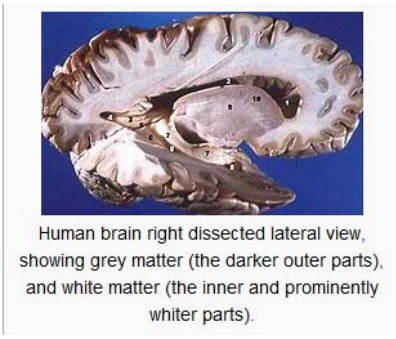
C2-Patient Related Measurements

Calculation of dose from photon and particle beams and radionuclide sources; radiotherapy treatment planning; physical factors affecting dose (e.g., beam intensity, field size, depth, thickness, filtration, half-life, screens, grids, concentration, etc.); special techniques and devices (e.g., rotational therapy, stereotactic radiosurgery; IMRT; wedge filters, infusion techniques, grids, tomography, computed tomography, ultrasound, computers and their applications, etc.); preparation of applicators; LDR and HDR brachytherapy; in vivo and in-phantom dose measurements; and related subjects.

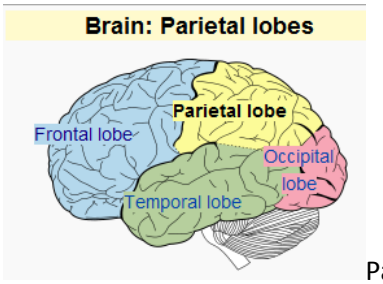
C2-A (Treatment Planning)

- **(H&N)**CT Imaging: Find structures in H&N (optic nerves, optic chiasm, frontal lobes, ethmoid sinus, nasal septum, lateral ventricles, brainstem, sagittal sinus, falx cerebri and white matter, cord, parotid)

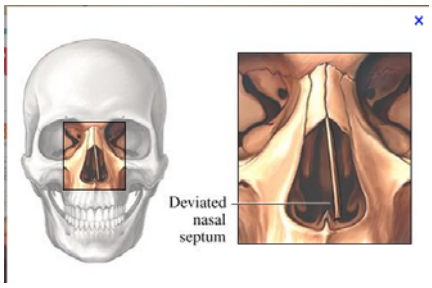
  Use the H&N anatomy & dose constraint powerpoint note

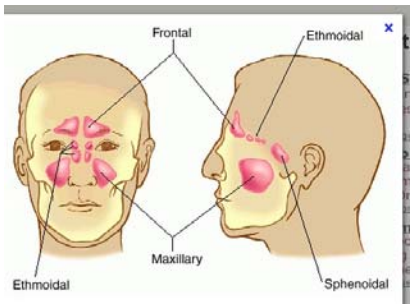


Human brain right dissected lateral view, showing grey matter (the darker outer parts), and white matter (the inner and prominently whiter parts).

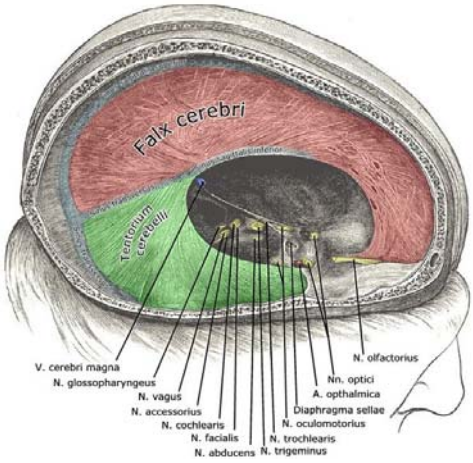


Parietal(頂葉)





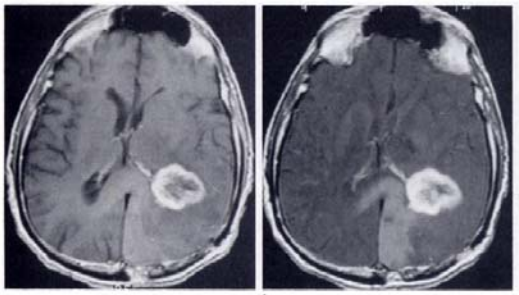
The **nasal septum** separates the left and right airways in the nose, dividing the two nostrils.



The **superior sagittal sinus** (also known as the **superior longitudinal sinus**), within the human head, is an unpaired area along the attached margin of falx cerebri. It allows blood to drain from the lateral aspects of anterior cerebral hemispheres to the confluence of sinuses. Cerebrospinal fluid drains through arachnoid granulations into the **superior sagittal sinus** and is returned to venous circulation.

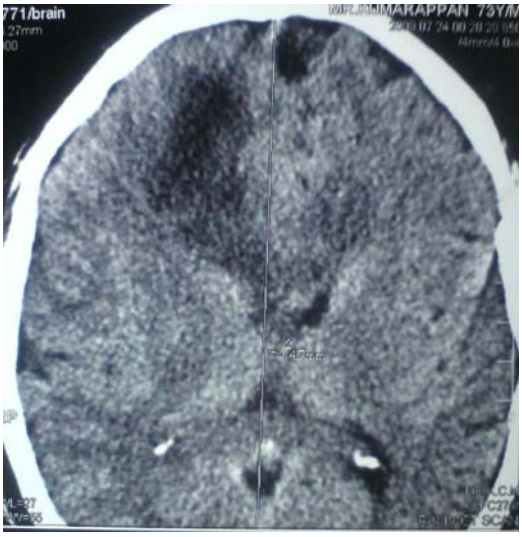
Do you see any tumor on these images? What would we call that volume (define GTV, CTV and PTV).

If it is a GBM, do you know what GBM is? Would we treat edema surrounding tumor? Why?

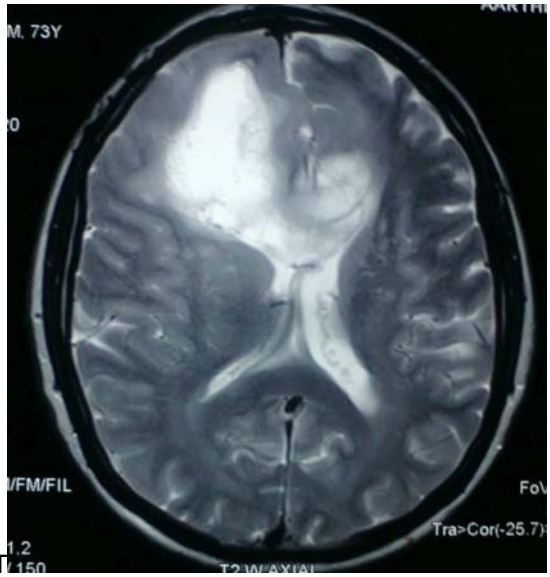


a. b.

Figure 2. Axial MR images from a patient with a recurrent glioblastoma multiforme in the left parietooccipital region. **(a)** Conventional T1-weighted SE (650/20) image shows the large ring-enhancing lesion. **(b)** MT T1-weighted SE (967/20) image shows improved relative contrast of the enhancing lesion. Also note the improved delineation of the enhancing tumor, which extends to the splenium of the corpus callosum.



CT



Glioblastoma multiforme (**GBM**) is the most common and most aggressive malignant primary brain tumor in humans. With the exception of the brainstem gliomas, glioblastoma has the worst prognosis of any central nervous system (CNS) malignancy. If T2 Flair MRI used here, the CSF signal will be reduced and the GBM range will be more clear.

(YY)I talked to our neurosurgeon, for GBM they like to cover edema because the disease tends to spread along edema direction. But this is fractionated Ebtp. I would guess they don't cover edema if it's srs, will confirm

- 3 field (AP + wedged lateral) plan on head and neck (nasopharynx) as in Khan's book. Why use wedge? Wedge angles? How to reduce dose to eye?

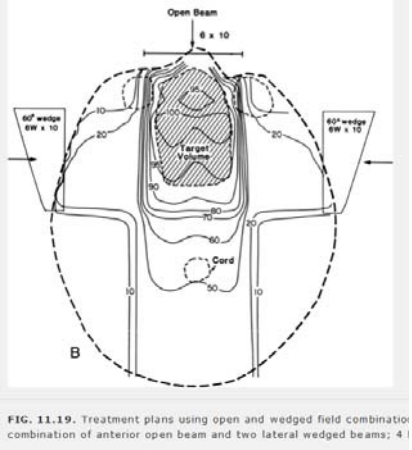


FIG. 11.19. Treatment plans using open and wedged field combinatio
combination of anterior open beam and two lateral wedged beams; 4

The principle is the dose contribution from the anterior field decreases with depth, the lateral beam with wedge provides a boost to offset this decrease.

The angle through which an isodose curve is titled at the central ray of a beam at a specified depth, currently the depth is 10 cm (khan sec. 11.4.a). Depending on the vendor, Varian and Simens define the wedge angle at 10 cm. One should know the **wedge angle** is the angle between the iso dose line of the wedge field and the normal to the CAX.

We can use (1). MLC to block the beam going through the eye at the AP field and lateral field

(2). Or we can increase the wedge angle of the lateral field . Or use MLC to block the beam

- Given CT, MRI and sagittal anatomic cutaway of H&N area (nasopharynx level). Point out some specific structures .. max sinus, nasopharyx region, etc. How to treat? Discuss several questions about IMRT.

- (2006) Picture of an IMRT H&N and a 3 field conformal H&N. What's the PTV and the OARs? How good are the plans?
  (2011) Shown pictures of IMRT and conformal plans of a brain lesion side by side. The lesion was right next to the brainstem. Optical chiasm, optic nerves, and orbits were also drawn. There was a series of questions about considerations for planning, tolerances of normal structures, field arrangements, advantages of each type of planning etc.

1. Volume needs to be smooth
2. The constraint should be reasonable and no conflict for overlapped organ
3. Depending on the treatment site, we need to consider the organ motion affecting the planning quality

(Read the H&N powerpoint)

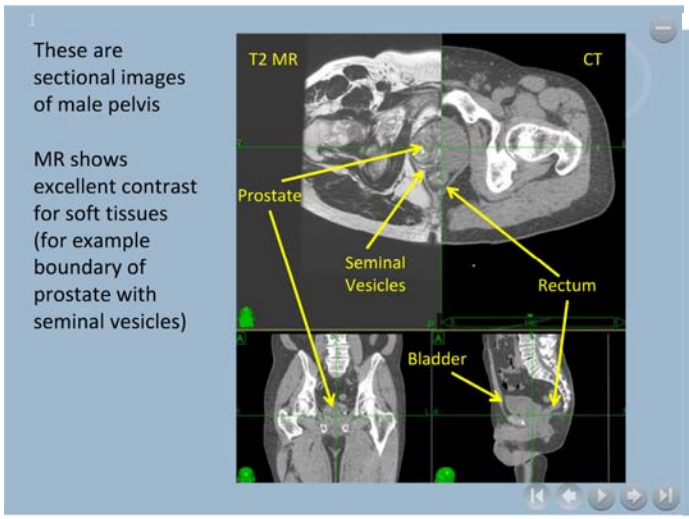
Advantage of IMRT for Head & Neck:

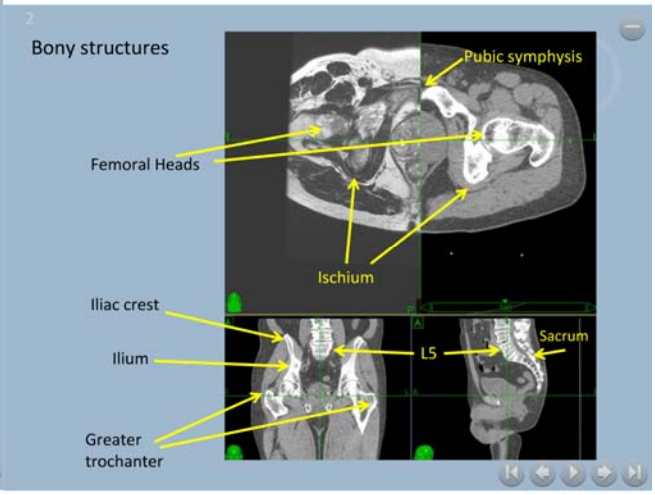
- Reproducible setup, limited motion
- Imaging permits precise delineation of target volume (CT, MR, PET, Endoscopy)
- IMRT can produce sharp dose gradient so it can lower the dose to OARs in close proximity to tumor
- IMRT suitable for concave and irregular dose shapes→ better conformal to target volume
- Allow Simultaneous boost (dose painting)
- IMRT incorporates inverse planning; Even the beam arrangement are complicated, we have good volume delineation and dose constraints, and we will still be able to achieve good plan. Compared to 3DCRT, for very complicated case, IMRT can reduce the planning effort from dosimetrist.

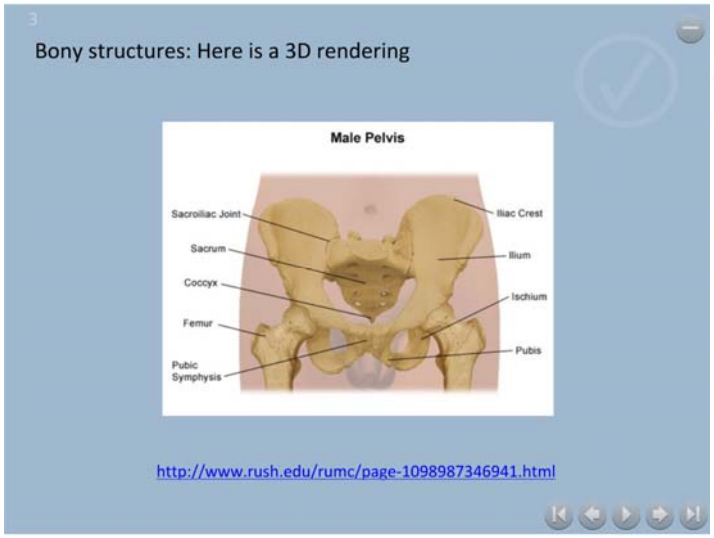
Disadvantage of IMRT (= advantage of 3DCRT:

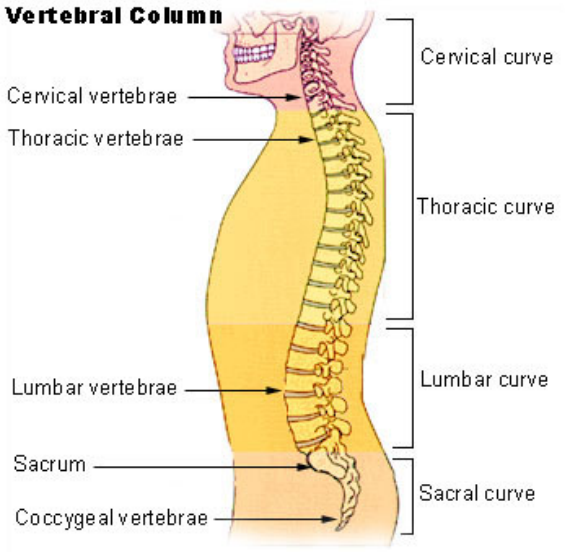
- Sensitive to organ motion
- MU is 3 – 10 times than the 3DCRT plan, leakage dose is a concern, which can increase the probability of secondary malignancies.
- It is very difficult to adjust an IMRT isodose line by a few mm. IMRT is not like 3DCRT, in which one can change block edge and get expected dose distribution. 3DCRT dose is more predictable.
- Compared to 3DCRT, the target dose is not homogeneous.
- More extensive QA
- Higher delivery time

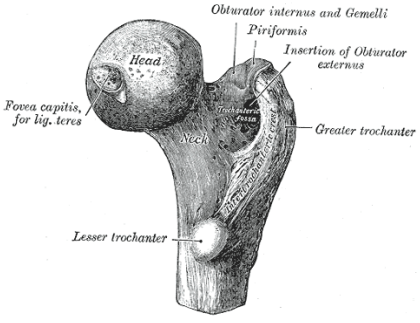
- **(Prostate)** Prostate DRR sagittal view: DRR with structure contours from TPS. What is this? Where is the bladder? Rectum? Iliac nodes? How much margin? What are the critical structures? Rx dose and tolerance dose for each?

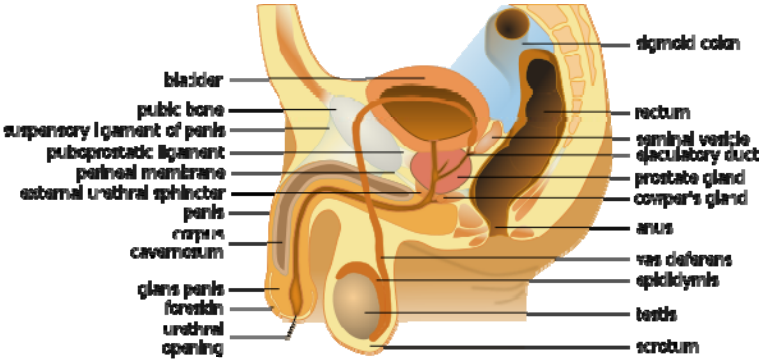


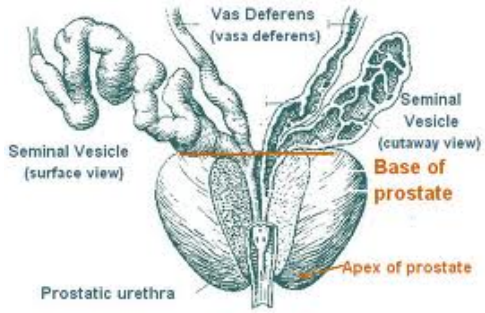


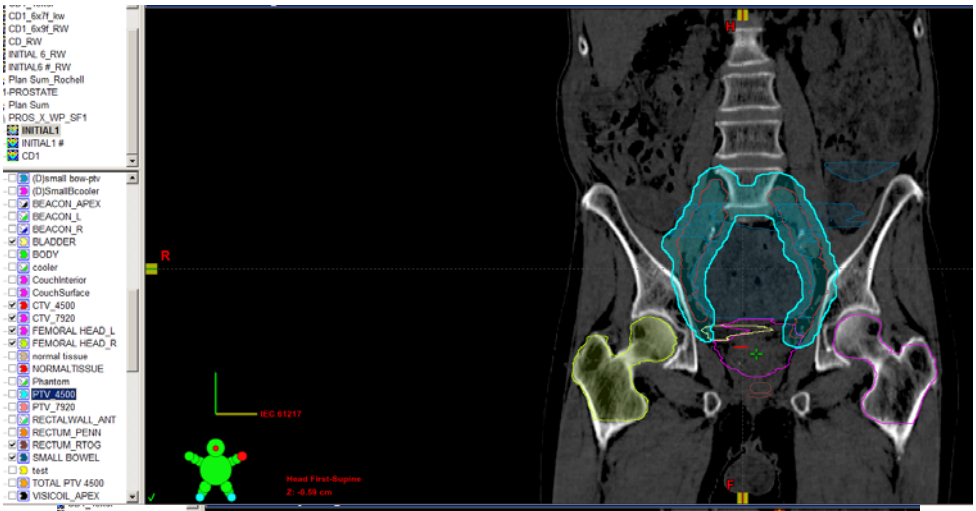









Vas Deferens
(vasa deferens)
Seminal
Vesicle
(cutaway view)
Seminal Vesicle
(surface view)
Base of
prostate
Apex of prostate
Prostatic urethra


CD1_6x7f_kw
CD1_6x9f_RW
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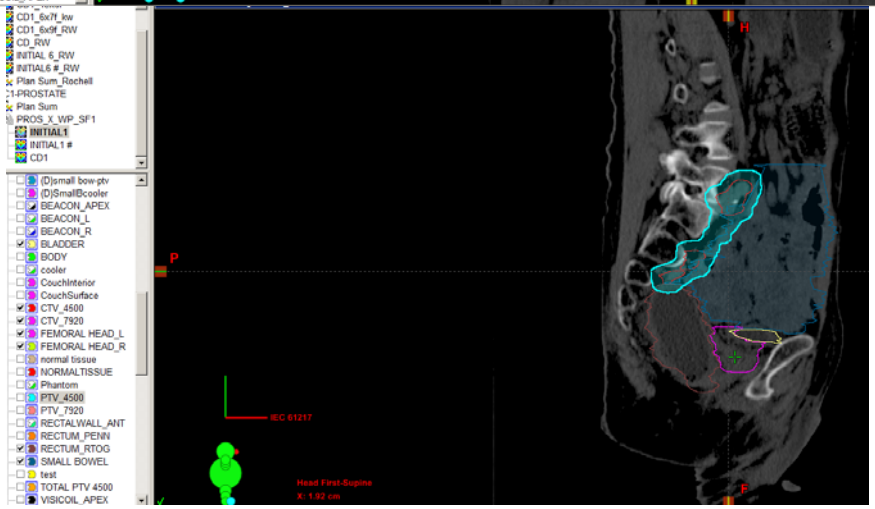
Plan Sum_Rochell
1-PROSTATE
Plan Sum
PROS_X_WP_SF1
INITIAL1
INITIAL1 #
CD1
(D)small bow-ptv
(D)SmallBcooler
BEACON_APEX
BEACON_L
BEACON_R
BLADDER
BODY
cooler
CouchInterior
CouchSurface
CTV_4500
CTV_7920
FEMORAL HEAD_L
FEMORAL HEAD_R
normal tissue
NORMALTISSUE
Phantom
PTV_4500
PTV_7920
RECTALWALL_ANT
RECTUM_PENN
RECTUM_RTOG
SMALL BOWEL
test
TOTAL PTV 4500
VISICOIL_APEX
H
R
F
IEC 61217
Head First-Supine
Z: -0.59 cm


