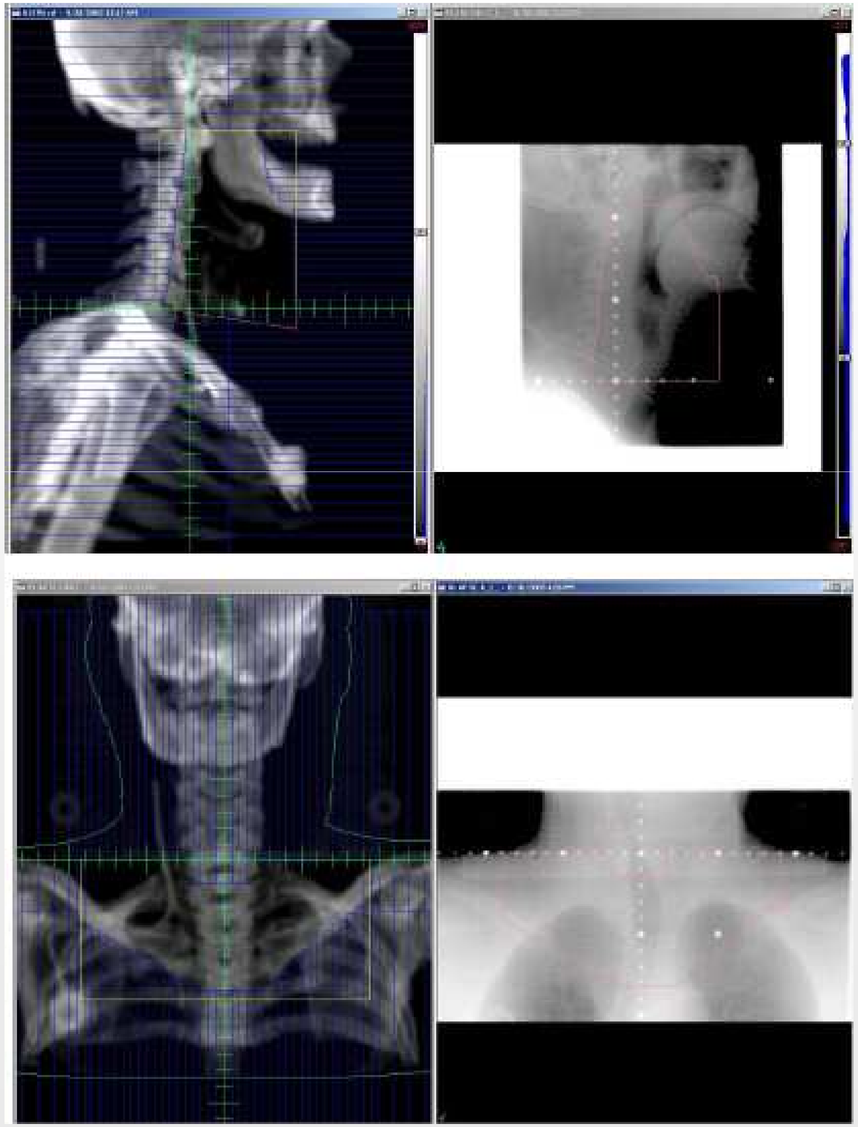
3-D-Treatment planning process (Image Field Control)



3-D-Treatment planning process (Image Field Control)

- The positioning uncertainty can be checked by comparing simulation / DRR images from the CT simulation with direct multiple acquisition of the field in use.

- computer-based video systems are available with versatile software support.



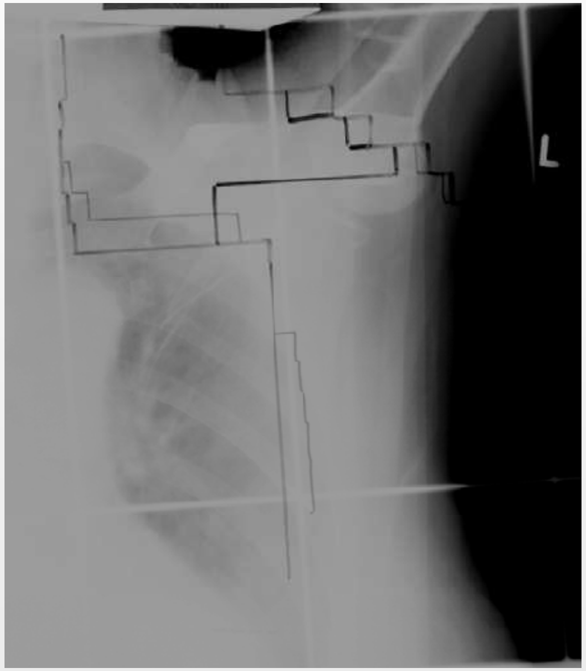
3-D-Treatment planning process (DRRs)

Radiotherapy example Breast-Ca.