CD1_6x7f_kw
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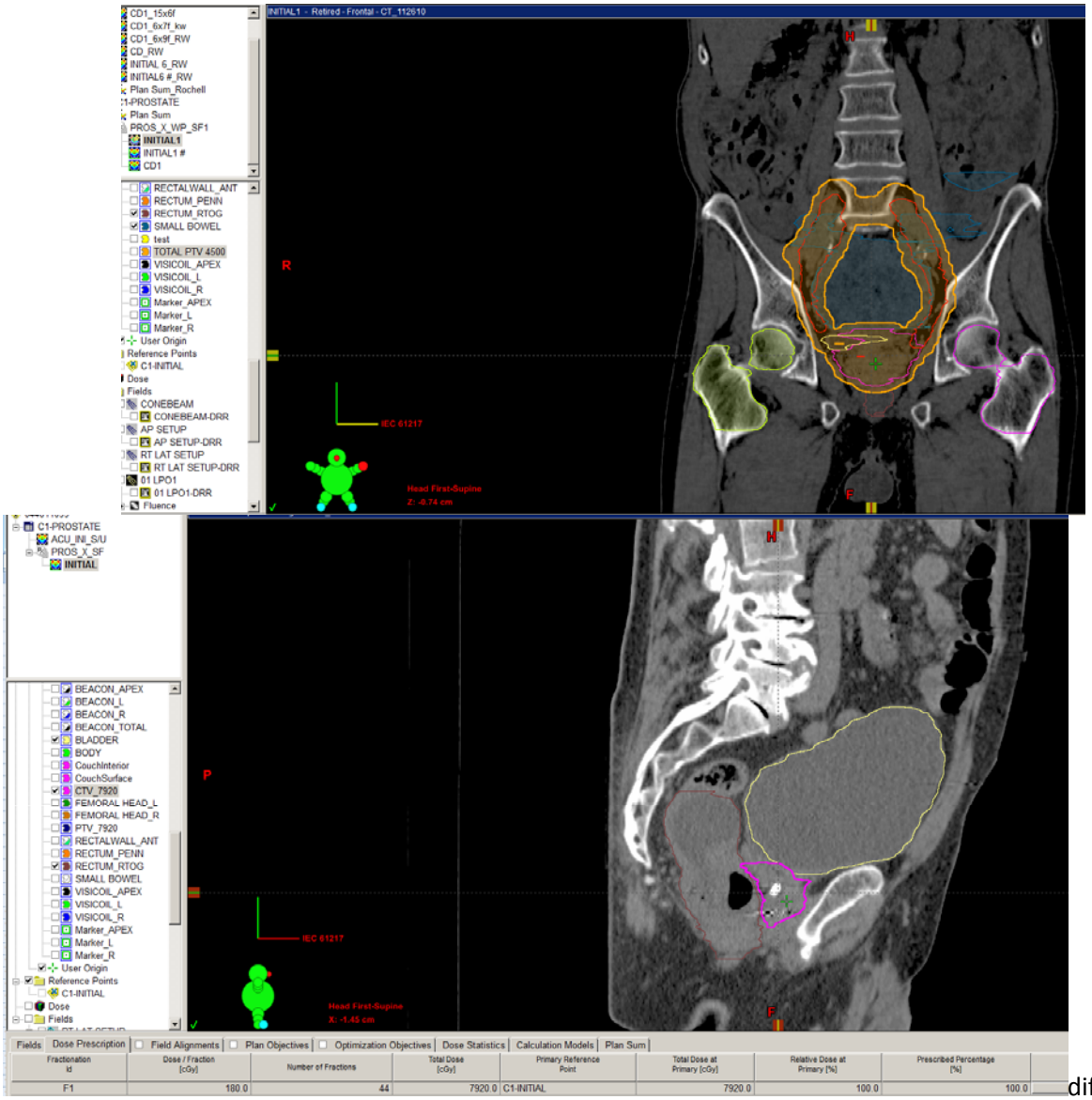
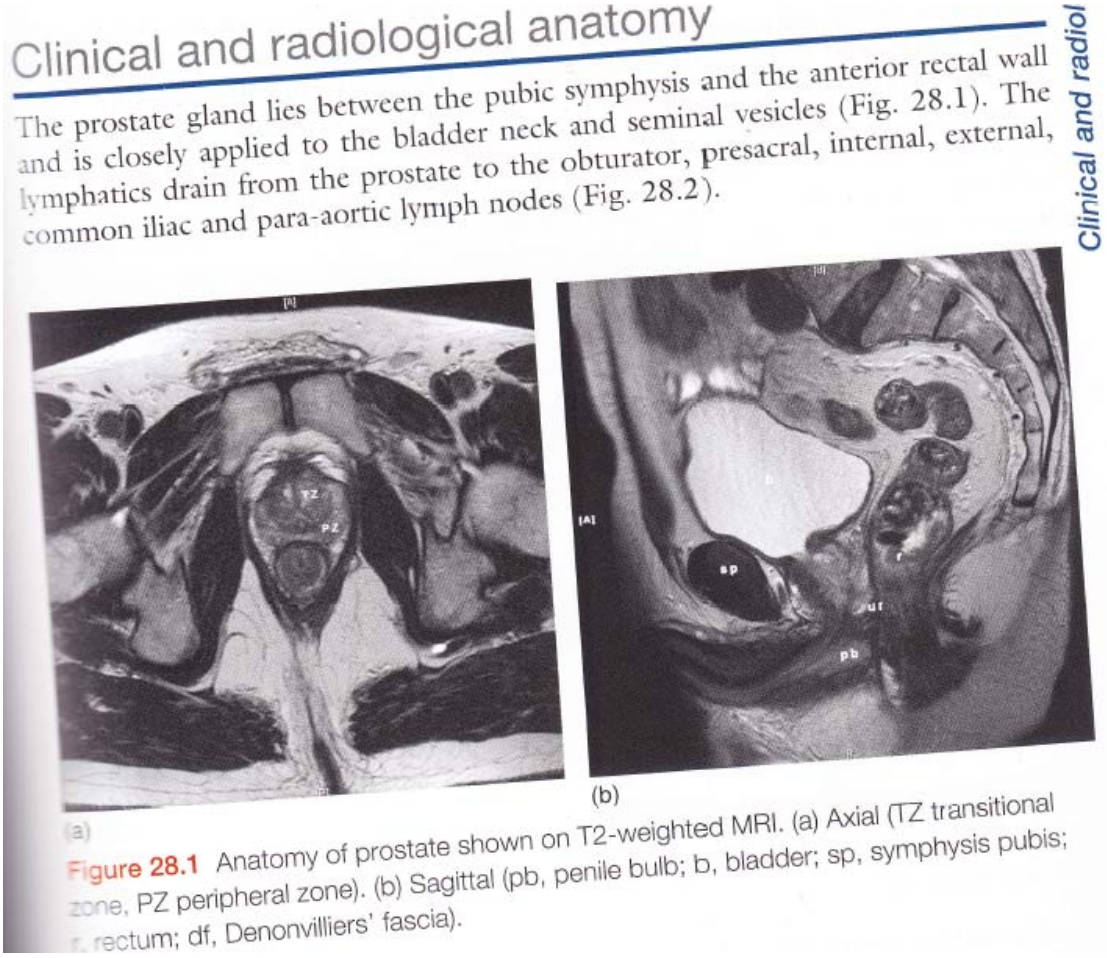
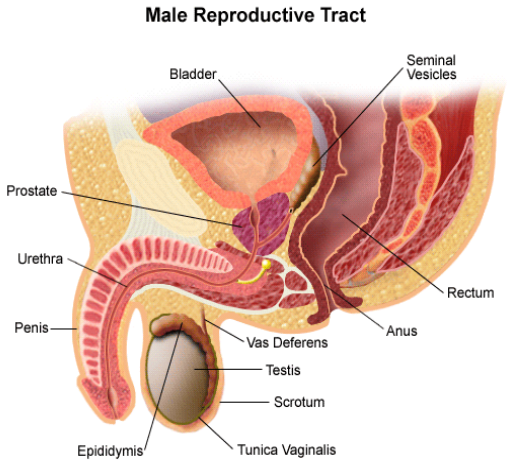
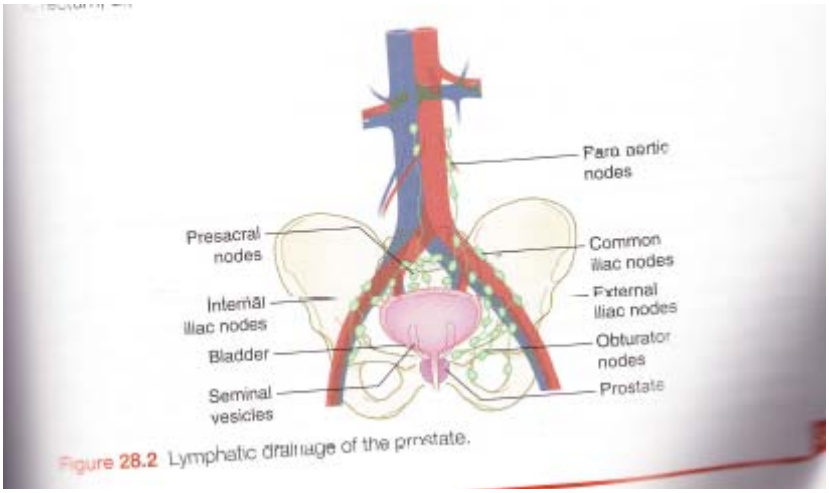
CD1
(D)small bow-ptv
(D)SmallBcooler
BEACON_APEX
BEACON_L
BEACON_R
BLADDER
BODY
cooler
CouchInterior
CouchSurface
CTV_4500
CTV_7920
FEMORAL HEAD_L
FEMORAL HEAD_R
normal tissue
NORMALTISSUE
Phantom
PTV_4500
PTV_7920
RECTALWALL_ANT
RECTUM_PENN
RECTUM_RTOG
SMALL BOWEL
test
TOTAL PTV 4500
VISICOIL_APEX
H
P
F
IEC 61217
Head First-Supine
X: 1.92 cm



different pt.







(Penn)

- Low Risk: 79.2 Gy in 1.8Gy fx IMRT **prostate/SVs**
- Intermediate Risk
  6 m hormones
  79.2 Gy in 1.8 Gy fx IMRT **prostate/SVs**
  1cm around prostate, 6mm posterior
- High Risk

2-3 years hormones, starting at time of consult
WP IMRT to 45 in 1.8Gy fx IMRT
conedown to 79.2 to prostate only
Vessels(lymph node) + 1 cm for WP IMRT

Rx: 180x25 (45Gy) initial + 18x19(28.8) cone down = 7920
PTV: D95 = 95% of dose,
PTV4500 = 1 cm margin **around nodes** + 1 cm around **prostate and SV** except 6 mm posterior
PTV7920 = 1 cm around **prostate** except 6 mm posterior

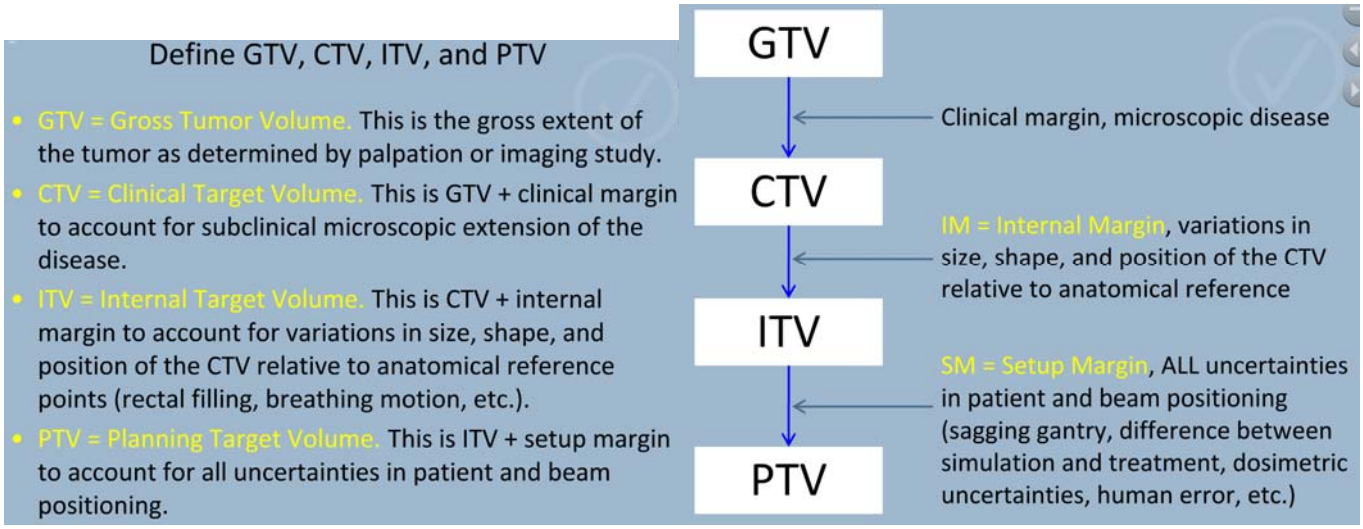
(Compared to p341 in Practical radiotherapy planning, if conedown or boost is only prostate not including SV.)

It is not possible to define the GTV accurately with current imaging techniques. It is therefore standard practice to define a CTV including the prostate and any possible extracapsular extension, with either the base of, or the entire seminal vesicles.

Bladder: D20 < 65Gy, D40 < 50 Gy, D50<45Gy
Rectum: D20<60Gy, D40<45Gy, D50<40Gy
Small Bowel: Max48Gy, D25<40Gy, D50<35Gy
Femoral Heads: D50<37Gy, D5<45Gy, D1<50Gy

- Define what is GTV, CTV, PTV, TV and ITV where does ITV fit in the sequence. What ICRU report defines these terms? (ICRU62) Why we create PRV from OAR contours?

(Wepassed: target definition)



The GTV concept consists the primary tumor, metastatic lymphadenopathy, or other metastases, so GTV already include **the lymph node**! CTV represents the potential extent and location of the tumor.

GTV: Gross tumor volume. Nothing else.
CTV: Clinical target volume = GTV + margin of microscopic disease.
ITV: Internal target volume = CTV + margin for organ motion.
PTV: Planning target volume = ITV + setup and positioning uncertainty

PTV = GTV + CTV + ITV

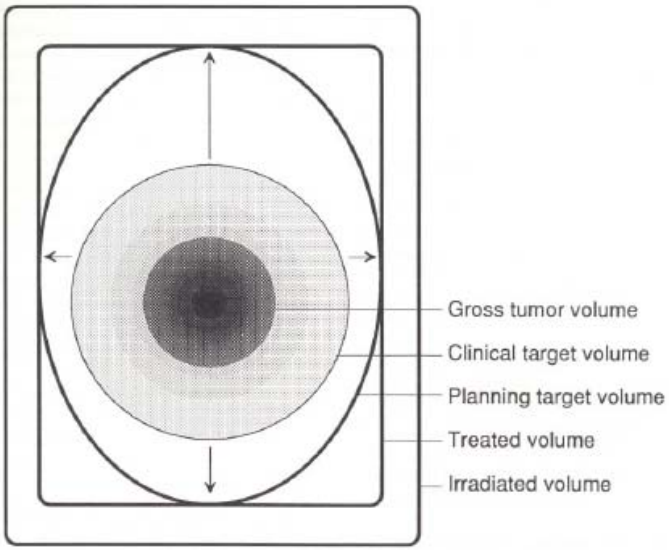
In addition to the above "volumes", the ICRU also defined a "Planning Organ at Risk Volume" or "POR". The main idea for its inception is that just as the PTV requires adequate coverage, the organ at risk next to it requires adequate protection.

Who defined these concepts?

- They were defined by the ICRU (International Commission of Radiation Units and Measurements)
- Original definition (ICRU 50, 1993) defined only GTV, CTV, and PTV.
- These concepts were defined to standardize the treatment planning nomenclature during the transition from 2D to image-based 3D planning in the early 1990's.
- The definitions were refined and new definitions (ITV, SM) were added to account for technological advances in ICRU 62, 1999.

You have a PTV, should you use its projection in the BEV as the field shape?

- No, if you do that you would under-treat because the inside edge of the field will be cold due to penumbra
- To account for penumbra, the Tx field needs to have margin ≈ penumbra width ≈ 7-8 mm
- ICRU recognized this issue and they defined 2 volumes:
  - Treated volume = volume enclosed by Rx isodose (for example, 95% isodose surface) → defined by PTV
  - Irradiated volume = volume that receives significant dose (for example, as defined by 50% isodose) → defined by Tx field



Should you simply add Internal Margin and Setup Margin in defining the PTV?

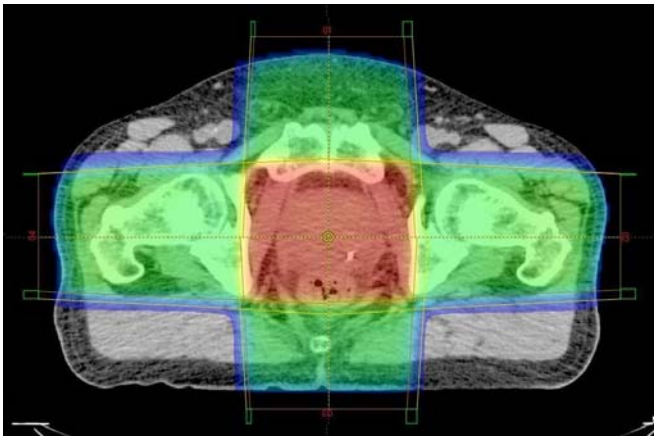
- No, if you do the simple addition, you usually end up with a total margin that is too large.
- Statistically, based on large patient setup data, several formulas have been proposed, ranging from adding them quadratically to linear addition with some coefficients: Margin = $2\Sigma + 0.7\sigma$, where Σ is the systematic error and σ is random error
- In practice, however, the total margin is a clinical decision made by radiation oncologist, based on experience.

What other points are recommended by ICRU in dose prescription and reporting?

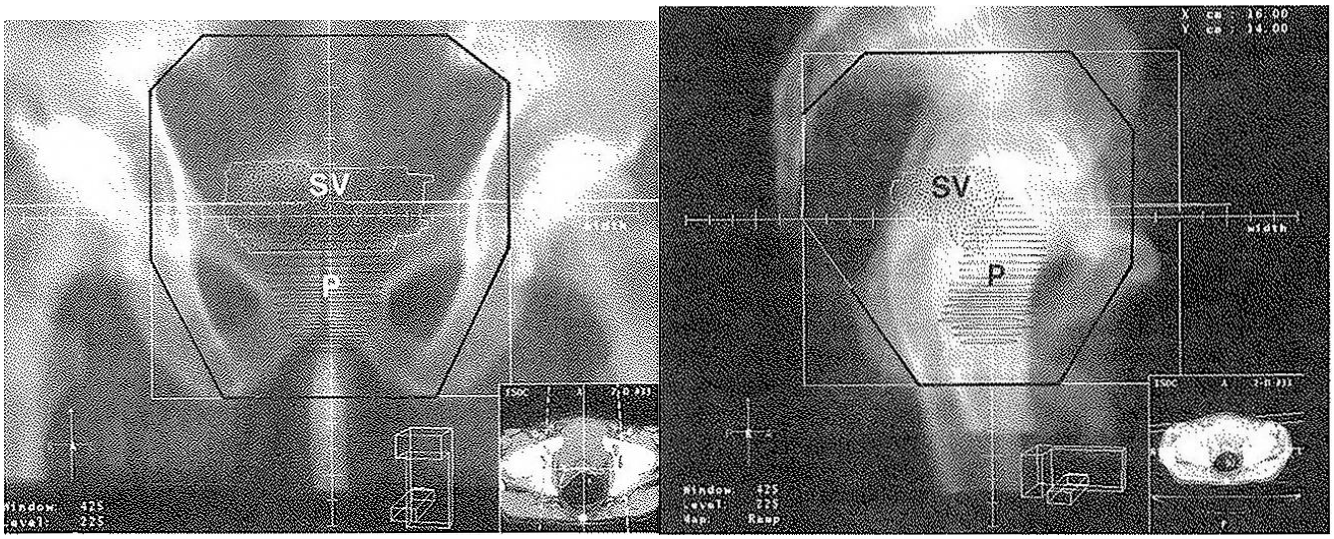
- ICRU 62 requires a reference point. It needs to be:
  - Inside the PTV
  - It must be clinically relevant
  - In a region of low dose gradient
  - For most cases, the isocenter is recommended
- ICRU also defines PRV (Planning Organ at Risk Volume). This is analogous to PTV for organs at risk.
- Level 1 dose reporting includes dose at the reference point and min and max inside PTV. Level 2 dose reporting includes full 3D dose distribution.

- Prostate CT (axial, coronal and sag) with contours. Identify structures. Typical beam arrangements: from two conventional techniques to IMRT
- Shown 3 views of conformal prostate plan and a 4-field box. Explain about critical structures and advantages and disadvantages of each plan
- A side-by-side comparison of 4-field and 6-field male pelvis plans from TPS. What are these? Point to prostate, seminal vesicles, bladder, prostate, femoral heads. What dose do you use? Do you boost?
  What are advantages of one over other? Discuss nodes. What would be the difference with an IMRT plan?

4 field box:

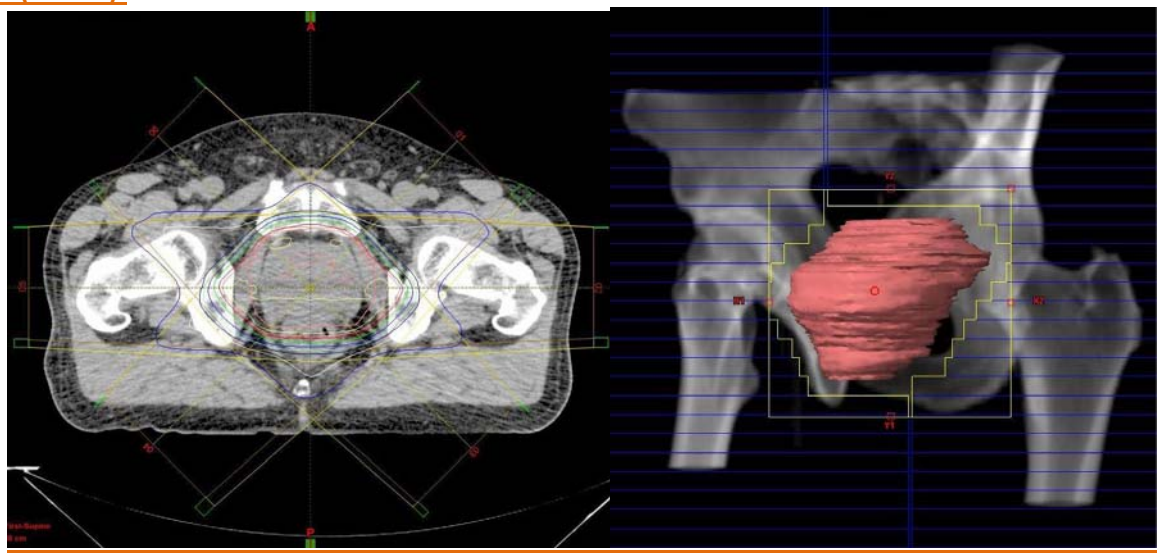


- 4 Field (AP/PA, Lt/Rt Lats)
- 2D Treatment planning with portal films.
- Whole Pelvis 45Gy – Boost to 70Gy or higher to prostate.
- **Dose limited by complication!**
- Beam energies: 6 MV – 18 MV
- Margin of 1-2 cm was used



- Superior border: L5/SI
- Inferior border: pelvic brim(邊緣) (or 1cm below narrowing of contrast)
- **AP/PA:** Lat: 1.5 cm lat of bony margin of true pelvis, **block femoral head and bone marrow**
- Lats: Ant border at pubic symphysis, Post border to sacrum **blocking rectum**

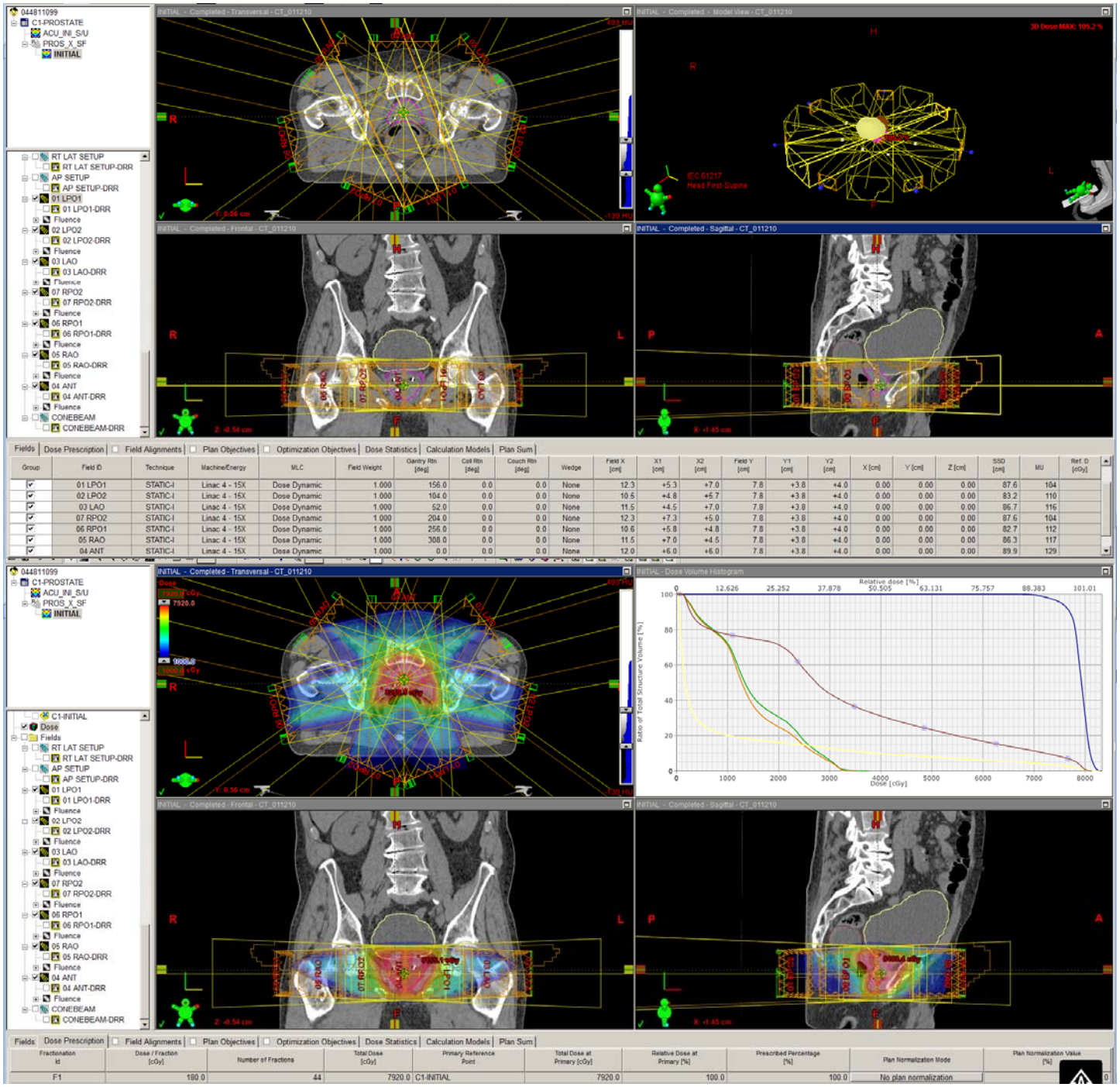
6 field box (3DCRT):



- Improvements vs 4 Field Box:
  - multiple static fields (6 fields provide more degree to optimize the plan, so it provides more uniform dose distribution than the 4 field plan)
  - custom blocks
  - patient immobilization devices
  - 3D CT simulations
  - computerized treatment planning
- Results in superior sparing of normal tissue over “Box”.
- Daily fractions of 180-200 cGy, 5 fx/week.
- Depending on staging, prescription~ 70 – 74 Gy for radical radiotherapy and Palliative doses ~ 60 to 65 Gy.
- PTV = Prostate + seminal vesicles + 0.5-0.8 cm margin

- Margin around target volume should be non-uniform (0.5 cm posterior to avoid rectal wall)

- **7 field IMRT:**



- **Beamlets created by MLC**
- With Inverse Treatment Planning, optimal dose conformity is calculated and delivered.

- Better tumor dose conformity with less dose to surrounding tissue = higher potential for dose escalation compared with 3D CRT.
- 5-7 beams (post, ant and post oblique) with qual (or close to) angular spacing
- Prescription ~ 78-86 Gy, 1.8-2 Gy per fraction, 5 fr/wk
- Or hypo-fractionated scheme ~70 Gy with 2.5Gy/fr

- Sagittal image of a treatment planning screen shot of subjects contours (bladder, rectum, prostate, Seminal vesicles, nodes) What is this image? Why there was a break between rectum contour and nodes contour
  my understanding for this hightlight is: dose fall off has a gradient, you cant have nodes and rectum right next to each other --> constrain conflict during planning.

- Where is the PTV for both primary and boost? (prostate +SV for primary, Prostate only for boost) How do you treat this and what dose do you prescribe?

- Picture of DRR & EPID snapshot: What are we treating here? What is the purpose of the gold seeds in the prostate? How do you localize prostate for daily treatment.

  We align the bony anatomy if we are treating the whole pelvis, and then we use the gold seed to align the patient when we cone down to the prostate.

(LUNG)
(Read lung powerpoint! & TG65)

(TG65):
Data trend (review p90-p94) figure

- Doses increase downstream beyond (> d_{max}) low-density media (air, lung).
- There are build-up and build-down regions within tissue near the interface of the low-density media. The severity increases with increasing energy, decreases with increasing field size.
- The penumbra increases in the region of low-density medium and increases with energy.
- Doses decrease downstream beyond (> d_{max}) high-density media (bone, metal prosthetics).

(2008)Shown 3 plans on lung for the same patient. Explain the difference between the three calculation algorithms. One has no homogeneity correction and the other two have homogeneity correction. Still need to differentiate the two. Which is more realistic? (read wepassed "dose algorithm")

- (2008) A DVH with lung, heart and PTV was shown. What is the max dose for each organ? Why does the PTV coverage have a round edge at 90% level instead of a sharp coverage? I mentioned the lack of lateral scattering between PTV and lungs.

Treat initial volume with 1.8-2 Gy per fraction to 66-72 Gy
Pre-/post-operative doses are typically 45-50 Gy

Penn: 1.8 x 28(initial) + 1.8 x 6(CD) = 50.4 + 10.8 = 61.2 Gy

Lung OAR
(Penn)
Lung: mean lung < 20 Gy, V20 < 30%
Heart: V50 < 40%
Cord max < 45Gy
Esophagus: mean dose < 34 Gy, V35 < 50%, V50< 40% (Qantec)

Brachiel plexus: max< 60 Gy

(TG65) Due to the high energy photon, the penumbra is enlarged in the low density material, so it losses the conformality.

- (2006) What's the difference between geometric, physical, and dosimetric penumbra? How does this affect lung treatments? What about the effects of blocks? What about Cobalt? How does that change those items?
-

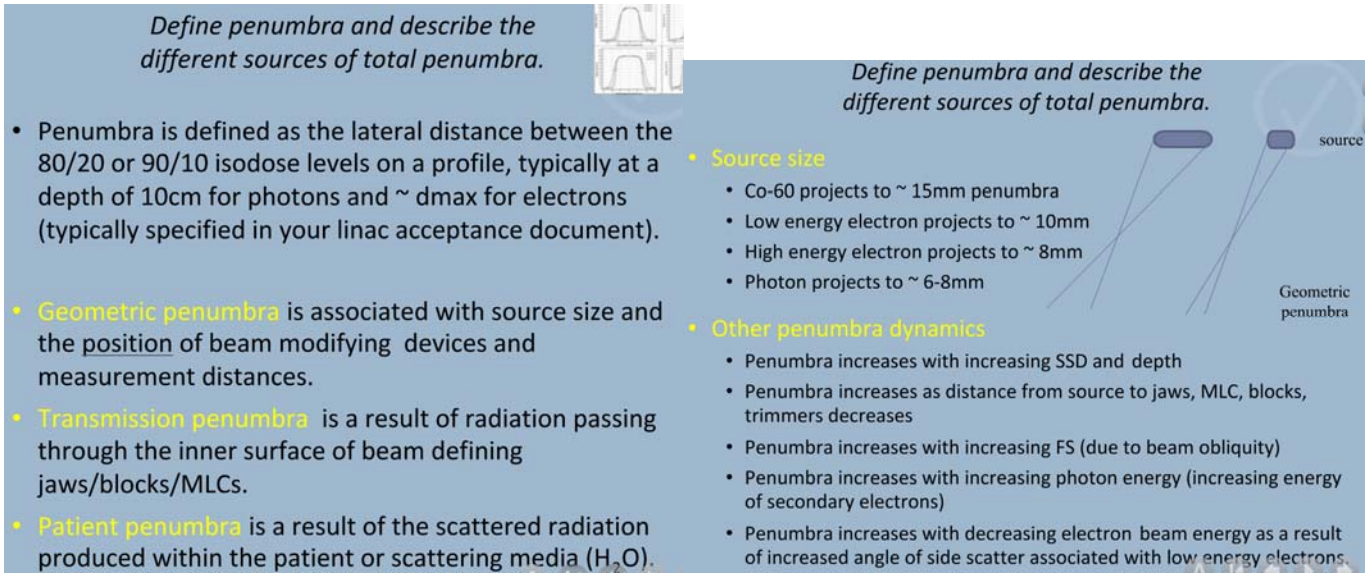
(read Porgorsak book p162 & (http://www.ncbi.nlm.nih.gov/pubmed/2112037))
(1). Transmission penumbra: A small component of dose due to transmission through the collimator jaws
(2). Geometric penumbra: a component attributed to finite source size
(3). Scatter(patient) penumbra: A significant component due to inpatient x-ray scatter
The total penumbra (physical penumbra or dosimetric penumbra) is a sum of the 3 individual penumbras
The physical penumbra depends on beam energy, source size, source-surface distance, source-collimator distance, and depth in phantom.

We really distinguished 3 types of penumbra:

1. Geometric penumbra related to the size of the source or focal spot. Geom Pen width~ source diameter, and therefore Co60 for example has a larger geometric penumbra then linacs(cm source size to cm SSD,vs mm source size to cm SSD)
2.Transmission penumbra due to variable beam transmission though the collimator edge(nondivergent).
3. Physical penumbra (90-20% , sometimes 80-20%) dose spread near the field border. When measured it is influenced by the geometric penumbra, transmission penumbra/beam energy and the lateral electron transport in the medium (water, tissue) .Dosimetric penumbra is measured and defined also as(90-20% , sometimes 80-20%)so it is the same with the physical penumbra.

Hope this helps,

S



Geometrical penumbra will not change for the lung treatment because it is defined by the source size, SSD, SDD and physical depth.
The scatter penumbra or the overall physical penumbra will change in the low density material such as lung, due to larger electron traveling range.

Due to large penumbra, the dose will not be as conformal as the dose distribution we see in the water, and **increase mean lung dose**

If we add a block, the geometric penumbra is decrease, because the block is like an additional beam trimmer. The geometric penumbra decrease along with the increase of source to beam trimmer distance.

The transmission penumbra is also decrease because the block provide an additional shielding.

Overall the physical penumbra is decreased when we put block on.

Co60 source is about 1 cm which is about twice large compared to linac target 2 – 3 mm.

So geometric penumbra will increase.

The transmission penumbra will decrease.

Due to the low energy of the Co60, the electron set in motion in the low density material will not travel as far as the e set in motion from high energy, and due to the low density material, the chance that the scattered photon travel outside the field is less compared to water.

Overall the physical penumbra for Co60 will be equal or even decrease according to the published literature, since the scatter/patient penumbra is a dominate effect, so the physical penumbra will not change much.

Choice of energy – penumbra/converage issue

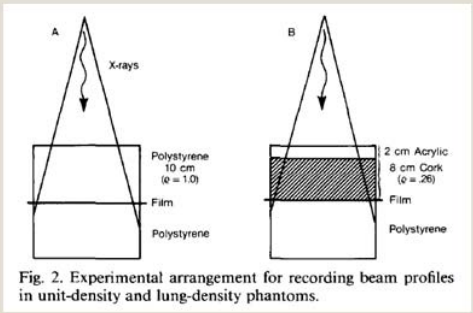


Fig. 2. Experimental arrangement for recording beam profiles in unit-density and lung-density phantoms.

Table 1. 20–80% penumbra and 50–90% fringe for various x-ray energies

Accelerator number	Nominal x-ray energy (MV)	Source to axis distance (CM)	20–80% beam penumbra (mm) Density 1.0	20–80% beam penumbra (mm) Density 0.26	50–90% beam fringe (mm) Density 1.0	50–90% beam fringe (mm) Density 0.26
1	4	80	7.0	6.5	4.7	4.7
2	6	80	8.5	8.5	4.0	5.0
3	10	100	6.0	11.0	4.1	8.6
4	18	100	7.5	18.2	6.0	13.0
5	18	100	8.0	15.8	6.1	12.8

Ekstrand *et al.*, Med. Phys. **18**, 249, (1990)

- (2011) Shown picture of transverse slice of AP beam in chest (half beam was through heart, other half through lung, about 10 cm width). What are the possible errors in dose calculation for this plan?

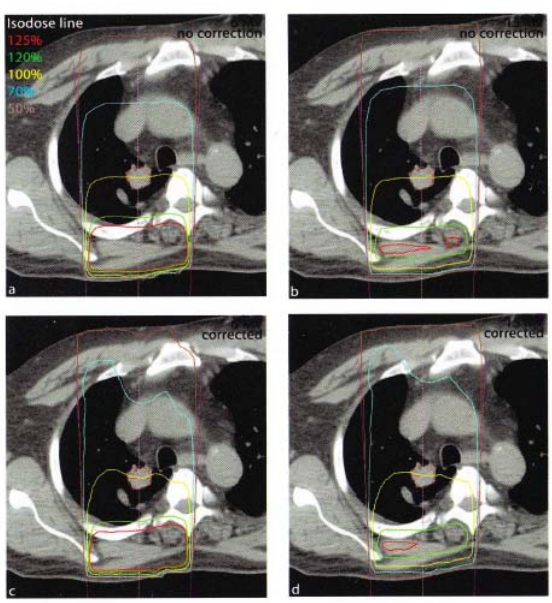


FIGURE 1.5 Posteroanterior beam, 10 × 10 cm fields, 100 SAD, dose normalized to isocenter placed at a 9-cm depth: (a) 6- and (b) 15-MV photons without heterogeneity correction; (c) 6- and (d) 15-MV photons with heterogeneity correction.

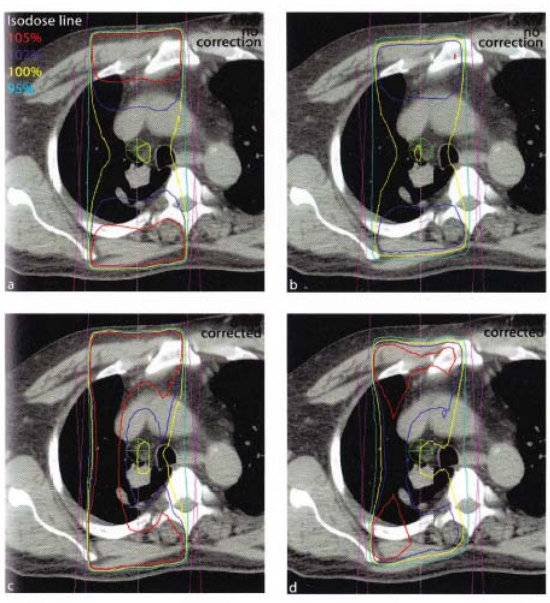
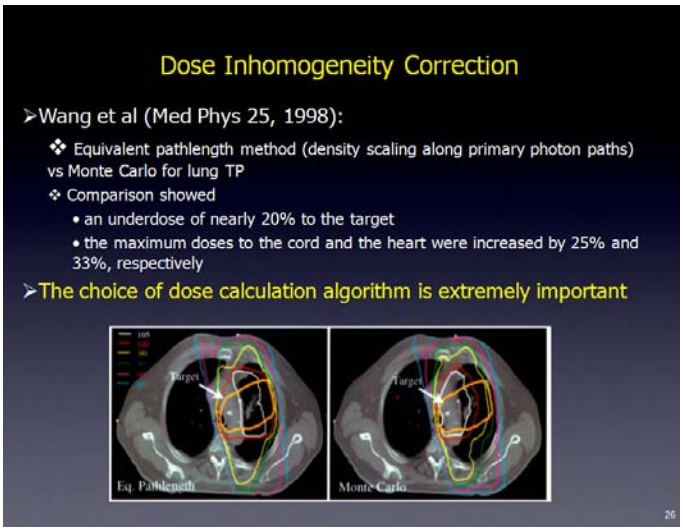


FIGURE 1.6 Anteroposterior/posteroanterior beams, 10 × 10 cm fields, 100 SAD, dose normalized to midplane: (a) 6- and (b) 15-MV photons without heterogeneity correction; (c) 6- and 15-MV (d) photons with heterogeneity correction.