DRR

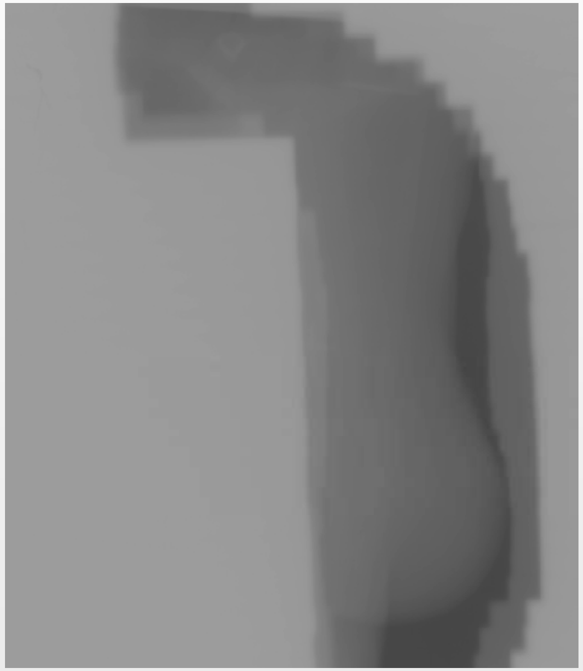
(335°) Photons

Simulation



(335°) Photons

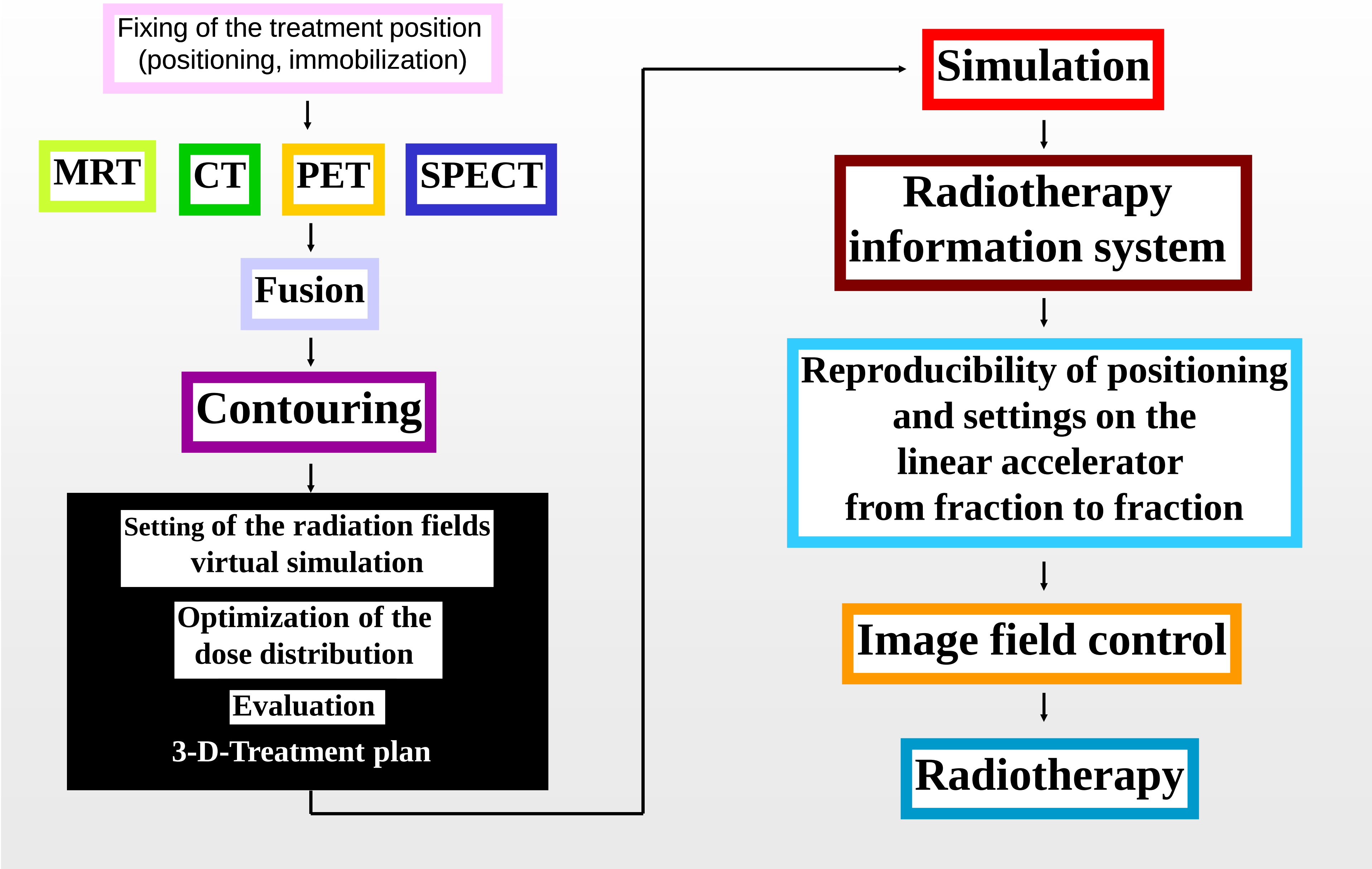
Verification



(335°) Photons

Breast-Ca. on the left o.a. pT1c pN1biii (7/15) G2 L1 V0

3-D-Treatment planning process (Image Field Control)



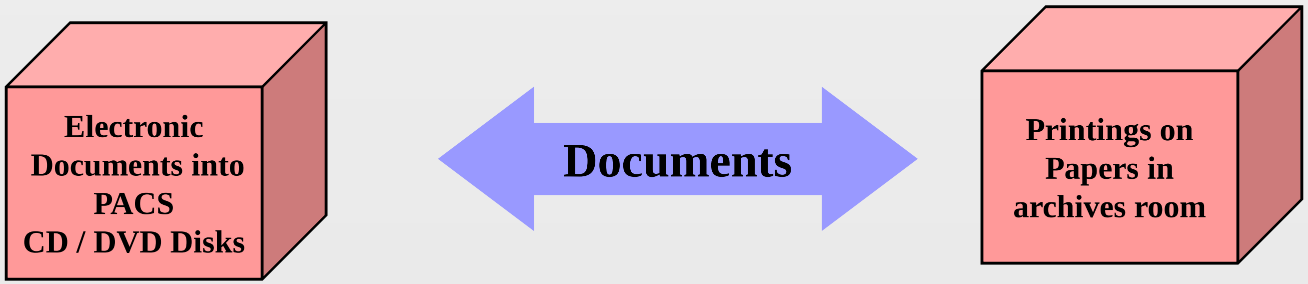
3-D-Treatment planning process (uncertainties)

- Random uncertainties
- Small variations in the positioning of the patient from day to day
  - Setting of the iso-centre
  - Breathing
  - Intestinal peristalsis
  - Different bladder, bowel and stomach fillings lead to internal organ motion and organ deformation

- Systematic uncertainties
- Delineation of target volumes
- A snapshot of the shape and position of the organs in the treatment planning CT
  - Changes in position of adjacent structures with a dotting of pleural effusion or seroma
  - Bladder and bowel movements lead to breathing or fillings position and deformation of organs
- Deviations in the transmission of geometrical data to the therapy simulator or directly to the irradiation device

3-D-Treatment planning process (Documentation/Archive)

- All documents relating to the implementation of radiotherapy must be kept for 30 years.
- The radiation treatment and the decisions must be transparent.
- Recordings include the duration and timing of radiotherapy, the dose to the target volume, localization and delineation of the radiation fields, setting parameters, setting of protection against scattered radiation.



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Thanks for your Attention