The potential dose calculation error can coming from (1). no heterogeneity correction, or (2). with heterogeneity correction but only consider primary fluence attenuation without considering the inhomogeneity effect to the secondary electron traveling (in this case, the width of iso dose is narrow in the case without inhomogeneity correction).



Therefore, (1). it can underdose the target due to the tissue and lung interface. Increase the mean lung dose

Pay attention to the cord & heart dose from the question (OAR), due to not considering heterogeneity correction.

- **(Photon+Electron)** 3 axial images with adjacent electron and photon field isodose lines (field matching question), What do you think is being shown here? What's the difference in the 3 pictures? They were photon/electron field abutments with different gaps. First one had typical hot spot on the photon side; the other two had increasing gap widths with cold spots. Which one is best (middle one has more uniform dose; left hot spot; right cold spot). Give

two examples of clinical sites /typical treatment you may do e + ph matching. How do you do field matching with electron and photon fields for these cases (geometry/design).

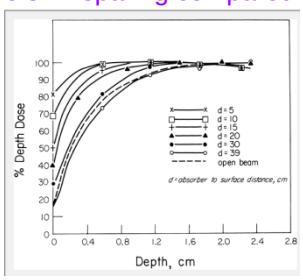
- *At what depth do you match abutting electron fields? What about if you are matching an electron and photon field?*

  - Electrons are typically employed for the treatment of superficial masses, therefore matching at the surface is normally considered adequate whether matching two electron fields or one photon and one electron field.

(read Kahn p328 – p329, Bentel p153-155)
Example: (1). Treat the neck tumor, anterior tumor and lymph node treated with photon field, and posterior lymph node using electron field to protect cord
(2) Breast treatment: e electron treatment to the IMN (Internal mammary node) abutting the photon field from tangent .

- What's another way of avoiding hot and cold spots in adjacent fields (other than junction shifts)?
  (1). Moving the location of field junction approximately every 10Gy to reduce the normal tissue complication and tumor recurrence
  (2). a polystyrene wedge put on the junction to reduce the hot spot (Bental p154) or we can put the beam spoiler to increase the superficial dose to reduce the cold spot (from Stefan)

FYI: For breast treatment, skin sparing is not desirable. Beam spoiler will increase the dose to the superficial area and also move d_{max} toward surface therefore decrease skin sparing compared to without spoiler (Kahn sec 13.3 D KW)



- (electron Three plans with two abutting fields were shown. Can you identify the energies of the two fields?
- 3 electron field matching cases (abutting, small gap, large gap). I think one is 6e the other is 9e (?) Why different energy? What happens in isodose lines in each case? Which case do you prefer?
  Use the R50 and D_{max} to decide the energy of electron or photon.
  Different energy so we can avoid the underlying OAR.

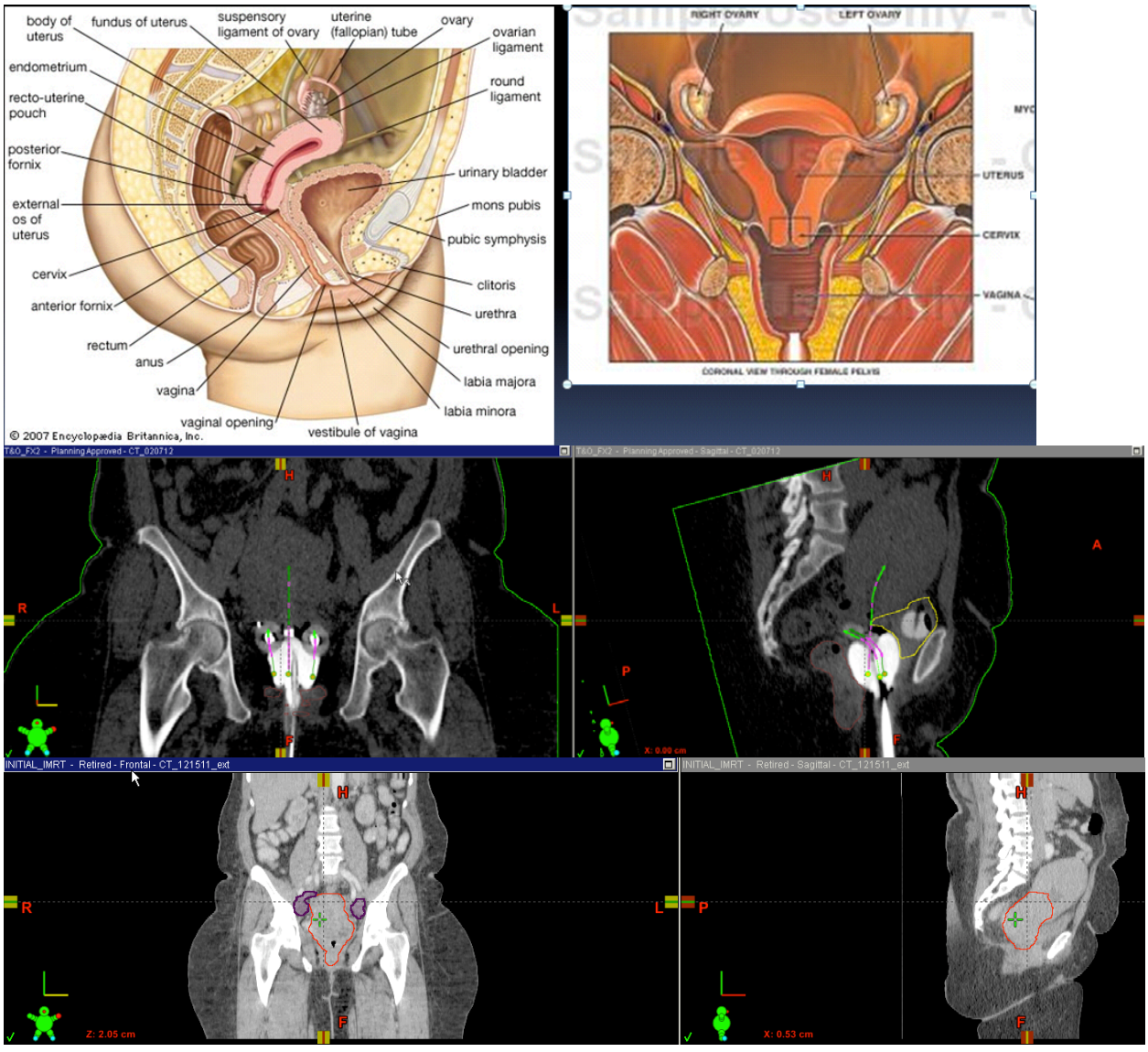
C2-B (Tandem & Ovoid)

- An illustration of a female pelvis with tandem & ovoid applicator inserted Identify what type of application what are we treating and identify cervix, uterus what's a typical Rx?

- Uterine or Cervical cancer
- Rx:

  External beam: Whole pelvis 45 Gy + sidewall boost to 50 – 54 Gy (1.8 Gy/fx);
  if bulky tumor will be 60Gy:

  Brachy: LDR 15-20 Gy x 2fx
  HDR 6Gy x 5 fx or 7Gy x 4 fx
  (similar to what we have in Penn) Handbook (p510)



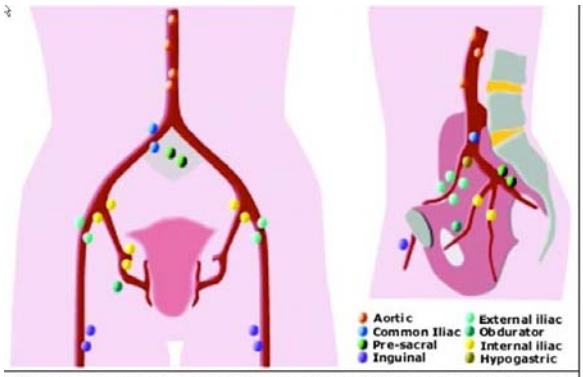


Figure 1. *Lymph node anatomy in the pelvis. A color diagram outlines the major nodal chains seen in the pelvis.* Reprinted with permission, Magnetic Resonance Imaging Clinics of North America © 2004.

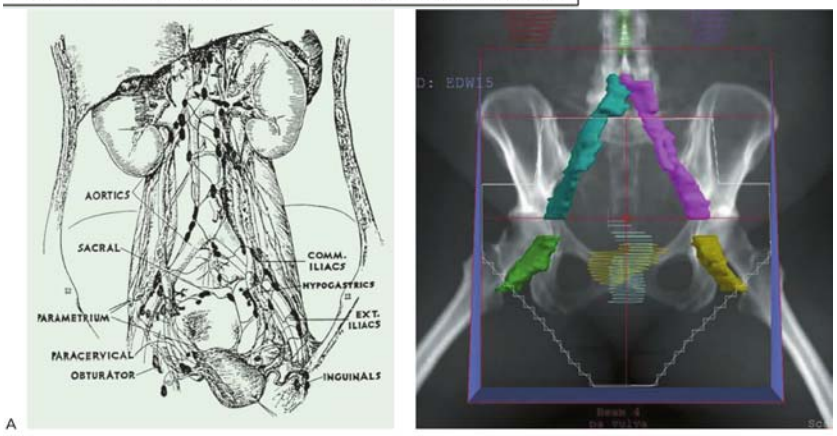
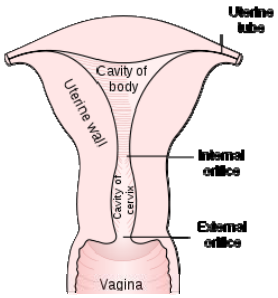


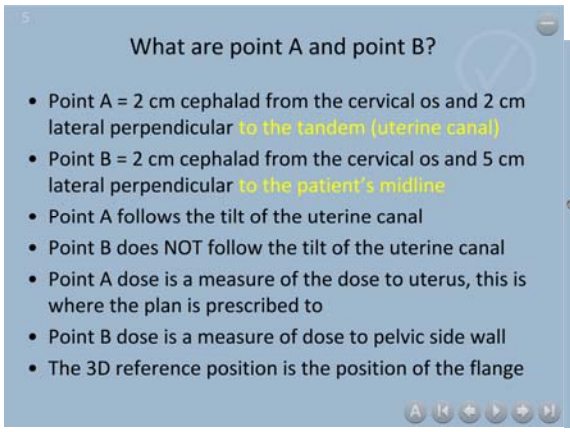
FIGURE 66.2. **A:** Lymph vessels and lymph nodes of the cervix and the body of the uterus. (From Henriksson E. The lymphatic spread of carcinoma of the cervix and of the body of the uterus: a study of 420 necropsies. *Am J Obstet Gynecol* 1949;58:924–942, with permission.). **B:** Three-dimensional reconstruction of location of pelvic and common iliac lymph nodes outlined on computed tomography scans in patient with carcinoma involving the distant vagina. Treatment portal is shown.

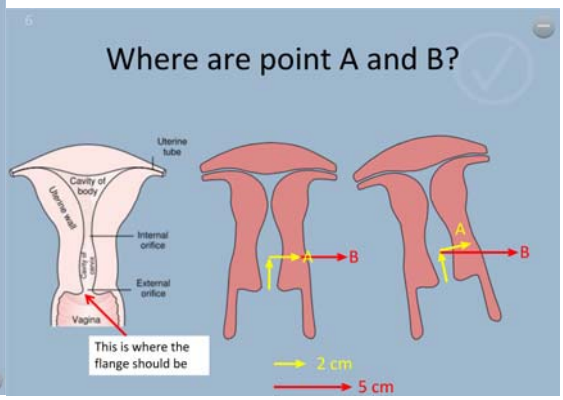
Where do you prescribe it (draw) and describe pt A & B?

At point A, point A is defined as the 2 cm lateral to the cervical canal and 2 cm superior to the cervical OS (that's also the reason we use the tandem as the guidance to define the point A) (DABR p156)

Cervical OS = cervical orifice (子)





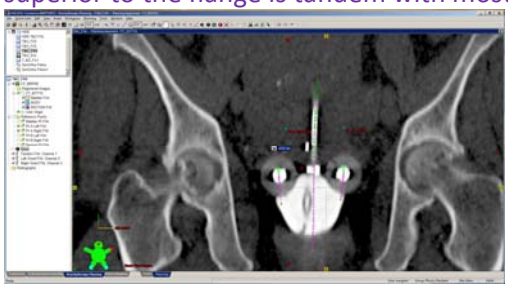


How do you identify cervical os?

Flange is at the cervical OS (DABR p157)

How do you verify/know that flange is really at os?

From the CT image, if the flange is at the cervical os, we will see the air around it which means it is in the cervix and superior to the flange is tandem with mostly tissue around it.

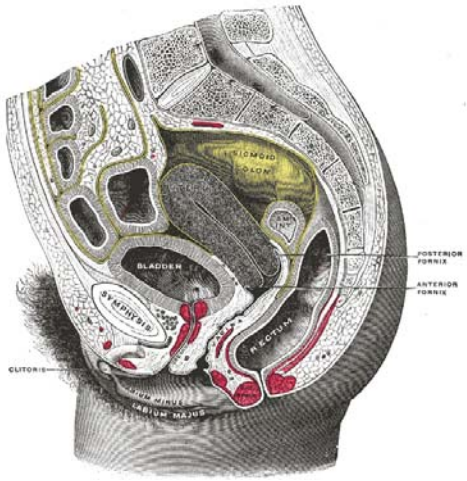


Physician usually placed a seed at the os level, so we can check to see if the flange is on the os level (Handbook p509)

Question: What's an optimal geometry?

From the AP view, the tandem should bisect the ovoid and not rotate, and the flange is at the cervical os marker location. Ovoids is around 4 cm in between each other.

Lateral view: Tandem bisects the ovoids, and between sacrum and bladder. Sufficient anterior and posterior packing. (Handbook p509- 510)



What are the critical structures and dose limits?

Bladder < 80% of the point A dose and rectum < 70% of the point A dose (Penn procedure, ICRU38)

How do you identify rectum, bladder point?
rectum point (in the lateral film) is defined as a point 5 mm posterior to the vaginal wall (in this case packing) located at the anterior rectum wall, at the midway of the 2 ovoids, perpendicular to the cervical os (Handbook p509 and practice brachytherapy p 92) (if our implant geometry is perfect, it will be perpendicular to the level of the bisection of the tandem and midsection of the ovoids, penn procedure)

Bladder point in the AP film is defined at the center of the foley, and in the lateral film, the point is located at the posterior surface foley.

- HDR tandem and ovoid picture. What is the difference between Fletcher suit and this (can be the machester or heschke sys).

Compared to the old Manchester system, the FS has internal shielding to rectum and bladder, and it is made by stainless steel (Large radonc book p457), which permits the use of Afterloading technique. (Manchester is made by rubber (Kahn p389). FS ovoid also angle posteriorly.

What type of sources used in LDR? What's Rx dose and typical dose rate? How long does it take?
Cs137 (662keV, 30 yr half life), 15 - 20 Gy x 2 fx, dose rate at point A is around 0.5 Gy/hr, so around 2 days (DABR p158 + Handbook p509) for 1 fx, and the 2nd fx is about 1 wk after (We passed powerpoint p7)

- A DRR of female pelvis, AP view. What is this? What would be treated with this field?
  Tandem and ovoid; Cervical cancer
  Be sure to discuss nodes and blocking. Locate the bladder and rectum. What is typical script? Would brachy be involved at some point?
  45 Gy 25 fx, 1.8 Gy/fx, (ABS LDR recommendation paper), after 45 Gy, brachytherapy kicked in
  Vaginal packing is used to reduce the dose to the bladder and rectum.
- Image of female pelvis. Point to iliac nodes. What structure are you treating?
- Picture of Gyn Applicators: What are these? What types of cancer do we treat with these? explain Henschke procedure, the way you use it at your facility, explaining the insertion of the applicator, the planning procedure stepwise, Rx doses and dose limiting structure doses, the second check procedure (~check the Penn 2nd check procedure) & equipment QA before the treatment. What else besides HDR can this equipment be used for (LDR?)?
  We used Fletcher-suit applicator instead of Henschke applicator
  {The Henschke applicator is different than the Fletcher-Suit applicator}

Henschke Applicator

The Henschke and other applicators are commercially available (69). The basic configuration of the ovoids is hemispheres that are inserted parallel to the lateral wall of the vaginal vault and the intrauterine tandem. Three ovoid diameters and various tandems are available. Although this applicator's configuration conforms better to a narrow vaginal vault, the radioactive sources are placed parallel to the long axis of the bladder and the rectum and do not have any shielding, thus potentially delivering a higher dose to these organs. Users should familiarize themselves with the dosimetric aspects of these devices. Delclos et al. (69) emphasized that the dosimetry with the Fletcher colpostats is unique and that treatment techniques and tables derived for this applicator should not be used with other applicators because this might result in significantly higher doses to the vagina, bladder, or rectum. Figure 20.37 illustrates the differences in dose delivered to the bladder or rectum with the Fletcher or the Henschke applicator for a normalized dose of 70 Gy to point A. Appropriate source loading and dose prescription will produce satisfactory clinical results.

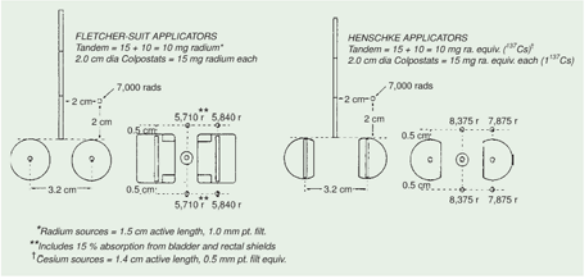


FIGURE 20.37. Comparison of doses delivered by Fletcher or Henschke colpostats to a plane 0.5 cm anterior and 0.5 cm posterior to the poles of the colpostats with the dose normalized at 70 Gy to point A. It is obvious that the number of milligram hours (mgh) must be reduced in the Henschke system to bring the dose to the bladder and rectum more in line with that obtained with the Fletcher applicator. (From Delclos L, Fletcher GH, Sampiere V, et al. Can the Fletcher gamma ray colpostat system be extrapolated to other systems? *Cancer* 1978;41:970, with permission.)

(Big Radonc handbook p512-513)

Procedure in Penn (simplified):

1. Patient arrives for placement of foley catheter and with contrast agent 7 cc.

Placement of T and O:

1. Place two gold seeds at cervix
2. Physician select the tandem with appropriate degree. This is based on the initial exam of the degree of flexion of the uterus. Set the flange at the predetermined distance (based on smit sleeve—usually 6-7 cm); Make sure that the tandem has not rotated during insertion;
3. Largest ovoid that can comfortably fit is used; Caps of two different sizes may be used depending on the situation; Flange should bisect the ovoids (can be seen on lateral films);
4. Radiadyne vagina balloon packing with contrast agent were used is our center to minimize bladder and rectum dose

Once packing is complete:

Imaging (Xrays)

1. Take a set of lateral/AP films **with dummy sources** in place
2. Images should include entire T and O system as well as appropriate bony landmarks
3. Look for correct positioning of ovoids: bisecting tandem, at the surface of the cervix (based on gold seeds), not displaced; make sure tandem is not rotated or displaced from the ovoids; packing is adequate (not in front of ovoids); ovoids should be at least **4 cm apart**; On the lateral film: make sure the tandem is not too close to the sacrum (tandem should be placed 1/3 to ½ the distance from the pubic symphysis to the sacrum)

<u>CT simulation</u>

1. Foley bulb should be inflated with 7 cc (remove the contrast from the foley bulb and insert sterile fluid)

2. Dummy seeds should be placed into tandem
3. 3mm scan thickness from L5 to 3 cm below the bottom of the ischial tuberosity
4. Scroll through CT slices to make sure there is no uterine perforation
5. Contour the bladder, rectum, sigmoid, (and tumor volume)

Treatment Planning:

- Digitise applicators
- Place reference points: A, B, bladder, rectum
- Insert potential dwell positions
- Set dwell-time weights
- Normalise weights to achieve prescribed dose to point A

Dose points
Point A (right and left): 2 cm cephalad from flange or Smit sleeve, 2 cm lateral to tandem
Point B (right and left): 2 cm cephalad from sail or Smit sleeve, 5 cm lateral from midline
ICRU rectum: 5 mm posterior to posterior vaginal wall as defined by radiopaque contrast soaked packing, or the most posterior ovoid position (at the level of the bisection of the tandem and ovoids)
ICRU bladder: AP film—center of foley bulb
Lateral film: midposterior position on foley bulb

HDR Planning
5 fractions x 5.5-6 Gy each (depending on stage)
Contour: bladder, rectum (from anus to sigmoid—level where rectum moves anterior), sigmoid (contour from top of rectum to flexure);
Schedule for HDR treatment:
1. HDR brachytherapy may begin at a minimum whole pelvic dose of 1800cGy (week 2) for favorable vaginal geometry. If vaginal geometry is not favorable, the first HDR insertion should be performed after 4 weeks of external beam (3600 cGy). (If a midline block is used, other acceptable fractionation schemes
are shown in Table 1).
2. HDR procedures can be performed once or twice per week with a minimum separation of 2 days. It is important to avoid prolongation of the overall treatment time beyond 56 days. Whether one or two HDR fractions are given per week, the external beam irradiation to the whole pelvis should not be given
the same day as the HDR fraction.

Brachytherapy Dose

• The dose to point A will be based on the external beam dose (see Table 1).
• The vaginal surface dose should be approximately 140-200% of the Point A dose.
• Maximum doses to the bladder, and rectum should be less than or equal to 80% and 70% of the Point A dose, respectively. In order to stay below an LDR equivalent of 70 Gy to the rectum for five HDR insertions (120 Gy3), including the 45 Gy contribution from the external beam radiation, the rectum (rectal reference point) should receive less than 4.1 Gy for each HDR fraction of 6 Gy (68% of the prescribed dose to Point A). The dose to the bladder (bladder reference point) should be less than 4.6 Gy per each HDR fraction of 6 Gy (77% of the prescribed dose to Point A).

Table 1-Equivalent Doses for Tumor and Late Effects for Doses of EBRT and HDR Brachytherapy used in Cervical Cancer

EBRT (Gy) @1.8Gy/fx	#HDR fractions	HDR dose/fx
19.8	7	6.7
19.8	6	7.4
39.6	5	6.6
39.6	6	5.8

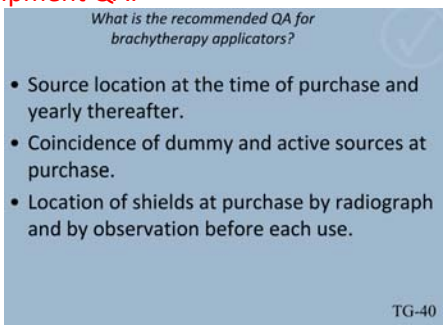
45	5	6.0-6.5**
45	6	5.3-5.8**
50.4	4	7.0*
50.4	5	6.0*
50.4	6	5.3*

**these doses are used in treating larger, more advanced tumors

*Nag S, Erickson B, Thomadsen B, et al. The American Brachytherapy Society recommendations for high dose rate brachytherapy for carcinoma of the cervix. *Int J Radiat Oncol Biol Phys*. 2000;48(1):201-211.

2nd check we simply used the dose at a certain point calculated using point source method.

Equipment QA:



TG40 Brachytherapy Applicators

Table XI lists QA tests to be performed for brachytherapy applicators. Of major concern is that the applicators position the sources where they are intended to be localized, and that any part of the structures which are used to attenuate the radiation (e.g., rectal and bladder shields) have not shifted.

TABLE .X1. QA tests for brachytherapy applicators. I. initial use or following malfunction and repairs; D, documented and correction applied or noted in report of measurement, when appropriate; and E, as a minimum, a visual inspection to verify that the dummy sources fairly represent the active source distribution.

Type of applicator	Test	Frequency	Tolerance
Intracavitary	Source location	I, yearly	D
	Coincidence of dummy and active sources	I	1 mm
	Location of shields	I[b]	D
Interstitial	Coincidence of dummy and active sources	I,E	1 mm

[a]To reduce personnel exposure, the dummy source location may be checked in place of the active source, if it is established that the dummy and active source locations are coincident.
[b]Location of shields should be verified by radiograph before the first use. Before every use, the applicator may be shaken to listen for loose parts.

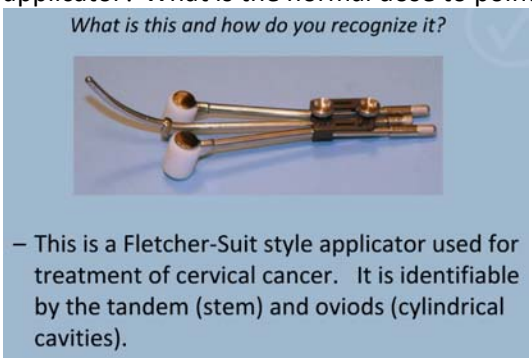
What else besides HDR can this equipment be used for?

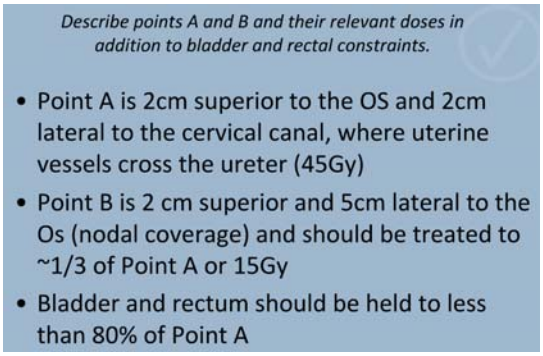
LDR normally with Cs137 loading.

- Brachy – Picture of a tandem and ovoid are shown. What are typical source loadings? Shielding in the ovoids? Tandem?

- Cartoon of T&O inserted in patient. What is the difference between what you see in picture and LDR Fletcher-suite applicator? How would you reduce dose to rectum?
- Shown an HDR Tandem and Ovoid. Know to identify bladder, how much contrast should be in bladder? Know to identify the function of the "metal blade" shown on the orthogs. Looked like a rectal shield. Define (according to ICRU) Point A, B, Rectal point and where its location on the lateral film, bladder point and its location on both the AP and lateral film.

- What kind of Brachytherapy is this (HDR), what is the difference between this applicator and Fletcher-Suite LDR applicator? What is the normal dose to point B?





uterine (子宮) ureter (輸尿管)

- Cervix HDR brachytherapy Which applicator? Volume to treat? Can you use Tandem alone? Can you use Tandem and cylinder? ICRU points. Are they good representative?
- (2006) HDR T&O Showing 4 planes of the dose distribution. What is this? What are the planes? Is this a good implant?
- (2008) Shown T&O of HDR. All notations were erased from the film. Explain each part (Blade and Foley catheter) and What do you call the device equivalent to the metal blade we used for LDR? What is the size of Foley catheter? Can we choose different size?

- LDR implant..what is the procedure, what is differential loading instrumentation, procedure for calibration of ir-192, I-125 and cs-137
- (2006) Evaluate an LDR prostate implant ? doses, isotope, isodose lines, structures
- How would you go about planning a brachy sarcoma case? Walk through from start to finish. Some guidance given.
- (2008) What device would you take to an I-125 implant? What if an Ir-192 implant?

- What is a Sievert integral? How is it calculated?
  The Sievert integral is used to calculate the exposure rate (in the air) at a point from a linear radioactive source. Basically, it calculates each source element within dx of a line source as a point source, and perform a spatial integral for the whole linear source (Kahn sec 15.4).

15.3. CALCULATION OF DOSE DISTRIBUTIONS

A. Exposure Rate

Exposure rate distribution around a linear brachytherapy source can be calculated using the Sievert integral, introduced by Sievert (40) in 1921. The method (1,41) consists of dividing the line source into small elementary sources and applying inverse square law and filtration corrections to each. Consider a source of active length L and filtration t (Fig. 15.9). The exposure rate dI at a point $P(x, y)$ contributed by the source element of length dx is given by:

$$dI(x, y) = \frac{A}{L} \cdot \Gamma \cdot dx \cdot \frac{1}{r^2} \cdot e^{-\mu' \cdot t \cdot \sec\theta} \qquad (15.9)$$

where A and Γ are the activity and exposure rate constant of the unfiltered source and μ' is the effective attenuation coefficient for the filter. Other variables are defined by Fig. 15.9.

Making use of the following relationships:

$$r = y \sec\theta$$
$$x = y \tan\theta$$
$$dx = y \sec^2\theta \, d\theta$$

and integrating Equation 15.9, we obtain the exposure rate $I(x, y)$ for the whole source.

$$I(x, y) = \frac{A\Gamma}{Ly} \int_{\theta_1}^{\theta_2} e^{-\mu' \cdot t \cdot \sec\theta} \, d\theta \qquad (15.10)$$

The above Sievert integral can be evaluated by numerical methods (1).

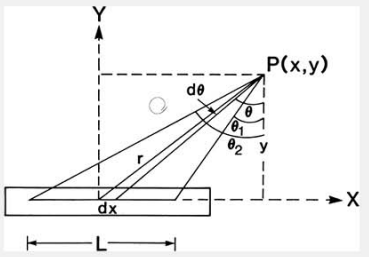
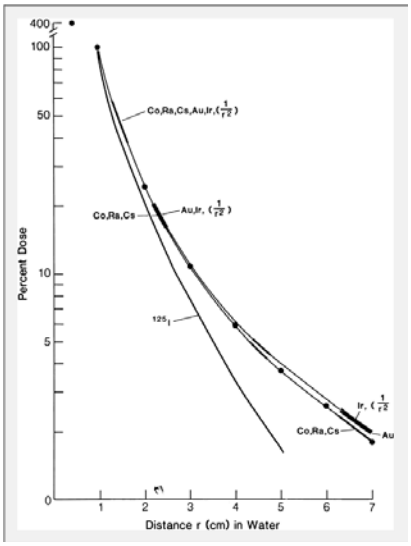


FIG. 15.9. Diagram illustrating geometrical relationships used in calculation of exposure at point P, from a linear source.

If the source intensity is specified in terms of exposure rate



YY: regarding this, another point is to look at figure 15.13. Ir and Au has almost identical depth dose curve as just inverse square. this is also why TG43 needs all those factors for LDR sources only.

KW: It is a good point though. Ir-192 is included in TG43, but was not included in the TG43 update report. Ir-192 can be taken as a point source, and TG43 also provided g(r) for Ir-192 but that factor only has max 2% variation up to 5 cm, and 13% up to 10 cm, which is already out off our interested treatment range (table 15.7). The anisotropic factor for Ir192 is pretty much equal to 1. Conclusion: Ir-192 can be approximately calculated as point source **with inverse square law to characterize it.**

C2-C (PDD, Kerma & Dose)

- **(Photon PDD)** How does it change with SSD, energy and field size & why? Why is surface dose low? why do we use an acrylic shield for TBI.

What is the purpose of using compensator?

- Goal: To deliver uniform dose to entire body within ±10% of the Rx dose (specified at the umbilicus)
- In addition to uniformity, also need to shield important organs (head, lungs, kidneys)
- For R-L lateral technique here, the arms are positioned to shield lung, but may need additional compensation

Because the compensator is designed to be dosimetrically equivalent to a bolus (of thickness equal to the tissue deficit) but placed at a distance from the skin surface, the bolus-equivalent thickness of the compensator is reduced to compensate for reduction in scatter reaching the point of dose compensation. The required thickness of a tissue-equivalent compensator that gives the same dose at the point of interest as would a bolus of thickness equal to the tissue deficit

compensator material should be selected so that the compensator is not too bulky or of too high a density that small errors in machining would amount to large errors in dose

- Shown 6X PDD 10 X 10. What happens at surface for larger field size? What is the build up region? What happens at surface at 110 SSD?

(PDD vs. energy)

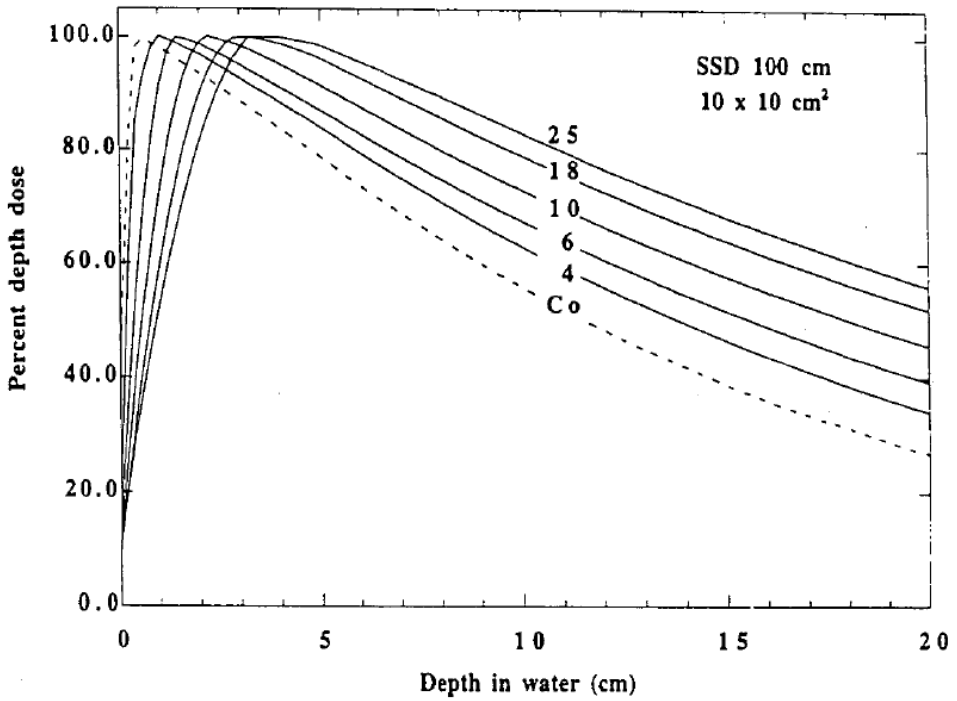


FIG. 6.10. Percentage depth dose curves in water for a 10× 10 cm² field at an SSD of 100 cm for various megavoltage photon beams ranging from cobalt-60 gamma rays to 25 MV x rays.

For constant z, A and f, the PDD beyond z_{max} increases with beam energy, because of a decrease in beam attenuation, *i.e.*, because of an increase in beam penetrating power.

An example of PDD distributions for 10×10 cm^2 fields and various megavoltage photon beams is given in Fig. 6.10 and Table 6.IV. The size of the build-up region increases with beam energy and the surface dose decreases with beam energy.

(Kahn p163)

The physics of dose buildup may be explained as follows:

(a) As the high-energy photon beam enters the patient or the phantom, high-speed electrons are ejected from the surface and the subsequent layers;

(b) These electrons deposit their energy a significant distance away from their site of origin; (So higher photon ejected electron can travel farther, the surface dose is lower)

(c) Because of (a) and (b), the electron fluence and hence the absorbed dose increase with depth until they reach a maximum.

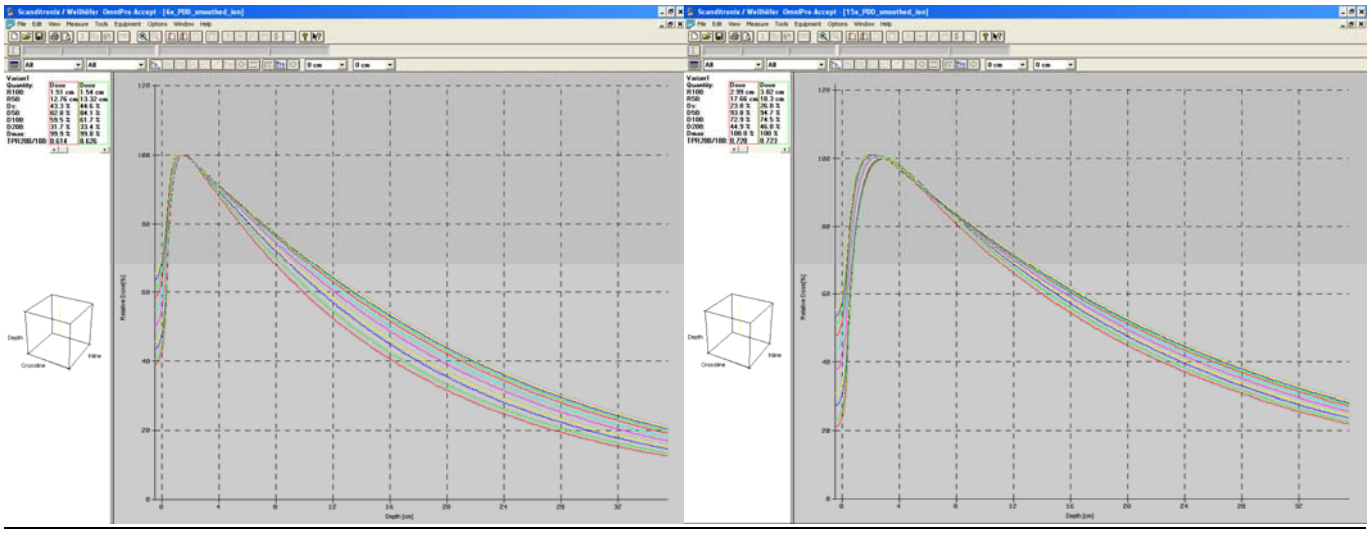
However, the photon energy fluence continuously decreases with depth and, as a result, the production of electrons also decreases with depth. The net effect is that beyond a certain depth the dose eventually begins to decrease with depth.

(PDD vs. field size) Kahn 9.3.B

The following figure shows the PDD increases along with the increase of the field size over all the depth range we considered.

The reason for that is the increase of field size increase the scattered photon, and the increase of scattered dose is larger at deeper depth than at d_{max}, PDD increase.

Low energy photon is easily scattered compared to high energy photon, so the field size effect is more obvious for 6x than 15x.



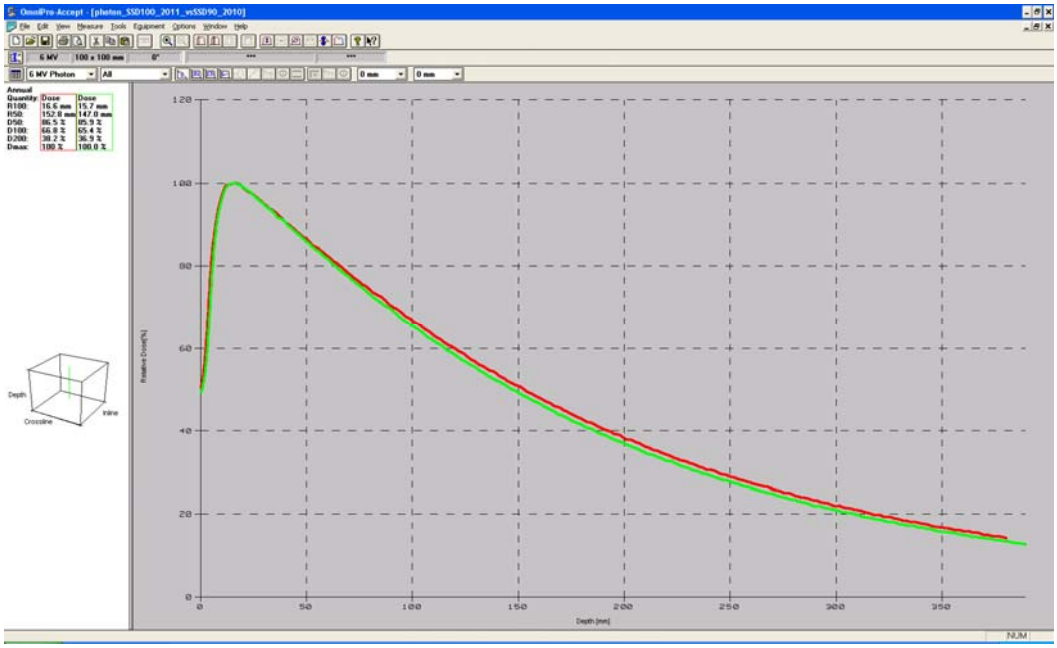
6x 15x

(PDD vs. SSD) The following figures are the 6x 10x10 comparison between SSD 90 **(green)** and 100 **(red).**

The PDD varies with the change of SSD is due to the inverse square law. When we increase larger SSD, the dose rate at the depth close to the source decrease more severe compared to the dose at the deeper depth. The PDD is normalized to the dose at the d_{max},

so SSD increase, PDD increase for d > d_{max}.

so SSD increase, PDD decrease for d < d_{max}.



6x 10x10 comparison between SSD 90 **(green)** and 100 **(red).**

If we want to see our PDD correct or not at SSD 100, we can check depth = 10 cm. Varian d10, SSD100, and 6x is around 67%. According to TG51, photon ionization curve can be approximated as depth dose curve due to the variation of stopping power ratio is negligible passing d_{max}.

-
- **(Kerma & Dose)**Picture of dose buildup curve. Explain KERMA, dose buildup region.
- (2008) Shown a plot of a PDD. Explain the buildup region, D_{max} and the attenuation. What is the definition of KERMA and difference between KERMA and dose?
- Shown a graph of KERMA vs dose. What are we looking at? Describe what is happening in this graph? Where does the electronic equilibrium take place? Show on the graph. Why is the KERMA part under the absorbed dose curve after d_{max}?
-

(This part read the Kerma and Dose in Wepassed)

Discuss this graph and its relevance to radiation therapy measurement.

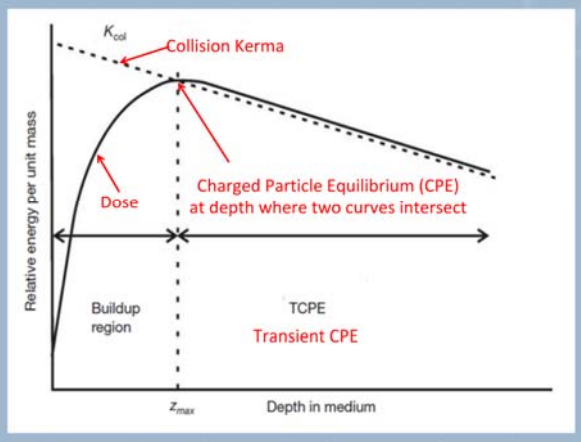


Image from IAEA Radiation Oncology Physics Handbook (Podgorsak et al.). Used with permission.

What is KERMA?

- KERMA = Kinetic energy released by uncharged ionizing radiation to charged particles per unit mass of matter.
- KERMA is highest at surface because photon fluence is highest there.
- KERMA is only applicable to uncharged particles (such as photons).

How is K related to Dose?

- Energy released at a given point (Kerma) is absorbed elsewhere (mostly downstream).
- Mostly downstream because the dominant interaction (mostly Compton) scatters particles (secondary electrons) forward.
- This is why we have build-up region for dose.
- Dmax increases with photon energy because higher energy photons = more forward scatter + secondary electrons have longer range.

C2-D (Algorithm)

- TPS algorithms. Describe TERMA and kernel. Where does each come from? How does your planning system handle heterogeneity? What are other ways? Explain convolution-superposition and how correction would work.
- Explain the dose calculation model for you TPS and explain the difference between Pencil beam, modified batho, ETAR, superposition convolution etc.

How does a TPS calculate dose distribution?

- The short answer is: Dose = TERMA * Kernel
- Note that the (*) sign is not a simple multiplication! It is a convolution sign (you need to know what that means)
- The math answer is: $\mathrm{Dose}(\mathbf{r}) = \iiint \mathrm{TERMA}(\mathbf{r}')\,\mathrm{Kernel}(\mathbf{r}-\mathbf{r}')\,\mathrm{d}^3\mathbf{r}'$
- Here is what it says:
  - Energy is released by primary photon at point r'. How much energy is deposited there is given by TERMA(r').
  - Secondary electrons that receive this energy travel away from the point where energy is released. As it travels, it deposits the energy along the way. The fraction of energy deposited at point r, from the energy released at point r', is specified by Kernel(r-r'). You multiply this with TERMA(r') to get the dose contribution to point r from point r'.
  - Sum up the contribution from all r' points to get the dose at r.

- What treatment planning system do you use? Explain how it works. Explain how heterogeneity corrections are done. Had listed on the screen (1). Batho Power Law, (2). ETAR, (3). Differential Scatter-Air Ratio,(4) PBC (5). superposition -Convolution and (6). Monte Carlo. Discuss what your TPS uses. Discuss each of these. Adv/disadv of each.

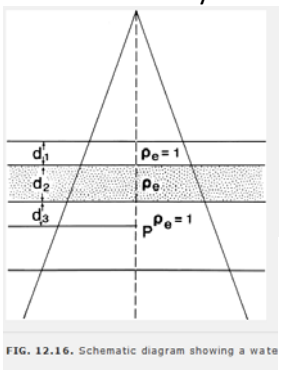


FIG. 12.16. Schematic diagram showing a wate

$$ICF = \frac{TAR(d', W)}{TAR(d, W)}$$

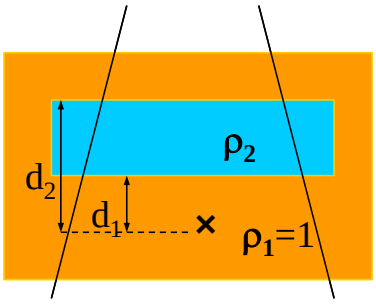
1. **Ratio of TAR method:** RTAR calculates the ICF at a point (p) under the semi-infinite slabs with inhomogeneity inside. In this method, the primary ray trace produces a radiological depth, and it is used to generate the revised TAR value.

   Adv: Simplicity (The primary photon fluence attenuation in **CPE** condition and the scatter part is approximately counted in this method)

   Dis: (1). Does not take into account the position of the inhomogeneity relative to point P. In other words, the correction factor will not change with d_3 as long as d_1 and d_2 remain constant. Therefore, the position of the inhomogeneity or the lateral component of the scattered photon affected by the inhomogeneity is compromised (changing the position of inhomogeneity will change the portion of the photon beam passing through the homogeneity and inhomogeneity medium)

   (2). It also assumes that the homogeneity is infinite in lateral extent, so again the lateral scattered photon was not corrected accounted.

2. **Batho Power law:** An empirical correction factor method for points lying within water and distal to an inhomogeneity by raising TAR to a power that depends on density.
   Adv: Compared to RTAR, Batho law can calculate the dose within an inhomogeneity as well as below it.
   Major Dis: **Batho law and RTAR methods have been** difficult to extend to situations **where CPE does not exist**, such as tissue interface and buildup region. Furthermore, the handling of scattered photon radiation was approximate and indirect, accounting only for radiological depth.



$$CF = \frac{T(d_3, r_d)^{\rho_3 - \rho_2}}{T(d_2 + d_3, r_d)^{1-\rho_2}}$$

(This method accounts **for the position relative to the inhomogeneity**. It **still assumes that the homogeneity is infinite in lateral extent**)

(MetCalf p600): Batho law **works well for smaller field and less density medium relative to the larger field and high density medium** because this method is based on an exponential characterization of the depth dose, and this is only a good approximation when scatter is minimized, as in the case of small fields and low densities.

3. **Equivalent TAR method (ETAR):**
   Adv: Similar to the RTAR method outlined above with the exception that the field size parameter is modified as a function of density to correct for the geometrical position of the inhomogeneity with respect to the calculation point p.

$$ICF = TAR(d', \tilde{r}) \,/\, TAR(d, r)$$

   Dis: The loss of scatter dose is determined by smaller effective field size. This approximation will overestimate the scatter dose when there is no lateral electron equilibrium such as large field beam passing through lung.

4. **Differential Scatter-Air Ratio (DASR): (MetCalf p589)** This method separates primary and scatter dose by explicitly summing the dose form scatter elements and adding this to the primary dose.
   Dose at point P is calculated as

$$D(P) = D_0 \frac{\overline{TAR}}{TAR(d_{\max}, r)} = D_0 \frac{TAR(d',0) + \overline{SAR}}{TAR(d_{\max}, r)}$$

$$\overline{SAR} = \sum_z \sum_r \sum_\varphi \overline{DSAR}(d, z, r, \varphi)$$

   The scatter dose is due to photons scattered from all voxels within the irradiated vol., where the value of SAR is the sum of all differential scatter-air-ratio values (DSAR) for elements within the vol.

   Attenuation correction is made for the primary photon reaching the scattering element, and then the scattered photon reaching the calculation point.

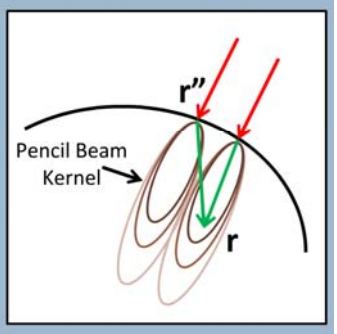
   Adv: well suited to situations where the field is of irregular shape.
   Dis: Only consider 1st order scatter, so this method is good for high energy beam. Another deficiency is that this method does not consider backscattered photon since the DSAR values represents increments in dose from scattering material above the calculation points. Again DSAR method is good for high energy photon.

5. **PBC – convolution**

How does Pencil Beam Convolution (PBC) work?

$$\text{Dose}(\mathbf{r}) = \iint \text{TERMA}(\mathbf{r}'') \frac{|\mathbf{r}''|^2}{|\mathbf{r}|^2} \text{Kernel}_{2D}(\mathbf{r}-\mathbf{r}'')\, d^2\mathbf{r}''$$

- PBC simplifies the original equation by pre-calculating the depth dependence of the kernel.
- Dose contribution is now summed over points on the surface of the phantom instead of the whole volume.
- PBC kernel is a 2D kernel, as opposed to 3D kernel in original convolution formula.
- It handles forward scattering component well but not so much for back and side scattering.



r = dose deposition point
r'' = photon interaction point

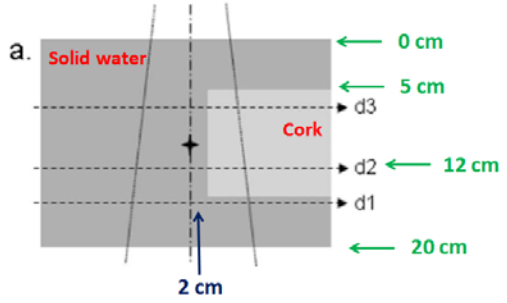
Avd: It use precalculated 2D PB kernel, so it's faster than the 3D convolution method. It accurately considers the secondary electron transport (kernel)

Dis: (1). handles the forward scattering well but not so much for back and side scattering.
(2). The secondary electron transport (kernel) still considers water medium not include the medium heterogeneity .

Therefore, the PBC does not handle the calculation inside the heterogeneity well, especially in the region losing electron equilibrium (tissue- lung interface, and the small field passing through lung).

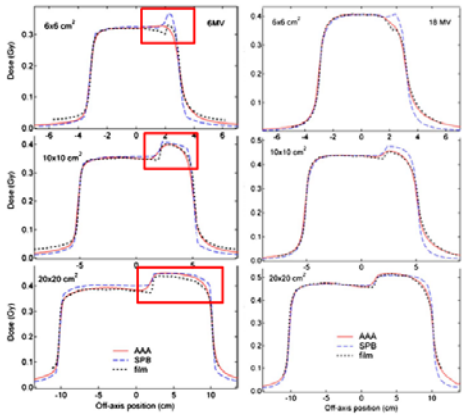
Results

- Inhomogeneity - Profiles
  - Measurement: 10 cm thick cork slab simulating lung density is inserted into the solid water piece. The film measurement was performed at depth d_2 12 cm below surface. FS is changed from 6 x 6 to 20 x 20 cm^2 with SPD = 90 cm.



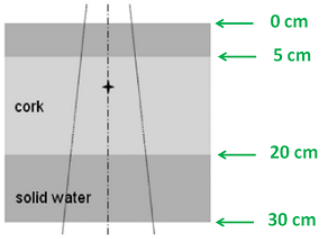
Results

- Inhomogeneity - Profiles
  - AAA offers better agreement with measurement within the heterogeneity region, especially for 18 MV.
  - AAA result is not able to agree with the measurement at the interface for 6 MV case.



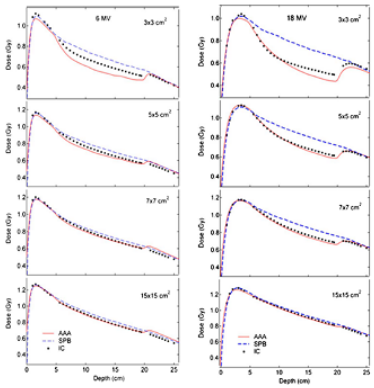
Results

- Inhomogeneity – Depth dose curve
  - Measurement: 15 cm thick cork slab simulating lung density is inserted into the solid water piece. Field size is changed from 3 x 3 to 20 x 20 cm² with SPD = 90 cm.



Results

- Inhomogeneity – Depth dose curve
  - AAA shows better agreement with measurement for 18 MV, compared to SPB.



6. Superposition-convolution:

What are the advantages and limitations of superposition/convolution algorithm?

- Advantage: With heterogeneity correction on (that is, using superposition rather than simple convolution) this algorithm is very accurate, second only to Monte Carlo. The accuracy depends a lot on the quality of the kernel, so it depends on the implementation and beam data used in commissioning it.
- Even in the worst case, S/C typically is only a few percent different from MC.
- Limitations: True S/C algorithm requires a lot of computation:
  - If there are N grid points along one dimension, there are N^3 points where dose needs to be calculated.
  - For each dose point, you need to sum the dose contributions from all interaction points, there are N^3 of them.
  - So to get the full dose distribution in your calculation volume, the computer needs to iterate the calculation N^6 times.
- Usually TPS uses various approximations to speed up the calculation. Each approximation will trade off some accuracy.

What is the difference between convolution and superposition?

- Convolution: $\text{Dose}(\mathbf{r}) = \iiint \text{TERMA}(\mathbf{r}')\,\text{Kernel}(\mathbf{r}-\mathbf{r}')\,d^3\mathbf{r}'$
- Superposition: $\text{Dose}(\mathbf{r}) = \iiint \text{TERMA}(\rho\cdot\mathbf{r}')\,\text{Kernel}(\rho\cdot(\mathbf{r}-\mathbf{r}'))\,d^3\mathbf{r}'$
- Convolution method uses the same kernel everywhere. It does not distinguish whether the photon energy is released in muscle or in lung, the energy will be spread out using the same kernel.
- Superposition method uses spatially dependent kernel. The kernel is scaled according to inverse density as shown in the formula above. If the energy is released in lung, it can spread out further away than if the energy is released in tissue.
- Superposition equation is obtained by replacing all distances in the convolution equation with radiological distances: $\mathbf{r} \rightarrow \rho \cdot \mathbf{r}$
- Superposition is better because it can handle heterogeneity more accurately. Convolution incorporates transport of secondary electron correctly but it assumes homogeneous medium.

(My note): The so called superposition-convolution algorithm used the density scaling method to scale the kernel by the electron density within the heterogeneous medium, and then do the convolution integral to sum the dose up. Mathematically, we can write down the equation as

$$D(\vec{r}) = \int T(\vec{r}'\cdot\rho')\cdot K(\vec{r}\cdot\rho;\vec{r}'\cdot\rho')d^3\vec{r}'$$

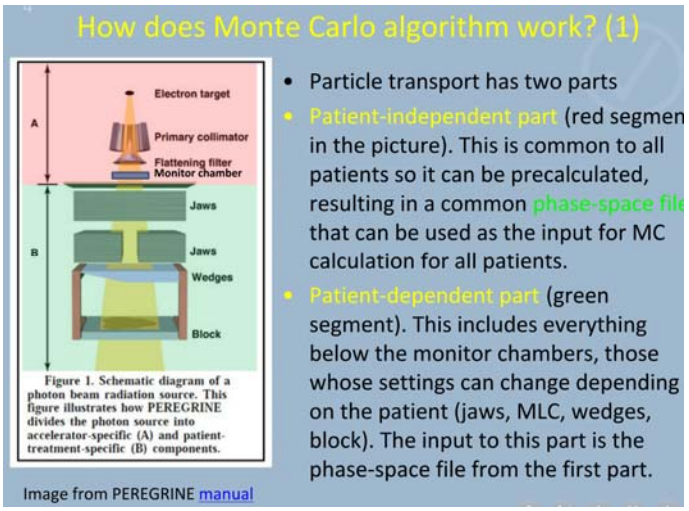
Therefore, the superposition-convolution considers the heterogeneity correction for primary photon fluence (Terma) as well as the secondary electron part (kernel) by summing up the dose with density scaling kernal. The following figure from TG65 shows the idea.

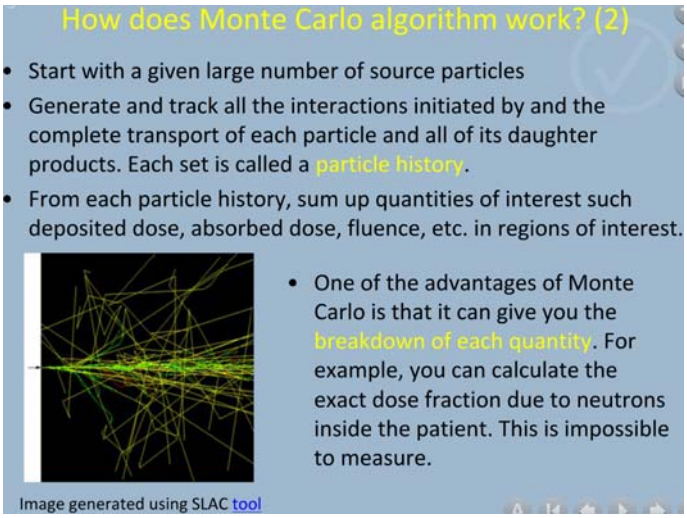
In fact, superposition convolution can use pencil beam kernel as well, such as AAA.

For convolution method, the kernel is generated by MC simulation.

7. Monte Carlo (MC)

(read wepassed)





Input: (1). Patient independent & dependent parts:
Idea: (1). Giving large number of source particles
(2). Generate & Track all the interactions history of the particle and its daughter particle
(3). From each history, we sum the quantities of interest.

- The Monte Carlo dose calculation method uses the **probability distributions** governing **the individual interactions of electron and photons** to simulate their transport through matter.
- By simulating a large number of interaction histories, the **average values** of macroscopic quantities such as energy deposition can be obtained as well as the **statistical fluctuations** of particular kind of event.
-
- (2). It requires accurate material & geometric specifications, basic physics data, and density & material map of the pt.

Adv: (1). Currently, MC is the most accurate calculation method, especially at the interfaces of heterogeneous tissue and in lung where particle disequilibrium is occurred.

(2). To extract dosimetric information when physical measurements are difficult or impossible to perform (different orders of scattering/spectra)

(3). Provide benchmark for analytical calculations

Dis: (1). The cost is the computational time, because it needs to use enough number of particles to achieve desired accuracy

What inputs are required for MC calculation?

- Accurate geometric and material specifications of the treatment head of the linac. The keyword is accurate; thus using pure tungsten will give you different result from an alloy with 90% tungsten, for example. These proprietary data need to be obtained from the manufacturer. Garbage in = Garbage out.
- Accurate basic physics data. This includes cross-section for photoelectric, Compton, pair-production (and other relevant processes), radiative stopping powers, scattering powers.
- Accurate density and material map of the patient. This is obtained from the CT data. You have 2 steps here: (1) convert Hounsfield number to density; (2) convert density to material. The second step could be non-unique and contribute to error. For example, a voxel with average density of 0.3 can be at an interface of tissue and air, but could be labeled as lung.

Important Monte Carlo transport parameters

(at least the ones that you need to know here)

- ECUT. Particle transport is forced to stop when its energy < ECUT. Its energy is then assumed to be deposited at its current voxel. Select ECUT such that electron with energy = ECUT has a range ≈ voxel dimension (so that its energy deposited outside that voxel ≈ negligible). If voxel size ≈ 2 mm, then ECUT needs to be < 500 keV in water, but in lung it will need to be < 200 keV.
- Phase-space file. This is an input to the patient-dependent part of the calculation. It tells you all the information that you need about the beam that is going to be transported toward the patient in order to simulate the dose to the patient downstream:
  - Particle type (photon, electron, positron, etc.)
  - Energy
  - XYZ position of the particle (where it is at)
  - 3 directional parameters (what direction it is heading)

8. AAA:

Introduction

- AAA was implemented in Eclipse to replace single pencil beam (SPB) algorithm, to improve the dose accuracy, especially in heterogeneous media.
- Total dose deposition is calculated as the superposition of the dose deposited by
  - 1. Primary photon source modeling bremsstrahlung radiation from target
  - 2. Secondary photon source modeling photon scatter in Linac head
  - 3. Source for modeling e contamination

Introduction

- In AAA, dose calculation is performed as a superposition of MC precalculated pencil beam, scaled according to tissue e density.
- The pencil beam kernel are separated into lateral and depth-directed components.
- 3D point spread kernel is the most ideal scatter kernel to model the 3D photon interaction in each voxel. However, AAA uses pencil beam kernel. The accuracy of dose calculation for AAA is not expected to be better than Helax or Pinnacle TPS.

Introduction

- The implementation of AAA
  - Configuration module:
    - An optimization algorithm was developed to determines the parameters or curves characterizing the multiple source model by optimizing the agreement between the calculated and measured basic beam data.

Introduction

- The implementation of AAA
  - Dose calculation module:
    - Based on the triple Gaussian analytical pencil beam model developed by Ulmer *et al**.
    - Exponential functions are now used instead of Gaussian to better model the lateral scatter near borders of heterogeneities.
    - Simplifications were made in the modeling of the dose in the build-up region to reduce the time required for dose calculation.

*Ulmer *et al.* Z. Med. Phys. **5**, 25 – 30 (1995)

Anisotropic: Scatter calculation according to density on 3D neighborhood surrounding each point
Analytical: Analytical mathematical functions used to model scatter
Algorithm: Convolution/ superposition of beamlet & scatter contributions.

The 1st 2 points are basically illustrating in the following 2 slides. The lateral anisotropic photon scattering is modeled by the exponential function according to the electron density around the calculation point.

Description of the AAA

- Dose calculation for the primary and 2nd source
  - Energy deposition by photon source is separated into

1. Depth component (along the beamlet), accounts for the total energy deposition of the pencil beam in layer/depth p_z in the calculation grid

$$I_\beta(p_z) = \Phi_\beta \int\int h_\beta(x,y,p_z)dxdy. \quad \Phi_\beta \text{ is photon fluence}$$

2. Lateral component (perpendicular to the beamlet) describes at layer/depth p_z and angle θ, the fraction of energy deposited into an small angular sector at a distance λ to CAX of the beamlet.

$$k_\beta(\theta,\lambda,p_z) = \sum_{i=1}^{6} c_i \frac{1}{\lambda}\exp(-\mu_i\lambda)$$

Description of the AAA

- Dose calculation for the primary and 2nd source
  - In a homogeneous phantom, the energy deposited by single beamlet into an arbitrary grid point p in the layer/depth p_z is

$$E_\beta(p) = I_\beta(p_z)k_\beta(\theta,\lambda,p_z).$$

  - The heterogeneous of pt. tissue is accounted for by relative e density and radiological distance such as

$$I'_\beta(p_z) = I_\beta(p'_z)\rho_w(p)$$

$$k'_\beta(\theta,\lambda,p_z) = k_\beta\left(\theta,\frac{p'_z}{p_z}\lambda',p'_z\right)\rho_w(p)$$

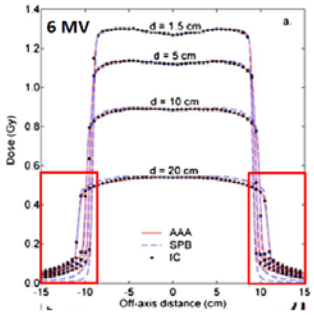
where $\rho_w(p) \equiv \rho^{el}(p)/\rho^{el}_{water}$.

So **AAA is a superposition convolution but using pencil beam kernel.** The monoenergenic pencil beam kernel is determined by MC simulations, and AAA adjusted the poly-energetic photon spectrum weights to match measured beam data. The unique feature of AAA is that for each pencil beamlet, it has depth & lateral component at each interaction site. Heterogeneity calculation is improved compared to PBC by including this lateral component to better describing the photon scattered around the interaction site within heterogeneity.

Adv: (1). Compared to the SPB, AAA improves the penumbra modeling (due to introduction of the 2nd source which better models the head scattering photon), as well as the dose calculation in heterogeneous media, especially for 18 MV case.

Results

- Open field – Profile comparison
  - Measured (IC) and calculated profile for AAA & single pencil beam (SPB) at SPD = 90 cm for FS 6 – 25 cm and 6 & 18 MV.
  - Only 6 MV, FS = 20 cm is shown. Other results are similar.
  - AAA improves the dose calculation in the penumbra region compared to SPB, due to introduction of the 2nd source which better models the head scattering photon.

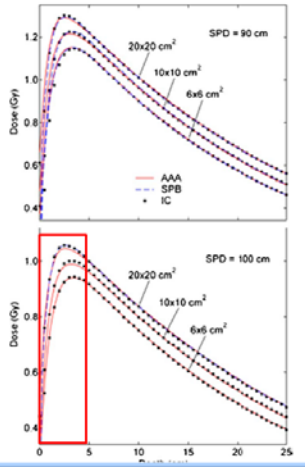


(2). Faster than MC.

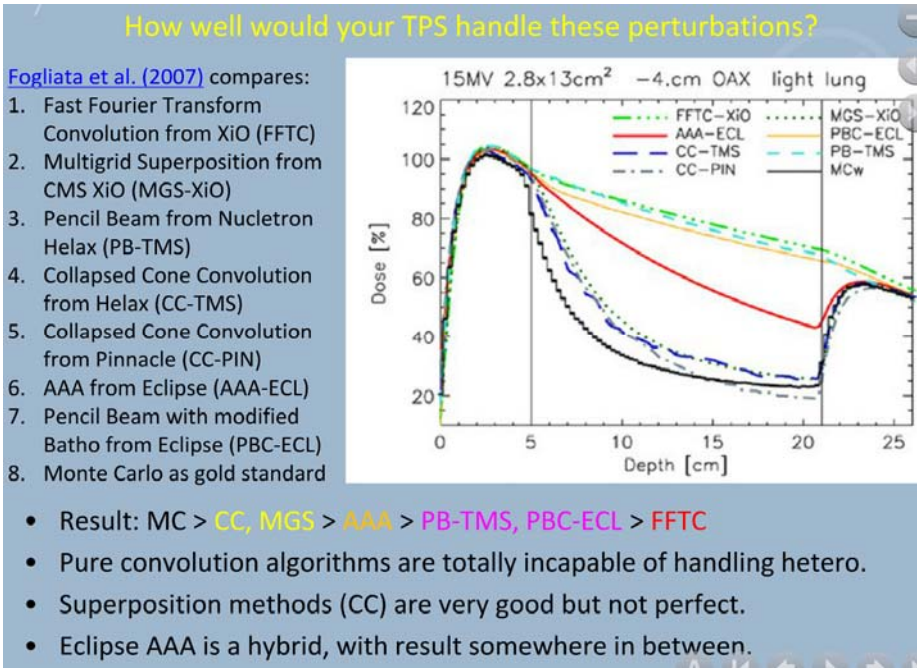
Dis: (1). However, suboptimal modeling of the dose are still observed at the heterogeneous interface and the build up area, not as accurate as MC.

Results

- Open field – Depth dose
  - Measured (IC) and calculated DD for AAA & SPB for 18 MV and two SPDs.
  - Deviation is seen in the build up region between AAA and measurement, suggesting not configure AAA using reference data at d_{max}
  - Due to oversimplified modeling of the electron contamination.



Comparison:



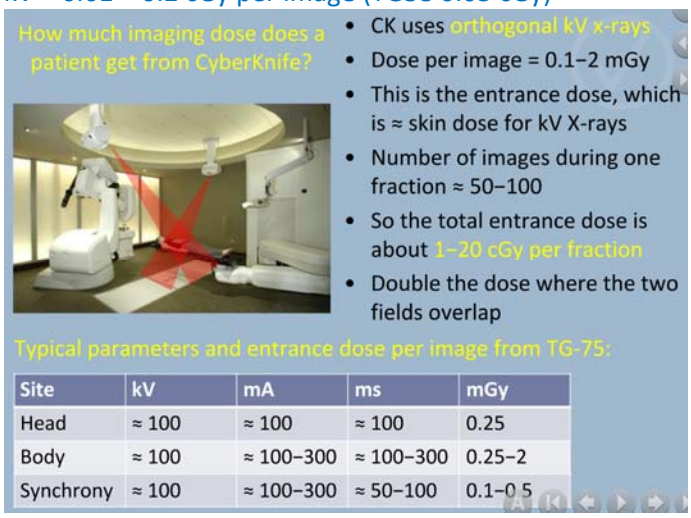
- **(IMRT)**3- IMRT optimization - Explain algorithm. How can we avoid more than one local minima? Why can't we have the same planned vs. measured IMRT plan (MLC speed difference, QA ± 3%)?
- (2008) IMRT: Shown a plot of mathematical 3-D (x,y and z) plot. How does optimization work? How many local maximums and global maximum? How do we know whether we are on local or global max? Can we implement an ideal IMRT plan?
- IMRT: concept, delivery technique and planning procedure. Pros and cons vs. 3D.
- (2011) Shown picture of transverse slice of prostate IMRT plan. What is IMRT, how does it work, describe the planning process, etc? How would you increase dose to the posterior part of the PTV near the rectum?

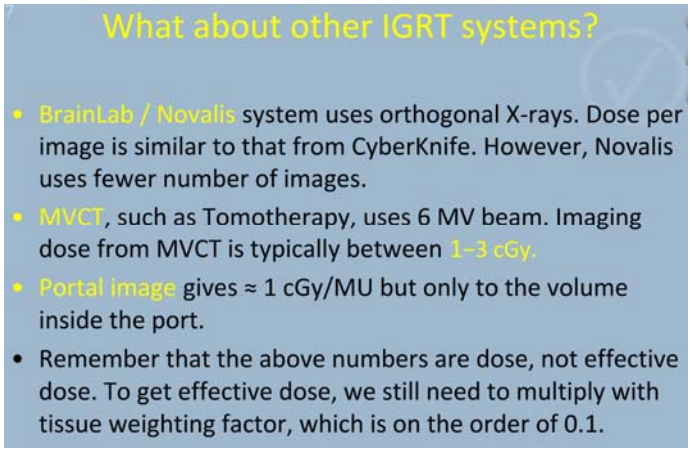
- Describe of characteristics of broad beam vs. narrow beam? How does the HVL graph between them differ? Which should be used for linac shielding? In diagnostic filter measurements?

- Picture of Compton scattering.

- (2011) Shown cartoon picture of Compton interaction (incoming photon and angles indicating direction of scattered photon and electron). There was a bunch of questions about it – describe it, what angles of scattered photon results in maximum/minimum energy transferred to electron, etc. This transitioned into a long discussion on the differences between kV and MV imaging (doses from each, how many MU do you use for portal images, how many for film etc). I guess this was the imaging question.

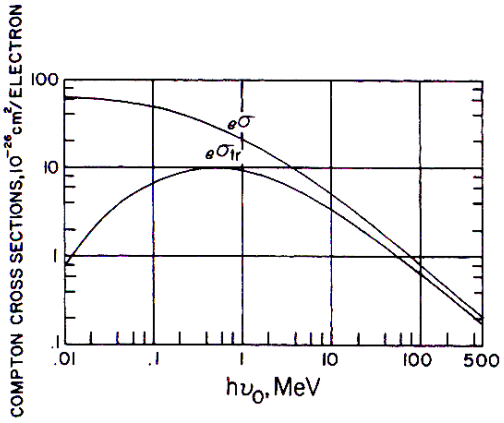
MV ~ 1cGy/MU (wepassed IGRT imaging dose) ~1 MU per image (TG58 P715)
kV ~ 0.01 – 0.2 cGy per image (TG58 0.05 cGy)





What is it? At what incident angle is the most energy transferred to the electron and at what incident angle the electron has the least energy. What clinical setting is this important in? Explain why this is important in therapeutic imaging.
(Use DABR p17-19 & We passed)
Because the portal imaging source is our treatment beam, and it is MV beam, Compton scattering is the dominate photon interaction at MV range.

- Klein-Nishina curve similar to shown on right. What's shown? Total Compton cross section σ, Compton transfer coeff. σ_{TR} and Compton scattered coeff. σ_S vs. energy, Explain Compton process What's σ_{TR} and σ_S Explain their relation to energy as shown on curves. Know how to identify the different areas and explain.



- (Attix p125, 130-133, Cunningham p151-153) Compton process can be described in kinematics and cross section. The 1st one is the Compton scattering figure we normally see. The cross section predicts the probability that a Compton cross section will occur. The cross section (which can be thought of as an effective target area) is equal to the probability of a Compton scattering event occurring when a single photon passes through a layer containing 1 electron/cm^2.

  Klein & Nishina applied relativistic theory of the electro to the Compton effect to obtain improved cross section.

  The above figure tells us the cross section (probability) of total Compton interaction σ vs. energy. The transfer Compton coeff. σ_{TR} tells us the relative probability of Compton interaction successfully transferring the energy to the recoil electron so determine the average frac. of the incident energy given to the electron. The difference between $\sigma - \sigma_{TR} = \sigma_s$ Compton scattered coeff. is the average frac. of the incident energy given to the scattered photon.

  The kinetic energy transferred to the electron E_{tr} can be written as $\sigma_{tr} = \sigma(E_{tr}/h\nu)$.

  The above figure shows that when low energy photons interact in a Compton process, very little energy is transferred to the electron (or medium) and most of the energy is merely scattered.

  & when the incident photon energy is increase, the available energy transferred to the recoil electron is increased as well, and very little energy is transferred to scattered photon.

  However, as the incident photon energy continuously increases, the probability of Compton interaction occurrence is decreased.

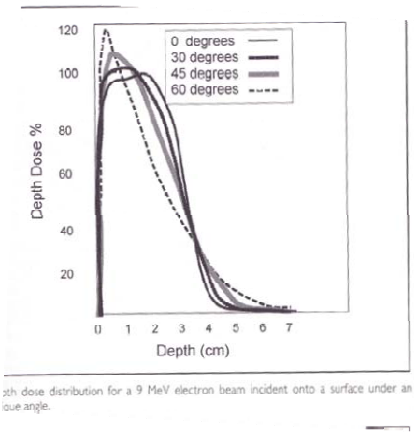
- There were two pictures of electron scatter voxels, one in a white background and another in a darker background. Question was what is this? How is it calculated? How do different materials affect it? How does density affect it?

- (2006) heterogeneity & homogeneity **TG65**

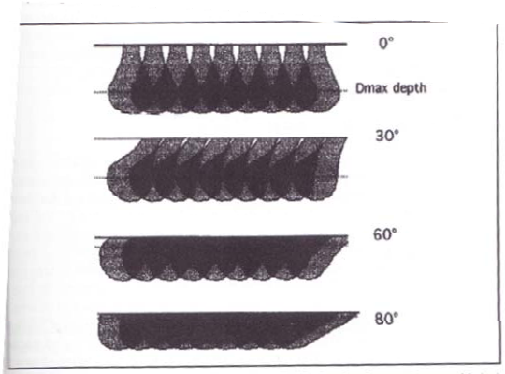
C2-E (Electrons)

- Image of an electron beam at about 40 degree angle from the surface: There was a hot spot on the side where the SSD was less also, but the lower isodose lines (20 and 30 %) were parallel to the surface. Question: Why are the isodose lines parallel to the surface?
- A 2D contour of 15x15 electron cone at a 30 degree angle to flat, homogenous phantom. Why are the distal contours parallel to phantom surface? Is that what you expect? Why?
- 16e beam entering surface at a 30 angle. Explain why are the isodose lines parallel to the skin surface?

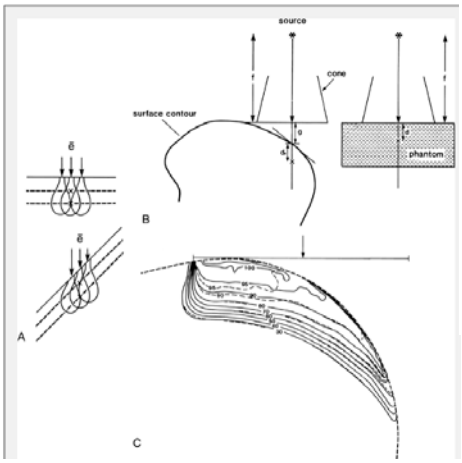
The oblique incident will bring the (1). d_{max} & the therapeutic depth close to the surface (decrease the dose penetration) as well as (2) increasing dose around the d_{max} region, as shown in Fig. 29 from TG25. This is due to the increase of the side scatter at the shallow depth as shown in the following figure on the right (MetCalf p349). Electron beam can be viewed as the sum of "pencil beam". Each pencil beam has a pear shaped angular dose distribution after the "pencil beam" passing through the medium. When we have the oblique incident, the overlapped region among each pencil beam at the shallow depth is increased (=increasing the side scattering effect). It is the reason that we see the d_{max} & the therapeutic 80% IDL shift to the shallow depth and the dose around the d_{max} increase.



pth dose distribution for a 9 MeV electron beam incident onto a surface under an ique angle.



A simple geometric interpretation of the dose distribution in electron beams with incidence oblique to a surface using "pencil beams." (Adapted from Ostwald and Kron 1996a.)



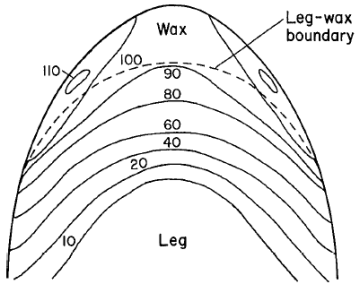


FIG. 30. Measured dose distribution in a phantom irradiated with a single incident beam of 10-MeV electrons. (Redrawn from McKenzie, 1979.)

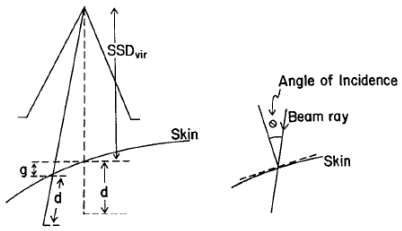


FIG. 31. Oblique incidence of a beam with an air gap.

$$D(d,\mathrm{SSD}_{\mathrm{vir}}+g)=D(d,\mathrm{SSD}_{\mathrm{vir}})\frac{(\mathrm{SSD}_{\mathrm{vir}}+d)^2}{(\mathrm{SSD}_{\mathrm{vir}}+d+g)^2}$$
$$\times f_{\mathrm{air}} f_{\mathrm{ob}}(\theta,d).$$

Kahn Sec14.5B Figure as well as TG25 Fig. 30 are shown here.

Another important factor is the inverse square law to account for the beam divergence. If we consider the electron beam parallel incident into the slopping surface as shown in "Okumura *et al.*, Radiology, **103**, 183 (1972), Fig 1" shown in the following, the inverse square law makes the IDL tilt and parallel to the surface. Please note the Fig 1. from Okumura published in 1972 "only" considering inverse square law, so it can't explain the IDL shifting toward the shallow surface which can be explained by the side scattering effect.

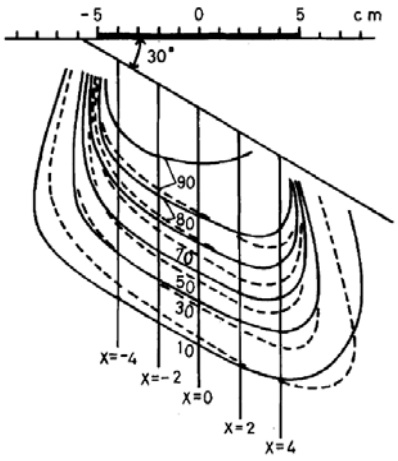


Fig. 1. Isodose curves of a 30° angle of incidence, 22 MeV, 10 × 10 cm. Solid curves are from measurements, and broken curves are from the standard isodose curves shifted the distance of the air space between the treatment cone and the phantom surface.

Moreover, the side scatter effect is less in the deeper depth compared to the shallow depth, so the inverse square law effect is the dominate factor affecting the dose distribution. Therefore, we can see the low IDL (ex: 20% or 30% IDL) parallel to the surface.

Due to the side scatter and beam divergence combination, we have higher dose in shallow depth and low IDL parallel to the surface at the deeper depth.

- Picture of electron beam isodose curves: What are we looking at? Can you guess what energy beam this is and how do you know? Why do electrons scatter more laterally?

- Shown the electron beam incident on the slab bone heterogeneity from Khan. What effects will a lead sheet on a patient skin have on the electron isodose curves?

- Isodose curve for a 16mev electron beam with a slopping incidence. Why does the isodose levels not change. Talk about lateral scatter equilibrium.

- With no plots given, asks to draw a PDD curve for electron Show, therapeutic depth, what gives rise to tail? Where is Bremm x-rays generated? What is the spectrum of electron energies out of the linac?

- Shown a PDD curve of a high-energy electron. Know how to explain; what causes the shape of the curve in the buildup region.
- Shown an electron PDD. How does it change with energy?
- (2006) Electron depth dose curve shown. Why does it look like this? Why is the surface dose so high?

Electron contamination, R50, d_{max} , surface dose, Rp increase along with the increase of the energy
Depth dose gradient decreases along w the increase of the energy

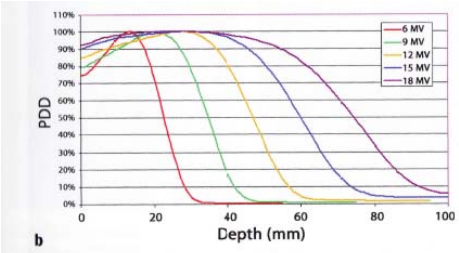
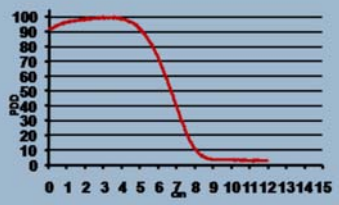


FIGURE 1.4 (a) Photon depth-dose curves, 10 × 10 cm field, 100 SSD. (b) Electron depth-dose curves, 10 × 10 cm electron cone, 100 SSD. Note: Surface dose decreases with increasing photon energy and increases with increasing electron energy.

The % depth dose at surface is higher for high energy e beam than low energy e beam is due to the larger e fluence at the d_{max} for low energy beam because the low energy electron is scattered easily than the high energy electron. Moreover, the low energy e beam is also scattered at larger angle than the high energy electron Kahn 14.4 B.

- Identify R_{50}, R_p, most probable energy E_p and energy at depth E_z for an e-beam. What are the rules of thumb for the practical range of electrons? What are the rules of thumb for electron dosimetry?
- Electron Questions. Ep, Ez, Rp. E0. Give all the formulas and write them down.

What is the energy of this electron beam



How is R_p defined?

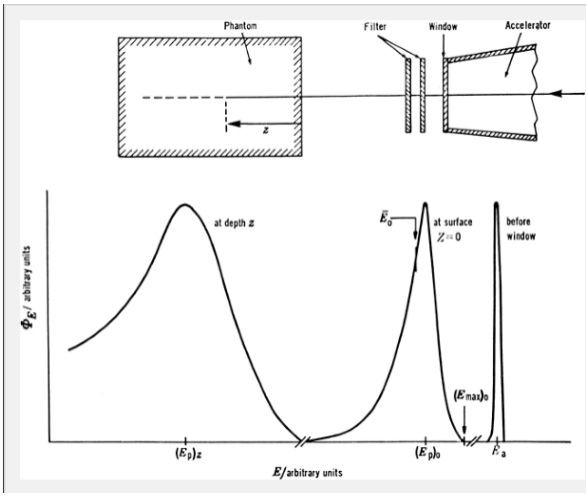
The practical range, Rp, is defined as the intercept of the tangent to the descending depth dose curve and the extrapolated photon contamination

The depth to 50% of max dose is approximately 7cm and since the mean energy at the surface, E_0 is ~ 2.33 x the R_{50} depth in cm, the mean energy ~16 MeV.

E0: is the mean energy of the electron beam at the surface
Ep0: is the most portable electron energy at the surface

$E_0 = 2.33R_{50}$;
$E_z(z) = E_0(1 - z/R_p)$

$Ep(Z) = Ep0(1 - Z/Rp)$
$E_{p0} = C_1 + C_2R_p + C_3R_p^2$ (Kahn 14.2) → $2R_p$
R80 = Ep0/2.8
R90 = Ep0/3.2



C2-F B

- 2 MU calculation equations one for SSD and one for SAD setup(Khan 10.9Define these two equations?), Explain each term.What is S_c ? Where does the scatter come from? why Sc increase with field size? How do you measure it? Why do you use the buildup cap? Know different build ups which one would use. How is the setup, depth, SSD, etc.? What is r_c ? What is S_p? how is the set up, depth? What is r_p ? what is Inverse Square law

- Dose calculation for I-125 prostate seed implant given the initial dose rate (D_o).
- What are the units for air kerma strength? How is it calculated? Units?
- Nuclear Energy Well diagram from Khan book: What keeps the nucleons together?
- (2006) Picture of a Mantel field with 2 points. How do you calculate dose to the point when there's a block there?

C2-G Special Technique

- **(4DCT)** A series of axial CT images with a lung/Mediastinum PTV contour on them. This looks like CT images during respiratory gating.

- What are these images for?

CT images were taken at different respiratory phase. These images are used to evaluate the patient respiratory motion during treatment to determine the internal target margin.

Discuss ICRU 62 nomenclature and where respiratory motion management fits in.

- *ICRU 62 supplements the PTV definition in ICRU 50*
  - *PTV = CTV + IM + SM*
    - *IM = internal margin = variations in size, shape and position of CTV relative to anatomical reference points (bladder filling, respiratory motion, etc.)*
    - *SM = setup margin = uncertainties in patient position and alignment of therapeutic beams (ex: linac mechanical tolerances, dosimetric uncertainties, etc.)*

- Explain IGRT? Why can't we expand the margins?

Image-guided radiation therapy may be defined as RT procedure that uses image guidance at various stages of its process: simulation, planning, and patient setup, target localization before & during treatment (Kahn 4ed p501)

We should avoid the margin expansion if it is not necessary because it will increase the probability of the normal tissue complication or inappropriate target coverage.

- A cartoon picture of patient in a CT/sim room with IGRT procedure

- Define each part (marker, infrared camera, goggles, respiratory cycle on a monitor)

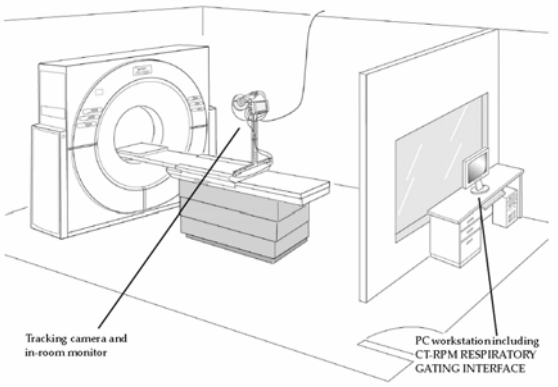
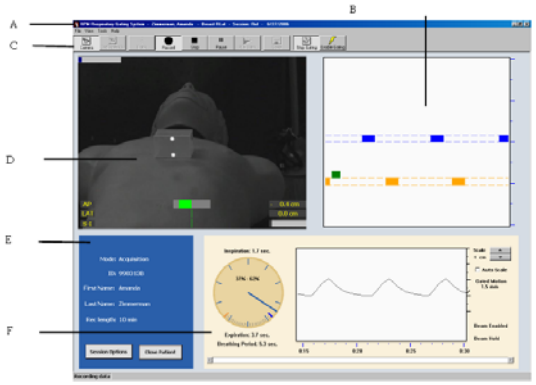


Figure 21 CT Scanner Simulation Room



A Title Bar B Visual Prompt area C Menu bar
D Image area E Session panel F Chart area

Figure 32 RPM Respiratory Gating System Window

Under the standard menu bar and toolbar appear session-specific areas:

- Image area displays video images from either the camera or the fluoroscope.

- Explain phase gating

(TG76, p3884): The phase gating means we deliver radiation, based on patient's breathing cycle or phase. The position and length of the gating within a respiratory cycle are determined by the monitoring the respiratory motion using either external respiratory signal or internal fiducial markers. Since the beam is not continuously delivered, the gating procedure is longer than non-gating procedure.

- How do we scan the patient? How much data are we getting? Are all these images sent to the treatment planning computer? Know about patient dose during this type of scan?

1. We used the Varian RPM system and retrospective mode to build the 4DCT data.

We set up patient in supine position with arm above head, and placed the external surrogate in between the xiphoid process and umbilicus (the location with the maximum AP motion). The external surrogate is a cube with infrared detectable markers. We also make sure the infrared camera catch the external marker signal so that the external box is shown on the camera LCD monitor. After setup, we start an evaluation session using the Varian RPM software. During the session, we evaluate the patient breathing pattern based on the motion of the external surrogate, depending on the patient breathing cycle per minute (BPM), we will decide which scanning protocol to be used. For slow breathing patient, we shouldn't use fast scanning, such as high pitch parameter; otherwise, we will miss the CT data set at some phases. After we deicide the scanning protocol, we start the RPM monitoring the patient breathing and CT scanning simultaneously. After scanning, the CT data gets binned according to the time at which it was acquired wrt the breathing cycle. We use 8 phases to bin our CT data set. The CT will reconstruct the images corresponding to different phases. We examine the reconstructed information for the artifacts and discontinuities. Artifacts relate to the fact that

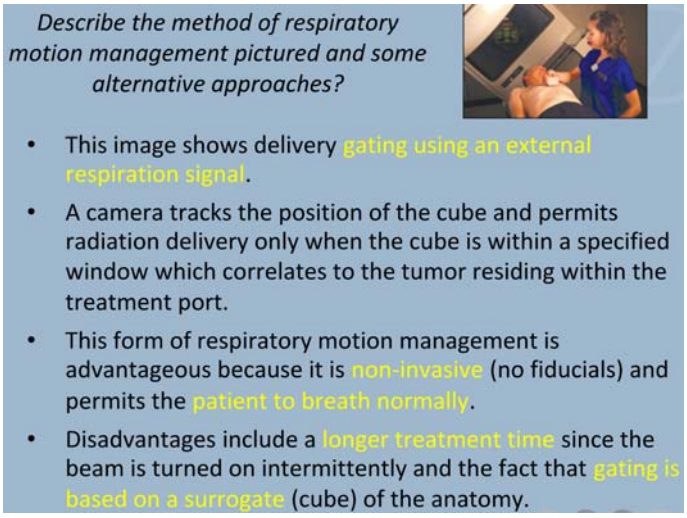
the surrogate breathing trace might not correlate to some structure motion (eg. Heart) so that the artifacts may show on the 4DCT image series. Discontinuities result from irregular breathing phase which in turn produce overlap or dark shadows in the resulting 4D scan.

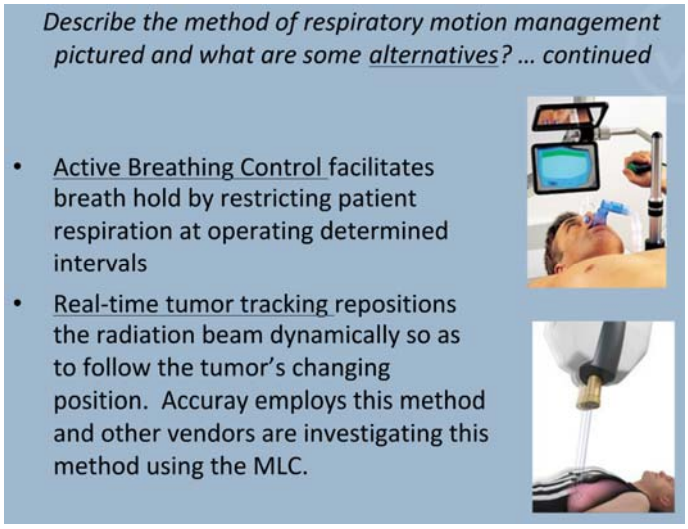
If we use 3 mm slice thickness, 30 cm scanning distance, we will get approximately 800 images for 8 phases. A regular 1 CT slice image is about 0.5 MB, so we have approximately 400 MB for a respiratory motion scan.

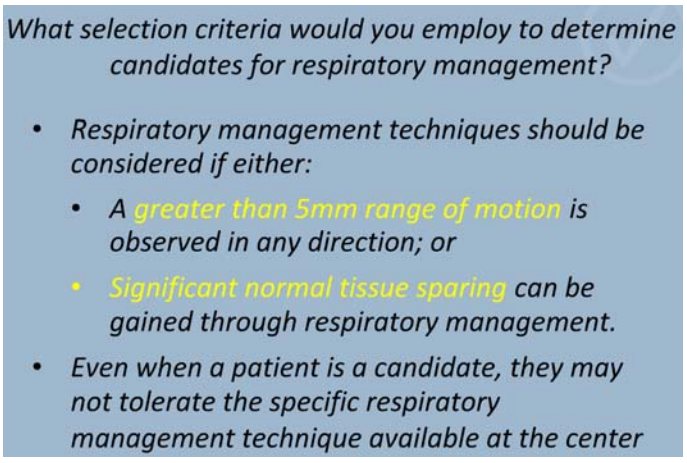
Free breathing scan is also acquired and imported into the planning system. All phases get imported as well and played as a movie file to assess the tumor and OAR intrafraction motion.

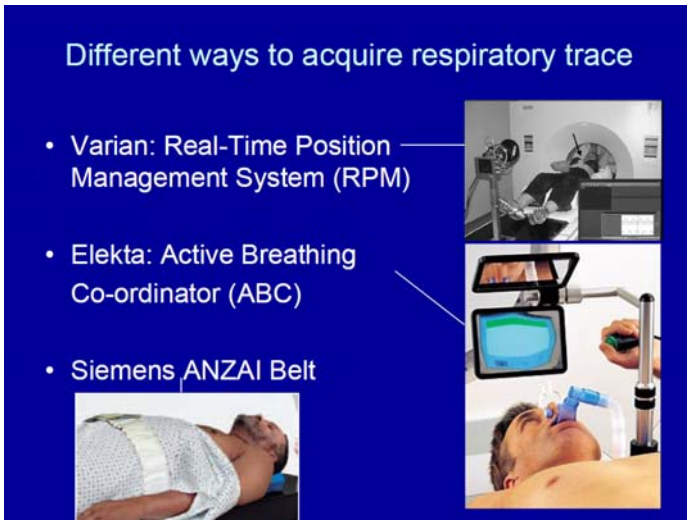
In Penn, the MIP and AVG images are reconstructed from all eight phases and are transferred into treatment planner as well

TG75: The $CTDI_{air}$ is approximately 250 – 400 mGy. (25 – 40 cGy)





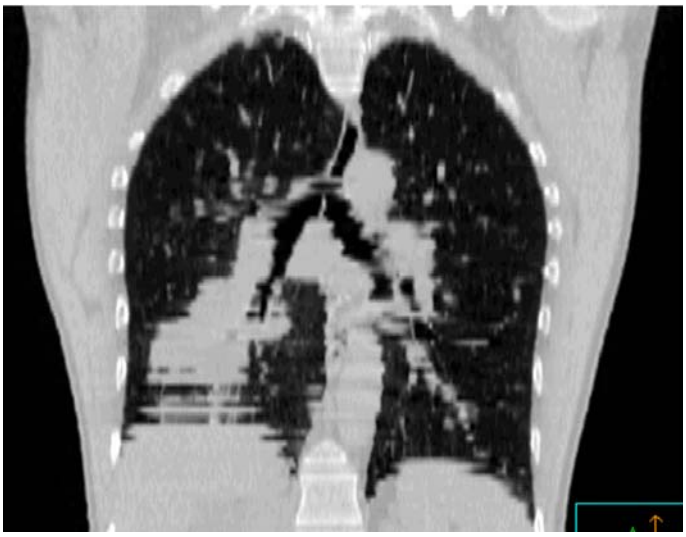




ABC: The ABC apparatus can pause breathing at any predetermined position and is often used at moderate or deep inhalation. It consists of a digital spirometer (肺活量計) to measure the respiratory trace, which is in turn connected to a balloon valve. In an ABC procedure, the patient breathes normally through the apparatus. The operator specifies the lung volume and stage of breathing cycle stage to "activate" the system, at which the balloon valve is closed. The patient is instructed to reach the specified lung volume, typically after taking two preparatory breaths. The valve is

inflated with an air compressor for a pre-defined duration of time, thereby "holding" the patient's breath. The breath-hold duration is patient dependent, typically 15–30 s, and should be well tolerated to allow for repeated (after a brief rest period) breath holds.

- Fig.1 of (TG76) report. The questions are: (1): which effects cause this artifacts and how to improve it (used we passed" motion artifacts").



(SRS)

The intent of the radiosurgery is to eliminate the lesion, under the consumption that this vol. only includes minimum normal tissue. Therefore, the target accuracy is very important, and also the dose must be confined to the target volume to eliminate the normal tissue complication.

Lesions treated w SRS are typically < 3 cm. Larger target vol. means a larger vol. of normal tissue irradiated, so the benefit of the SRS is diminished.

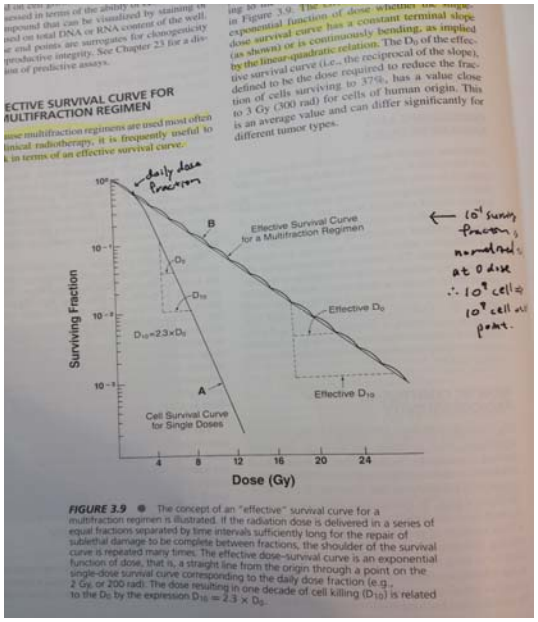


FIGURE 3.9 ● The concept of an "effective" survival curve for a multifraction regimen is illustrated. If the radiation dose is delivered in a series of equal fractions separated by time intervals sufficiently long for the repair of sublethal damage to be complete between fractions, the shoulder of the survival curve is repeated many times. The effective dose-survival curve is an exponential function of dose, that is, a straight line from the origin through a point on the single-dose survival curve corresponding to the daily dose fraction (e.g., 2 Gy, or 200 rad). The dose resulting in one decade of cell killing (D_{10}) is related to the D_0 by the expression $D_{10} = 2.3 \times D_0$.

If we look at the above figure from E. Hall, for the multiple frac. treatment (following the linear-quadratic model), we are extend the surviving region of α (initial shoulder region), and for a single fraction the β region is

large. For normal tissue $\alpha/\beta = 3$, and tumor $\alpha/\beta = 10$, it is the reason we want to use multiple frac treatment regime, but studies showed that for some tumor the $\alpha/\beta = 3$, so we can use single frac large dose such as SRS

- Axial, sagittal and coronal images of brain with isodoses overlaid. Is this a linac based stereo-tactic treatment or gamma-knife? Do you do SRS? What is important for SRS? (target accuracy)What is the prescription isodose line?
  Gamma knife dose distribution is more conformal compared to linac cone based because gamma knife has 201 sources and it has large possible solutions to produce more conformal dose.

  Gamma knife we normally prescribe as 50%.
  Cyber knife 70 – 80%
  Linac based is about 80%

- Diagram of SRS plan with oval isodose lines on it. The questions were what are the two different types of SRSs. Compare cone sizes. Difference and advantages if any between cone based SRS and MLC based SRS. What are the limitations, if any, why is there a limitation. Whether cone based SRS was better that MLC based SRS to which I replied yes as the penumbra in the cone based would be better. He asked me that what was the limitations, I answered that treatment size was a limitation, on which he further probed me why is there a limitation.
  Gamma knife cone 4, 8, 14, 18 mm diameter at focus point
  Linac cone: 10 – 40 mm at Isocenter, 15 cm long cerroband to reduce the geometric penumbra

  MLC: for irregular shape of tumor, better conformation compared to cone size SRS, and cone size need to use multiple iso, so MLC based can save more treatment time. MLC based can treatment large field size tumor (max field size 10 x 12 cm for mini MLC, & leaf width is 3 – 4 mm at iso)

  As treatment size increase, we will have large chance to irradiate normal tissue and we will need to multiple iso to cover the tumor so the treatment time will be increased

- Stereotactic surgery. Three views with isodose distribution were shown. How was this treatment plan produced? Explain what are the other means of doing stereotactic surgery? Told mini MLC based. Could have said Cyberknife as well.

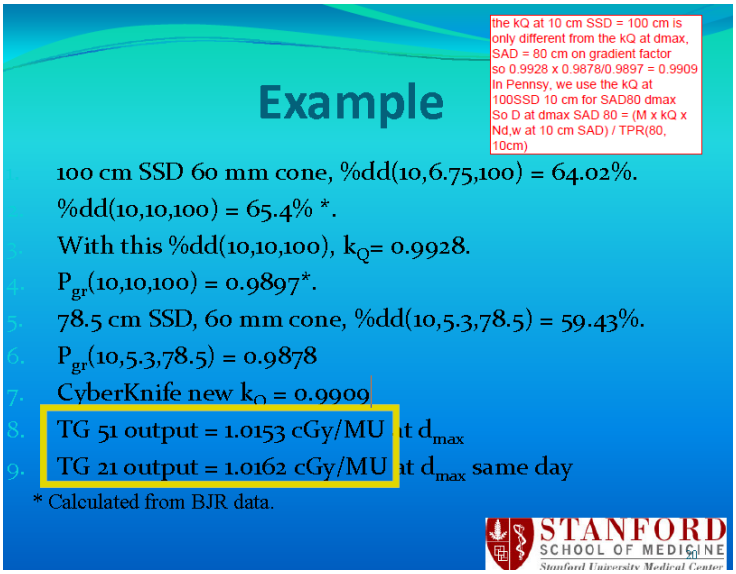
- What is the smallest and largest diameters (0.4 cm ~ 3 cm) for radiosurgery and why? In Arctherapy, MLC change the shape? (Yes, for dynamic conformal arc fields (like our RA SBRT), the MLC changes while gantry moving, Metaclf p463) Coplanar or Non-coplanar? What technology is used to produce the isodose line here?

- Stereotactic Radiosurgery isodoses, axial, coronal, sagittal pictures. Where are the arcs, comparison of micro MLC and cones, description of procedures, comparisons, upper and lower limit on the cone sizes, accuracy issues:

  Linac mechanical Isocenter accuracy: +/- 1 mm diameter
  Frame accuracy is within +/- 0.1 mm
  Overall accuracy deliver accuracy is 1 mm for linac based SRS
  Gamma knife is < 0.5 mm accuracy

- Discuss Stereotatic LINAC therapy. What it is called stereotatic. How you check calibration ;

Stereotactic radiation surgery means delivering large dose in a single fraction in a very confined beam and high accuracy stereotactic aperture to treat intracranial tumor. Stereotactic radiotherapy uses multiple fraction.

- 

- What commissioning data would you need to obtain for a SRS system (TMR, output factor, OAR).
  – How would you calibrate the output?
  – What can you use to measure that data? (film, SRS diode, pinpoint chamber A16 (0.007 cm^3))
  – What do you have to be careful with your detector? (chamber volume)
  For small field output normalization, two steps normalization: 1. 1x1 normalized to 5x5 with one measurement setup; 2. 5x5 normalized to 10x10 with another measurement setup. – Energy fluence may change.
  (read wepassed small field output factor)

(for small field measurement the detector size and lack of e equilibrium is the issue)